AN ABSTRACT OF THE THESIS OF

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Paired 30-day trials were conducted to evaluate Agropyron spicatum germination when treated with two concentrations of throughfall leachates from western juniper slash in two stages of decomposition. Data from a second pair of 49-day greenhouse trials were analyzed to evaluate emergence and growth of Agropyron spicatum, Oryzopsis hymenoides, and Poa ampla when watered with throughfall leachates from fresh green slash and year-old red slash from western juniper. The objectives of these studies were to assess plant responses to the addition of chemicals derived from the leachates.

Few differences in ion concentrations were evident between the two slash sources. No detectable quantities of nitrogen were leached from either source. Losses of Al, B, P, S, and Sr appeared greater from the red slash than from the green slash. Real additions of nutrients

from slash relative to controls appeared greatest for Al, B, Ca, K, Mg, Na, P, S, and Sr.

Leachates did not affect Agropyron spicatum germination, and final total emergence of the 3 test species was unaffected by either leachate. Leachates generally inhibited growth, but effects varied among species depending upon the parameter measured. Red slash leachates most often inhibited growth significantly, while effects of green slash leachates were intermediate and seldom significantly reduced growth. Growth of Oryzopsis hymenoides was the least inhibited by leachates, while Poa ampla growth was very much inhibited by leachates.

A further objective of the study was to explore allelopathic inhibition of ion uptake as a possible explanation for the observed general pattern of reduced growth associated with the leachates. A sample of the red slash leachate contained 5x more volatile compounds than a paired sample from the green slash leachate, and contained 4 phenolic compounds while the green slash leachate contained no detectable phenolics. The lack of phenolics may explain the relatively more moderate inhibition of growth caused by the leachates from the green slash. Morphological responses did not indicate reduced availability or uptake of nitrogen due to allelopathic inhibition, but may implicate interference

with uptake of other ions or inhibition of growth hormone functions. Implications are discussed for slash management on sites converted to improve productivity.

Influence of Leachates from Western Juniper Slash on Three Native Grasses

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INFLUENCE OF LEACHATES FROM WESTERN JUNIPER SLASH ON THREE NATIVE GRASSES

Western juniper (Juniperus occidentalis) (Vasek 1966) is one of several juniper species found regionally across the western United States. This particular species occurs throughout the semiarid interior Pacific Northwest, but is concentrated most heavily in central and eastern Oregon.

Like many other aridland woody species, nutrients tend to accumulate beneath juniper canopies, tied up in slowly decomposing litter. On many sites, juniper has aggressively invaded over the past 140 years, and nutrients are now patchily distributed, being concentrated beneath tree canopies and relatively scarcer in soils between trees. The uneven distribution of nutrients probably partially explains the lack of perennial understory species between trees, even on sites where they once dominated.

Efforts to reclaim juniper-dominated sites generally start with the eradication of juniper. Frequently, juniper slash is burned, for reasons including aesthetics, improvement of livestock access to forage, control of small junipers, or seedbed preparation for subsequent seeding. Depending upon the thoroughness and intensity of the burn, significant quantities of nitrogen may volatilize and be lost long-term to the site, lengthening the time needed to restore

the site's productivity. Aridland soils are recognized world-wide as nutrient-poor, particularly with respect to nitrogen, which is considered the limiting nutrient (West and Skujins 1978).

An alternative practice would be to leave the slash unburned and thereby retain nutrients otherwise volatilized by fire. However, other potentially allelopathic compounds would also be retained on the site. This study was primarily designed to evaluate the benefits of retained slash to native perennial grasses through nutrient enrichment of infertile interspace soils from mature juniper communities. Given the potential for negative responses, a second purpose of the study was to evaluate the possibility of allelopathic inhibition of nutrient availability, ion uptake or related processes as reflected in plant growth.

Benefits were hypothesized to accrue as juniper slash decomposed and nutrients leached to the underlying soil during significant rainfall events. Therefore, in this study, simulated rainfall on slash was used to approximate the release of nutrients in these leachates at rates similar to those likely to occur during the early growing season in natural communities. Leachates from slash were analyzed for individual ion content to relate to plant responses. Allelopathic effects from slash leachates were an alternative possibility.

Therefore, leachates were scanned for the presence and relative amounts of potentially allelopathic compounds.

Germination and early seedling growth are critical stages in the life of an individual plant (Mayer and Poljakoff-Mayber 1975). Because successful type conversions on pinyon and juniper-dominated sites depend upon the re-establishment of forage species, responses of native species were evaluated from germination through the first six weeks of growth.

LITERATURE REVIEW

Western juniper distribution is concentrated in Oregon, east of the Cascades, extending its boundaries into northern portions of California and Nevada, southwestern Idaho, and into eastern Washington (Vasek 1966). Since the late 1800's, western juniper has expanded its range to twice its former extent, and stand densities have increased markedly (Eddleman 1984). This phenomenon appears to be tied both to long-term climatic cycles (Mehringer and Wigand 1987), and to a more recent history of heavy grazing and fire suppression which was initiated in the 1860's by white settlement of the interior Northwest (Dealy et al 1978, Tonsfeldt 1984, Burkhardt and Tisdale 1969).

Seral juniper communities currently expanding the species' range have primarily invaded mesic sites formerly dominated by mountain big sagebrush (Artemisia tridentata ssp. vaseyana) and perennial bunchgrasses, principally Idaho fescue (Festuca idahoensis) and bluebunch wheatgrass (Agropyron spicatum) (Burkhardt and Tisdale 1969, 1976). In southwestern and eastern Oregon, Driscoll (1964), Eckert (1957) and Hall (1973) have identified western juniper climax associations with big sagebrush, low sagebrush (Artemisia arbuscula), and stiff sage (Artemisia rigida), along with bunchgrasses

such as bluebunch wheatgrass, Idaho fescue and Sandberg bluegrass (Poa sandbergii).

Climax sites identified by the USDA Soil Conservation Service include very deep coarse sands (Barrett 1984), along with shallow, undeveloped, fine-textured rocky soils overlaying fractured bedrock through which juniper roots penetrate to access deep moisture (Sowder and Mowat 1958). The latter sites are found on shallow ridgetops, rimrock and rock outcrops. Fire histories indicate such sites support a meager understory incapable of carrying fire (Young and Evans 1981, Burkhardt and Tisdale 1969, 1976) unlike more productive seral communities in the deeper soils of mountain big sagebrush and bunchgrass habitats. Typical deeper soils may be coarse loams at the surface with low to moderate clay content in deeper horizons. Accumulations of carbonates or silicates are sometimes present in subsurface soils (Dealy et al 1978, Hall 1973, 1978, Leonard et al 1987).

Throughout North America, Juniperus spp. have extended their ranges and changed plant communities. Juniper berries are carried to suitable new sites by several vectors including birds (Salomonson 1977) and overland flow of water on frozen soils (Eddleman 1984). Seedlings establish within favorable microclimates provided by sagebrush canopies primarily, but also within bunchgrass clones or under mature junipers

(Eddleman 1984). Once established, pinyon-juniper stands gradually dominate sites with subsequent losses in understory diversity and production (Koniak and Everett 1982, Jameson and Reid 1965, West et al 1979). These losses are also reflected in major understory increases in diversity, cover, vigor and productivity over time when trees are removed (Aro 1971, Barney and Frischknecht 1974, Clary and Jameson 1981, McKinney 1984, Everett and Sharrow 1985, Vaitkus 1986).

Juniper trees strongly influence the distribution of associated understory species. Everett et al (1983) found that as a growing tree expands its influence outward, individual understory plants respond to changes in their local environments primarily through effects of canopy and underlying duff. They believe that an individual plant's ability to survive in a given location depends upon the species-specific degree of tolerance to changes in its immediate vicinity wrought by the encroaching tree.

The developing juniper community begins to show a regular mosaic pattern of microsites including: a canopy zone where associated duff deepens and spreads as the tree ages and the canopy grows outward, a transition zone at the edge of the canopy, and a relatively barren interspace zone between trees (Everett and Sharrow 1985). Each zone may differ as to its species richness, cover and productivity in the understory (Vaitkus 1986,

Evans and Young 1985, Everett and Ward 1984). Everett and Sharrow (1985) found removal of Utah juniper trees allowed expression of microsite differences for perennial grasses, both collectively and for individual species, which had been overshadowed by competition for resources when the trees were present. As a general trend, palatable perennial forage species gradually disappear from the understory with increasing pinyon-juniper or juniper cover (Arnold et al 1964, Blackburn and Tueller 1970, Tausch et al 1981). This may be despite the fact that some cool-season grasses may find locally favorable microsite conditions along the edge of the duff zones (Everett and Sharrow 1985, Schott and Pieper 1985, Vaitkus 1986, Everett et al 1986).

Efforts to reverse forage loss trends in juniper and pinyon-juniper woodlands generally begin with overstory removal but may or may not include reseeding with forage species. Juniper eradication alone does not guarantee an improved forage base, at least within a time frame acceptable to land managers (Evans and Young 1985, Vaitkus 1986). When seed reserves and/or existing individuals of desirable forage grasses are lacking in older or disturbed seres chosen for juniper control, 'initial floristics' successional dynamics (Egler 1954), operating in pinyon-juniper and juniper ecosystems (Everett et al 1983, Tausch et al 1981, Koniak 1985), predict only minor increases in forage

grass cover and production (Everett and Ward 1984, O'Rourke and Ogden 1969).

A number of causal factors have been proposed to explain overstory-understory dynamics in juniper and pinyon-juniper communities, and to explain understory responses when overstories are partially or completely removed. Combinations of temperature and moisture characteristics beneath the canopies of western juniper may either inhibit or favor understory species relative to interspaces (Evans et al 1970, Eddleman 1984, Vaitkus 1986). Light intensity can influence species diversity and production (Shirley 1945), but Anderson et al (1969) believed that in coniferous forest communities, precipitation throughfall and stemflow more strongly influence the understory.

Precipitation acquires new chemical properties as it passes through the foliage or flows down the stem to the ground, properties which interspace precipitation does not possess. This is at least partly due to the chemical composition of mineral dust which accumulates on tree and shrub canopies during long dry periods of the year (Parent 1972, Skuijins and West 1973). This dust then washes into understory litter and soils when a storm event occurs. Hart and Parent (1974) found cation concentrations three times higher in throughfall from a mixed stand of Douglas fir and Rocky Mountain juniper in Utah, than in precipitation collected in the open.

Findings by Young and Evans (1987) appear to agree with Skujins and West (1973) that foliar entrapment of airborne dust may be the source of nutrient enrichment of throughfall, rather than leaching from dust-free foliage.

Ion additions from throughfall appear to partially explain observed patterns of nutrient accumulations beneath woody species in general. Subcanopy zones of nutrient enrichment have been studied in hardwood species (Eaton et al 1973, Gersper and Holowaychuk 1970, 1971) and in conifers (Zinke 1962). Doescher et al (1987) observed surface accumulations of Ca, K, organic matter (OM) and higher pH under western junipers relative to interspaces.

For both western and Utah junipers, studies have revealed more plant-available nitrogen in subcanopy soils relative to interspaces, grading outward from the bases of the trees (Young and Evans 1987, Everett et al 1986, Klopatek and Klopatek 1987). Similar comparisons for total N have been variable (Doescher et al 1987, Brotherson and Osayande 1980, Klopatek and Klopatek 1987).

Barth (1980) believed two different mechanisms operated in a mature pinyon (Pinus edulis) community to create higher concentrations of nutrients beneath trees relative to interspaces: eolian deposits concentrated phosphorus, while concentrations of other nutrients

resulted from long-term accumulations from decomposing litter. Lack of horizontal patterning led DeBano et al (1987) to conclude that nutrients were recycled vertically in a mature Utah juniper stand.

Rooting patterns of pinyons and junipers reveal lateral roots extending well out into interspaces (Thran and Everett 1987, Everett et al 1986, Tiedemann 1987, Young et al 1984). Some researchers conclude that these lateral roots allow the trees to translocate nutrients, sequestering them into the condensed volume represented by the tree's biomass (Young et al 1984, Tiedemann and Klemmedson 1973).

Mineral concentrations in foliage of junipers and other woody plants may or may not reflect relative availabilities in associated soils, in semiarid and aridland ecosystems (Brotherson and Osayande 1980, Bunderson et al 1985, Wentworth and Davidson 1987). The general concensus is however, that nitrogen and phosphorus are the most limiting elements for plant growth in these ecosystems (West 1981, Cline and Rickard 1973). In central Oregon, analyses of pumice soils and native woody plants have shown sulfur to be an additional limiting factor for plant growth (Will and Youngberg 1978, 1979).

Concern has been expressed about losses of nutrient capital from sites where pinyons and junipers are harvested, through the removal of fuelwood. DeBano et al

(1987) found that the majority of the nutrient capital contained in tree biomass, remained on-site in slash and branches (<7.6 cm diameter). They estimated the nutrients removed via fuelwood could be replaced by atmospheric input over a 200-year harvest rotation. In Tiedemann's (1987) model for nitrogen allocations to various compartments of the pinyon-juniper ecosystem, he estimated that fuelwood harvest could export 2 percent of total N from a site. In chaining operations where trees are subsequently piled and burned, he estimated only 3 percent of total nitrogen would be volatilized because subcanopy litter and duff accumulations would most likely remain unburned. If, however, chaining of mature stands was followed by broadcast burning to eradicate remaining small trees and seedlings, potentially up to 13 percent of on-site N could be volatilized through partial to complete consumption of the litter and duff. In this nitrogen-limited ecosystem, losses this high could significantly impact subsequent site productivity.

When Wallace (1976) simulated prescribed burns in the central Oregon ponderosa pine zone, he found only moderate percentage (17 %) losses under conditions similar to a cool, slowburning ground fire, as opposed to 72 percent losses of nitrogen from a 'hot' fire which consumed aboveground vegetation. However, mineral soil (0-8 cm) contained only 0.03 to 0.16 percent nitrogen.

In a companion study by Nissley (1978) in the same study area, actual prescribed burns resulted in average nitrogen losses of 10-30 percent, with highest losses of 65 percent on the hottest burns. Fuel loading (understory fuels) was only 23-30 kg/ha and the duff contained 75 percent of the total nutrient capital contained in understory aboveground biomass.

While Wallace (1976) did not quantify effects on sulfur, Nissley found that up to 50 percent of total sulfur was lost from burned sites. He attributed losses at least partially to leaching which occurred prior to post-burn sampling. However, sulfur, like nitrogen, volatilizes at temperatures of 200 C unlike other nutrients which do not volatilize until temperatures of at least 500 C are reached (Grier 1975, White et al 1973). Therefore, on sulfur-deficient pumice soils, burning could result in losses of both sulfur and nitrogen which could significantly affect subsequent site productivity.

Counterbalancing absolute potential losses, most nutrients remain on-site after burning in forms more readily available for plant uptake since they are no longer bound up in slowly decaying biomass (Wright et al 1979, Grier 1972, DeBano et al (1987). Even remaining nitrogen may be proportionately higher in available forms, e.g. ammonium ($NH4^{+}$) and nitrate-nitrogen (NO3_) (Lewis 1974). But substantial losses from desert soils

may occur from the soil as volatile ammonia (NH_3) if ammonium forms are not quickly taken up by microbial populations or higher plants (O'Brien 1978).

Ten months after burning juniper slash, DeBano et al (1987) found that former canopy locations left without further treatment produced significantly more ammonia than did sites where slash had been piled and burned. Mineralized-nitrogen conversion rates were also greatest on sites left without further treatment after cutting, but highest accumulations of nitrates were measured on duff sites where slash had been piled and burned. Interspaces contained the least mineralized nitrogen, irrespective of post-harvest treatment.

Along with mineral nutrients required by plants, the genus Juniperus contains species-specific combinations of volatile oils. Quantitative analyses of oils from western juniper foliage show that 46-61% of the volatile material is composed of compounds implicated as allelopathic agents against microorganisms and higher plants (Fahey and Kurth 1955, von Rudloff et al 1980). They include the following: borneol and p-cymene (Fischer 1986), a-pinene (Friedman 1987), dipentene (Muller et al 1969), terpinen-4-ol (Heisey and Delwiche 1983), acetic acid (Tang and Waiss 1978) and unspecified phenols. Phenolics are a highly complex and diverse group. Chou and Young (1975), Rice (1984), Wang et al (1967), and del Moral et al (1978) conducted

studies linking allelopathic activity to phenolic compounds.

Various juniper species have been suspected of allelopathic interactions with associated flora and microflora. Jameson (1966) concluded that allelochemicals released from Utah juniper litter reduced basal area and productivity of blue grama (Bouteloua gracilis) more than did tree canopy cover or root competition. Extracts from Utah juniper foliage and fresh undecomposed litter inhibited growth of seedling grasses more than older litter, but results also depended upon soil textures, both in the laboratory and in natural communities (Jameson 1968, 1970). Jameson (1970) isolated two unidentified, active allelopathic compounds from Utah juniper foliage, each decomposing at different rates.

Other laboratory studies on allelopathy have demonstrated a range of effects, from positive to negative, on both germination and early growth. Effects depended on the species used, plant parts extracted, the state of decomposition of materials from which extracts were prepared, and the concentration of the leachates (Rietveld 1977, Schlatterer and Tisdale 1969, Hoffman and Hazlett 1977).

Allelopathy in the laboratory and in the natural community are two different situations. As Rice (1984) observed,

> "The fact that phytotoxins have been demonstrated in extracts of various plant parts does not mean that they will leach or exude from the plant. Of course, water-soluble toxins, which are still present after death of a plant part, can leach out."

Though compounds with laboratory-demonstrated toxicity may be leached from living plants or litter, their effectiveness against neighboring plants may be neutralized at various points in the soil, at the point of uptake, or within the receiving plant (Fisher 1987, Rice 1984, Wang et al 1978, Tubbs 1973, Turner and Rice 1975, Balke et al 1987).

Some studies have indicated that allelopathic inhibition of nitrifying bacteria may play a role in pinyon-juniper ecosystem processes (Klopatek and Klopatek 1987, DeBano et al 1987, Rice and Pancholy 1972). Alternative explanations of the evidence concerning allelopathy have been proposed (DeBano et al 1987, Doescher et al 1987).

If allelopathy from Juniper is not a critical factor in germination and/or seedling establishment of understory grasses, perhaps interspace soils could be marginally enriched through the slow decomposition and release of nutrients from slash material left on-site, rather than producing a flush of cations through slash or broadcast burns, where critical nitrogen or perhaps sulfur may volatilize and be lost from the site. Also, leaving slash on-site may recreate the mesic environment

favoring cool-season grasses, but without the competition for water and nutrients from live trees.

Where seeding is deemed necessary to restore the forage base after juniper is removed from a site, species should be chosen which are site-adapted. Obvious choices would be species strongly represented in the former plant community of the particular site (Vallentine 1980, Hassel and Oaks 1987).

Once seeded with appropriate plant species, successful germination followed by successful establishment of seedlings must occur. Germination depends upon a variety of factors, some extrinsic and some intrinsic to the seed. Germination requires an optimal combination of moisture, temperature and oxygen (O_2), and occasionally light, in the seed's local microenvironment. Germination also depends upon the degree of contact between seed and soil (Harper 1977, Koller 1972).

Three common cool-season grasses endemic to the zones being invaded by western juniper were selected for this study: bluebunch wheatgrass (Agropyron spicatum), Indian ricegrass (Oryzopsis hymenoides), and big bluegrass (Poa ampla). Of the three species, Agropyron spicatum germinates most readily over a wide range of environmental conditions (Young et al 1981). 'Secar' bluebunch wheatgrass was developed for use in the Pacific Northwest (USDA 1981). Temperatures higher than

25 C limit total germination for 'Secar' when moisture stress is minimal (Young and Evans 1982). Speed of germination for 'Secar' may vary significantly at temperatures between 10-25 C, even though total germination is unaffected (Goebel et al 1988). Evenden (1983) found that germination rates slowed and final germination was reduced with increasingly negative water potentials, regardless of temperature regimes.

Young et al (1978) generalized the germination criteria for bluegrasses (Poa spp.), saying that most of the 50+ species in North America require KNO_3 for germination, and that some species require light. Wasser (1982) recommended planting seeds no deeper than .25-.5 inches for both big bluegrass and for Kentucky bluegrass (P. pratensis). Since Kentucky bluegrass requires light to germinate (Maguire 1970), it may also be true for big bluegrass. Wasser (1982) further recommended a short period of cold-stratification for big bluegrass to speed germination. 'Sherman' big bluegrass was used in this study.

The hard seeds of Indian ricegrass germinate poorly without prior treatment to break dormancy. Innate dormancy (Harper 1977) can be released when the tenacious lemma and palea are removed either by rodents or by acid scarification (McAdoo et al 1983, Young and Evans 1983, Stoddart and Wilkinson 1938). Either natural overwintering to meet cool-moist stratification

requirements, or the addition of gibberellic acid in the laboratory will dissipate innate dormancy (McDonald and Kahn 1983). In any case, the age of the seedlot ultimately influences its germinability (Young et al 1985).

Planting depths between 3-7 cm are optimal for Indian ricegrass (Wasser 1982). Young et al (1983) found that 20 C with adequate available moisture optimizes conditions for germination. However, even at suitable temperatures, with acid scarification and added gibberellic acid, Young et al (1985) achieved only 50-60 percent germination.

MATERIALS AND METHODS

Materials

Western juniper slash was collected in April 1987 from a site located 8.8 km southeast of Prineville in central Oregon. Mixed-age stands of western juniper dominate the area. Foliage and smaller branches were collected from trees recently felled, and this new slash material was termed 'green slash'. Foliage was also collected from trees felled the preceding year, which had recently turned reddish-brown. This one-year old slash was termed 'red slash'.

Air-dry red and fresh green slash were placed in two separate columns and compacted as much as possible. The density of the green material was lower than the density of the red material since the old needles were falling off the branches enabling more compaction. In the interest of uniformity and compactness, no twig diameters greater than 1.3 cm were used. Cylinders were constructed of hard plastic, 28.6 cm in diameter and 71.1cm high. Plastic screens at the bottom of the cylinders trapped most particulates during leaching.

Leachates were prepared by spraying 12 l of distilled water onto the surface of each column at a rate of approximately 12 l/hour, using a hand-pressurized 3-gal garden sprayer. This delivery rate is equivalent to a rate of 2.54 cm of rainfall/10.2 cm

depth of slash/hour. Variation in spray duration was caused by losses in pressure which required frequent repressurization until the sprayer was emptied, and also by gradual deterioration of the sprayer. Spray rates were described in linear terms for easier comparability to field conditions (i.e, precipitation and slash depths on juniper conversion sites).

Fresh leachates were prepared for each watering event by reusing the original slash each time. Repeated leachings of the same materials were intended to simulate processes in a natural community where slash would be exposed to repeated leachings from spring precipitation and snowmelt. Fresh leachates were applied to greenhouse plantings as they were prepared. Excess volumes of each leachate were recorded and placed in airtight plastic 1-liter bottles, labeled and refrigerated for use in the germination section of the study and for later chemical analyses. Where prolonged storage was required, leachates were transferred to labeled plastic freezer bags and frozen.

'Sherman' big bluegrass (POAM), 'Nezpar' Indian ricegrass (ORHY), and 'Secar' bluebunch wheatgrass (AGSP), are all varieties developed for use in the semiarid zones of the Pacific Northwest. All three species are indigenous to western juniper-dominated communities in the pumice sand zone of central Oregon and are well-adapted to coarse-loamy and sandy soils.

In addition, these species are considered good forage species, once they establish. The USDA Soil Conservation Service's Plant Materials Center in Bridger, Montana provided 6-year old 'Nezpar' seed, while the Pullman (WA) Plant Materials Center provided 1-year old seed of both 'Secar' and 'Sherman'.

Germination

Bluebunch wheatgrass seeds were germinated on Kimpak cellulose pads (double layered), in petri dishes. Fifty seeds were placed in each dish which was then randomly assigned one of the following five treatments with which the substrate was moistened: control (distilled water), half-strength green slash leachate, full-strength green slash leachate, half-strength red slash leachate, and full-strength red slash leachate. The undiluted leachates were composites from the first 3 leachings. Initially, 30 ml of a liquid were added per petri dish to moisten the pad. An additional 30 ml was added to each dish later during the trial period.

Germination records were kept for 30 days. Seeds were considered germinated when both radicle and coleoptile were visible under a dissecting microscope. Germinated seeds were removed as they were recorded. Throughout the trial, petri dishes were kept in a dark germinator at 20 C, in a closed cardboard box which was

then wrapped in a dark plastic bag. Petri dish locations within the box were rotated daily.

Each treatment was replicated five times, and the entire experiment was repeated following completion of the first trial. Data from each trial were analyzed separately by one-way ANOVAs in a completely randomized design (Snedecor and Cochran 1982), using SAS software on an IBM-PC. Variables were rate of germination (Maguire 1962) and final germination percent. Means were separated by Least Significant Difference (LSD) for significant differences (Snedecor and Cochran 1982).

Emergence and Growth

Soil was collected from the interspaces in mature western juniper stands 9.7 km east of Cloverdale in central Oregon (T14S, R11E, sec. 5 sw1/4 and sec. 6 se1/4. The Soil Conservation Service (unpubl.) has tentatively identified the soil series in this area of the pumice sand zone as a Houstake soil, a coarse-loamy, mixed, mesic Aridic Duric Haploxeroll. Soil was taken from the surface 10 cm, and coarse fragments and organic matter were removed by hand as encountered. The total volume of collected soil was later mixed manually to reduce variation and transferred into tapered growth tubes (cells) 25.5 cm deep, with a 6 cm top diameter, and with a volume of 500 cm^3, leaving headroom for watering.

Five seeds of one species were planted per cell to ensure at least one seedling emerged. Where more than one seedling emerged, the first emergent was allowed to grow and all later seedlings removed. Each cell received one of the following treatments: distilled water (C), undiluted green slash leachate (GSL) or undiluted red slash leachate (RSL). The nine treatment-species combinations were randomly assigned to cells clustered into a rack, with 3 replications of each combination. Five racks were arranged lengthwise on each of four tables in a greenhouse, creating a 3x3 factorial arranged in a completely randomized block design, where tables were the blocking factor with a total of 540 cells.

Data were analyzed separately for each trial in a 3x3 factorial within a two-way ANOVA with tables as blocks, using SAS software on an IBM-PC. Data from 15 cells were averaged for each treatment-species combination per block, and means were analyzed. Due to problems with missing data, the fourth table was dropped from the analysis in both trials. Differences between means were examined by LSD for main effects and for treatment effects within each species. Greenhouse temperatures were maintained between 21.0 and 26.7 C.

Cells were initially brought to field capacity over 4-5 days with 30 ml additions of an assigned treatment, which required three successive leachings of each set of

slash. Field capacity of the cells was achieved with the cumulative 90 cm of liquid, and seeds were then planted in previously assigned cells, over a 2-3 day period. Equal proportions of excess water from each of these first 3 leachings for red and green slash respectively, were composited for subsequent chemical analysis.

Five holes 1.5 cm deep were punched in moist sand in each cell. Seeds were planted and the soil firmed over the seed to assure seed-soil contact. Emergence records were kept daily for 24 days after which no further emergence was observed. Emergence data were subsequently analyzed for rate of emergence (Maguire 1962) and final emergence percent. Cells were watered every 2-3 days with 30-35 ml increments of leachates calculated to maintain cells at field capacity. Soil surfaces were observed to begin drying even before daily watering cycles were completed. Leachate samples were retained every third watering (once a week) for chemical analyses.

Plants were harvested on day 43 post-planting in the first greenhouse trial, and on day 36 post-planting in the second trial due to miscalculation of the date. Because of variation in dates of emergence, the actual number of days growth in each trial was adjusted to a base number of 42, and measurements adjusted accordingly. These standardized measurements were calculated

for individual plants by the following formula: (Final actual measured parameter/number of days plant grew from emergence to harvest)*42. Prior to harvest, the following morphological parameters were measured on each plant: number of leaves, number of tillers, plant height (soil surface to tip of the longest tiller). Plants were then clipped at ground level for later determinations of aboveground oven-dry biomass. Root samples were rinsed by hand and oven-dried for belowground biomass determinations.

Data were analyzed separately for each trial in a 3x3 factorial within a two-way ANOVA with tables as blocks, using SAS software on an IBM-PC. Data from 15 cells were averaged for each treatment-species combination per block, and means were analyzed. Due to problems with missing data, the fourth table was dropped from the analysis in both trials. Differences between means were examined by LSD for main effects and for treatment effects within each species.

Chemical analyses

Unwatered soils from the collection site and juniper slash material were analyzed for total N and phosphate (PO_4) by the Forest Sciences Laboratory at Oregon State University. Methodology was adapted from Schuman et al (1973); micro-Kjehldahl digestion followed

by measurement with a Rapid Flow Analyzer, manufactured by Alpkem Corporation.

The Oregon State University Soil Testing Laboratory performed analyses for soil cations (Ca, K, Mg, Na), borate (BO_3) and sulfate (SO_4). Cations were extracted with ammonium acetate. Sulfate was extracted with CaPO and analyzed with a Dionex ion chromatograph. Boron was extracted with hot water followed by azomethiene extraction. Laboratory methods of the Soil Testing Laboratory are described in Horneck et al (1989, in press).

Leachate samples were sent to the Oregon State University Plant Analysis Laboratory for macro- and micronutrient content analyses. Dehydrated 100 ml samples were acidified with 10 ml acid, and ions quantified with an ICP (Jim Wernz, pers. comm.). Nitrogen was measured separately with micro-Kjehldahl digestion techniques (Bremner 1965). The pH of leachate samples was measured with a Beckman glass electrode pH meter (Jackson 1958). Suspended volatile compounds and phenolics were assayed by gas-chromatography and by high-performance liquid chromatography (HPLC) methods respectively (by Rick Kelsey, OSU Entomology Dept.). Plant, soil and leachate analyses were all performed in triplicate, with the exception of analyses for volatiles and phenolics. For these assays, only the initial

composited slash leachate samples from the first trial were used.

RESULTS

CHEMICAL ANALYSES

Soils

The Houstake series has a neutral pH. Chemical analyses (Table 1) reveal that this soil has a moderate to high supply of most cations, with the exception of sodium and nitrogen. The nitrogen supply in this soil is quite low, only .05 percent. Sulfur in the form of sulfate appears plentiful, whereas boron, in the form of borate is scarce.

Foliage

Nitrogen content of both green and red slash was close to 1 percent (Table 2). Amounts of phosphorus and calcium were high relative to slash contents of other macronutrients. Differences were expected between green and red slash contents for specific ions (Table 2), since the red slash had been exposed to weathering action for one year and the green slash was freshly cut for this study. However, even though some ions were present in reduced quantities in the older slash, differences were not significant for any individual ions, indicating that major leaching of ions had not taken place.

Table 1. Chemical characteristics of interspace soil (top 10 cm.) (Houstake series) from a mature western juniper community.

Soil		Mean	se	n
pH		7.00	.03	3
N	%	0.05	0.006	3
P	ppm	669	24.8	3
K	ppm	400	13.3	3
Ca	ppm	1400	70.4	3
Mg	ppm	216	10.6	3
Na	ppm	62	3.9	3
BO3-	ppm	0.26	0.017	3
SO4-	ppm	880	280.0	2

Table 2. Foliar chemical analyses for western juniper slash.

Material		Green slash*			Red slash		
		Mean	se	n	Mean	se	n
N	%	0.84	0.006	3	0.99	0.029	3
P	ppm	1772	52.0	3	1582	23.0	3
K	ppm	330	12.0	3	320	6.0	3
Ca	ppm	1380	17.0	3	1290	17.0	3
Mg	ppm	120	6.0	3	120	6.0	3
Na	ppm	60	4.3	3	77	5.5	3
BO3-	ppm	10	0.3	3	5	0.3	3
SO4-	ppm	70	6.0	3	80	0.0	3

* There were no significant differences between content of green and red slash material for any individual ions ($\alpha = .05$).

Leachates

Across both trials, only 4 nutrients showed significantly greater average concentrations in leachate samples from the red slash relative to the green material (Tables 3 and 4). These were Ca, K, Mg, and Na. A number of other nutrients were released at significantly higher rates from the older material, but only in the second trial. These included: Al, B, Ba, Fe, P, Sr and Zn. In the first trial, however, the red slash appeared to release greater cumulative amounts of these same elements compared to quantities leached from the green slash. In this case, sampling variation may have masked real differences which were clearer in the second trial.

The pH of weekly leachate samples was generally mildly to moderately acidic for new slash and mildly alkaline for the older slash (Table 5). Starting with a neutral soil with very low organic content to buffer pH changes, it is probable that soil pH became progressively more acidic where acidic GSL was added, and more alkaline where alkaline RSL was added.

Due to the methology used to analyze leachates for volatiles, compounds suspended in the leachates were not identified by name. However, they were

Table 3. Mean ionic content (ppm) and total added (ug) in leachates from western juniper slash in two stages of decomposition (trial 1).

ELEMENT	Al		As		B	
MATERIAL	GSL	RSL[1]	GSL	RSL	GSL	RSL
Grand mean	0.3 a	1.4 a	T a	T a	0.2 a	1.1 a[2]
se	0.1	0.6	0.0	0.0	0.1	0.3
total added	433	2433	25	55	368	2070

	Ba		Ca		Cd	
	GSL	RSL	GSL	RSL	GSL	RSL
Grand mean	T a	0.2 a	1.0 a	29.6 b	0.0 a	0.0 a
se	0.0	0.1	0.6	26.2	0.0	0.0
total added	66	442	1137	33119	0	0

	Co		Cu		Fe	
	GSL	RSL	GSL	RSL	GSL	RSL
Grand mean	0.0 a	0.0 a	T a	0.1 a	T a	0.2 a
se	0.0	0.0	0.0	0.0	0.0	0.1
total added	0	0	93	664	32	890

	K		Li		Mg	
	GSL	RSL	GSL	RSL	GSL	RSL
Grand mean	1.2 a	17.7 b	0.1 a	0.2 a	0.9 a	12.7 b
se	0.5	4.0	0.1	0.1	0.2	3.2
total added	786	11194	33	92	1130	16050

	Mn		N		Na	
	GSL	RSL	GSL	RSL	GSL	RSL
Grand mean	0.0 a	0.1 a	0.0 a	0.0 a	3.4 a	14.1 b**
se	0.0	0.0	0.0	0.0	0.6	1.1
total added	0	290	0	0	2406	9957

	Ni		P		S	
	GSL	RSL	GSL	RSL	GSL	RSL
Grand mean	0.0 a	0.0 a	1.6 a	5.1 a	0.3 a	2.5 a
se	0.0	0.0	0.4	1.2	0.1	0.7
total added	0.0	0.0	2690	8579	460	3662

	Se		Sr		Zn	
	GSL	RSL	GSL	RSL	GSL	RSL
Grand mean	0.0 a	0.0 a	T a	0.5 a	T a	0.2 a
se	0.0	0.0	0.0	0.1	0.0	0.0
total added	0.0	139	52	8463	114	761

1 GSL=Freshly cut green slash, RSL=1 year old red slash.
2 a-b Means with same letter are not significantly different ($\alpha = .05$).
* Differences are very significant ($\alpha = .01$).
** Differences are extremely significant ($\alpha = .001$).

Table 4. Mean ionic content (ppm) and total added (ug) in leachates from western juniper slash in two stages of decompostition (trial 2).

ELEMENT	Al		As		B	
MATERIAL	GSL	RSL[1]	GSL	RSL	GSL	RSL
Grand mean	0.1 a	0.5 b*	0.0 a	0.0 a	0.3 a	1.7 b[2]
se	0.0	0.1	0.0	0.0	0.2	0.5
total added	147	792	0	0	555	3015

	Ba		Ca		Cd	
	GSL	RSL	GSL	RSL	GSL	RSL
Grand mean	0.0 a	0.1 b*	4.3 a	23.1 b	0.0 a	0.0 a
se	0.0	0.0	2.5	6.2	0.0	0.0
total added	0	189	4583	24614	0	0

	Co		Cu		Fe	
	GSL	RSL	GSL	RSL	GSL	RSL
Grand mean	0.0 a	0.0 a	0.0 a	0.0 a	T a	0.3 b*
se	0.0	0.0	0.0	0.0	0.0	0.1
total added	0	0	0	0	30	1420

	K		Li		Mg	
	GSL	RSL	GSL	RSL	GSL	RSL
Grand mean	2.2 a	22.6 b	0.0 a	0.0 a	1.4 a	7.9 b
se	1.0	7.7	0.0	0.0	1.1	2.6
total added	1340	13599	0	0	1735	9560

	Mn		N		Na	
	GSL	RSL	GSL	RSL	GSL	RSL
Grand mean	0.0 a	T a	0.0 a	0.0 a	4.1 a	18.3b*
se	0.0	0.0	0.0	0.0	1.6	3.5
total added	0	171	0	1	2726	12303

	Ni		P		S	
	GSL	RSL	GSL	RSL	GSL	RSL
Grand mean	0.0 a	T a	1.0 a	9.7 b*	0.5 a	3.5a
se	0.0	0.0	0.3	2.1	0.3	1.5
total added	0	66	1604	15703	678	4851

	Se		Sr		Zn	
	GSL	RSL	GSL	RSL	GSL	RSL
Grand mean	0.0 a	0.0 a	0.0 a	0.4 b*	0.0 a	0.1b
se	0.0	0.0	0.1	0.1	0.0	0.0
total added	0	0	77	693	136	434

1 GSL=Freshly cut green slash, RSL=1 year old red slash.
2 a-b Means with same letter are not significantly different (α =.05).
* Differences are very significant (α =.01).
** Differences are extremely significant (α =.001).

Table 5. Average pH of weekly samples from leachates of green and red slash from western juniper (trials 1 and 2).

Material	Trial 1		Trial 2	
	GSL	RSL	GSL	RSL
	pH	pH	pH	pH
Samples				
Week 1	6.1	6.3	5.2	6.0
Week 2	6.8	7.5	5.8	7.4
Week 3	6.5	6.8	5.6	7.1
Week 4	7.5	8.0	5.4	8.0
Week 5	6.3	8.8	5.9	7.5
Week 6	5.8	9.4	6.8	7.6
Mean for trial	6.5	7.8	5.8	7.3
se	0.60	1.18	0.56	0.69
n	6	6	6	6

individually quantifiable (Table 6). Altogether, gas chromatography revealed the presence of 17 separate compounds among the two leachate samples, identified by retention times (RT) relative to a standard compound, fenchone. The majority of these compounds (16) were leached from the older slash. Green slash produced 3 volatiles, 2 of which were also released from the red slash: RT 15.27 and 21.80 in the GSL, and RT 15.28 and 21.81 in the RSL. The initial leachings from the green slash contained double the amount of both compounds relative to the initial leachings from the older slash. By weight, however, the GSL only contained 12% of the total amount of volatiles leached from the red slash.

Preliminary analysis for phenolic contents in the two leachates revealed that the green slash released no detectable quantities of such compounds (Table 7). On the other hand, 4 phenolic compounds were detected in the initial leachings from the red slash. With the methods used, (HPLC), compounds could neither be identified nor quantified. However, the GSL sample analyzed was evaporated to twice the concentration of the RSL sample and thus increased the relative importance of the presence of the compounds detected in the RSL.

Table 6. Assays* for volatile compounds in leachates of green and red slash from western juniper (from composites of the first 3 leachings in the first trial only).

Compound	GSL		RSL	
	RT[a]	Quantity (ug/100 ml)	RT	Quantity (ug/100 ml)
1	-	-	10.75	1.29
2	-	-	11.38	1.65
3	-	-	12.50	12.01
4	-	-	13.45	7.42
5	15.27	6.73	15.28	3.09
6	-	-	16.24	5.48
7	-	-	17.57	6.00
8	-	-	18.12	1.31
9	-	-	19.40	1.73
10	21.80	3.41	21.80	1.86
11	25.72	1.95	-	-
12	-	-	27.27	3.63
13	-	-	27.57	11.50
14	-	-	31.70	3.86
15	-	-	32.18	2.38
16	-	-	33.87	6.80
17	-	-	37.51	2.70
Total		12.09		72.71

*Assays by gas chromatography.
[a] Relative retention time based on fenchone internal standard.

Table 7. Assays* for phenolic compounds in leachates of green and red slash from western juniper (from composites of first 3 leachings in the first trial only).

Compound	GSL	RSL
	RT[a]	RT
1	-	17.41
2	-	21.22
3	-	21.52
4	-	27.36

*Assays by high-performance liquid chromatography (HPLC).
[a] Relative retention time based on resorcinol internal standard.

GERMINATION

Neither the addition of nutrients nor the presence of secondary compounds had any significant impact on the final percent of seeds germinated in either trial (Fig. 1). The 'Secar' bluebunch wheatgrass seed lot contained 95% viable seed. Mean germination percent among all treatments was 90 percent or better, with ranges generally 75-100 percent. One exception was a low of 59 percent for the control in the first trial.

Examination of germination rates calculated with Maguire's (1962) formula proved inconclusive. Effects of the various treatments were variable between trials (Fig. 2). While no significant differences in rates occurred in the first trial, the second trial showed significantly slower rates for seeds treated with the undiluted RSL (FR) relative to the controls and those receiving dilute leachate from the green slash. The dilute GSL (HG) treatment produced significantly faster germination than any of the other leachate treatments in the second trial.

EMERGENCE

The percent of seedlings emerging in a 24-day period was not significantly different between

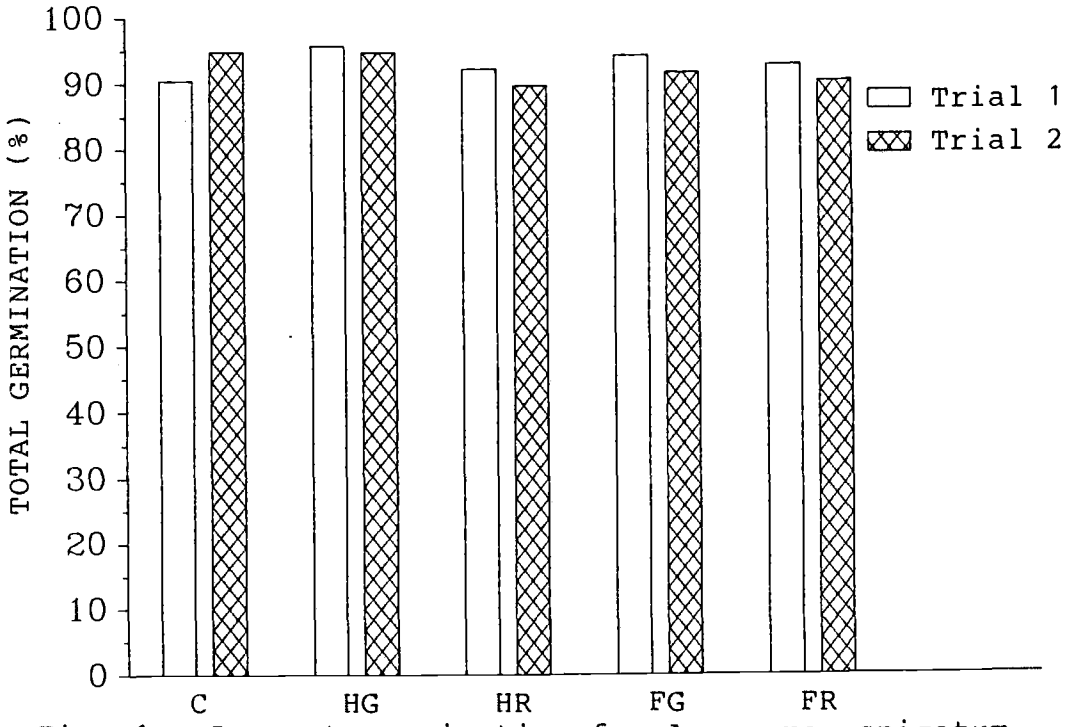

Fig. 1. Percent germination for Agropyron spicatum at 24 days post-planting (50 seeds per sample.). Treatments = distilled water (C), 50% diluted (v/v) green slash leachate (HG), 50% diluted (v/v) red slash leachate (HR), undiluted green slash leachate (FG), undiluted red slash leachate (FR). Means within trials were not significantly different ($\alpha = .05$).

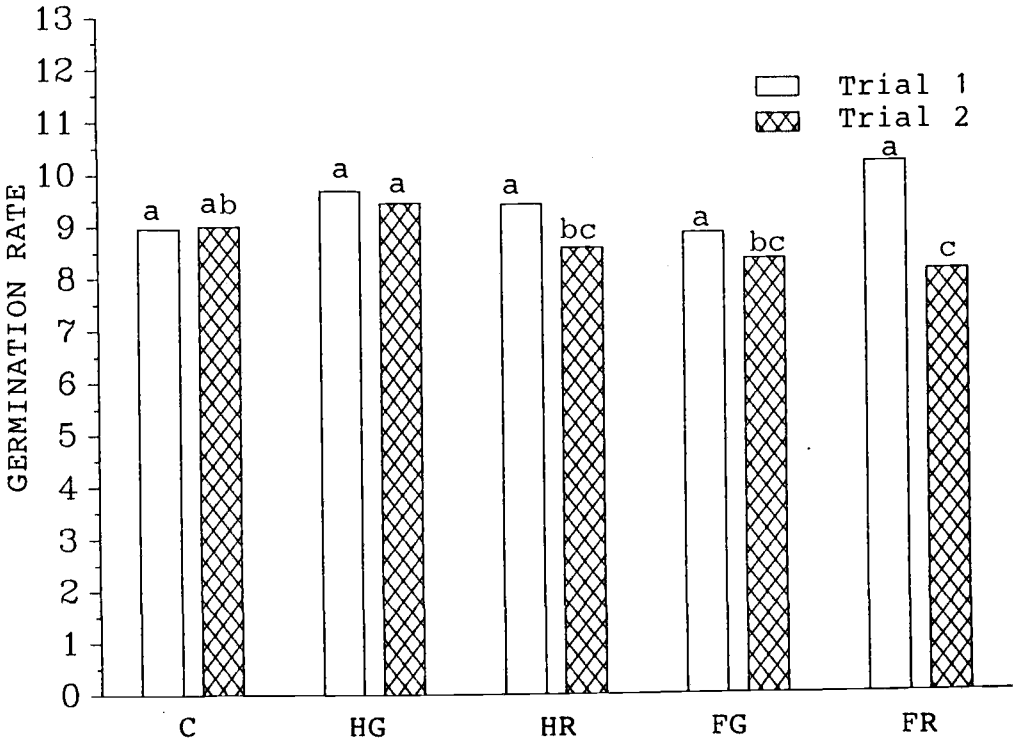

Fig. 2. Maguire's germination rate for Agropyron spicatum. Treatments = distilled water (C), 50% diluted (v/v) green slash leachate (HG), 50% diluted (v/v) red slash leachate (HR), undiluted green slash leachate (FG), undiluted red slash leachate (FR). Within trials, means with the same letter are not significantly different (α =.05).

treatments for either trial (See Appendix B for ANOVA tables). The only main effect differences were between species, with no interaction. In the first trial, the percent of Secar seedlings emerging was comparable to the percent of viable seed in the seedlot (Fig. 3). The confidence limits for percent emergence (trial 1) are comparable to those resulting in the germination trials with the species. In the second trial, 'Secar' average emergence was much lower than expected from previous results, regardless of treatment.

For Nezpar and Sherman, emergence was well below the percent of viable seed in their respective seedlots, as described by the suppliers: Nezpar being 79% viable seed (BPMC, unpubl.) and Sherman being 77% viable seed (PPMC, unpubl.). The confidence limits on 'Nezpar' emergence include the percentage of viable seed, but only for controls in the first trial.

For 'Sherman' big bluegrass in the first trial, the confidence limits for all treatments included the percentage of viable seed available, but the confidence intervals were extremely wide, particularly for RSL treatments. In the second trial, the upper limit on Sherman emergence fell well below the percent viable seed, with the RSL treatment. Results for controls and GSL treatments approached or marginally included the percent of viable seed within their upper limits for total emergence.

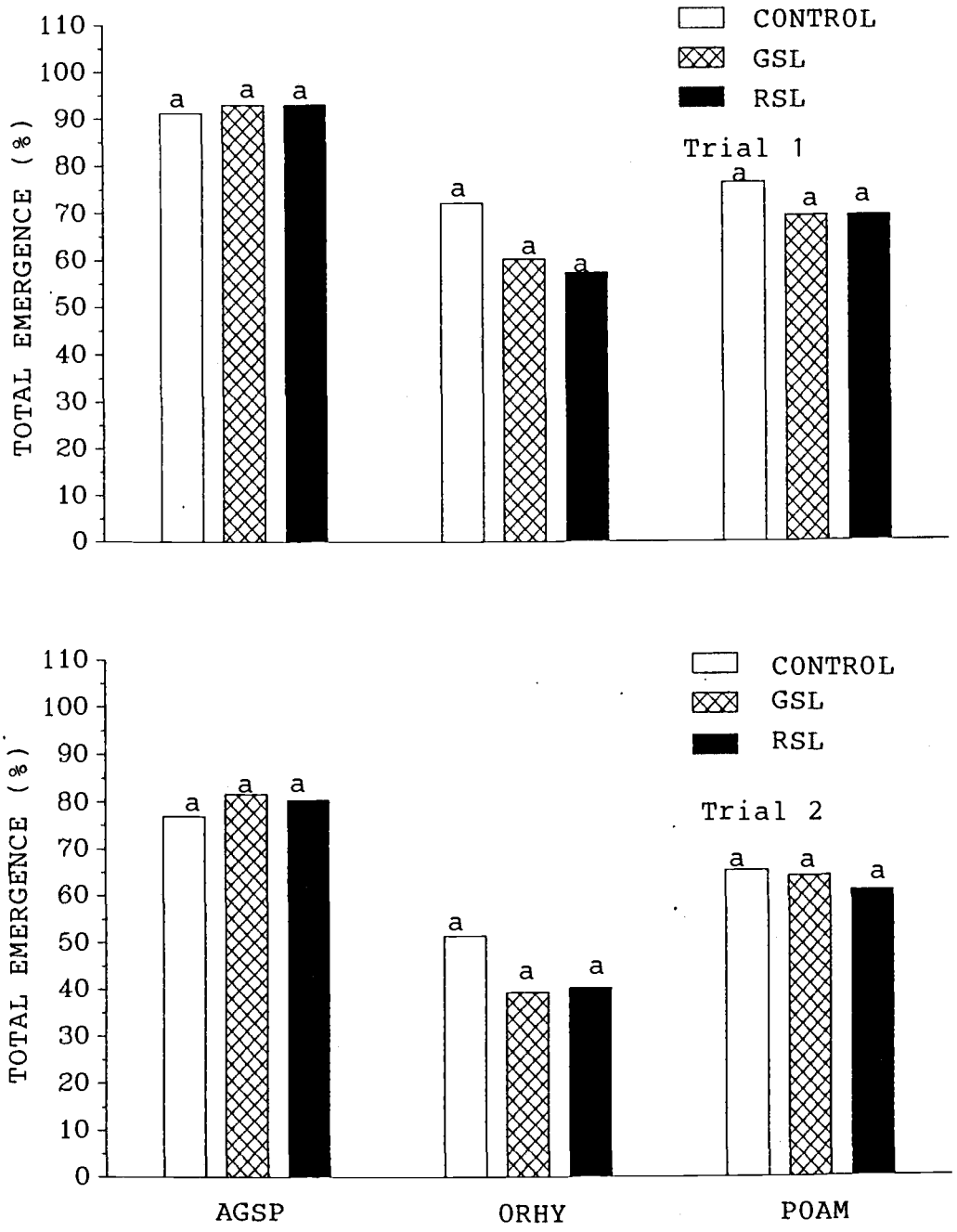

Fig. 3. Mean percent emergence for 'Secar' bluebunch wheatgrass (AGSP), 'Nezpar' Indian ricegrass (ORHY), and 'Sherman' big bluegrass (POAM). CONTROL = distilled water, GSL = green slash leachate, RSL= red slash leachate. Within trials, means with the same letter, within species, are not significantly different (α =.05).

As with percent emergence results, emergence rates in both trials showed significant differences only among species, with no interactions (Table B-4). Generally, emergence rates in the second trial were slower than those in the first trial (Fig. 4). Results paralleled those for percent emergence.

GROWTH

Root biomass

Blocking effectively removed some of the variability in results. Here, the species-treatment interactions were significant (Fig 5). Root growth in 'Secar' bluebunch wheatgrass control plants showed similar differences between the first and second trials. In both trials, root growth showed significant inhibition in plants watered with RSL relative to that of control and GSL. Green slash leachate produced significant reductions in root biomass relative to control only in the first trial. For each species, root biomass was similar between trials for plants treated with GSL or RSL leachates. Growth of control plants appeared greater in the first trial, for each species.

For Nezpar Indian ricegrass, there were no significant differences between treatments for root biomass in either trial. For Sherman big bluegrass,

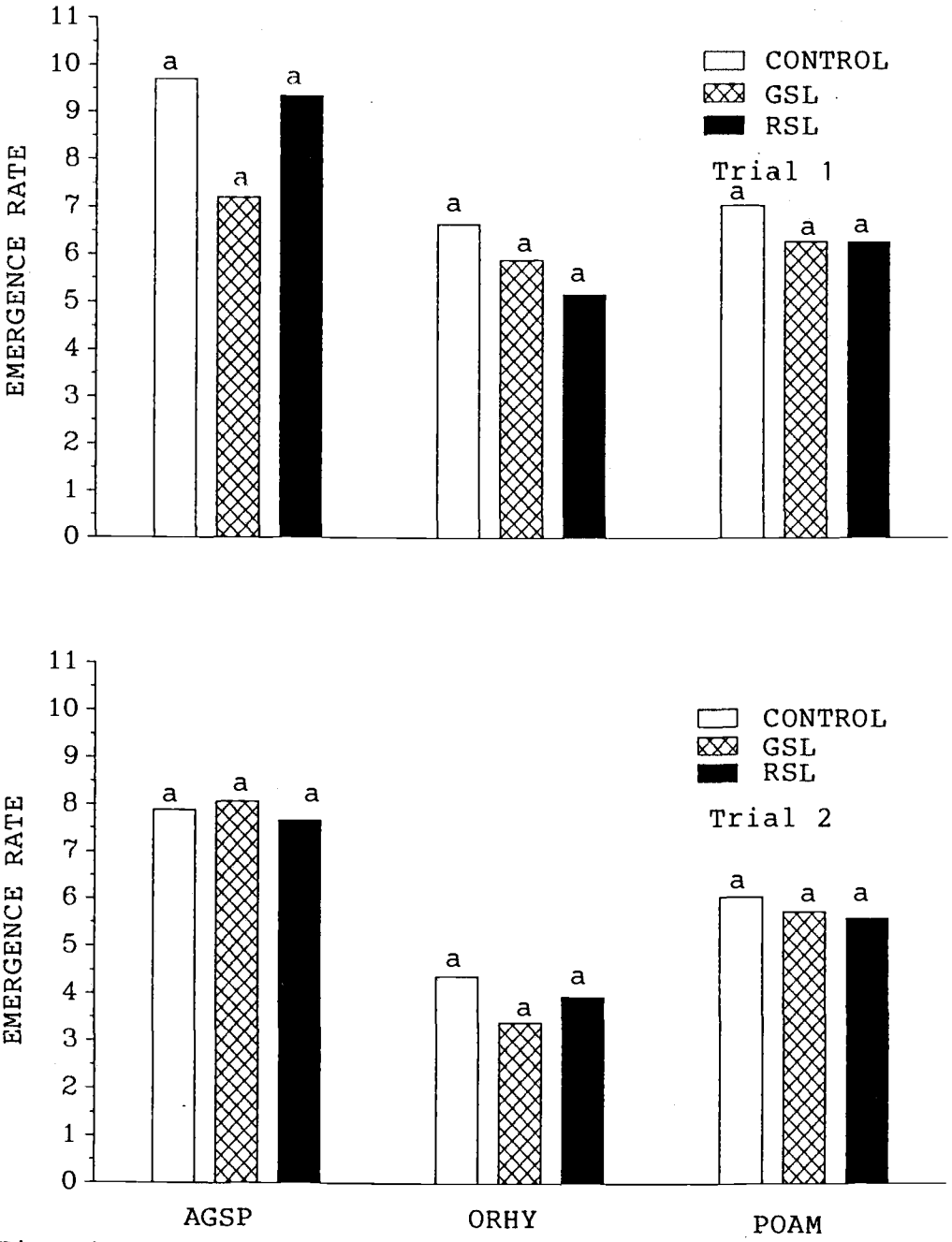

Fig. 4 Mean emergence rate (Maguire's statistic) for 'Secar' bluebunch wheatgrass (AGSP), 'Nezpar' Indian ricegras (ORHY), and 'Sherman' big bluegrass (POAM) at 44 days growth. Treatments = distilled water (CONTROL), green slash leachates (GSL), red slash leachates (RSL). For each trial, means with the same letter, within species, are not significantly different ($\alpha = .05$).

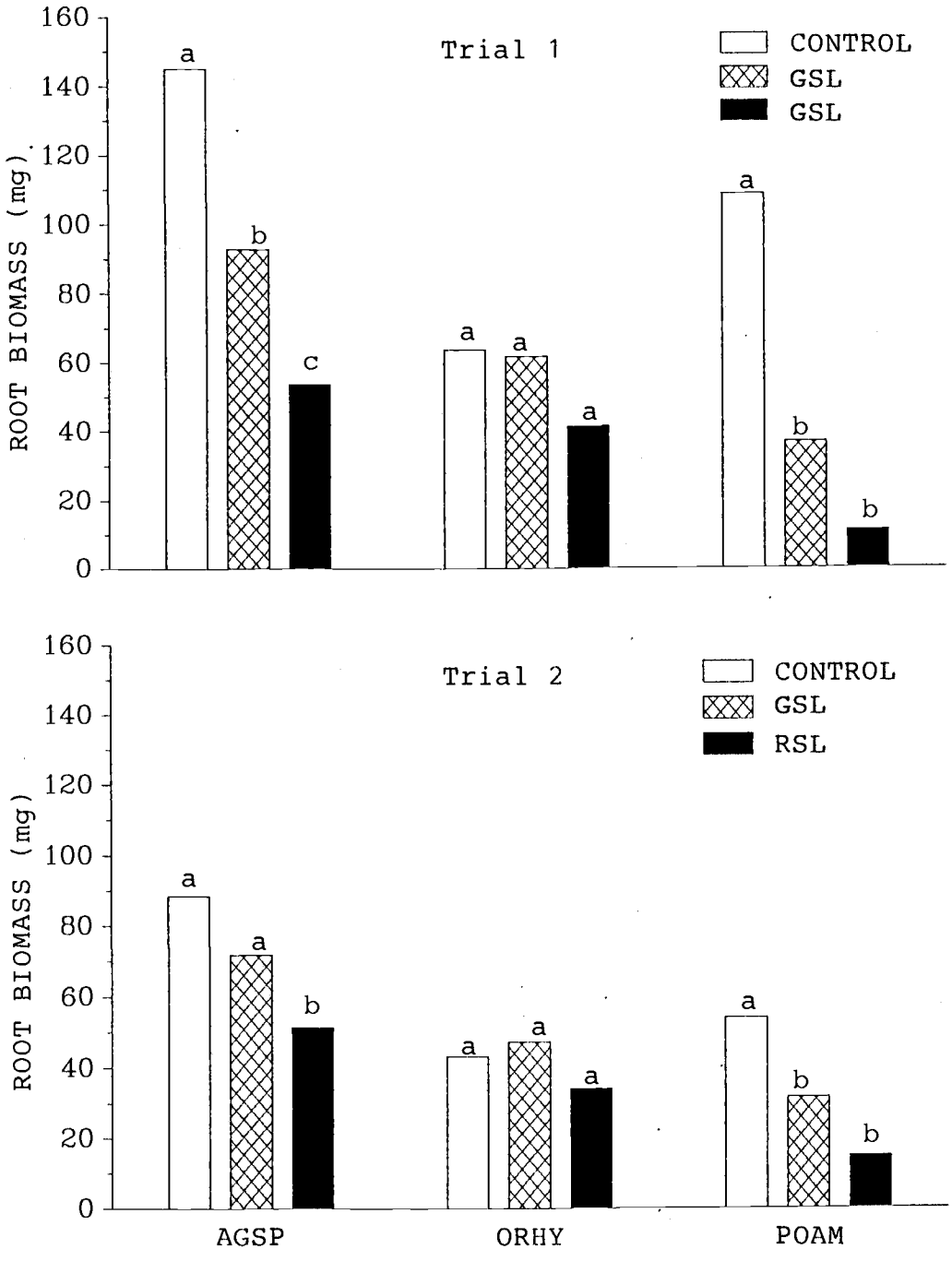

Fig. 5. Average root biomass per plant for 'Secar' bluebunch wheatgrass (AGSP), 'Nezpar' Indian ricegrass (ORHY), and 'Sherman' big bluegrass (POAM) at 44 days growth. Treatments = distilled water (CONTROL), green slash leachate (GSL), red slash leachate (RSL). For each trial, means with the same letter, within species, are not significantly different (α =.05).

however, both leachate treatments significantly reduced the amount of root growth relative to control plants. Root growth was similar between GSL and RSL treatments for the bluegrass, irrespective of trial. Root biomass growth by control plants in the first trial was twice that of the second trial.

Shoot biomass

Blocking removed variation in results for shoot development in both trials. Both treatment and species main effects were significant, with no interactions in either trial. Separation of means by LSD revealed however, that responses to treatment did depend upon the species (Fig. 6). Indian ricegrass plants grown with the RSL showed significantly less top growth than controls or plants receiving the GSL, in both trials. Big bluegrass plants responded similarly to either leachate, and both leachates inhibited shoot growth relative to controls, irrespective of trial.

For bluebunch wheatgrass, results were less clean-cut, but in both trials the plants watered with the RSL produced significantly less shoot biomass than did control plants. In the first trial, each of the three treatments produced significantly different quantities of top growth, with GSL producing intermediate amounts of biomass. In the second

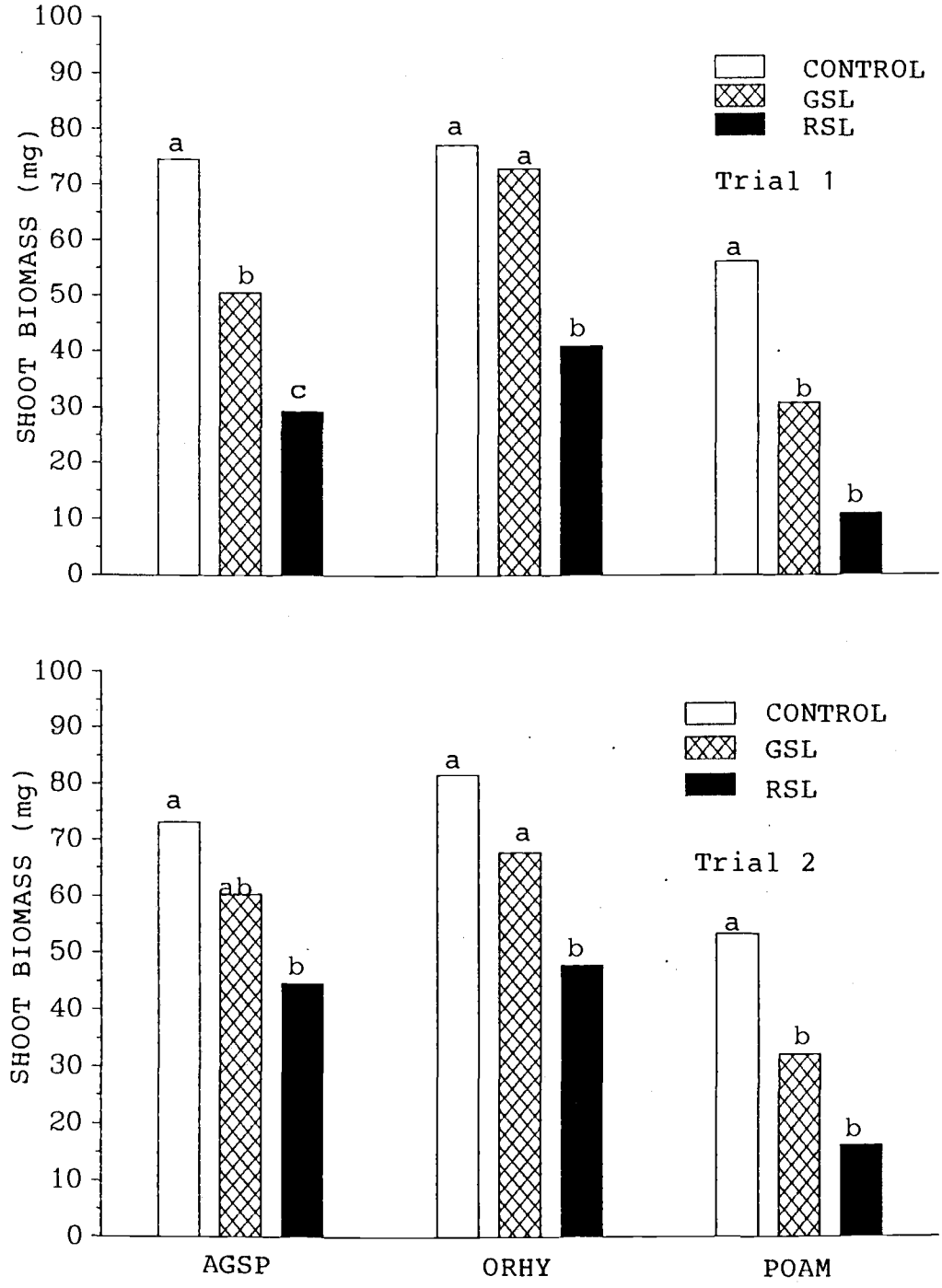

Fig. 6. Average shoot biomass per plant for 'Secar' bluebunch wheatgrass (AGSP), 'Nezpar' Indian ricegrass (ORHY), and 'Sherman' big bluegrass (POAM) at 44 days growth. Treatments = distilled water (CONTROL), green slash leachate (GSL), red slash leachate (RSL). Within trials, means with the same letter, within species, are not significantly different (α =.05).

trial, aboveground biomass produced under the GSL treatment again was intermediate, but was not significantly different from either of the other two treatments. Production within species, within treatments, was similar between the two trials, with no outstanding relative differences.

Root-to-shoot Ratios

The only significant factor in the analysis of variance for root-shoot ratios was the species. The LSD showed however, that while there were no overall differences between treatments in the second trial, that plants grown with the GSL allocated significantly more resources to aboveground biomass compared to allocations by control plants (Table 8). For both trials, Indian ricegrass allocated half or more of its resources to top growth, whereas the other two species placed more than 50 percent of their growth into root development. All allocations to preferred sinks were relatively greater in the first trial than in the second trial. Relative allocations to roots in control plants for each species in the first trial, were twice the allocations in the second trial.

For bluebunch wheatgrass and for Indian ricegrass, there were no significant differences between treatments in either trial for relative allocations to roots versus shoots. In the first trial, control big

Table 8. Mean root/shoot ratios, standard errors and sample sizes for leachates, species and leachate by species at 42 days growth.

	Trial 1			Trial 2		
Leachate	$\bar{X}$	se	n	$\bar{X}$	se	n
Control	1.91	(0.304)	9a	0.91	(0.121)	9a
Green	1.37	(0.154)	9b	1.02	(0.143)	9a
Red	1.67	(0.186)	9ab	1.02	(0.167)	9a
Species						
A. spicatum	2.16	(0.186)	9a	1.29	(0.112)	9a
O. hymenoides	1.04	(0.113)	9b	0.75	(0.171)	9b
P. ampla	1.75	(0.203)	9a	1.10	(0.094)	9ab
Leachate by Species						
A. spicatum						
Control	2.37	(0.505)	3a	1.21	(0.151)	3a
Green	1.94	(0.059)	3a	1.40	(0.288)	3a
Red	2.17	(0.330)	3a	1.27	(0.189)	3a
O. hymenoides						
Control	1.09	(0.363)	3a	0.48	(0.052)	3a
Green	0.93	(0.101)	3a	0.66	(0.087)	3a
Red	1.10	(0.044)	3a	1.11	(0.484)	3a
P. ampla						
Control	2.26	(0.467)	3a	1.04	(0.092)	3a
Green	1.24	(0.071)	3b	1.00	(0.142)	3a
Red	1.74	(0.107)	3ab	1.27	(0.237)	3a

* Within trials, within groups, means with the same letter are not significantly different ($\alpha = .05$).

bluegrass plants allocated significantly greater growth to roots relative to shoots, compared to plants receiving the GSL, which grew relatively greater shoot biomass. In the second trial however, there were no significant differences for big bluegrass between treatments for relative allocations to roots versus shoots.

Shoot height

Treatment and species main effects were significant in both trials, with no interactions for shoot height. In both trials, the plants receiving the RSL developed shoots which were significantly stunted relative to control plants (Fig. 7). The only exception was Secar bluebunch wheatgrass in the second trial. Only big bluegrass in the first trial showed significant differences in shoot height development between all three treatments, with GSL-treated plants showing moderate stunting and RSL-treated plants displaying severe stunting. Within treatments, height growth for each species was generally less in the first trial than in the second, reflecting the proportionately greater allocations to roots in the first trial.

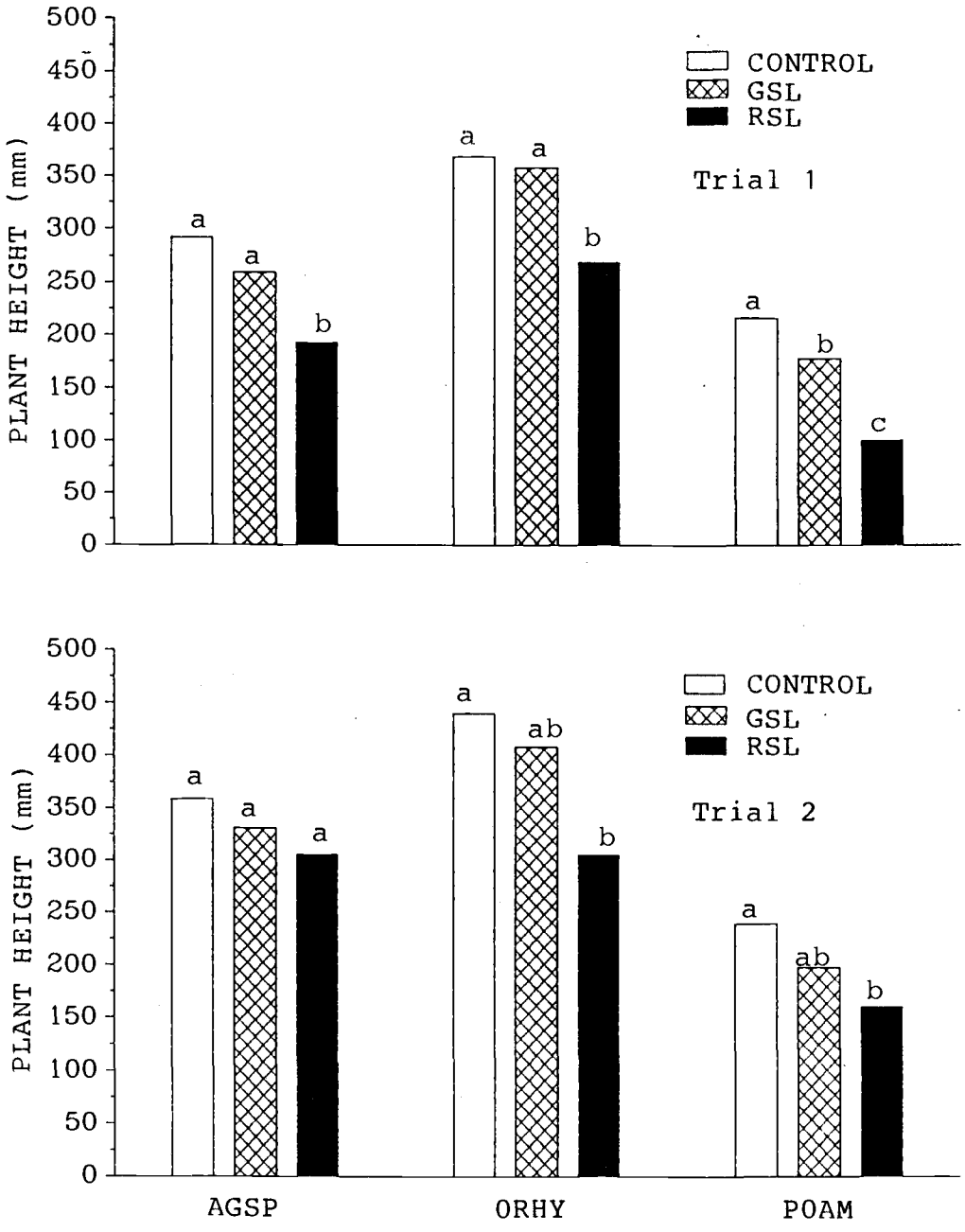

Fig. 7. Plant height (from plant base to tip of longest leaf) for 'Secar' bluebunch wheatgrass (AGSP), 'Nezpar' Indian ricegrass (ORHY), and 'Sherman' big bluegrass (POAM) at 44 days growth. Treatments = distilled water (CONTROL), green leachate (GSL), and red slash leachate (RSL). Within trials, means with the same letter, within species, are not significantly different ($\alpha = .05$).

Tillering

Blocking effectively reduced variation in tillering for both trials. Effects were dissimilar between the two trials for tiller development. In the first trial, there was interaction between species and treatments, whereas, in the second trial only the treatments had any effect, according to analysis of variance. Confidence intervals for treatment differences within a species, using , showed that only big bluegrass had significantly less tillering with the RSL treatment, with similar results for both trials (Fig. 8).

Number of leaves

Blocking removed some of the variation in results for number of leaves, but treatment-species interactions were highly significant in both trials. Paralleling the development of tillering, as discussed above, there were no significant differences between treatments for either bluebunch wheatgrass or Indian ricegrass (Fig 9). However big bluegrass grew significantly reduced numbers of leaves when treated with the RSL, relative to controls. As with tillering, big bluegrass plants receiving the GSL showed some intermediate reductions in leaf development in both trials, which were not different from either control plants or RSL plants.

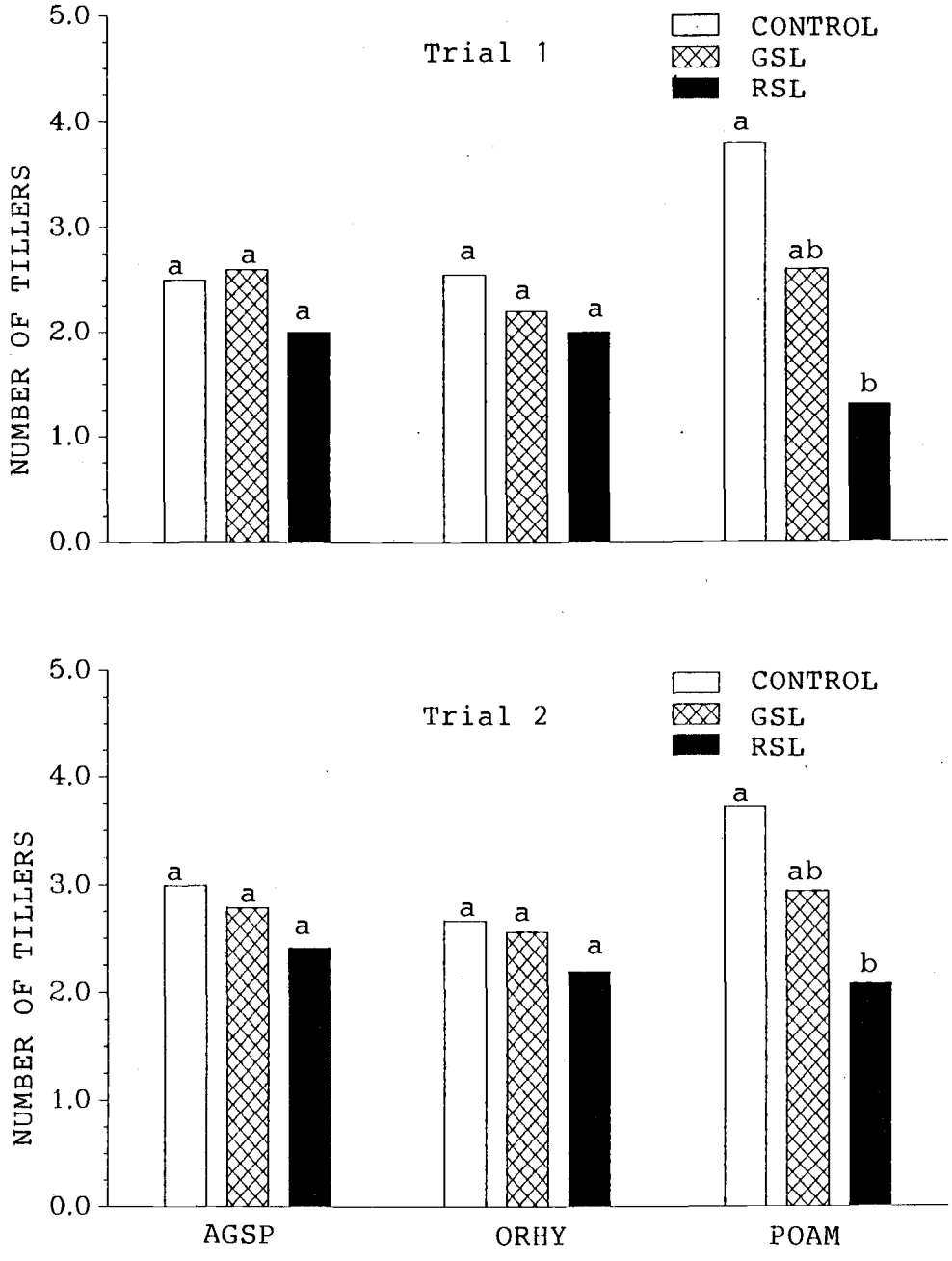

Fig. 8. Average tillers per plant for 'Secar' bluebunch wheatgrass (AGSP), 'Nezpar' Indian ricegrass (ORHY), and 'Sherman' big bluegrass (POAM) at 44 days growth. Treatments = distilled water (CONTROL), green slash leachate (GSL), and red slash leachate (RSL). Within trials, means with the same letter, within species, are not significantly different (α =.05).

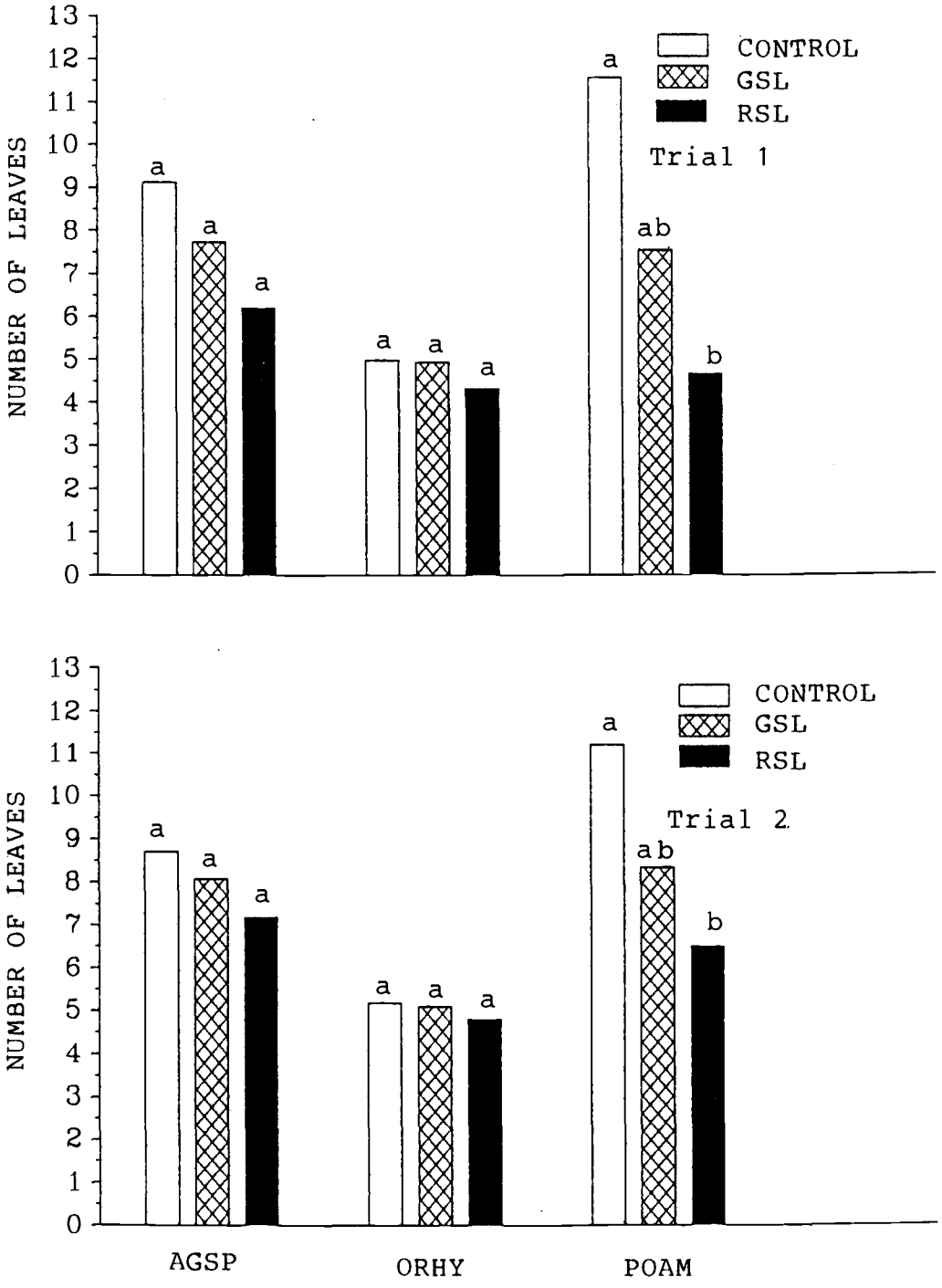

Fig. 9. Mean leaves per plant for 'Secar' bluebunch wheatgrass (AGSP), 'Nezpar' Indian ricegrass (ORHY), and 'Sherman' big bluegrass (POAM) at 44 days growth. Treatments = distilled water (CONTROL), green slash leachate (GSL), red slash leachate (RSL). Within trials, means with the same letter, within species, are not significantly different ($\alpha = .05$).

DISCUSSION

This study was designed first, to evaluate potential positive effects on the germination, emergence and growth of native forage grasses in low-fertility soils such as those found in juniper-dominated communities, when nutrients leached from juniper slash are added to the soil. Secondly, the study examined the alternative possibility, negative effects on plant growth associated with the concurrent release of potentially toxic compounds from slash into the soil. Plant growth patterns reflect the complex environment surrounding a plant, including the plant's nutritional status.

Both plant and soil analyses are used to identify plant nutrient deficiencies. Soil analysis defined the potential supply of nutrients available in the initial growth medium for plant uptake and growth. Plant tissue analyses clarified the kinds and amounts of nutrients potentially available for leaching, while bioassays indirectly demonstrated probable treatment-related deficiencies through reduced growth when leachates were added to an already deficient soil.

Soil used in this study contained total N levels of (< 0.05%) considered marginal to deficient for semiarid and aridland soils (Skujins and West 1973, Tiedemann 1987). This value is considerably below values for

interspace soils in western juniper communities (0.15%) recorded by Doescher et al (1985), and for singleleaf pinyon-Utah juniper communities (Thran and Everett 1987). Phosphorus levels were higher than values recorded from Utah juniper soils, where this element was considered more directly limiting to juniper growth than was nitrogen (Bunderson et al 1985).

Sulfur content of green slash was deficient, similar to values considered deficient by Will and Youngberg (1978, 1979), for conifer foliage on central Oregon pumice soils. Their conclusions were based on both plant tissue analyses and bioassays with native woody plants. Levels of N and P in green slash were comparable to those found in Utah juniper foliage by Bunderson and Weber (1986), though levels of Ca, Mg, and K were considerably less in western juniper.

There was little evidence of nutrient loss from the year-old red slash relative to freshly-cut green slash, prior to water leachings. However, Doescher et al (1987) commented on the apparent slowness of decomposition in juniper litter beneath mature western junipers, and associated low levels of total N in subcanopy soils relative to quantities measured beneath juvenile trees.

From the few studies which have been done (Skujins and West 1973, West 1981, Young and Evans 1987) leaching does not contribute more than minute amounts of nitrogen

to desert soils, either from foliage or litter. Both Whitford (1986) and Santos et al (1984) found seasonal decomposition rates of Larrea tridentata litter responded poorly if at all to increased seasonal precipitation. Initial increases in decomposition rates with winter precipitation were credited to leaching losses of materials which photo-oxidized during the previous dry season (Whitford 1986). The above explanation may also apply to evidence for leaching losses of N and K from Utah juniper foliage correlated with heavy September rains in Utah (Bunderson and Weber 1986). Hart and Parent (1974) believed that additions of N and K in throughfall from early fall storms in Rocky Mountain juniper and Douglas fir were largely produced by the washing of dry fallout and dust accumulated by foliage through the dry summer months.

Either process (fall-winter leaching of previously photo-oxidized material or washing of foliar-trapped dust) could explain the lack of added nitrogen in both GSL and RSL in this study. Both slash sources were collected in early spring, when photo-oxidized products and/or dust would already have been removed by fall-winter precipitation prior to collection. If photo-oxidation is the process which makes nitrogen and potassium available for leaching, green slash had not yet been exposed to a season of solar breakdown.

The chemical analyses of the leachates in this study give further evidence for the slowness of litter breakdown, since there were few differences ($p < .05$) between RSL and GSL for incremental losses of individual ions. Apparent higher incremental losses of some nutrients from the red slash may simply have been related to its greater bulk density relative to the less compactable green slash.

The differences in cumulative additions of some nutrients from the two sources may be more important than differences between average weekly samples would suggest, particularly in the first trial for Al, B, P, S and Sr. In the second trial, these same elements showed not only strongly suggestive cumulative differences, but also significant differences between average leaching events. Thus, real differences may exist between leaching losses of these elements from the two sources. Relative to controls, juniper slash from either source may lose biologically significant amounts of Al, B, Ca, K, Mg, Na, P, S, Sr and Zn.

The primary evidences for progressive physical-chemical breakdown in the two slash sources were: a) the progressive discoloration of each leachate over the course of 6-7 weeks, from pale yellow to dark yellow-green for GSL and from bright orange to deep rust-red brown for the RSL; b) the generally acidic pH of GSL samples and the moderate alkalinity of the RSL; c) the

much greater variety and quantity of volatile and phenolic compounds represented in the RSL compared to the GSL.

The two leachates together yielded 18 secondary compounds (including phenolics as a class), which probably represented the majority of the 26 volatile compounds identified by von Rudloff et al (1980). Due to the much higher concentration of volatiles and the sheer number of potentially allelopathic compounds, the RSL were chemically more likely to inhibit plant processes at various points in the life cycles of the receiver species. Although concentrations of individual volatile compounds seem quite low, researchers are still uncertain as to the importance of synergistic interaction among allelochemicals where the concentration of isolated compounds may be too low to inhibit plant processes (Mandava 1985, Putnam and Duke 1978, Einhellig et al 1985, Einhellig et al 1982, Williams and Hoagland 1982).

Release of nutrients from the slash would not be expected to increase germination percentages for 'Secar' bluebunch wheatgrass since this accession has 95% viable seed and control germination was equally high. Stimulation of overall germination would have been difficult to prove, since, as Koller (1972) stated, "...exposure of seeds to an environment of adequate

moisture, aeration and normal temperatures should suffice...for germination to take place."

There was no evidence for allelopathic interference with final germination, agreeing with results from Leather and Einhelllig (1985) and Einhellig et al (1982). Results for germination rate were mixed, however. While rates were unaffected in the first trial, rates were slower in the second trial with the undiluted RSL relative to controls. Conceivably, in the second trial allelopathic activity could have been triggered by a threshold concentration of one or more compounds, which was not achieved in the first trial.

In the greenhouse trials, there were no treatment effects on final emergence nor on emergence rates for any species within trials. However, final emergence was generally lower in the second trial and emergence rates were slower compared to the first trial, for any treatment-species combination, though differences between trials were not statistically tested. The presence of a few chlorotic seedlings which emerged in each trial gave evidence of allelopathic activity, lack of available N or both. Some researchers have correlated reductions in chlorophyll content to allelopathic activity (Colton and Einhellig 1980, Rice 1984, Leather and Einhellig 1985).

Although allelopathy may negatively affect both germination and seedling growth, some researchers believe that seedling growth, especially long-term seedling growth may be a more sensitive assay for allelopathic effects (Einhellig et al 1982, Rietveld 1983). In the present study, this would appear to be the case. In both trials, biomass, tillering and leaf development, and shoot elongation (height), irregardless of species, displayed a general pattern of progressive stunting of growth from treatments with distilled water to GSL slash leachates to red slash leachates, although not all such reductions were significant.

The sensitivity of a particular parameter generally depended upon the species. 'Nezpar' Indian ricegrass was most affected in terms of plant height and shoot biomass, but only by leachates from the red slash.

'Secar' bluebunch wheatgrass was reduced in terms of both root and shoot biomass by both leachates, but particularly by the RSL. Plant height was affected only slightly by the RSL in the second trial.

'Sherman' big bluegrass, with one exception, was inhibited in every aspect of growth measured, particularly by the RSL, and to some extent by the GSL. The single exception was the root/shoot ratio, where, in the first trial, the GSL reduced root/shoot ratios significantly more than the control, and RSL produced an intermediate effect. Thus, leachates from the red slash

appear to be more inhibiting to plant growth than leachates from the green slash.

The slight inhibitions by GSL suggest that at least one volatile compound in the GSL was actively allelopathic, since no phenolic compounds were detected in the sample analyzed. The two volatiles found in both leachates were twice as concentrated in the GSL leachate, yet the RSL appeared more inhibiting. This suggests various possibilities: 1) more than one compound was active in the RSL with additive or synergistic effects, 2) the active compound(s) in the GSL were not present in the initial sample but were released in subsequent leachings, 3) if the same compound was active in both leachates, it was probably less concentrated in the GSL, since allelopathic activity is generally concentration-dependent (Einhellig et al 1985), 4) one or both classes of compound (phenolics, volatiles) may have been responsible for the observed effects.

Most of the discoveries about the physiology of inhibition have come from studies using plant extracts, purified flavonoids or especially purified phenolic compounds identified from plant extracts. Fig. 10 outlines logical inter-relationships between various physiological processes (Einhellig et al 1985). Studies have shown that each of these processes may be altered by allelochemicals, whether directly or indirectly

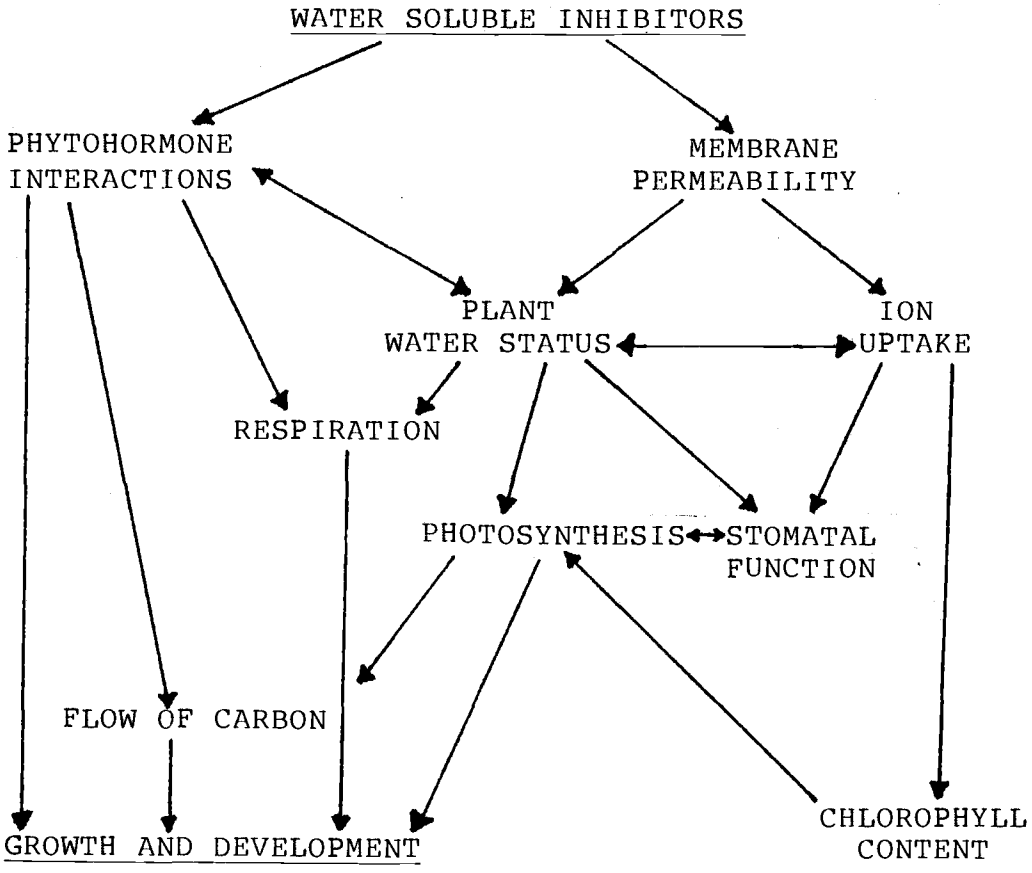

Fig. 10. Hypothetical action sequence suggesting allelochemical involvement in plant processes. Each arrow suggests a negative impact. From: Einhellig et al (1985).

(Harper and Balke 1981, Danks et al 1975a, Einhellig et al 1985, Van Sumere et al 1971, Danks et al 1975a, Glass and Dunlop 1974, Einhellig and Rasmussen 1979).

Roots are generally the first plant tissues to encounter both nutrients and potential allelochemicals, including phenolics and partially water-soluble volatiles. Reduced root growth has been observed by other researchers in allelopathy (Rice 1984, Einhellig et al 1985) as well as in the present study. However, few researchers have considered the effects of volatiles partially suspended in solution with relation to roots (Mandava 1985, Hoagland and Williams 1985, Balke 1985).

Balke (1985) has reviewed the accumulating evidence that one pathway by which allelochemicals reduce plant growth is by inhibiting the uptake of ions and altering related physiological processes. From Balke's review, the uptake of the PO_4^{3-} ion is most consistently reduced, followed by nitrogen, while potassium and magnesium uptakes were only occasionally lowered.

Reduced root growth is inconsistent with a limited supply of either nitrogen or phosphorus. Plants respond to limitations in the supply or uptake of either ion by increasing root growth at the expense of shoot growth, thereby increasing root/shoot ratios (Drew and Saker 1978, Maizlich et al 1980, Anghinoni and Barber 1980). Within each trial, root/shoot ratios did not vary among

treatments for any of the three species, with the exception of big bluegrass in the first trial. These results indicate that while nitrogen was probably already limiting, the mechanism of inhibition was not necessarily the further reduction of nitrogen or phosphorus uptake.

A limited supply, however, of magnesium will reduce root growth (Bouma et al 1979) and a limited supply of K or gibberelic acid (plant growth hormone) will slow the rate of shoot growth (Bussler 1964). The production of giberrellic acid depends on the supply of cytokinins (growth hormone) transported from the roots where it is produced (Marschner 1986, Carmi and Van Staden 1983). The production of cytokinin depends primarily on the supply of nitrogen (Wagner and Michael 1971) and secondarily on the supply of phosphorus and potassium (Horgan and Wareing 1980). Cytokinins are transported from the roots in the phloem, thus inhibition of potassium uptake affecting stomatal closures and/or plant water potentials may have led to reduced transport of cytokinins and indirectly inhibited top growth of all three grasses. Baranov (1979) has also shown that phenolics may interfere directly with plant hormonal activity. Therefore, the growth reductions in separate targeted plant parts may have occurred via more than one pathway related to reduced uptake of both magnesium and

potassium, or plant hormonal activity may have been directly altered.

Stowe (1979) conducted allelopathic studies on a number of old-field herbaceous species in the laboratory. He attempted to correlate laboratory results with observed micropatterns of associations of the same species in an old field, meeting with little success. He concluded that bioassays may have little relevance to ecological interactions in many natural communities. He hypothesized that certain modes of inhibition may operate in bioassays, while different pathways of inhibition may operate in natural communities.

In a subsequent laboratory study, Stowe and Osborne (1980) found that significant allelopathic inhibition by phenolics occurred universally at low levels of nitrogen and/or phosphorus, with little or no inhibition as supplies of these nutrients increased. They concluded that phenolics most likely inhibit plant growth on sites where nutrients are already limiting. The results from the present study would appear to support Stowe's and Osborne's conclusions. Although the specific mode of action and the specific inhibitors may only be speculated, the mechanisms of inhibition of nutrient uptake, inhibition of hormonal activity, or both are probably at least partially responsible.

To summarize, juniper slash did not release measureable amounts of nitrogen with simulated rainfall events, although other ions were released in measurable quantities. When compared to green slash, red slash released significantly greater amounts of some ions. Red slash also released many more potentially allelopathic compounds relative to green slash. These compounds were phenolics and volatile oils. Differences in magnitudes of losses of ions and secondary compounds may be more closely related to higher densities of the more compacted red slash than to actual differences in decomposition status between the two sources of slash. Leachates produced neutral or negative effects on plant growth. The specificity and magnitude of effects varied among species, with RSL generally producing more negative effects on growth. Allelopathic compounds, based on plant growth patterns, may have inhibited ion uptake, hormonal functions, or both.

MANAGEMENT IMPLICATIONS

When a juniper-dominated site is to be converted back to a grass or shrub-grass community, slash disposal should maximize benefits to the new community. Where seeding is necessary, grasses could be seeded before clearing the juniper or seeded immediately into the green slash. Slash could be left in the interspace areas until scales turned brown and actually began to drop. Interspace soils would receive some benefits from marginal release of some nutrients from the slash up to this point. If slash was scattered rather than concentrated, insignificant quantities of toxic secondary compounds should accumulate.

Grass species used in this study, and perhaps other species as well, should germinate and emerge satisfactorily from beneath green or red slash. The greatest problem appears to arise with seedling establishment and growth associated with red slash. Toxic concentrations of phenolics (and perhaps volatiles) are most likely to develop under conditions where litter is compacted and waterlogged (Pingel 1976, Borner 1957, Harper and Lynch 1982). Based on this study, these conditions may be expected beneath dense layers of red slash but may also develop over time in the lower part of the green slash layers.

Since foliar tissue in slash remains green for approximately 6-12 months, trees could be cut and grasses seeded in the fall prior to fall precipitation. Seedlings could then establish and gain one season of growth the following spring while slash was still relatively green. Seedlings could derive some benefits from shading and a favorable microclimate, along with slightly improved soil levels of phosphorus and sulfur, during the first season of growth, thus aiding establishment.

Because allelopathic toxicity is concentration-dependent, it is directly related to the density of the slash. Once slash turns red and scales begin to drop, further treatment may be needed. The slash could be scattered to reduce inhibitory buildups of allelo-chemicals, while still allowing for long-term return of nutrients to the site.

Another possibility would be to combine treatments. Some trees could be patch cut and small slash piles created in the interspaces one year. Accumulations of allelochemicals would probably be minor from such small piles while the slash was still green. Piles would be burned the following year in the spring while soils are still wet to reduce losses of organic matter from the A horizon (Frandsen and Ryan 1983) and reduce leaching losses from the system before plants and fungal/microbial populations can immobilize them. The

large woody debris would remain on-site to continue slowly returning nutrients to the soil. The area could then be seeded.

Burning slash piles would give a short-term flush of nutrients (including nitrates) to the soils while seeded plants are establishing. Once piles are burned, and the area seeded, a very light scattering of new slash could be placed on the burn sites to continue long-term release of nutrients, provide some moderating influences on soil temperature and soil moisture regimes. Although this option would be more labor-intensive, the long-term benefits may offset the costs.

Any management option involving the use of fire to reduce the amount of on-site slash may entail the long-term loss of significant amounts of total nitrogen from the site, particularly where broadcast burning is used to eliminate small junipers, by consuming accumulated duff and litter along with newly created slash (Tiedemann 1987). Burning slash piles probably would entail small overall losses of on-site nitrogen since duff and litter would not be consumed (Tiedemann 1987). Short-term trade-offs are the increased amounts of mineralizable nitrogen available for plant growth.

Where broadcast burning is part of the program to reduce the possibility of allelopathic effects from juniper slash and eliminate young juniper, burns should be delayed for several years until seeded grasses are

well established. Plans should also include methods to replace or ameliorate the longer-term losses of nitrogen from sites. One possibility to achieve these goals would be to include nitrogen-fixing species as part of a seed mix.

Of the species used in this study, species selections for seeding would be 'Nezpar' Indian ricegrass or 'Secar' bluebunch wheatgrass where allelopathy is a concern related to site management. Because Indian ricegrass has the capacity to fix nitrogen through its rhizosphere associations (Wullstein 1978), planting this species on suitable sites could offset the negative effects of site losses of nitrogen from a light prescribed burn. 'Sherman' big bluegrass would only be chosen for sites where slash management plans do not predict future problems with allelopathy after other site factors are considered.

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APPENDICES

Appendix A: Mean Germination, Emergence and Growth Responses to Slash Leachates

Table A-1. Mean germination (%) at 30 days, for *Agropyron spicatum* watered with leachates from juniper slash in two stages of decomposition (50 seeds per sample).

Leachate	Conc.	Trial 1		
	(% v/v)	Mean	C.I.	n
Control		90.4	59.0-99.9	5
Slash				
Green	50	95.7	89.3-99.3	5
	100	92.2	75.3-99.7	5
Red	50	94.1	81.8-99.7	5
	100	92.7	82.6-98.5	5

Leachate	Conc.	Trial 2		
	(% v/v)	Mean	C.I.	n
Control		94.8	91.2-97.6	5
Slash				
Green	50	94.7	91.6-97.1	5
	100	89.6	85.2-93.2	5
Red	50	91.6	87.5-94.7	5
	100	90.2	75.7-98.4	5

Table A-2. Mean germination rates of Agropyron spicatum watered with leachates from juniper slash in two stages of decomposition (50 seeds per sample).

Leachate	Concentration (% v/v)	Trial 1 Mean	se	n	
Control		8.97	0.451	5	a
Green slash	50	9.69	0.051	5	a
	100	8.85	0.216	5	a
Red slash	50	9.41	0.167	5	a
	100	10.18	0.528	5	a

Leachate	Concentration (% v/v)	Trial 2 Mean	se	n	
Control		9.00	0.115	5	ab
Green slash	50	9.45	0.509	5	a
	100	8.34	0.132	5	bc
Red slash	50	8.57	0.152	5	bc
	100	8.10	0.305	5	c

Table A-3. Mean seedling emergence (%), 24 days after planting, for plants watered with leachates from juniper slash in two stages of decomposition (trial 1).

Leachate	$\bar{X}$	C.I.	n
Control	81.1	57.6-95.7	9a
Green	76.6	33.3-98.9	9a
Red	75.7	34.5-97.9	9a
Species			
A. spicatum	92.7	82.3-98.6	9a
O. hymenoides	63.4	43.0-80.4	9b
P. ampla	71.9	51.2-87.6	9ab
Leachate by Species			
A. spicatum			
Control	91.4	74.7-99.4	3a
Green	93.2	82.3-99.1	3a
Red	93.2	85.8-98.0	3a
O. hymenoides			
Control	72.4	61.5-81.8	3a
Green	60.3	53.2-66.9	3a
Red	57.3	37.9-73.9	3a
P. ampla			
Control	76.6	56.4-91.1	3a
Green	69.4	48.9-85.3	3a
Red	69.4	12.1-98.7	3a

*Within groups, means with the same letter are not significantly different (=.05).

Table A-4. Mean seedling emergence (%), 24 days after planting, for plants watered with leachates from juniper slash in two stages of decomposition (trial 2).

Leachate	$\bar{X}$	C.I.	n
Control	65.1	36.8-86.3	9a
Green	63.2	15.2-93.8	9a
Red	61.8	15.9-92.2	9a
Species			
A. spicatum	79.7	67.4-89.3	9a
O. hymenoides	43.7	26.8-59.2	9b
P. ampla	63.3	50.1-74.9	9ab
Leachate by Species			
A. spicatum			
Control	57.7	67.1-85.1	3a
Green	81.7	80.9-82.6	3a
Red	80.4	61.3-93.5	3a
O. hymenoides			
Control	51.4	39.6-62.3	3a
Green	39.3	28.3-49.7	3a
Red	40.2	26.9-52.7	3a
P. ampla			
Control	65.2	52.9-76.0	3a
Green	63.9	45.4-79.3	3a
Red	60.8	55.0-66.3	3a

*Within groups, means with the same letter are not significantly different (=.05).

Table A-5. Mean emergence rate (Maguire's formula) for plants watered with leachates from juniper slash in two stages of decomposition

	Trial 1			Trial 2		
Leachate	$\bar{X}$	se	n	$\bar{X}$	se	n
Control	7.80	(0.500)	9a	6.11	(0.533)	9a
Green	6.46	(0.888)	9a	5.74	(0.686)	9a
Red	6.92	(0.663)	9a	5.74	(0.581)	9a
Species						
A. spicatum	8.75	(0.925)	9a	7.88	(0.190)	9a
O. hymenoides	5.90	(0.316)	9b	3.91	(0.213)	9c
P. ampla	6.53	(0.284)	9b	5.79	(0.581)	9b
Leachate by Species						
A. spicatum						
Control	9.70	(0.219)	3a	7.89	(0.265)	3a
Green	7.20	(2.890)	3a	8.07	(0.262)	3a
Red	9.34	(0.193)	3a	7.67	(0.504)	3a
O. hymenoides						
Control	6.65	(0.174)	3a	4.38	(0.427)	3a
Green	5.90	(0.672)	3a	3.40	(0.034)	3a
Red	5.16	(0.392)	3a	3.95	(0.342)	3a
P. ampla						
Control	7.05	(0.429)	3a	6.05	(0.274)	3a
Green	6.28	(0.455)	3a	5.74	(0.342)	3a
Red	6.26	(0.613)	3a	5.59	(0.439)	3a

*Within trials, means with the same letters are not significantly different (=.05).

Table A-6. Mean root biomass (mg) for plants watered with leachates from juniper slash in two stages of decomposition.

	Trial 1			Trial 2		
Leachate	$\bar{X}$	se	n	$\bar{X}$	se	n
Control	105.7	(14.59)	9a	61.9	(9.01)	9a
Green	63.7	(9.15)	9b	50.2	(7.51)	9b
Red	35.2	(7.03)	9c	33.4	(6.57)	9c
Species						
A. spicatum	97.2	(14.97)	9a	70.5	(8.27)	9a
O. hymenoides	55.4	(6.40)	9b	41.5	(5.73)	9b
P. ampla	52.0	(15.38)	9b	33.4	(5.97)	9b
Leachate by Species						
A. spicatum						
Control	145.1	(21.75)	3a	88.5	(15.54)	3a
Green	92.8	(8.37)	3b	71.8	(11.55)	3a
Red	53.6	(6.53)	3c	51.4	(9.97)	3b
O. hymenoides						
Control	63.5	(12.37)	3a	43.2	(12.97)	3a
Green	61.6	(10.94)	3a	47.3	(9.92)	3a
Red	41.2	(8.11)	3a	34.1	(9.04)	3a
P. ampla						
Control	108.4	(16.05)	3a	53.9	(2.25)	3a
Green	36.8	(5.42)	3b	31.6	(5.94)	3b
Red	10.9	(1.11)	3b	14.8	(1.68)	3b

*Within trials, means with the same letters are not significantly different (=.05).

Table A-7. Mean shoot biomass (mg) for plants watered with leachates from juniper slash in two stages of decomposition.

	Trial 1			Trial 2		
Leachate	$\bar{X}$	se	n	$\bar{X}$	se	n
Control	69.3	(5.08)	9a	69.4	(7.20)	9a
Green	51.4	(6.86)	9b	53.4	(6.24)	9b
Red	27.0	(5.47)	9c	36.2	(6.17)	9c
Species						
A. spicatum	51.4	(7.20)	9b	59.4	(5.24)	9a
O. hymenoides	63.7	(7.27)	9a	65.8	(7.94)	9a
P. ampla	32.6	(7.03)	9c	33.9	(5.98)	9b
Leachate by Species						
A. spicatum						
Control	74.5	(6.76)	3a	73.1	(7.93)	3a
Green	50.5	(3.32)	3b	60.3	(3.34)	3ab
Red	29.3	(7.32)	3c	44.7	(7.19)	3b
O. hymenoides						
Control	77.2	(8.97)	3a	81.7	(17.74)	3a
Green	73.0	(9.63)	3a	67.8	(8.71)	3a
Red	41.0	(8.27)	3b	47.9	(8.72)	3b
P. ampla						
Control	56.2	(7.24)	3a	53.3	(5.57)	3a
Green	30.8	(4.13)	3b	32.2	(5.23)	3b
Red	10.8	(2.57)	3b	16.2	(4.92)	3b

* Within trials, within groups, means with the same letter are not significantly different (=.05)

Table A-8. Mean plant height (mm) for plants watered with leachates from juniper slash in two stages of decomposition.

	Trial 1			Trial 2		
Leachate	$\bar{X}$	se	n	$\bar{X}$	se	n
Control	292.0	(22.92)	9a	345.8	(31.43)	9a
Green	265.0	(26.61)	9b	312.1	(32.24)	9a
Red	187.1	(24.82)	9c	272.0	(30.69)	9b
Species						
A. spicatum	247.6	(15.90)	9b	331.3	(14.14)	9b
O. hymenoides	331.9	(17.14)	9a	399.7	(16.99)	9a
P. ampla	164.7	(17.22)	9c	198.9	(14.71)	9c
Leachate by Species						
A. spicatum						
Control	291.3	(17.68)	3a	358.3	(24.69)	3a
Green	259.0	(12.06)	3a	330.7	(18.41)	3a
Red	192.3	(5.37)	3b	305.0	(27.21)	3a
O. hymenoides						
Control	368.7	(11.79)	3a	440.0	(30.55)	3a
Green	358.3	(12.17)	3a	197.7	(16.07)	3ab
Red	268.7	(14.72)	3b	351.0	(15.50)	3a
P. ampla						
Control	216.0	(5.20)	3a	239.0	(9.64)	3a
Green	177.7	(4.18)	3b	197.7	(23.67)	3ab
Red	100.3	(6.39)	3c	160.0	(19.55)	3a

*Within trials, within groups, means with the same letter are not significantly different (=.05).

Table A-9. Mean tillers per plant, for plants watered with leachates from juniper slash in two stages of decomposition. (trial 1)

Leachate	$\bar{X}$	C.I.	n
Control	3.1	2.0-4.4	9a
Green	2.4	1.8-3.2	9a
Red	1.8	1.0-2.8	9a
Species			
A. spicatum	2.5	1.6-3.6	9a
O. hymenoides	2.3	0.6-5.4	9a
P. ampla	2.5	1.5-3.1	9a
Leachate by Species			
A. spicatum			
Control	2.5	2.0-4.1	3a
Green	2.6	1.8-3.3	3a
Red	2.0	1.5-2.6	3a
O. hymenoides			
Control	2.6	1.9-3.3	3a
Green	2.2	1.8-2.9	3a
Red	2.0	1.0-3.3	3a
P. ampla			
Control	3.8	2.6-5.3	3a
Green	2.6	1.5-3.9	3ab
Red	1.3	0.9-1.8	3b

*Within groups, means with the same letter are not significantly different (=.05).

Table A-10. Mean tillers per plant, for plants watered with leachates from juniper slash in two stages of decomposition (trial 2).

	$\bar{X}$	C.I.	n
Leachate			
Control	3.1	2.1-4.3	9a
Green	2.8	1.8-3.9	9a
Red	2.2	1.5-3.1	9a
Species			
A. spicatum	2.7	2.0-3.6	9a
O. hymenoides	2.5	1.1-4.3	9a
P. ampla	2.9	2.0-3.9	9a
Leachate by Species			
A. spicatum			
Control	3.0	2.3-3.8	3a
Green	2.8	1.2-5.0	3a
Red	2.4	1.7-3.2	3a
O. hymenoides			
Control	2.7	1.8-3.7	3a
Green	2.6	2.2-3.0	3a
Red	2.2	1.1-3.7	3a
P. ampla			
Control	3.7	3.3-4.2	3a
Green	2.9	1.4-5.0	3ab
Red	2.1	1.1-3.3	3b

*Within groups, means with the same letter are not significantly different (=.05).

Table A-11. Mean leaves per plant, for plants watered with leachates from juniper slash in two stages of decomposition (trial 1).

Leachate	$\bar{X}$	C.I.	n
Control	8.3	2.7-16.7	9a
Green	6.7	3.7-10.5	9a
Red	5.0	3.2-7.3	9a
*Species			
A. spicatum	7.6	4.9-11.0	9a
O. hymenoides	4.7	2.3-8.0	9a
P. ampla	7.7	4.9-11.1	9a
Leachate by Species			
A. spicatum			
Control	9.1	5.9-13.0	3a
Green	7.7	6.3-9.3	3a
Red	6.2	4.8-7.8	3a
O. hymenoides			
Control	5.0	3.2-7.2	3a
Green	4.9	2.5-8.1	3a
Red	4.3	2.7-6.3	3a
P. ampla			
Control	11.6	6.8-17.6	3a
Green	7.6	5.3-10.2	3ab
Red	4.7	3.6-5.8	3b

*Within groups, means with the same letter are not significantly different (=.05).

Table A-12. Mean leaves per plant, for plants watered with leachates from juniper slash in two stages of decomposition (trial 2).

Leachate	$\bar{X}$	C.I.	n
Control	8.2	3.4-14.9	9a
Green	7.1	3.6-11.7	9a
Red	6.1	3.8-8.9	9a
Species			
A. spicatum	7.9	6.8-9.2	9a
O. hymenoides	5.0	2.0-9.3	9a
P. ampla	8.6	6.6-10.8	9a
Leachate by Species			
A. spicatum			
Control	8.7	7.0-10.6	3a
Green	8.1	5.0-11.8	3a
Red	7.2	5.9-8.6	3a
O. hymenoides			
Control	5.2	4.2-6.3	3a
Green	5.1	4.5-5.7	3a
Red	4.8	3.2-6.7	3a
P. ampla			
Control	11.2	10.1-12.3	3a
Green	8.3	4.1-14.0	3ab
Red	6.5	3.2-7.7	3b

*Within groups, means with the same letter are not significantly different (=.05).

Appendix B: ANOVA Tables for Germination, Emergence and Growth Responses to Slash Leachates

Table B-1. Analysis of Variance for percent germination of *Agropyron spicatum* at 24 days post-planting (Trial 1)

Source of variation	d.f.	Mean square	F-ratio	Pr > F
Treatment	4	.0159	1.23	.3295
Error	20	.0129		
Corrected total	24			

Table B-2. Analysis of Variance for percent germination of Agropyron spicatum at 24 days post-planting (Trial 2)

Source of variation	d.f.	Mean square	F-ratio	Pr > F
Treatment	4	.0215	1.02	.4201
Error	20	.0210		
Corrected total	24			

Table B-3. Analysis of Variance for germination rate of Agropyron spicatum at 24 days post-planting (trial 1)

Source of variation	d.f.	Mean square	F-ratio	Pr > F
Treatment	4	1.47	2.72	.0585
Error	20	.54		
Corrected total	24			

Table B-4. Analysis of Variance for germination rate of Agropyron spicatum at 24 days post-planting (trial 2).

Source of variation	d.f.	Mean square	F-ratio	Pr > F
Treatment	4	1.45	3.58	.0234*
Error	20	.41		
Corrected total	24			

Table B-5. Analysis of Variance for total seedling emergence (%) over 24 days (trial 1).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	4.5926	0.27	0.7638
Water	2	0.0196	1.49	0.2546
Species	2	0.6097	46.41	0.0001*
Water by Species	4	0.0141	1.07	0.4032
Error	16	0.0131		

Table B-6. Analysis of Variance for total seedling emergence (%) over 24 days (trial 2).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	0.0009	0.13	0.8795
Water	2	0.0040	0.56	0.5816
Species	2	0.4970	68.91	0.0001*
Water by Species	4	0.0105	1.46	0.2619
Error	16	0.0072		

Table B-7. Analysis of Variance for rate of emergence (trial 1).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	4.5142	1.44	.265
Water	2	4.1770	1.34	.291
Species	2	20.0863	6.43	.009*
Water by Species	4	1.7938	.57	.686
Error	16	3.1257		

Table B-8. Analysis of Variance for rate of emergence (Trial 2).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	.1413	.37	.700
Water	2	.4181	1.08	.363
Species	2	35.5119	91.85	.000*
Water by Species	4	.3009	.78	.555
Error	16	.3867		

Table B-9. Analysis of Variance for root biomass (trial 1).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	1723.4059	7.20	.006*
Water	2	11289.7737	47.18	0*
Species	2	5684.0959	23.75	0*
Water by Species	4	1567.3404	6.55	.003*
Error	16	239.3163		

Table B-10. Analysis of Variance for root biomass (trial 2).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	1563.1137	12.10	.001*
Water	2	1841.7159	14.26	0*
Species	2	3426.0370	26.52	0*
Water by Species	4	243.3615	1.88	.163
Error	16	129.171		

Table B-11. Analysis of Variance for shoot biomass (trial 1).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	769.888	11.97	.000*
Water	2	4051.573	63.01	0*
Species	2	2208.563	34.35	0*
Water by Species	4	105.403	1.64	.213
Error	16	64.300		

Table B-12. Analysis of Variance for shoot biomass (trial 2).

Source	d.f.	Mean square	F-Ratio	P > F
Table	3	1065.3426	8.88	.003*
Water	2	2472.9294	20.62	0*
Species	2	2567.6993	21.41	0*
Water by Species	4	22.4559	0.19	.942
Error	16	119.9368		

Table B-13. Analysis of variance for root/shoot ratios trial 1).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	.1307	0.50	.618
Water	2	.6475	2.46	.117
Species	2	2.8911	10.97	.001*
Water by Species	4	.1485	.56	.693
Error	16	.2636		

Table B-14. Analysis of variance for root/shoot ratios (trial 2).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	.3177	2.32	.131
Water	2	.2169	1.58	.236
Species	2	.6723	4.92	.022*
Water by Species	4	.0931	.68	.616
Error	16	.1370		

Table B-15. Analysis of Variance for plant height (trial 1).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	90.2593	.23	.797
Water	2	26696.0370	68.23	0*
Species	2	62918.9259	160.81	0*
Water by Species	4	218.5926	.56	.696
Error	16	391.2593		

Table B-16. Analysis of Variance for plant height (trial 2).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	1273.0370	.91	.423
Water	2	12278.2593	8.77	.003*
Species	2	93784.0370	67.01	0*
Water by Species	4	318.5926	.23	.919
Error	16	1399.6204		

Table B-17. Analysis of Variance for tillers per plant (trial 1).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	.0585	12.22	.001*
Water	2	.4116	86.07	0*
Species	2	.0147	3.07	.074
Water by Species	4	.0828	17.31	0*
Error	16	.0048		

Table B-18. Analysis of Variance for tillers per plant (trial 2).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	.0238	1.53	.247
Water	2	.1702	10.95	.001*
Species	2	.0347	2.23	.140
Water by Species	4	.0260	1.68	.205
Error	16	.0155		

Table B-19. Analysis of Variance for number of leaves per plant at 44 days post-emergence (trial 1).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	.1695	11.50	.001*
Water	2	.9261	62.86	0*
Species	2	1.0424	70.75	0*
Water by Species	4	.2310	15.68	0*
Error	16	.0147		

Table B-20. Analysis of Variance for number of leaves per plant at 44 days post-emergence (trial 2).

Source	d.f.	Mean square	F-Ratio	P > F
Block	2	.0269	1.22	.322
Water	2	.3345	15.16	0*
Species	2	1.2379	56.10	0*
Water by Species	4	.1054	4.78	.01*
Error	16	.0221		