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Early seedling responses of Agropyron spicatum Koeleria gracillis and Sitanion hystrix grown in association with Bromus japonicus and Kochia scoparia

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EARLY SEEDLING RESPONSES OF *AGROPYRON SPICATUM, KOELERIA GRACILIS,* AND *SITANION HYSTRIX* GROWN IN ASSOCIATION WITH *BROMUS JAPONICUS* AND *KOCHIA SCOPARIA*

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Director: Lee E. Eddleman LEE

The objectives of this research were: 1) to determine the influences of *Bromus japonicus* and *Kochia scoparia* competition on the seedling population dynamics and early seedling growth of *Agropyron spicatum, Koeleria gracilis* and *Sitanion hystrix*; 2) to determine the effects of moisture and salinity stress on the germination and early seedling growth of *Bromus* and *Kochia*; and 3) test the hypothesis that species establishment potential is correlated with germination response in controlled moisture stress levels and successional status.

Agropyron, Koeleria and *Sitanion* were grown in field competition with 0, 50, 100, 200 and 400 *Kochia* or *Bromus* plants per square meter. *Kochia* and *Bromus* competition did not significantly influence seedling emergence rates, amount or seedling survival. The growth rates of native species were however, signficantly slower in competition than control. Reductions of vigor were indicated in leaf and tiller number, plant height and inflorescence development. The biomass of native seedlings in competition was significantly reduced and the biomass apportionment was species specific.

Kochia and *Bromus* were germinated in 0, -3, -6, -9 and -12 bars of osmotic stress using Polyethylene glycol 6000 and sodium chloride to depress osmotic potentials. Germination responses were compared between species and used to explain ecological differences. In general, *Bromus* was more sensitive to moisture stress than *Kochia*.

It was concluded that species establishment potential was not related to seral position, but establishment appears related to the species germination response to moisture stress and to the diversity of sites occupied in natural conditions. The variability of data suggests that selection for traits or ecotypes should be possible and that uniform genotypes must be selected to insure consistent success. Criteria for selecting competitive ecotypes for reclamation of drastically disturbed lands in southeastern Montana are also discussed.

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CHAPTER I

INTRODUCTION

Western stripmining and postmining procedures create an open biological system. Predictably, weeds invade these unoccupied sites and threaten or limit desirable seedling establishment success. Because of the introduction of alien annuals into the biological system, natural succession has been altered. At present alien annuals, rather than indigenous pioneer species, are the usual dominant invaders on disturbed sites. Alien annuals do not mesh with the intricate successional pattern of indigenous species. Therefore schemes must be developed which bypass ecological voids that alien annuals successfully occupy. If allowed some alien annuals may form closed or slow developing communities.

The importance of a weedfree seedbed or selection of desirable perennial species which compete with alien annual weeds is emphasized in the literature. Given the amount of disturbance encompassing mine sites, the omnipresent nature of weeds, and the pending reclamation laws, successful reclamation and community development are dependent on planting competitive perennials. Perennial species which quickly establish, reproduce, and compete spatially and temporally with weeds should provide most consistent success and hasten community development.

The most critical phases of the plant life cycle are seed germination, seedling emergence and plant establishment. Plants that endure stress during these stages can usually endure succeeding environmental fluctuations. In semiarid environments, water is the most important component limiting advancement through plant establishment. Major causal factors of moisture stress are climate, salinity, and moisture depletion by competing species. Because of the inevitable success of weeds, moisture depletion by weeds may be one of the most consistent causal factors of moisture stress on seedlings. Given the severity of semiarid environments, seed and seedling responses that should increase species establishment and increase community stability and development are: 1. Relatively rapid germination rate and amount over a wide range of osmotic potentials; 2. Rapid seedling emergence and phenological development; 3. Tolerance of a wide range of environmental conditions; and 4. Survival of interspecific competition. It must be emphasized that most alien weed species possess these characteristics except they are not ecologically desirable nor do they form stable communities.

To date, few indigenous species of the Fort Union Coal Basin have been characterized regarding seed and seedling responses to environmental extremes. Perennial species which are not adversely affected by environmental extremes and qualify ecologically and economically should be most desirable and successful in reclamation. The basic relationships of perennials and annuals must be understood if more than hit or miss attempts at reestablishing diverse and stable plant communities are expected.

CHAPTER II

RESEARCH OBJECTIVES

The general objective of this research was to evaluate the competitive responses of previously recommended grasses (Eddleman and Doescher 1977) when grown in association with two alien weeds common on reclaimed land. The ultimate objective was identification of laboratory procedures which facilitate rapid screening for species and genotypes best adapted to the severities of mine land reclamation.

It is assumed that rapid germination, emergence, and phenological development as well as hardy and competitive seedlings are essential for establishment. Seeds and seedlings must efficiently exploit soil and moisture resources spatially and temporally in order to survive interspecific competition and associated environmental extremes and promote community development.

The following species representing different seral stages, ecological roles and varied seed and seedling ecological tolerances were studied. These selected native species show favorable germination characteristics and survival under controlled environmental conditions, are ecologically and economically important and show promise for commercial seed production.

Seral Position	Species	Common Name
Native		
Climax	*Agropyron spicatum* (Pursh.) Scribn.	Bluebunch wheatgrass
Mid-high Seral	*Koeleria gracilis* Pres. (Formerly *Koeleria cristata* (L.) Pers.)	Junegrass
Early	*Sitanion hystrix* (Nutt.) J. G. Smith	Squirreltail
Alien Annuals		
Invaders	*Bromus japonicus* (Thurb.)	Japanese Brome
	Kochia scoparia (L.) Schrad.	Kochia

Taxonomy is based on Hitchcock, et al. (1964, 1969) and Looman (1978).

In order to accomplish the general objective, the following evaluations were conducted:

1. The determination of the influence of exotic species on the emergence, growth and survival of indigenous seedlings under field conditions. Stripmining and subsequent reclamation provide a favorable culture for alien weed species. Considering pending reclamation laws, successful reclamation must be accomplished by seeding desirable native species which establish themselves, compete with, dominate, and limit successful reproduction of undesirable alien annuals. Interspecific competition studies may help ascertain whether or not indigenous species will be difficult to establish on harsh sites such as coal mine spoils. The use of mixtures of native plants with varied ecological tolerances, perhaps best expressed by different seral roles, is essential for continued community stability and successional development.
2. The determination of the effects of various moisture and salinity stress conditions on germination and early seedling

development of alien species. Thorough understanding of the biology of weeds can aid selection of perennials which compete with and dominate undesirable species. Results may also provide insight into potential problems resulting from various cultural practices.

3. Identification of potential laboratory screening procedures which facilitate rapid screening of species and genotypes. Because germination and early seedling development are the most critical life cycle phases, species which respond favorably in vitro may give most consistent results under field conditions.

CHAPTER III

LITERATURE REVIEW

Overview

The topsoil of any land supporting vegetation is a reservoir of seeds which have either been produced on the area or have migrated into the area by means of wind, water, or other special adaptations for migration (Beauchamp et al. 1975). In mined land reclamation, weed seeds in the topsoil promote weed infestations on spoilbanks (Sindelar et al, 1973; Meyn et al. 1976). Farmer and coworkers (1974) stated that the principal objection to topsoiling raw spoils will probably be the weed seeds contained. However, not only do pending reclamation laws (Dept. of Interior 1979) require the use of salvaged topsoil, but research (Farmer et al. 1974; Sindelar et al. 1973, 1978) has shown that topsoil can significantly increase establishment and production of desirable species. Control of alien weeds can be accomplished by chemical, mechanical, or biological means. Given plant community diversity and time restraints required by pending laws, mechanical and chemical control probably will not be ecologically or economically feasible on mined land.

Once certain undesirable introduced species are established on mined land, they tend to dominate the site and prevent or limit further reestablishment of desirable species (Eddleman and Doescher 1977). This is substantiated by Young and Evans (1977) who concluded that alien species tend to preempt seral roles of native plants. Therefore, considering the amount of time required by law for successful reclamation, revegetation strategies should be based on desirable species which will quickly establish and dominate the site. Desirable species that compete with exotic weeds during early spring growth, the most critical phenological stage, should be included in seed mixtures (Eddleman and Doescher 1977; Evans 1961; Hironaka and Sindelar 1973). Also, revegetation plans should include cool season perennials. Cool season grasses survive well on mined land, but warm season grasses seldom do (Power et al. 1975; Sindelar and Plantenberg 1978). Similarly, warm season grasses have been most difficult to establish on abandoned farmland in the central plains (Wilson and Briske 1979). Because soil moisture usually is the factor limiting establishment of later maturing species (Wilson and Briske 1979; Harris 1967) the relative success of cool and warm season species may be resultant of available moisture during critical phenological stages. These findings are supported by phenology studies conducted in southeastern Montana that show that cool season perennial grasses most actively grow, flower and develop seed during late April, May and June, respectively (Eddleman 1977a, 1978a). These same studies show that cool season plants are dormant in July, August and September, but vegetative regrowth occurs in October. These periods of growth and activity correspond with approximately 53% of the average annual precipitation (based on years 1931-1960 at Colstrip, Montana, U.S. Weather Bureau, 1952 and 1961). It must be emphasized that many exotic annuals are well adapted to this moisture regime. Generally, they germinate in the autumn or spring, grow and reproduce before seasonal drought. Considering the more xeric conditions of mined land compared to native rangeland, increased salinity, destruction of microsites, sporadic late spring and summer precipitation, cool season perennials will probably yield most consistent success until superior warm season perennials are developed. Species physiologically active during peak precipitation should germinate, establish and persist most consistently, limit weed dominance and decrease the length of time necessary to reestablish a stable and diverse community.

Indigenous Species in Reclamation

Revegetation research of stripmined lands in the Northern Great Plains has developed only recently. Most research (DePuit et al. 1978; DePuit and Dollhopf 1978; Dollhopf and Majerus 1975; Farmer et al. 1975; Hodder et al. 1971, 1972; Hodder and Atkinson 1974; Richardson et al. 1975; Sindelar et al. 1973, 1975) has focused on exotic agronomic selections. Initial success has generally been acceptable using exotic species; however, limited community diversity has resulted. Indigenous species response has been erratic with response attributed to unadapted ecotypes, undefined germination requirements and characteristics, and inclusion in mixtures of agronomically developed strains. Recent research (Eddleman 1977, 1978, 1979; DePuit 1978; Dusek 1975; Farmer et al. 1974; Richardson et al. 1975) has been conducted using locally adapted indigenous species. Farmer et al. (1974) and Richardson et al. (1975) reported favorable establishment using adapted ecotypes on the Decker Coal Mine in southeastern Montana. Similarly, Eddleman (1979) reported optimistic results of revegetation trials on mined land in eastern Montana. Eddleman and Doescher (1977) evaluated thirteen indigenous species of southeastern Montana and recommendations of potentially favorable species were based on successional status and germination response in varied moisture and salinity stress. Generally species of more xeric sites and possessing inherently high seed germination responded best. In a similar study, nine prairie species of southeastern Montana were examined for potential seedling establishment limitations (Eddleman and Meinhardt 1978). Characteristics used to rank species were seed vitality, including germination rates and totals, and seedling vigor under simulated drought. Conclusions were that species which germinate well even under suboptimal conditions should be best for seeding in severely altered habitats. Eddleman (1977, 1978, 1979) has made recommendations for ecotypes of indigenous species of southeastern Montana. Germination requirements and ecological characteristics were the basis for recommendations. Unique ecotypes are suggested due to responses different from previously reported research. Coal mined land succession has been studied in southeastern Montana (Sindelar and Plantenberg 1978). Succession is very slow and markedly influenced by species seeded, initial success, weather conditions and cultural practices. Even after 50 years, species diversity is limited, but succession can be hastened by topsoiling, fertilizing, mulching and seeding mixtures of plant species (Sindelar and Plantenberg 1978).

In general, native species have had limited use in reclamation. Considering the number of indigenous species with excellent development potential and which are ecologically and economically desirable, few selections are available and/or adapted to the Fort Union Basin. Adapted native ecotypes have exhibited their utility when grown in the absence of agronomically developed exotic perennials. Scarcity of seed, lack of adapted (commercially available) strains and the paucity of information regarding cultural requirements and critical ecological traits are major reasons for restricted application of indigenous species.

Seed and Seedling Vigor

Dewey (1960) concluded that germination tests and field studies are not highly correlated. However, screening species or ecotypes based on germination in saline conditions is important in improving the ability of seed germination under high osmotic stress in field conditions. Likewise, Choudari (1968) concluded that seeds are less tolerant of salinity than seedlings. Eddleman and Doescher (1977) described the ability of seeds and seedlings to cope with moisture stress as an ecological advantage and seeds of species which are more tolerant of adverse environmental conditions should be selected for sowing (Eddleman and Meinhardt 1978; Young and Evans 1977; Perry 1972). Evidence also indicates that high vigor seeds emerge better than lower grades over a wide range of soil types and conditions (Perry 1970). Maguire (1962) suggested that speed of germination be used to select species or varieties and evaluate seedling emergence or germination treatments. Speed of germination is important in stand establishment of perennials in difficult conditions (Johnston 1961; Whalley et al. 1966). Rapid germination and high germination amount are important in competition on disturbed areas (Evans 1961; Lawrence 1966; Robocker and Miller 1955), because early establishment in large numbers often results in site dominance (Harris 1977).

The dependence of seedling survival on rapid and extensive root development is confirmed in the literature. A close relationship exists between the rate of root development in the seedling stage and subsequent establishment (Plummer 1943). Rapid extension of the seminal root, deep seminal root penetration and a high capacity for adventitious root development are important for drought resistance (Briske and Wilson 1977; Wilson and Briske 1979). Adventitious root development is second in importance only to germination (Weaver and Mueller 1942). Also, Harris (1967) postulated that development of adventitious roots is essential for seedling establishment because the seminal root system is apparently annual. Where growth water is limiting throughout the summer, the relative rapidity of root penetration generally governs seedling success (Daubenmire 1959; Frishnecht 1951; Harris 1977; Hull and Stewart 1958; Robertson and Pearse 1945). Extensive root development is essential for surviving winter (Wilson and Briske 1979) and seasonal drought dormancy. In short, a seedling needs a well developed root system before it is subjected to adverse environmental conditions (Troughton 1957).

Species Response to Competition

The concept of species specific response to competition is born out in the literature. However, it is apparent that only generalizations can be made due to the range of ecological tolerances. Scanty information is available describing *Kochia scoparia* and *Bromus japonicus*, with little more than brief mention of infestations and competition. Some close relatives such as *Bromus tectorum* have received extensive study and many concepts revealed illustrate traits that dictate species success.

The ecological relationships of *Agropyron spicatum* and *Bromus tectorum* have been studied extensively. Rummel (1946) and Nelson et al. (1970) concluded that *Bromus tectorum* reduced *Agropyron* seedling establishment and although established plants persist (Robertson et al. 1966), initial competition has long lasting effects. Robertson and Pearse (1945), Hironaka and Tisdale (1963), Harris (1967), and Robertson et al. (1966) stress the point that initial establishment of native perennials is of utmost importance because *Bromus tectorum* stands are closed to invasion. Harris (1967, 1977) attributed root phenology and moisture depletion as major factors dictating closed *Bromus tectorum* stands. Robertson et al. (1966), Hull (1963), Evans (1961) and Rummel (1946) reported reduced *Agropyron* vigor when grown in competition with *Bromus tectorum*. Decreased herbage yield, reduced root growth, decreased leaf growth and heights, and earlier growth cessation were reported *Agropyron* responses. Furthermore, Harris (1967) observed an inverse relationship between *Agropyron spicatum* seedhead production and *Bromus tectorum* density.

Certainly the competitive abilities of *Sitanion hystrix* have long been recognized. Studies by Piemeisel (1951) and later Hironaka and Tisdale (1963) credit abundant seed production, mobile seed, rapid seedling development, and competition during establishment as major attributes of successful squirreltail invasion of *Bromus tectorum* stands. Also the lack of restrictive germination requirements are apparent competitive assets (Eddleman and Doescher 1977; Young and Evans 1977). Hironaka and Sindelar (1973) and Eddleman and Doescher (1977) recommended *Sitanion* for use in management plans because it competes with alien annuals and allows native perennials to establish themselves and succession to proceed. Hironaka and Sindelar (1975) studied *Sitanion* in competition with medusahead (*Taeniantherum asperum*) and the ability of seedlings to store sufficient root reserves was cited as a competitive asset. As medusahead density increased, the shoot-root ratio decreased. Eddleman (1978) noted that squirreltail was the most vigorous and had the most rapid growth of several species tested under simulated drought.

Koeleria gracilis has received minimal attention in past research. Weaver and Mueller (1942) ranked junegrass seedlings twelfth of fourteen species in drought resistance. Eddleman (1979) however, classified *Koeleria* seedling vigor under simulated drought as medium. Poor seedling emergence (Blake 1935) and 25 - 33 percent seedling survival characterize *Koeleria* (Weaver and Mueller 1942). On mined land in eastern Montana, seedling emergence of 12 - 19 percent and only 23 percent seedling mortality were reported for *Koeleria* (Eddleman 1979).

Kochia scoparia's adaptability is presumably best expressed by the more than 80 percent germination regardless of temperatures reported (Eddleman 1979; Lacher et al. 1963; Maguire and Overland 1959). Lacher et al. (1963) reported maximum germination rate and amount of *Kochia* at 16^{o} C, but Maguire and Overland (1959) reported maximum germination with an alternating temperature 20 - 30^{o} C. Similarly, southeastern Montana ecotypes have maximum germination rates between 20 and 30^{o} C (Eddleman 1979b). Root growth and soil moisture extraction profiles of nine weeds were reported by Davis et al. (1965). Of the species studied, *Kochia* had a moisture extraction profile of 20 square feet, the smallest root system of species studied.

CHAPTER IV

STUDY AREA DESCRIPTION

Geography

Research materials were obtained from the Fort Union Basin in southeastern Montana and tested at the University of Montana in Missoula. Southeastern Montana is part of the Missouri Plateau, an unglaciated region of the northern Great Plains (Hanson and Whitman 1938). The topography is characterized by gently rolling to steep uplands and mountain-like areas above the valleys. To the west lie the Rocky Mountains and to the east the Great Plains. Within the Fort Union Basin, abundant exploitable coal reserves exist.

Climate

The climate of southeastern Montana is a mid-continental type. Southeastern Montana lies in the Alberta storm belt, and receives continental air from the eastern slopes of the Rocky Mountains twelve months of the year (Bochert 1950; Coupland 1950). The area is characterized by 33 - 38 cm of annual precipitation, wide temperature extremes, a large number of sunny days, and relatively low humidity (Gieseker 1953). Yearly summer drought of 30 - 35 days is common but prolonged drought occurs at infrequent intervals (Thornwaite 1941). Approximately 75 percent of annual precipitation is received during April through September (Morris 1975). Average annual temperature is approximately 10° C, but temperatures range from 30° C to 40° C during July and August to more than -20° C during January (Dightman 1963).

Soils

The geological materials of the study area are the principal parent materials of the soils (Brown 1965). Common soil associations are the Bainville-Midway and Bainville-Fort Collins (Southard 1973). Sandy soils are common near sandstone capped ridges, outcrops, or terraces and silty or clay soils are most abundant below scoria or clay outcrops and the lowlands. The most common soil textures are silt loams (Brown 1965; Parker et al. 1971). Exposed geologic material and mixed colluvium are the principal soil materials in the badlands with limited soil development in talus and benches shallowly underlain by sandstone. Soil development is generally characteristic of upland benches, terraces and moderate north slopes (Brown 1965). Alluvial and residual materials dominate the lowlands.

Vegetation

Vegetation exhibits distinct and repeated patterns of distribution in southeastern Montana. Observations suggest that most relationships are controlled by geologic processes, perturbations, aspect, elevation and soil gradients. It must be emphasized that southeastern Montana lies in a transitional zone of several vegetation types, but is best described as mixed prairie. True prairie species are represented in this region by the north and western most range of their distribution. Some southern desert or semi-desert flora apparently reach their northern limit in this region and some northern and western species near the eastern and southern margins of their ranges. The integration of these distinct vegetation types may be controlled by the transitional zone of seasonal moisture modified into diverse environmental conditions by irregular topography. Morris (1975) concluded that May and June precipitation is important for both cool and warm season species.

High gentle north and east slopes have developed sandy soils and a cool moist environment which supports *Festuca idahoensis* communities (Morris 1975). Steeper north slopes composed of stony, well-drained and undeveloped soils support *Pinus ponderosa* and *Juniperus scopulorum*. Sandstone capped ridges generally support open *Pinus ponderosa* stands whereas porcellanite capped ridges and slopes generally support *Rhus trilobata* communities (Brown 1965; Gieseker 1953). Subdominants include *Agropyron spicatum*, *Calamovilfa longifolia*, *Schizachyrium scoparium* and *Bouteloua curtipendula*. Seven shrub or tree dominated communities characterize the badland topography. Southerly exposures are dominated by *Artemisia tridentata wyomingensis*, *Atriplex confertifolia*, *Sarcobatus vermiculatus*, *Rhus trilobata*, *Juniperus scopulorum* and *Pinus ponderosa* communities (Brown 1971). Furthermore, *Agropyron spicatum*is a subdominant in four of seven recognized badland communities (Brown 1971). Gently sloping alluvial formations and residual knolls constitute foot slopes and broad valleys. *Agropyron spicatum*, *Schizachyrium scoparium*, *Stipa comata* and *Artemisia cana* are usually abundant on coarser textured soils, but *Artemisia tridentata wyomingensis*, *Bouteloua gracilis*, *Poa sandbergii* and *Koeleria gracilis* are common on heavier soils. Lowlands are dominated by *Stipa viridula*, *Artemisia cana* and *Agropyron smithii*, and saline bottom lands and basins are occupied by *Sarcobatus* *vermiculatus, Ceratoides lanata, Atriplex nuttallii* and *Distichlis stricta*. Drainages throughout the area support deciduous trees and shrubs including *Acer negundo, Crataegus columbiana, Fraxinus pennsylvanica, Prunus americana, Prunus virginiana, Shepherdia argentea, Symphoricarpos occidentalis* and *Rosa woodsii*.

Bromus tectorum and *Bromus japonicus* have spread over the country, especially on disturbed land, since the drought of 1930-37 (Gieseker 1953).

CHAPTER V

MATERIALS AND METHODS

Plant Materials

Seeds used in field trials and germination tests were collected on the Custer National Forest in southeastern Montana in conjunction with current research by Dr. Lee Eddleman, School of Forestry, University of Montana. Seeds were collected and cleaned as outlined by Eddleman (1977a). Approximately the heavier half of seed lots were used for testing; a seed blower was used for separation. Additionally, *Sitanion hystrix* and *Agropyron spicatum* seeds were back-lighted to insure seed fill. Prior to testing, seeds were stored at 20° C ±5 with approximately 20 percent humidity. Collection date, site description, test date and tests are shown in Table 1.

Table 1. Seed Collection and Test Information

Species	Collection Date	Site Description	Test Date	Test
Agropyron spicatum	7/22/76	Ridge	4/8/78	Field
Koeleria gracilis	7/21/76	Bench Slope	4/8/78	Field
Sitanion hystrix	7/27/76	West Facing Roadcut	4/8/78	Field
Bromus japonicus	7/15/76	Bench	4/8/78 12/15/78	Field Osmotic and Salinity Stress
Kochia scoparia	10/26/77	Roadcut	4/8/78 12/15/78	Field Osmotic and Salinity Stress

Field research was conducted at the University of Montana Range Department research area at Fort Missoula. Field research commenced March 28, 1978, and final measurements were gathered August 18, 1978. The field experimental design was intended to simulate spring scarification of the seedbed to kill germinated weeds, followed by seeding. The early spring planting date was based on tentative recommendations by Eddleman (1977a).

Plant Species Description

Agropyron spicatum is a long-lived, cool season, climax bunchgrass abundant throughout the study area. *Agropyron* is most abundant on poorly developed soils in the badlands and the ridges of the rolling uplands. It is also an indicator species in the *Pinus ponderosa* ecosystem habitat type (Pfister et al. 1977). Of particular interest and promise is the successful invasion of unleveled spoilbanks and exposed roadcuts by *Agropyron*. *Agropyron* appears as an excellent choice in reclamation, but its use has not passed beyond the experimental stage.

Koeleria gracilis is a mid to high seral, small, short-lived, cool season bunchgrass most abundant on medium textured soils. Of the three indigenous species studied, *Koeleria* usually has the earliest seasonal phenology. An extensively branched root system and early spring growth may be vital competitive assets of *Koeleria*. To date,*Koeleria* has not been used in reclamation.

Sitanion hystrix is a small, caespitose, short-lived perennial that inhabits harsh sites ranging from saline flats to badlands and unleveled spoilbanks. *Sitanion* is scattered throughout the grasslands, but is most abundant on disturbed sandy soils. Prolific seed production and mobile seed, rapid spring growth and broad ecological tolerances are important traits of *Sitanion*.

Bromus japonicus is an exotic, cool season, winter or spring annual. Distribution in eastern Montana tends toward slightly xeric disturbed sites such as alluvium and medium textured soils.

Kochia scoparia is an introduced warm season annual of the Chenopodiceae family. In southeastern Montana *Kochia* does well on all sites, but particularly well on disturbed sites that are relatively salty or sterile and support few other species. *Kochia* appears to have the potential to increase site salinity if allowed to persist. *Kochia* is a prolific seed producer and effectively distributes them by forming an abscission layer at ground level and tumbling in the wind.

Field Competition Study

Field test plot preparation included thorough rototilling on March 25, 1978. The area was retilled April 6, and raked to remove debris and firm the seedbed.

Soil of the experimental area was described using standard soil description techniques (Soil Survey Staff 1975). Uniform fluvial deposited silt loam characterizes the experimental area.

Experimental design was a complete randomized block replicated five times. Separate blocks were established for *Kochia* (Figure 1) and *Bromus* (Figure 2) competition. Each block contained twenty 1m x .6m plots and within each plot, two permanently paired 40cm x 50cm subplots (A and B) were established. After planting, but before seedling emergence, subplot A or B was randomly chosen from each plot and used for plant measurement throughout the study. The unselected subplot was used for sacrificial

Figure 1. *Kochia scoparia* competition study.

Figure 2. *Bromus japonicus* competition study.

sampling at the end of the study. Approximately .5m buffer zones were established between plots and 3m buffer zones were left between blocks. Buffer zones were periodically rototilled during the study.

Prior to planting native species, sufficient *Bromus japonicus* and *Kochia scoparia* seeds were broadcast sowed and raked into the soil to insure that the desired number of weeds germinated in respective plots. Weeds were grown as monocultures with a central row of native species. The third and sixth week following planting, weed seedlings were thinned to 0, 10, 20, 40 and 80 plants per 40cm x 50cm subplot (Equivalent to 0, 50, 100, 200 and 400 plants per square meter). Each subplot was arbitrarily divided into four equal quadrants and as nearly as possible, one fourth of the desired weed number was left in each quarter. A leave plant was determined on phenological development. It was assumed that the most phenologically advanced plants were the earliest emergers, hence they were left.

Indigenous species were hand sown (on the same day as weeds) in a one meter row central to each plot. Fifty seeds (approximately 5.4kg pure live seed per hectare or 20 seeds per subplot) of *Sitanion* and *Agropyron* and .03 grams (approximately 7.4kg pure live seed per hectare) of *Koeleria* were planted approximately 5mm - 10mm deep in each plot. Native species were grown monospecifically in competition with weeds and in a mixture composed of combined seeding rates. Native species were not thinned.

Soil temperature the day of planting was 7° C at 10cm.

Parameters Measured

Seedling numbers, plant height, leaf numbers and tiller numbers of native species were recorded for each competition level. A leaf was recorded if it was fully expanded and green. Only *Koeleria* growth parameters were recorded in the mixture. Sample number, sample date and the number of days following planting are presented in Table 2.

Table 2. Sample Dates and Days Following Planting

Sample No.#	Date	Days Following Planting
1	5/1/78	23
2	5/20/78	42
3	6/3/78	56
4	6/17/78	70
5	6/29/78	82
6	7/14/78	97

Throughout this treatise, densities will be referred to as Control and *Bromus* (B) or *Kochia* (K) density, i.e. *B* 100 is the *Bromus japonicus* density of 100 plants per square meter, etc.

Data Analysis

Population dynamics (seedling emergence rate, amount and seedling survival) were determined using recorded seedling numbers for each sample date. Differences in rate of emergence (ER) were determined using ER equation (Eddleman 1979c). The emergence rate incorporates the percentage of total emergence for a given sample date. Emergence rate facilitates tests between species and within species regardless of the number of seeds planted or the number of emergent seedlings. The equation of ER is:

$$ER = \Sigma \left[\frac{En - E(n - 1)/n}{TE} \right] \qquad \text{Equation (1)}$$

Where: En = cumulative emergence on a given day
E(n - 1) = cumulative emergence on the previous day
n = sample date of test
TE = total emergence at the end of test.

The larger the ER value, the faster the emergence rate. In this study, ER's were determined by substituting the sample number (Table 2) for n. Total emergence and establishment were also tested between and within species.

Initial intent was to sample each plant in selected subplots, however, as the study progressed sampling was reduced to only a portion of the populations. The entire populations were sampled the first three dates, but subsequent sample size was based on the equation (Freese 1962):

$$\eta = \frac{\frac{1}{(E)}\,2}{t^2 s^2} + \frac{1}{N} \qquad \text{Equation (2)}$$

Where: E = the desired precision about the mean (E was equal to .05 in this calculation)
t = student's t value
s^2= variance of the parameter used
N = population size

Plant height variance was used to determine sample size for each competitive level for *Agropyron* and *Sitanion*. Samples were equally distributed among respective competition level replicates. *Agropyron* and *Sitanion* seedlings were systematically selected for measurements, but because of the small number of *Koeleria* seedlings all plants were measured throughout the study.

Biomass Study

Approximately 130 days following planting (August 14 - 18), native species were excavated and used for biomass determination. An attempt was made to remove three plants from each treatment replication, however, scarcity of seedlings (especially *Koeleria*) sometimes necessitated removal of more from certain subplots. Seedlings were systematically selected before excavation. Due to the stoney nature of the soil, it was not feasible to extract entire root systems. Thirty five centimeters was selected as an arbitrary depth and diameter for excavating plants. Soil was washed from the roots by placing the plant on a 6mm screen and gently agitating in water. Plants were labeled and dried at least 48 hours at 70^{o} C ± 5. Plants were sectioned and weighed as root (root system below nodal attachment), crown (basal 2.5cm of *Sitanion* and *Agropyron* seedlings and the basal 1.5cm of *Koeleria*) and the aerial portions. This allowed computation of total biomass per plant, root to shoot biomass ratios, and the portion each segment contributed to total plant biomass. *Koeleria gracilis* biomass was weighed to the nearest milligram and *Agropyron* and *Sitanion* were weighed to the nearest centigram.

Biomass data was analyzed and tested within species and between treatments. Analysis of variance was used for initial separation of responses and the Student-Newman-Keuls test (Sokal and Rohlf 1969. Sec. 9.6) was used for further segregation.

Osmotic Stress Germination

Kochia scoparia and *Bromus japonicus* seeds were germinated at moisture and salinity stress levels of 0, -3, -6, -9 and -12 bars (ψs). Polyethylene glycol 6000 (PEG) and sodium chloride were used to depress moisture and osmotic potentials, respectively. PEG moisture potentials were determined from equations (3 and 4) outlined by Michel and Kaufman (1973):

Equation (3)

$$\psi s = (-1.18 \times 10^{-2})G - (1.18 \times 10^{-4})G^2 + (2.67 \times 10^{-4})GT + (8.39 \times 10^{-7})G^2T$$

Where: G = grams of PEG 6000 per kg of deionized, distilled water
T = temperature in degrees Centigrade

Furthermore, at T = 20° C

Equation (4)

$$G = \frac{-.00646 + \sqrt{.0004173 - .0004048\ \psi s}}{.0002024}$$

Specific osmotic potentials and concentrations of PEG 6000 are presented in Table 3.

Table 3. Concentration of PEG 6000 for Specific Osmotic Potentials at 20° C.

ψs	Grams of PEG 6000/kg of Water
0	0
-3	143
-6	214
-9	268
-12	314

Osmotic concentrations of sodium chloride were prepared using equation (5) as outlined by Wiggins and Gardner (1959).

$$g = \frac{PVm}{RT}$$ Equation (5)

Where: g = grams of solute
P = osmotic pressure
V = volume in liters
m = molecular weight of chemical
R = .0825 atmosphere per degree per mole
T = absolute temperature

Specific osmotic potentials, concentrations and electrical conductivity (E.C.) of solutions (MMHO/cc) are presented in Table 4. Electrical conductivity was determined using a VSI Model 33 S-C-T Meter.

Table 4. Electrical Conductivity and Grams of Sodium Chloride for Specific Osmotic Potentials

ψs	Grams of Nacl per Liter of Water	E.C. (MMHOs/cc)
0	0	<.001
-3	7.25	4.4
-6	14.51	9.5
-9	21.76	13.0
-12	29.02	17.0

Deionized distilled water was used for control.

Environmental conditions for stress germination were 20^{o} C ± 2 with 14 hours fluorescent light and 10 hours darkness. Methodology of germination closely parallels that of Eddleman and Doescher (1977). Five centimeter square Kimpac cellulose germination blotters were placed in 10cm x 1.5cm petri dishes and saturated with 25 milliliters of osmotica. Each treatment was replicated five times with 25 seeds per replication. Petri dishes were stacked five high on trays which had moistened blotters on the bottom and the tray was enclosed in a clear plastic bag to prevent dessication. Trays and petri dishes were systematically rotated in the growth chamber on germination recording dates. Germination was recorded at two day intervals through 12 days and six day intervals thereafter. Germination trials were terminated at 30 days. *Kochia scoparia* seeds were considered germinated when the embryo was fully uncoiled, when the radicle was approximately 5mm long, or when the cotyledons had reflexed. Germination was tallied when the radicle and/or plumule of *Bromus japonicus* was approximately 5mm long.

Germination response to varied osmotic potentials was based on Germination Rate (GR), coefficient of rate of germination (CRG), and total germination. CRG (Maguire 1962) is a value calculated on the basis of germination amount and velocity. Equal number of seeds is a requisite for this calculation.

$$CRG = \Sigma \left[gn - g(n - 1) \; / \; \eta \right] \qquad \text{Equation (6)}$$

Where: gn = cumulative germination on a given check
$g(n - 1)$ = cumulative germination of a previous germination tally
η = number of days of germination

The larger the CRG, the faster the rate of germination. Germination rate was graphically illustrated by plotting mean cumulative germination against time. The steeper the line, the greater the velocity. Germination rate was calculated by substituting germination values in equation 1. Total germination is the mean number of seeds that germinated by the end of the test.

All data was initially analyzed using analysis of variance, and a two sample T-test was used to further segregate responses. Procedures follow those outlined by Ott (1977) sections 5.4 and 13.3.

CHAPTER VI

RESULTS

Field Study

The results of the field study are segregated into population dynamics, seedling growth and seedling biomass production. These parameters were analyzed to determine differences within and between species. Total leaf number per seedling and total tiller number per seedling were used to analyze growth responses between treatments and successive sample dates. On the 97th day of study the average number of leaves per tiller, average plant height and the total number of inflorescences produced in each subplot were compared. Growth responses of *Koeleria* grown monospecifically and in the native species mixture were compared.

Population Dynamics

No significant differences in seedling emergence rate, number of emergent seedlings, number of established seedlings, or establishment percentage resulted between levels of competition within species (Tables 5, 6, 7). Therefore, data was pooled within species for all levels of *Bromus* and *Kochia* competition (Tables 8 and 9) and used to test responses within and between species. Within native species, seedling emergence rates were not significantly different in *Kochia* or *Bromus* competition. In *Bromus* competition *Agropyron* seedling emergence was significantly more rapid than *Sitanion* and *Koeleria* (Table 8). Both *Agropyron* and *Sitanion* seedlings emerged significantly faster than *Koeleria* in *Kochia* competition (Table 9). *Koeleria* seedling emergence was significantly faster in the native species mixture than when grown monospecifically (Tables 8 and 9).

Although statistical support is lacking, *Koeleria* apparently has some unique microsite requirements as evidenced by the aggregation of emergent seedlings around the periphery of stones on the soil surface. No such responses were noted for *Agropyron* or *Sitanion.*

Agropyron and *Sitanion* had significantly more seedlings establish in *Kochia* competition than in *Bromus* competition (Tables 5 and 6). There was, however, no significant difference in the number of *Koeleria* seedlings that established in *Bromus* or *Kochia* competition (Table 7). Significantly fewer *Koeleria* seedlings established in the native species mixture than when grown monospecifically (Table 7).

Establishment percentages of *Agropyron* seedlings in *Kochia* and *Bromus* competition were not significantly different (Table 5). Compared to *Kochia* competition, *Sitanion* and *Koeleria* seedling establishment percentage was significantly reduced by *Bromus* competition (Tables 6 and 7). In *Kochia* competition *Koeleria* had a significantly lower establishment percentage in the native species mixture than when grown monospecifically, but there was not significant difference between the two in *Bromus* competition.

Seedling Growth Response Between Dates

From the first sample date, native species exhibited significant increases in leaf numbers between successive sample dates, but significant

Table 5. Mean seedling emergence rate, amount and establishment of *Agropyron spicatum* per 40cm x 50cm subplot. A similar letter within a parameter indicates non-significant differences. α=.05.

	ER		Number of Emergent Seedlings		Number of Established Seedlings		Percent Established of Emergent		n
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	
Control	.70	.05	12.3b	5.3	7 c	2.8	59d	17	10
50 *Bromus*/m^2	.73a	.17	8.0b	2.4	5.2c	2.9	61d	20	5
100 *Bromus*/m^2	.75a	.09	12.0b	2.7	6.6c	3.4	52d	20	5
200 *Bromus*/m^2	.73a	.09	14.2b	2.3	8.0c	1.6	57d	11	5
400 *Bromus*/m^2	.74a	.06	10.6b	4.1	6.8c	2.7	67d	21	5
Pooled	.72A	.09	11.6B	4.1	6.8C	2.7	59D	17	30
Control	.70e	.05	12.3f	5.3	7 g	2.8	59h	17	10
50 *Kochia*/m^2	.68e	.07	15.6f	6.4	10.4g	3.5	71h	16	5
100 *Kochia*/m^2	.70e	.11	13.0f	2.8	10.2g	4.7	79h	10	5
200 *Kochia*/m^2	.75e	.13	15.8f	7.3	10.2g	4.7	65h	8	5
400 *Kochia*/m^2	.73e	.10	12.2f	4.3	7.6g	2.9	63h	8	5
Pooled	.71A	.09	13.5B	5.3	8.7	3.4	66D	14	30

Table 6. Mean seedling emergence rate, amount and establishment of *Sitanion hystrix* per 40cm x 50cm subplot. A similar letter within a parameter indicates non-significant differences. α=.05.

	ER		Number of Emergent Seedlings		Number of Established Seedlings		Percent Established of Emergent		n
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	
Control	.64a	.10	14.8b	6.3	8.7c	1.7	65d	20	10
50 *Bromus*/m^2	.63a	.08	14.6b	6.5	6.8c	1.1	52d	18	5
100 *Bromus*/m^2	.62a	.07	13.0b	3.8	7.2c	1.3	59d	18	5
200 *Bromus*/m^2	.74a	.11	12.6b	3.1	7.4c	1.5	60d	10	5
400 *Bromus*/m^2	.67a	.08	11.0b	2.4	6.6c	.6	61d	9	5
Pooled	.66A	.09	13.5B	4.9	7.6	1.5	60	16	30
Control	.64e	.10	14.8f	6.3	8.7g	1.7	65h	20	10
50 *Kochia*/m^2	.72e	.12	14.0f	3.4	10.8g	1.6	79h	9	5
100 *Kochia*/m^2	.66e	.16	9.8f	2.2	8.2g	1.3	85h	11	5
200 *Kochia*/m^2	.65e	.05	12.6f	3.0	9.0g	2.7	71h	13	5
400 *Kochia*/m^2	.64e	.12	16.6f	2.7	13.0g	2.2	78h	6	5
Pooled	.66A	.11	13.8B	4.6	9.7	2.5	74	15	30

Table 7. Mean seedling emergence rate, amount and establishment of *Koeleria gracilis* per 40cm x 50cm subplot. A similar letter within a parameter indicates non-significant differences. $\alpha=.05$.

	ER		Number of Emergent Seedlings		Number of Established Seedlings		Percent Established of Emergent		n
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	
Control	.56a	.12	7.6b	3.0	4.4c	2.0	60d	20	10
50 *Bromus*/m^2	.61a	.10	7.0b	2.9	4.2c	1.6	62d	11	5
100 *Bromus*/m^2	.64a	.11	8.0b	3.3	4.0c	1.6	50d	6	5
200 *Bromus*/m^2	.63a	.19	7.0b	3.7	3.0c	3.2	34d	31	5
400 *Bromus*/m^2	.61a	.18	5.4b	1.3	2.0c	1.2	36d	22	5
Pooled	.60A	.13	7.1B	2.9	3.7C	2.1	50D	22	30
Control	.56e	.12	7.6f	3.0	4.4g	2.0	60h	20	10
50 *Kochia*/m^2	.41e	.07	5.6f	.9	3.6g	1.1	64h	18	5
100 *Kochia*/m^2	.58e	.15	7.4f	2.7	4.6g	2.5	59h	21	5
200 *Kochia*/m^2	.65e	.21	5.4f	3.0	4.0g	3.1	75h	31	5
400 *Kochia*/m^2	.53e	.15	6.0f	2.1	2.8g	1.3	52h	31	5
Pooled	.55A	.15	6.6B	2.6	4.0C	2.1	62H	23	30
<u>Native Species Mixture</u>									
Control	.70i	.25	5.4j	2.5	3.1k	1.8	60l	28	10
50 *Bromus*/m^2	.74i	.20	7.0j	2.5	2.6k	1.5	37l	13	5
100 *Bromus*/m^2	.64i	.13	6.6j	2.9	1.6k	2.2	32l	17	5
200 *Bromus*/m^2	.62i	.25	6.6j	4.0	1.5k	2.8	45l	12	5
400 *Bromus*/m^2	.71i	.18	4.8j	2.1	1.8k	1.6	39l	40	5
Pooled	.69D	.20	6.0E	2.7	2.6F	1.6	47G	26	30
Control	.70m	.25	5.4n	2.5	3.1o	1.8	63p	28	10
50 *Kochia*/m^2	.71m	.17	7.8n	2.2	2.2o	2.5	26p	31	5
100 *Kochia*/m^2	.52m	.03	4.2n	1.3	1.4o	1.3	39p	35	5
200 *Kochia*/m^2	.74m	.28	4.4n	2.2	1.8o	1.9	32p	28	5
400 *Kochia*/m^2	.57m	.17	5.8n	2.8	2.0o	2.4	27p	30	5
Pooled	.65D	.20	5.5E	2.5	2.3F	2.0	42G	32	30

Table 8. Pooled seedling emergence rate (ER) and establishment of indigenous species in *Bromus* competition. A similar letter indicates non-significant differences. α=.05.

	ER		Percent of Emergent Established		
	$\bar{X}$	s	$\bar{X}$	s	n
Agropyron spicatum	.72A	.09	59C	17	30
Sitanion hystrix	.66B	.09	60C	16	30
Koeleria gracilis	.60	.13	50CD	22	30
Mixture *Koeleria gracilis*	.69AB	.20	47CD	26	30

Table 9. Pooled seedling emergence rate (ER) and establishment of indigenous species in *Kochia* competition. A similar letter indicates non-significant differences. α=.05.

	ER		Percent of Emergent Established		
	$\bar{X}$	s	$\bar{X}$	s	n
Agropyron spicatum	.71E	.09	66F	14	30
Sitanion hystrix	.66E	.11	74	15	30
Koeleria gracilis	.55	.15	62F	23	30
Mixture *Koeleria gracilis*	.65E	.20	42	32	30

increases in tiller numbers appeared only after the forty-second day of study. Termination of significant increments (between successive sample dates) of leaves and tillers varied between species and competition treatments. In all cases the growth rate was significantly faster in control seedlings than in competition.

Compared to control, the magnitude of the increase of variation of leaf and tiller number through time (expressed by the coefficient of variation) was greatest in seedlings grown in competition.

Bromus Competition

Agropyron seedlings in control and *Bromus* competition showed significant increases in leaf numbers between consecutive sample dates for the entire study (Figure 3 and Table 10). After 42 days and through the remainder of the study, control seedlings had significant increases in tiller numbers (Figure 4 and Table 11), but seedlings in competition had significant tiller increments only between 42 and 70 days.

Sitanion leaf numbers increased significantly in control seedlings between each successive sample date, although seedlings in *Bromus* competition had significant leaf number increases only to 82 days (Figure 5, Table 12). From 42 days onward control seedlings had significant tiller increases between each successive sample date (Figure 6, Table 13), but seedlings in competition had significant tiller increases at successive sample dates only between 42 and 82 days.

Koeleria control and seedlings in *Bromus* competition showed significant increments of leaves between each successive sample date throughout the study (Figure 7, Table 14). Significant tiller number increases in control seedlings resulted only after 42 days and continued throughout

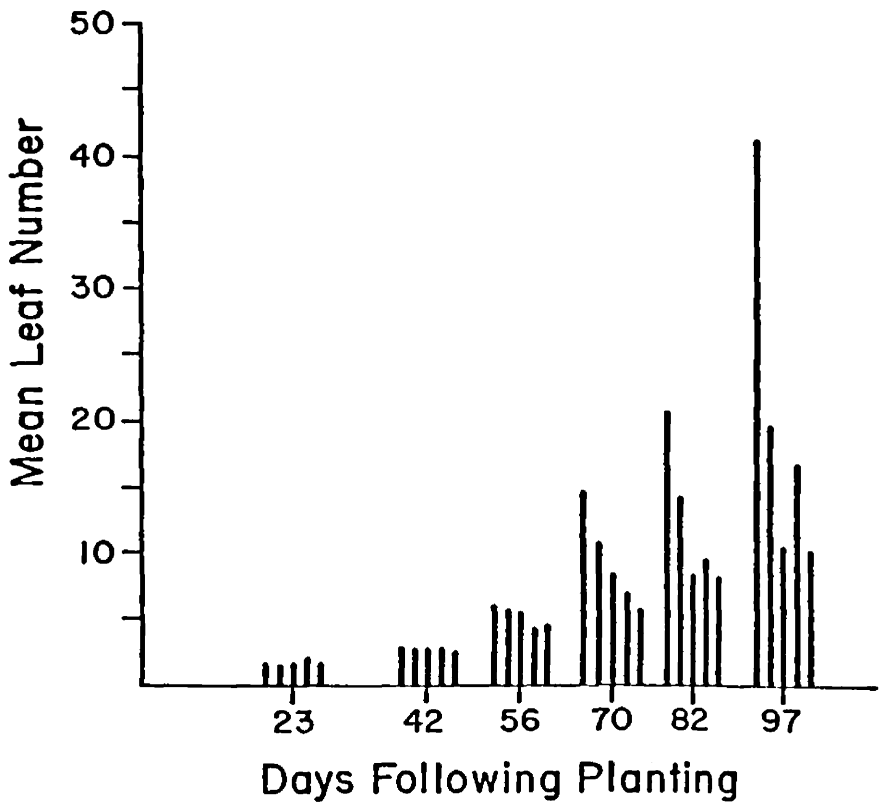

Figure 3. *Agropyron spicatum*. Mean cumulative leaf number per seedling through study. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Bromus japonicus* plants per square meter.

Table 10. Mean number of leaves of *Agropyron spicatum* grown in *Bromus* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.2a	2.8b	5.7b	14.0e	20.7h	41.6i
50 *Bromus*/m^2	1.1a	2.6b	5.4c	10.9f	14.0f	19.8fj
100 *Bromus*/m^2	1.2a	2.9b	5.3c	8.4f	8.4f	10.4fj
200 *Bromus*/m^2	1.0a	2.6b	4.5d	6.7g	9.5f	16.6fj
400 *Bromus*/m^2	1.1a	2.5b	4.2d	6.4g	8.3gf	10.0fj

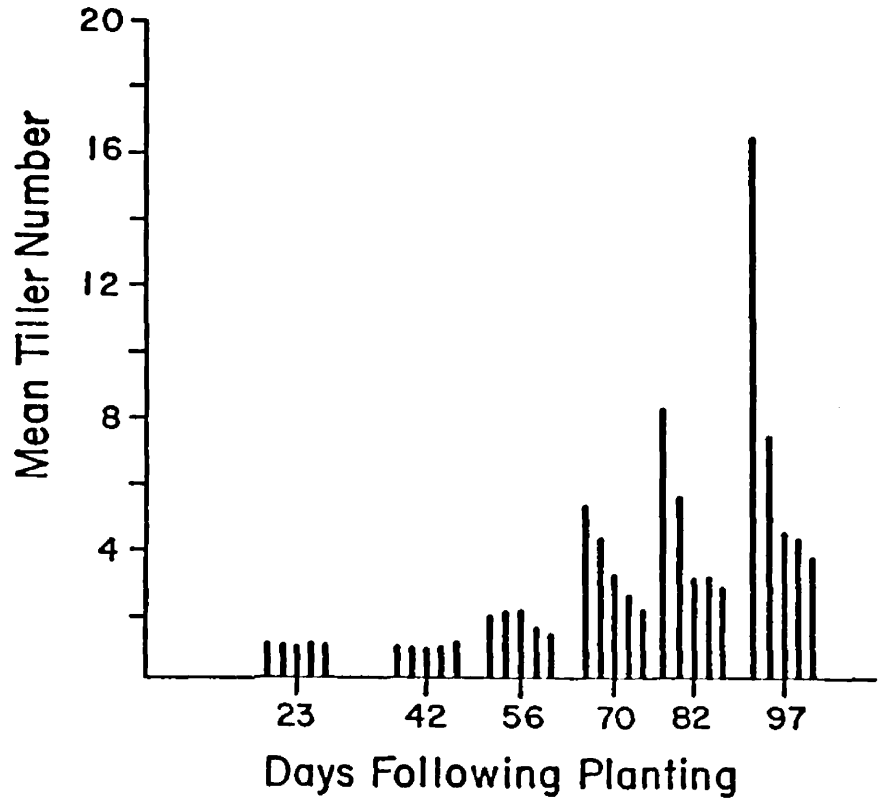

Figure 4. *Agropyron spicatum*. Mean culumulative tiller number per seedling through study. Within each sample date, resepective competition levels from left to right are 0, 50, 100, 200 and 400 *Bromus japonicus* plants per square meter.

Table 11. Mean tiller number of *Agropyron spicatum* grown in *Bromus japonicus* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. α = 0.05.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.0a	1.1a	1.9d	5.2e	8.1h	16.5k
50 *Bromus*/m^2	1.0a	1.0a	2.0d	4.2f	5.5f	7.5il
100 *Bromus*/m^2	1.0a	1.0a	1.9d	3.1g	2.8gj	4.5m
200 *Bromus*/m^2	1.2a	1.0a	1.4d	2.3g	3.1gj	4.3jm
400 *Bromus*/m^2	1.0a	1.0a	1.3d	1.9g	2.8gj	3.7jm

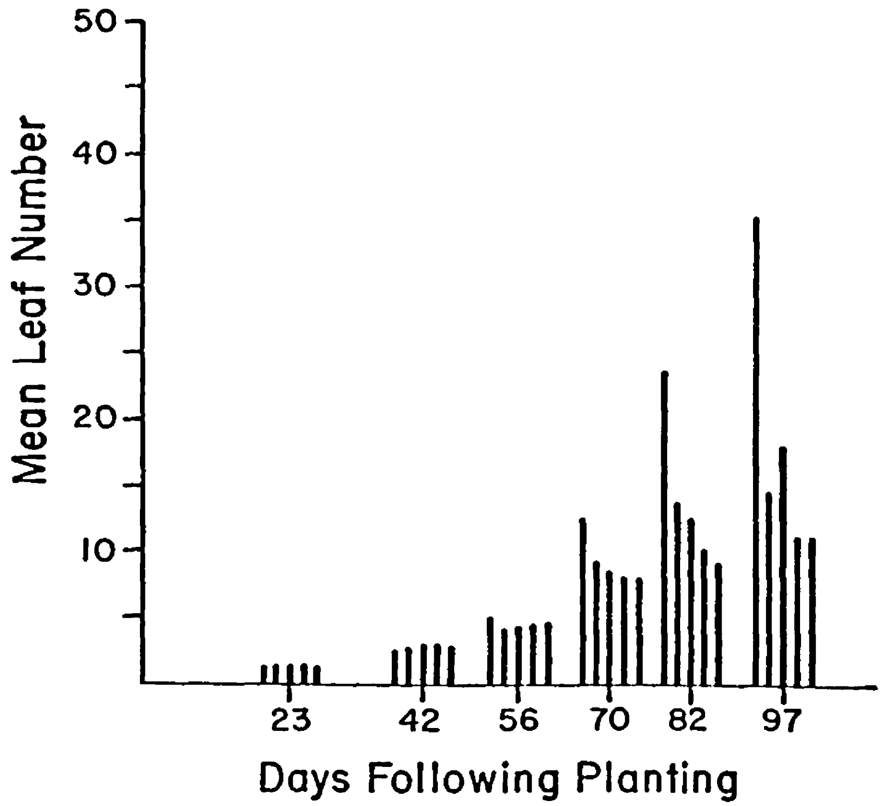

Figure 5. *Sitanion hystrix.* Mean cumulative leaf number per seedling through study. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Bromus japonicus* plants per square meter.

Table 12. Mean number of leaves of *Sitanion hystrix* grown in *Bromus* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.0a	2.5b	5.3c	12.9e	24.0g	36.5i
50 *Bromus*/m^2	1.0a	2.5b	4.7d	9.8f	13.8h	14.7hj
100 *Bromus*/m^2	1.0a	2.8b	4.6d	8.6f	12.4h	18.6hj
200 *Bromus*/m^2	1.1a	2.5b	4.5d	8.1f	11.0fh	11.4hj
400 *Bromus*/m^2	1.1a	2.4b	4.4d	8.0f	9.2fh	11.1hj

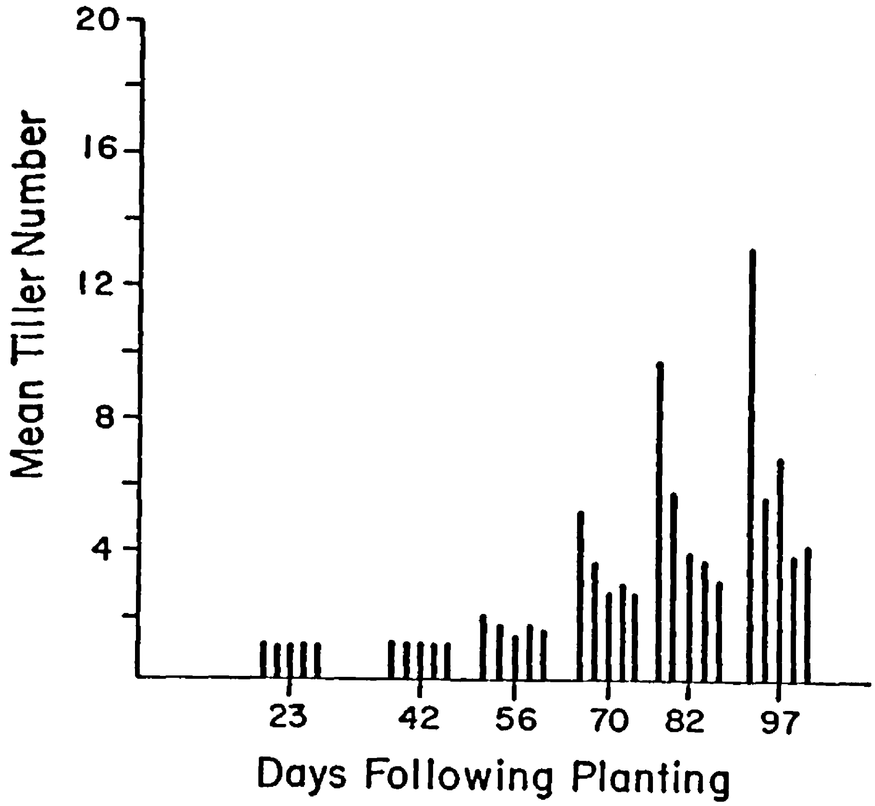

Figure 6. *Sitanion hystrix*. Mean cumulative tiller number per seedling through study. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Bromus japonicus* plants per square meter.

Table 13. Mean tiller number of *Sitanion hystrix* seedlings grown in *Bromus* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. α = 0.05.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.0a	1.0a	1.9b	5.0d	9.5g	13.1k
50 *Bromus*/m^2	1.2a	1.0a	1.7c	3.4e	5.5h	5.6hl
100 *Bromus*/m^2	1.0a	1.0a	1.4c	2.7e	3.8i	6.7l
200 *Bromus*/m^2	1.0a	1.0a	1.6c	2.8e	3.7ei	3.8im
400 *Bromus*/m^2	1.0a	1.0a	1.4c	2.3f	2.8fl	4.0jm

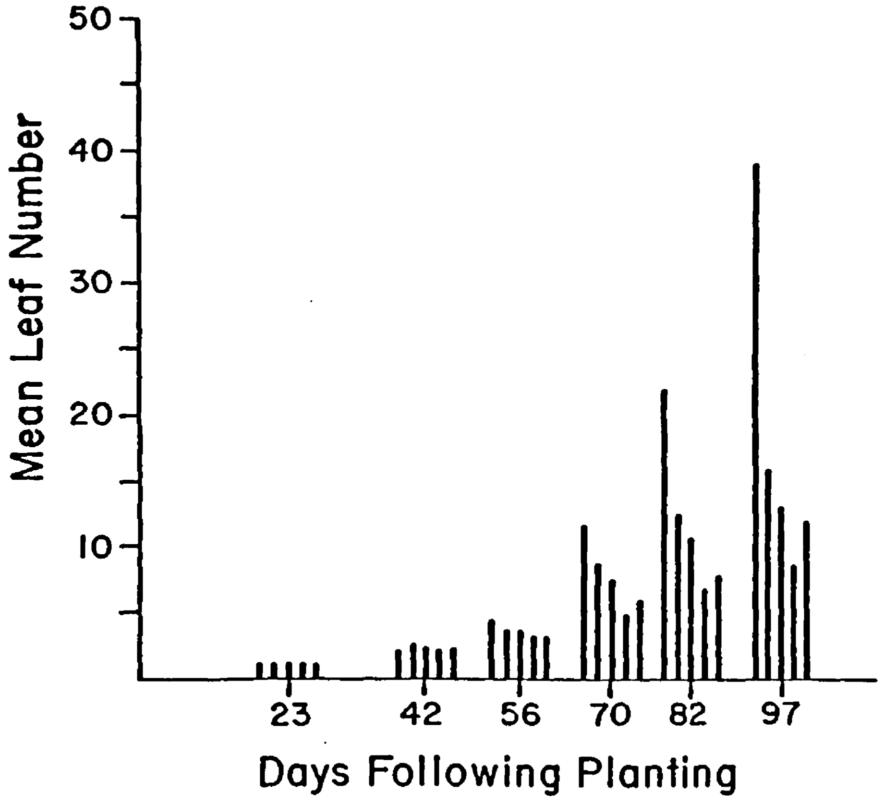

Figure 7. *Koeleria gracilis*. Mean cumulative leaf number per seedling through study. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Bromus japonicus* plants per square meter.

Table 14. Mean number of leaves of *Koeleria gracilis* grown in *Bromus* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.0a	2.3b	4.4c	11.5d	21.9f	38.9i
50 *Bromus*/m^2	1.2a	2.3b	3.6c	8.9e	12.3eg	16.1gj
100 *Bromus*/m^2	1.1a	2.3b	3.6c	7.3e	10.5eg	13.3gj
200 *Bromus*/m^2	1.0a	2.2b	3.3c	5.0e	6.9h	8.3hj
400 *Bromus*/m^2	1.0a	2.1b	3.2c	6.1e	7.8eh	11.8hj

the study (Figure 8, Table 15). However, seedlings in competition had significant increases in tillers on consecutive dates only between 42 and 82 days.

In the indigenous species mixture, *Koeleria* control had significant increases in leaf numbers at each successive date during the study (Figure 9, Table 16). Seedlings in competition responded similarly except new leaves were not observed after 82 days. Control and seedlings in competition showed significant tiller increases on successive sample dates between 42 and 82 days (Figure 10, Table 17).

Kochia Competition

Agropyron seedlings in *Kochia* competition and control produced significant increases in leaf number between each successive date of the entire study (Figure 11, Table 18). Control seedlings had significant tiller increases on successive sample dates between 42 and 97 days (Figure 12, Table 19), but seedlings in competition ceased tillering by day 82.

Sitanion seedlings in control and *Kochia* competition had significant increments in leaf numbers between successive sample dates the entire study (Figure 13, Table 20). On successive sample dates between 42 and 97 days, tiller numbers increased significantly in both control and competition (Figure 14, Table 21).

Koeleria exhibited significant increments of new leaves in control and competition at each successive sample date through the study (Figure 15, Table 22). Control seedlings had significant tiller increases at each successive sample date between 42 and 97 days (Figure 16, Table 23).

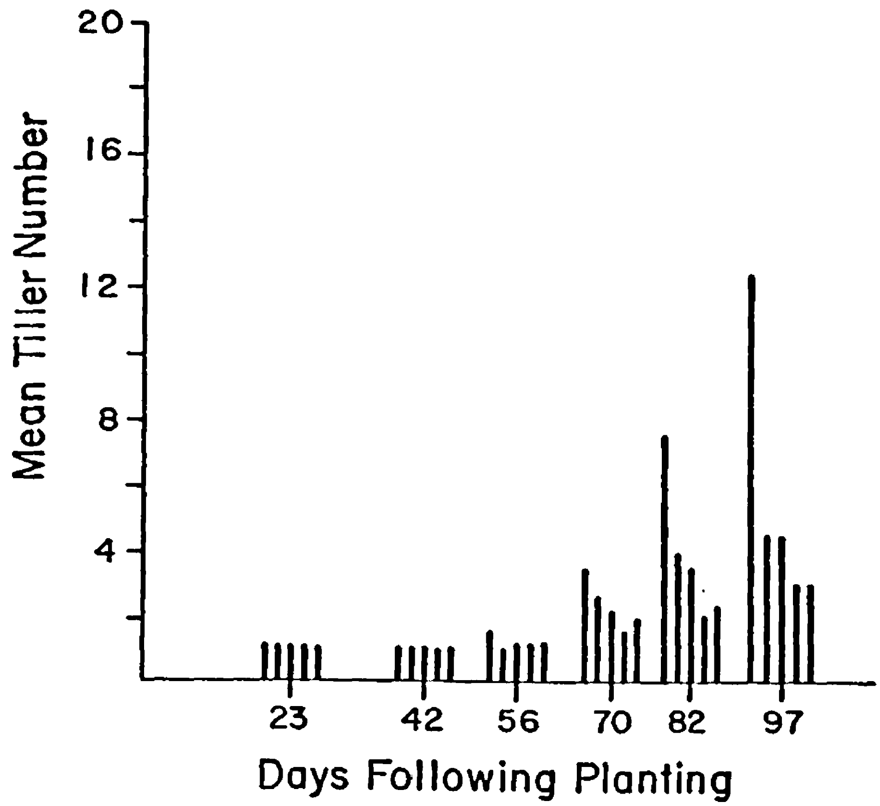

Figure 8. *Koeleria gracilis*. Mean cumulative tiller number per seedling through study. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Bromus japonicus* plants per square meter.

Table 15. Mean number of tillers of *Koeleria gracilis* grown in *Bromus* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.0a	1.0ab	1.3c	3.3d	7.1g	12.5i
50 *Bromus*/m^2	1.0a	1.0ab	1.1bc	2.6e	3.9eh	4.5hj
100 *Bromus*/m^2	1.0a	1.0ab	1.1c	2.1e	3.4h	4.3hj
200 *Bromus*/m^2	1.0a	1.0ab	1.1bc	1.5f	1.9fh	3.0hj
400 *Bromus*/m^2	1.0a	1.0ab	1.2bc	1.9f	2.3h	3.0hj

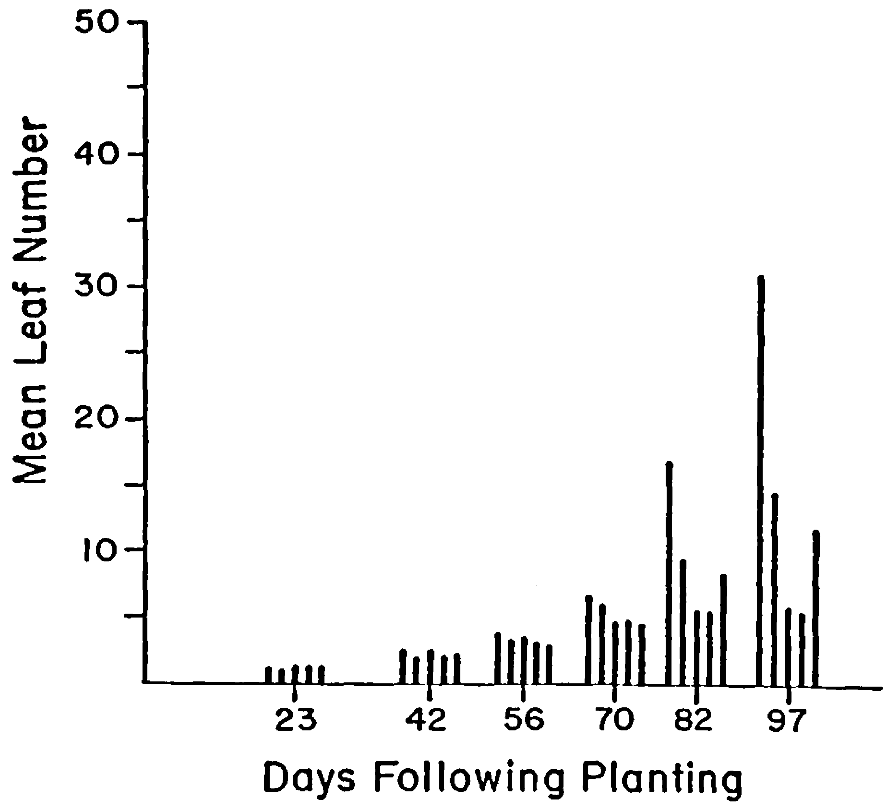

Figure 9. *Koeleria gracilis.* Mean cumulative leaf number per seedling grown in the indigenous species mixture. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Bromus japonicus* plants per square meter.

Table 16. Mean number of leaves of *Koeleria gracilis* grown in the indigenous species mixture grown in *Bromus* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.1a	2.1b	3.6b	6.1d	16.9e	31.2i
50 *Bromus*/m^2	1.0a	2.0b	3.3c	6.0d	9.1f	14.5fj
100 *Bromus*/m^2	1.2a	2.1b	3.4c	4.7cd	5.6dg	5.9gj
200 *Bromus*/m^2	1.1a	2.1b	2.9c	4.8d	5.7dg	5.2gj
400 *Bromus*/m^2	1.1a	2.1b	2.9bc	4.5cd	8.4fh	11.8hj

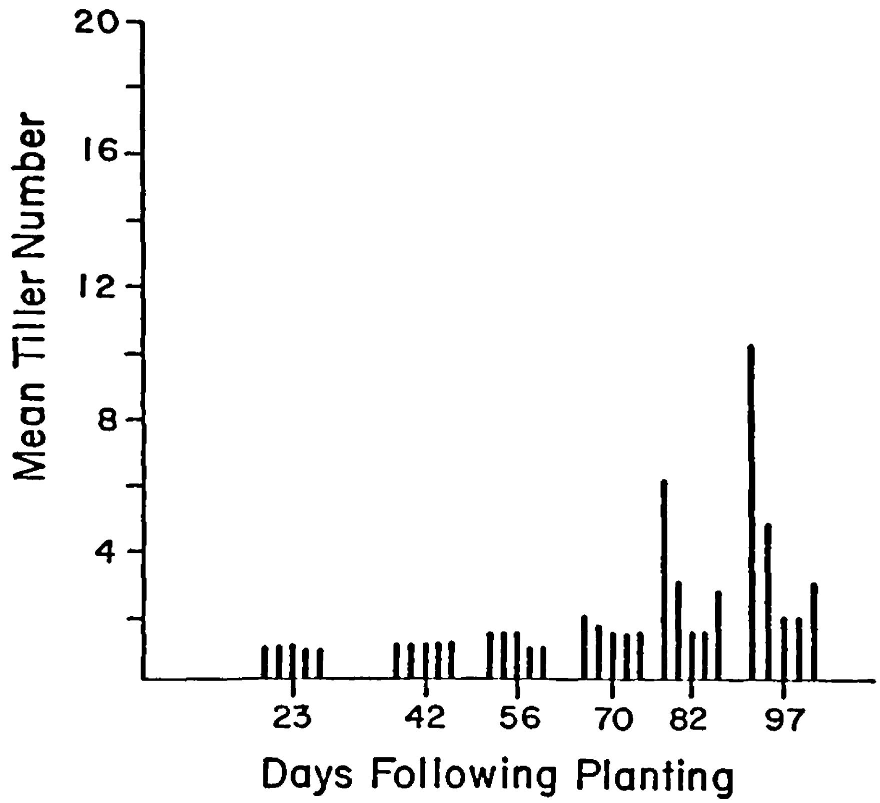

Figure 10. *Koeleria gracilis.* Mean cumulative tiller number per seedling grown in the indigenous species mixture. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Bromus japonicus* plants per square meter.

Table 17. Mean number of tillers of *Koeleria gracilis* in the indigenous species mixture grown in *Bromus* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.0a	1.0ab	1.2c	2.0d	6.1e	10.1eh
50 *Bromus*/m^2	1.0a	1.0ab	1.2bc	1.8d	3.0f	4.6fh
100 *Bromus*/m^2	1.0a	1.0ab	1.2bc	1.4cd	1.4dg	1.7gi
200 *Bromus*/m^2	1.0a	1.0ab	1.0bc	1.5d	1.5dg	1.7gi
400 *Bromus*/m^2	1.0a	1.0ab	1.1bc	1.5cd	2.8f	3.1fh

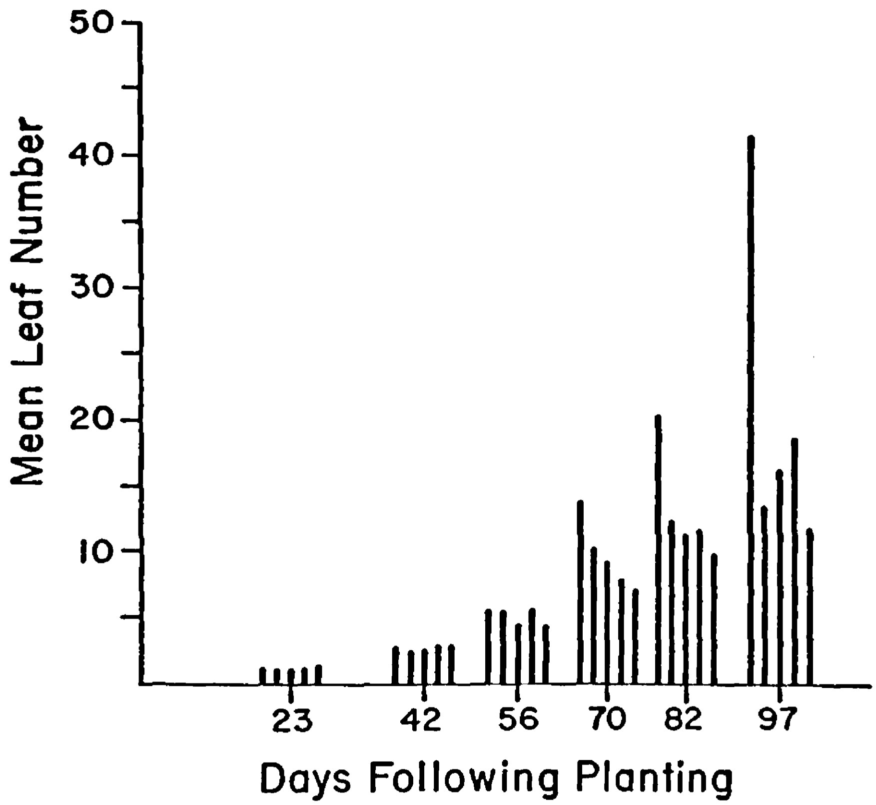

Figure 11. *Agropyron spicatum.* Mean cumulative leaf number per seedling through study. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Kochia scoparia* plants per square meter.

Table 18. Mean number of leaves of *Agropyron spicatum* grown in *Kochia* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.2a	2.8b	5.7c	14.0d	20.7f	41.6h
50 *Kochia*/m^2	1.1a	2.7b	5.3c	10.1e	12.5eg	13.8gi
100 *Kochia*/m^2	1.2a	2.5b	4.9c	9.3e	11.3eg	16.6i
200 *Kochia*/m^2	1.3a	2.7b	5.5c	8.4e	12.0g	18.9gi
400 *Kochia*/m^2	1.3a	2.6b	4.4c	7.6e	10.0eg	12.1gi

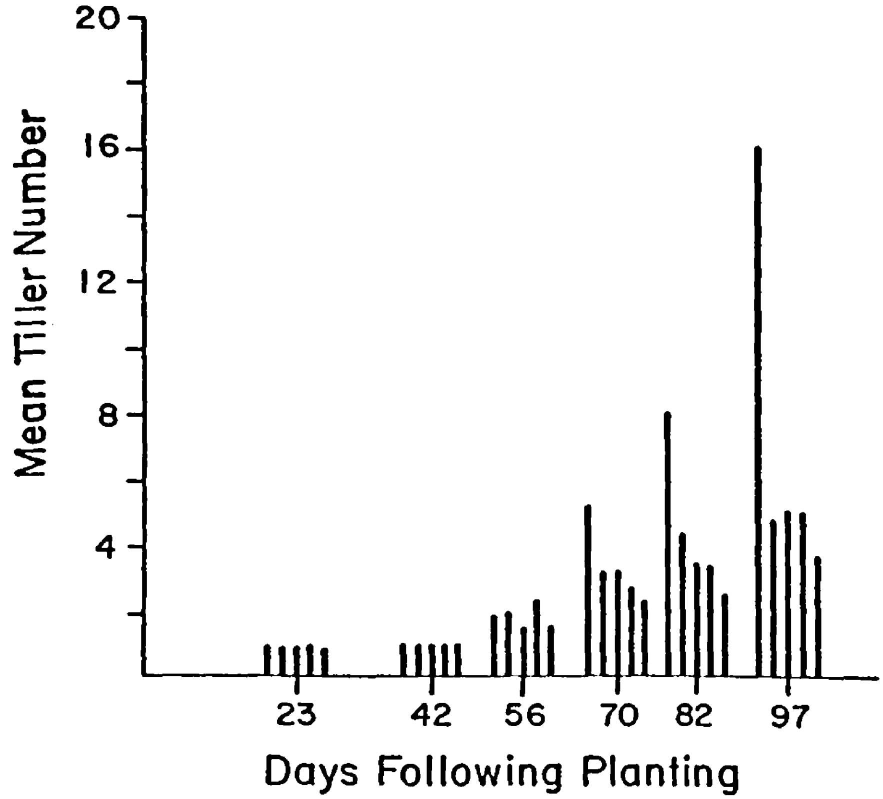

Figure 12. *Agropyron spicatum*. Mean cumulative tiller number per seedling through study. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Kochia scoparia* plants per square meter.

Table 19. Mean tiller number of *Agropyron spicatum* seedlings grown in *Kochia* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.0a	1.1a	1.9b	5.2c	8.1f	16.5j
50 *Kochia*/m^2	1.0a	1.0a	2.0b	3.3d	4.3g	4.7gk
100 *Kochia*/m^2	1.0a	1.0a	1.6b	3.1d	3.6dh	5.0hk
200 *Kochia*/m^2	1.0a	1.0a	2.3b	2.6e	3.4h	5.1hk
400 *Kochia*/m^2	1.0a	1.0a	1.4b	2.2e	2.6i	3.5il

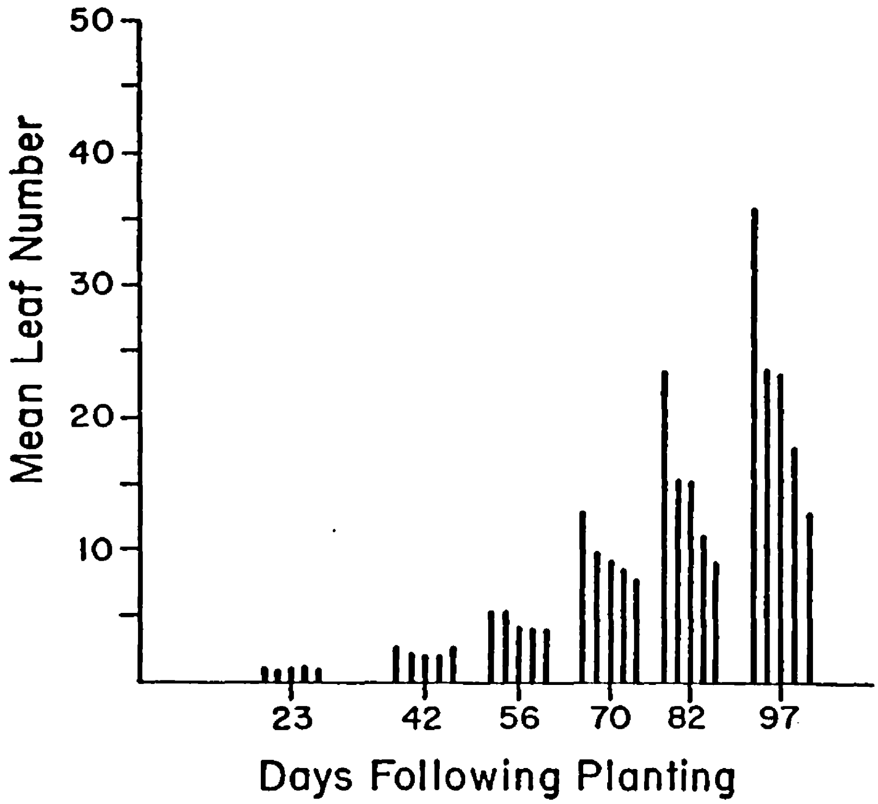

Figure 13. *Sitanion hystrix*. Mean cumulative leaf number per seedling through study. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Kochia scoparia* plants per square meter.

Table 20. Mean number of leaves of *Sitanion hystrix* grown in *Kochia* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.0a	2.5b	5.3c	12.9e	24.0g	36.5j
50 *Kochia*/m^2	1.0a	2.3b	5.3c	10.0f	15.6h	23.9k
100 *Kochia*/m^2	1.1a	2.0b	4.6d	9.3f	15.6h	24.1k
200 *Kochia*/m^2	1.0a	2.1b	4.6d	8.7f	11.3i	17.9l
400 *Kochia*/m^2	1.1a	2.3b	4.3d	7.8f	9.6fi	13.0il

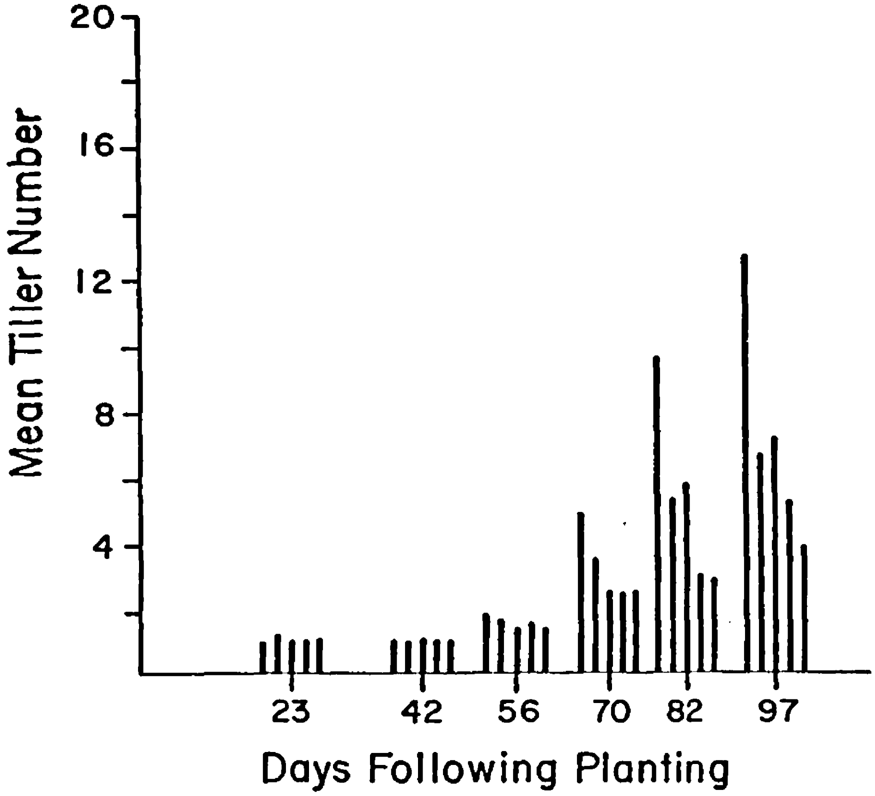

Figure 14. *Sitanion hystrix*. Mean cumulative tiller number per seedling through study. Within each sample date, respective competition levels are 0, 50, 100, 200 and 400 *Kochia scoparia* plants per square meter.

Table 21. Mean tiller number of *Sitanion hystrix* seedlings grown in *Kochia* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.0a	1.0a	1.9b	5.0e	9.5g	13.1i
50 *Kochia*/m^2	1.3a	1.0a	1.8c	3.3f	5.2g	6.8hk
100 *Kochia*/m^2	1.0a	1.0a	1.6d	2.6f	5.8g	7.2hk
200 *Kochia*/m^2	1.0a	1.0a	1.6d	2.6f	3.2fh	5.2k
400 *Kochia*/m^2	1.0a	1.0a	1.5d	2.6f	3.0fh	4.0hk

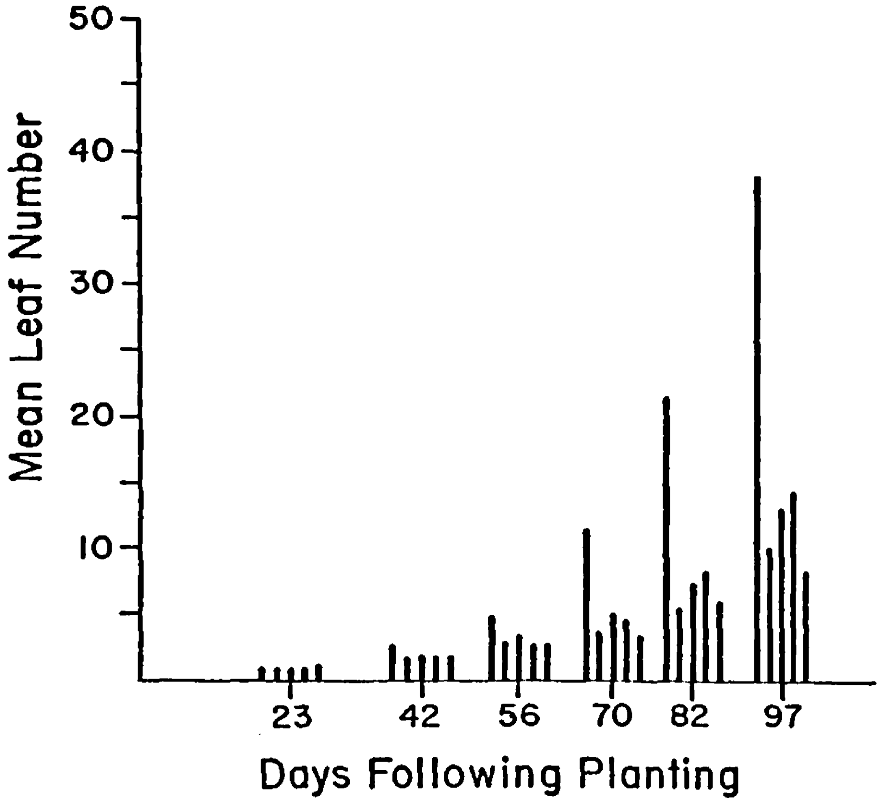

Figure 15. *Koeleria gracilis.* Mean cumulative leaf number per seedling through study. Within each sample date, respective competition levels from left to right are 0, 5, 100, 200 and 400 *Kochia scoparia* plants per square meter.

Table 22. Mean number of leaves of *Koeleria gracilis* grown in *Kochia* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.0a	2.3b	4.4c	11.5e	21.9g	38.9j
50 *Kochia*/m^2	1.0a	1.7b	2.8d	3.6df	5.3fg	10.1hk
100 *Kochia*/m^2	1.3a	1.9b	3.2d	5.3f	7.3fh	13.2k
200 *Kochia*/m^2	1.0a	1.9b	2.9d	4.8f	8.2h	14.8k
400 *Kochia*/m^2	1.3a	1.7ab	2.9bd	3.5df	5.9fh	8.4hk

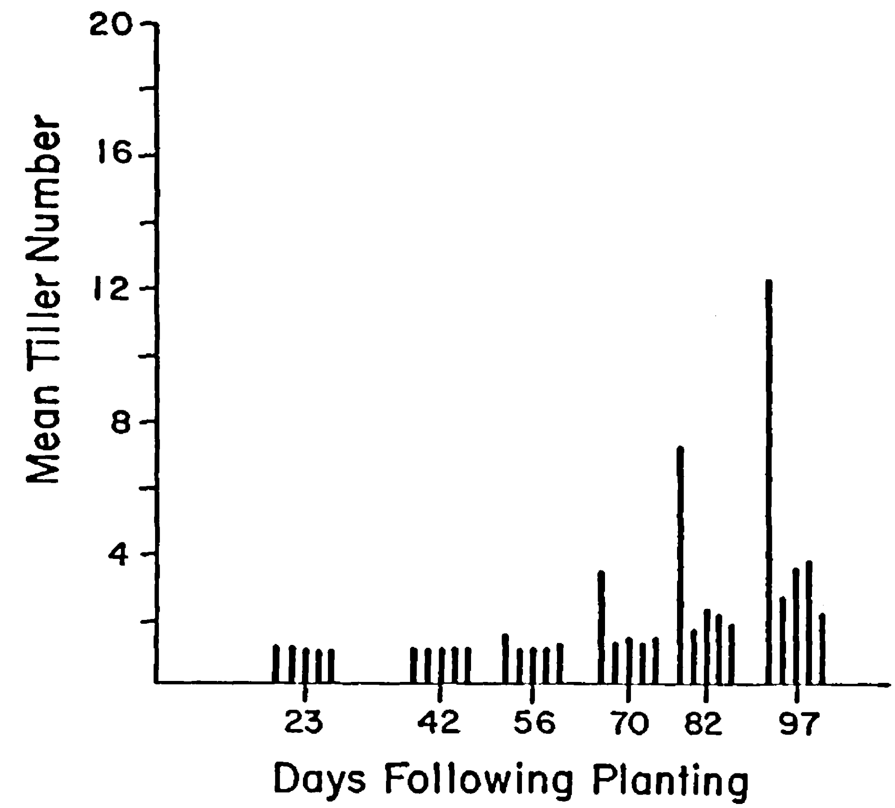

Figure 16. *Koeleria gracilis.* Mean cumulative tiller number per seedling through study. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Kochia scoparia* plants per square meter.

Table 23. Mean number of tillers of *Koeleria gracilis* grown in *Kochia* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.0a	1.0ab	1.3c	3.3e	7.1g	12.5i
50 *Kochia*/m^2	1.0a	1.0ab	1.0bd	1.2df	1.5fh	2.5hj
100 *Kochia*/m^2	1.0a	1.0ab	1.0bd	1.6f	2.2fh	3.4hj
200 *Kochia*/m^2	1.0a	1.0ab	1.0bd	1.4f	2.2h	3.6hj
400 *Kochia*/m^2	1.0a	1.0ab	1.1bd	1.3df	1.7fh	2.2hj

Tillering was delayed in seedlings in *Kochia* competition, but significant increases resulted on successive dates between 56 and 97 days.

Control seedlings of *Koeleria* in the native species mixture, had significant increases in leaf numbers at each successive date throughout the study (Figure 17, Table 24), but leaf numbers of seedlings in competition increased significantly only until the eighty-second day. Seedlings in competition and control had significant tiller number increases on successive dates between 42 and 82 days (Figure 18, Table 25).

Seedling Growth Responses in *Bromus* versus *Kochia* Competition

Differential responses of native species to *Bromus* and *Kochia* competition were determined at 97 days. Leaf number and tiller number per plant, average number of leaves per tiller, plant height and inflorescence production were compared.

Agropyron and monospecifically grown *Koeleria* did not respond significantly differently in any parameters between *Bromus* and *Kochia* competition.

Sitanion produced significantly fewer leaves per tiller and plants were significantly shorter in *Bromus* competition than *Kochia*. But, tillering and seedhead production were not significantly different.

Koeleria, grown in the native species mixture, had significantly more leaves per tiller and seedlings were significantly taller in *Kochia* competition than *Bromus*. However, tiller and leaf number per plant were not significantly different.

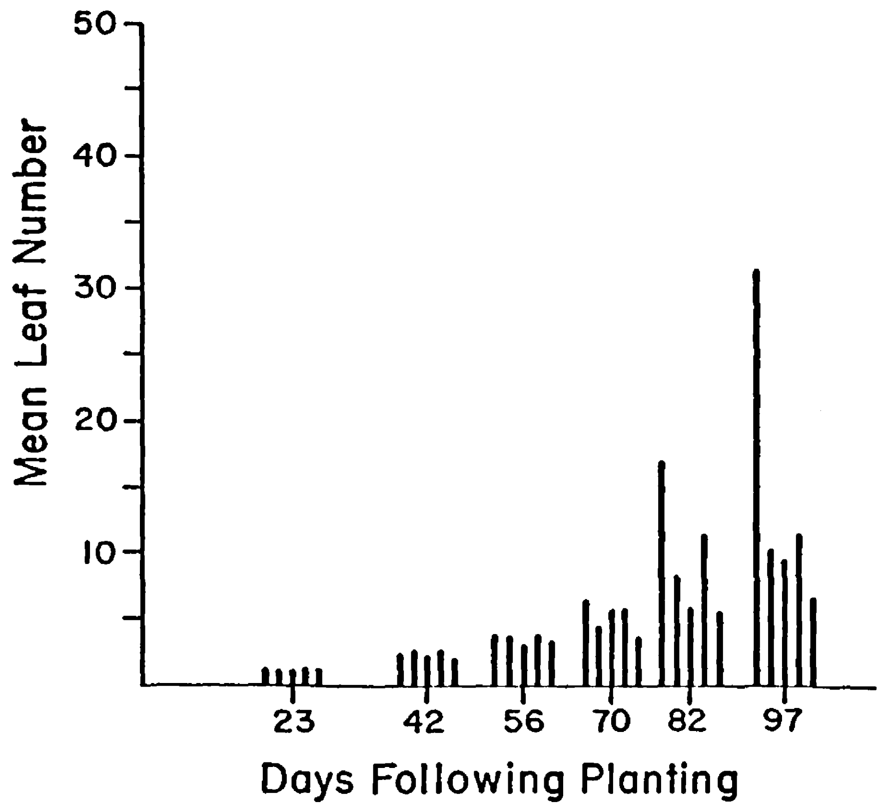

Figure 17. *Koeleria gracilis.* Mean cumulative leaf number per seedling grown in the indigenous species mixture. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Kochia scoparia* plants per square meter.

Table 24. Mean number of leaves of *Koeleria gracilis* seedlings in the indigenous species mixture grown in *Kochia* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. $\alpha = 0.05$.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.1a	2.1b	3.6c	6.1d	16.9f	31.2i
50 *Kochia*/m^2	1.0a	2.3b	3.7c	4.3ce	8.3g	10.3gj
100 *Kochia*/m^2	1.2a	2.0b	2.9c	5.3e	5.9eg	9.8gj
200 *Kochia*/m^2	1.2a	2.6b	3.9c	5.5ce	11.1g	11.3gj
400 *Kochia*/m^2	1.0a	1.7b	3.1c	3.5ce	5.5h	6.6hj

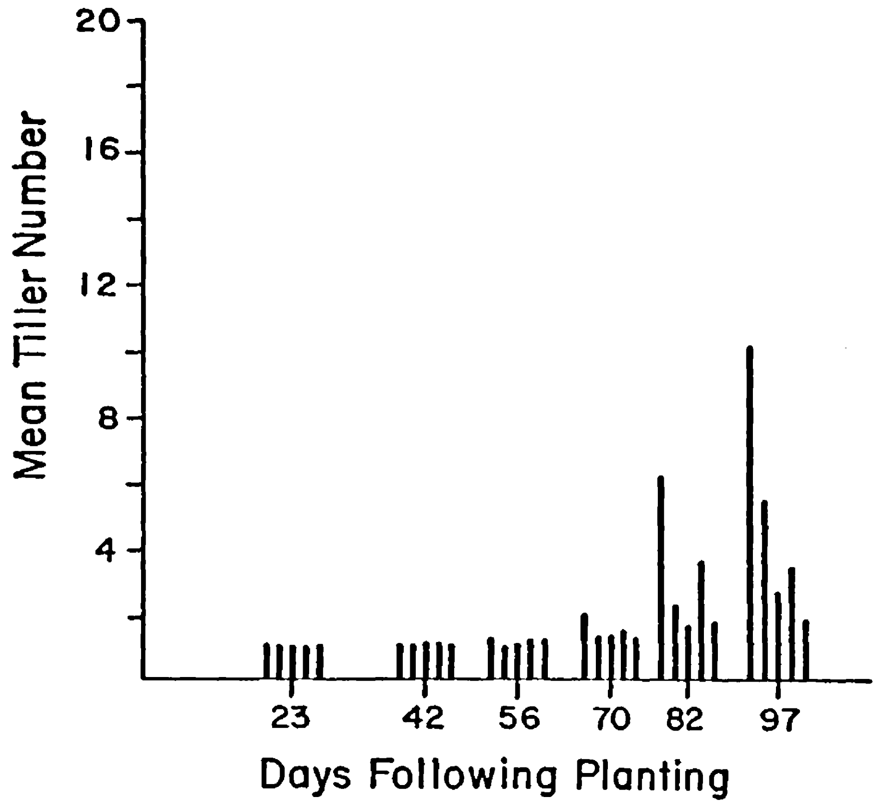

Figure 18. *Koeleria gracilis*. Mean cumulative tiller number per seedling grown in the indigenous species mixture. Within each sample date, respective competition levels from left to right are 0, 50, 100, 200 and 400 *Kochia scoparia* plants per square meter.

Table 25. Mean number of tillers of *Koeleria gracilis* seedlings in the indigenous species mixture grown in *Kochia* competition. A similar letter indicates non-significant differences between treatments within dates and between successive dates for each competition level. α = 0.05.

Treatment	Sample Days					
	23	42	56	70	82	97
Control	1.0a	1.0ab	1.2c	2.0d	6.1f	10.1fi
50 *Kochia*/m^2	1.0a	1.0ab	1.1bc	1.4ce	2.3g	3.3gj
100 *Kochia*/m^2	1.0a	1.0ab	1.1bc	1.5ce	1.6eh	2.7hj
200 *Kochia*/m^2	1.0a	1.0ab	1.2bc	1.5ce	3.5g	3.5gj
400 *Kochia*/m^2	1.0a	1.0ab	1.1bc	1.2ce	1.5eh	1.5hj

Seedling Responses Between Treatments

In general, the effects of competition were reflected in leaf and tiller number concomitantly. Whenever discrepancies occurred, responses were reflected in leaf number prior to tiller number.

Bromus Competition

Differences in *Agropyron* vigor were first detected in total leaf number the forty-second day of study (Figure 3, Table 10), but differential responses in tiller numbers were identified only after 56 days. (Figure 4, Table 11). Based on population means, at the end of study, control seedlings averaged approximately three times more leaves and tillers than seedlings in competition. Compared to control, the mean plant height of seedlings in competition was significantly reduced and control produced significantly more seedheads than seedlings in competition (Table 26). There were no significant differences in mean number of leaves per stem between control and seedlings in *Bromus* competition.

Tiller number and leaf number of *Sitanion* indicated differential growth responses by the fifty-sixth day of study (Figures 5 and 6, Tables 12 and 13). Control plants were significantly larger than competing seedlings the remainder of the study. Based on statistical means of the final field measurements, control plants averaged more than two and one half times more leaves and tillers than seedlings in *Bromus* competition. *Bromus* competition also significantly reduced plant height and seedhead production (Table 27), but the mean number of leaves per tiller was not altered.

The effects of *Bromus* competition on *Koeleria* seedlings was first reflected in tiller and leaf numbers by the seventieth day (Figures 7 and

8, Tables 14 and 15). Control seedlings were significantly larger than seedlings in *Bromus* competition the remainder of the study. Seedling height was also reduced by *Bromus* competition, but the mean number of leaves per tiller was not significantly different.

Growth of *Koeleria* in the native species mixture closely parallels *Koeleria* grown monospecifically in *Bromus* competition. Seedlings in the mixture were, however, smaller than seedlings grown monospecifically. *Bromus* competition reduced *Koeleria* vigor only after 70 days and from this date forth control seedlings had significantly more leaves and tillers than seedlings in competition (Figures 9 and 10, Tables 16 and 17). Based on population means, control seedlings averaged more than three and one half times more tillers and leaves than seedlings in *Bromus* competition, but the mean leaf number per tiller was not altered.

Kochia Competition

Kochia induced competition responses were first noted for *Agropyron* in tiller and total leaf number after 56 days (Figures 11 and 12, Tables 18 and 19). From this date, control seedlings were significantly more vigorous than seedlings in *Kochia* competition. At 97 days, control seedlings averaged more than three and one half times more tillers and nearly two and one half times the number of leaves as seedlings in competition. Seedlings in *Kochia* competition averaged approximately 3.5 leaves per tiller whereas significantly fewer leaves (2.5) developed on tillers of control seedlings. Seedhead production was significantly reduced by competition (Table 26), but seedling height was not significantly affected by *Kochia* competition.

Kochia competition produced significant differences in leaf and tiller number of *Sitanion* by the fifty-sixth day (Figures 13 and 14, Tables 20 and 21). Thereafter, control seedlings were significantly more vigorous than seedlings in competition. On the ninety-seventh day, control seedlings averaged more than twice the number of leaves as compared to seedlings grown in *Kochia* competition. However, seedlings in *Kochia* competition had significantly more leaves per tiller (3.4) than control seedlings (2.8). Competition significantly reduced *Sitanion* seedhead production (Table 27), but seedling height was not significantly changed by *Kochia* competition.

Differences in *Koeleria* seedling vigor were detected after 42 days of *Kochia* competition (Figures 15 and 16, Tables 22 and 23). Through the remainder of the study control seedlings were significantly more vigorous than seedlings in *Kochia* competition. At 97 days, control seedlings averaged more than four times more tillers and three times more leaves than seedlings in competition. However, seedlings in competition produced significantly more leaves per tiller (approximately 4) than control seedlings (3.4). Seedling height was not significantly different between control and *Kochia* competition levels.

Koeleria, grown in the indigenous species mixture and *Kochia* competition, had significantly fewer leaves and tillers than control by 70 days. Thereafter, control seedlings were significantly more vigorous than seedlings in competition (Figures 17 and 18, Tables 24 and 25). At the termination of the study, control seedlings averaged more than three times more leaves and slightly fewer than three times more tillers than seedlings in competition. However, seedling height and the mean number of leaves per tiller were not significantly different.

Table 26. Mean number of *Agropyron spicatum* seedheads per 40cm x 50cm subplot on the ninety seventh day of study. A similar letter indicates non-significant differences. α=.05.

Treatment	n	$\bar{x}$	s
Control	10	7.0	6.5
Bromus competition	20	1.3a	1.7
Kochia competition	20	.9a	1.3

Table 27. Mean number of *Sitanion hystrix* seedheads per 40cm x 50cm subplot on the ninety seventh day of study. A similar letter indicates non-significant differences. α=.05.

Treatment	n	$\bar{x}$	s
Control	10	5.0	4.9
Bromus competition	20	.4a	.7
Kochia competition	20	.2a	.4

Biomass Study

Sectioning and weighing seedlings as root, crown and aerial portions allowed calculation of total biomass as well as partitioning. Additionally, potential carbohydrate storage (combined root and crown weight) and the ratio of roots and crown weight to aerial biomass was obtained. This will be referred to as the root-shoot ratio throughout this treatise. The importance of root to shoot biomass ratios are discussed in literature (Younger and McKell 1972, Monk 1966), but review did not disclose whether the crown is included in the root or shoot portion. However, it is recognized that both roots and crown are important carbohydrate sinks (White 1973). Therefore, with the assumption that increased root and/or crown weight indicates more potential carbohydrate storage, the ratio of combined root and crown weight to aerial biomass weight was used for calculation. As the ratio increases, proportionally more of the total plant biomass is in the roots and crown.

Bromus and *Kochia* competition significantly reduced seedling biomass of all native species (Figures 19 and 20). Additionally, native species responses in *Kochia* and *Bromus* competition were distinct, especially in root biomass apportionment and root-shoot ratios. Crown development, expressed as a percent of total biomass, was unaffected in all species and competition types.

Bromus Competition

Agropyron control seedlings were significantly heavier than seedlings that competed with *Bromus* in all biomass categories (Figure 21, Table 28). The root percentage of the total biomass was significantly greater in seedlings in *Bromus* competition (27%) than control (19%). Seedlings from

Figure 19. Representative *Agropyron spicatum* seedlings 130 days following planting. Seedlings from *Kochia scoparia* competition are top row and bottom row seedlings were grown in *Bromus japonicus* competition. From left to right respective competition, densities are 0, 50, 100, 200, and 400 weeds per square meter.

Figure 20. Representative *Sitanion hystrix* seedlings 130 days following planting. Seedlings from *Kochia scoparia* competition are top row and bottom row seedlings were grown in *Bromus japonicus* competition. From left to right respective competition densities are 0, 5, 100, 200, and 400 weeds per square meter.

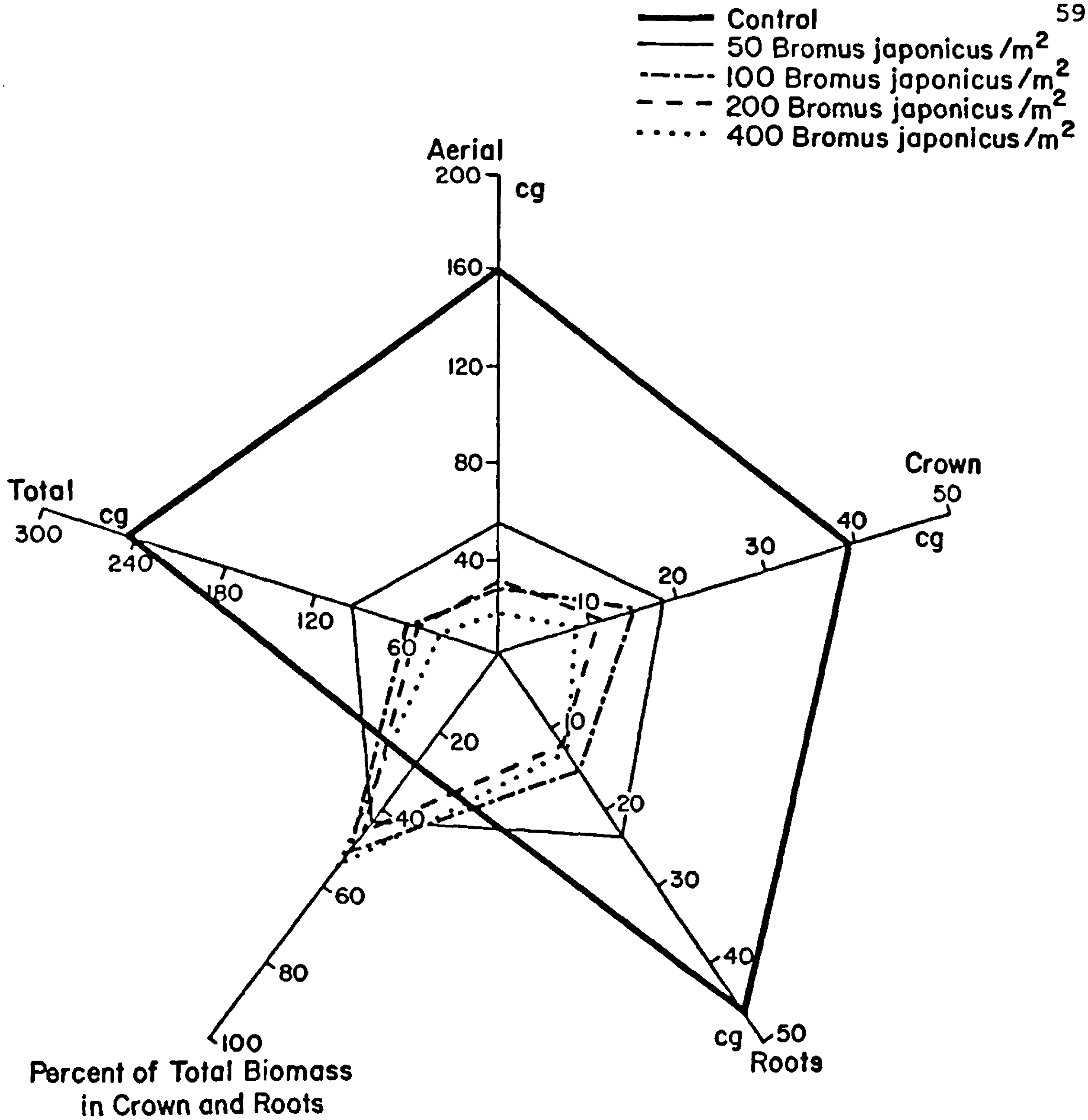

Figure 21. Biomass of *Agropyron spicatum* seedlings after 20 weeks in *Bromus* competition.

Table 28. Summary of *Agropyron spicatum* biomass data presented in Figure 21. A similar letter within groups indicates non-significant differences. α=.05.

Treatment	n	Roots cg			Crown cg			Aerial cg			Total cg		Root-Shoot Ratio	
		$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	$\bar{x}$	s
Control	30	46	31	19	40	29	16d	161	93	72	247	135	.72	.81
50 *Bromus*/m^2	15	23	16	25b	18c	12	19d	55	46	56f	96	68	.89j	.49
100 *Bromus*/m^2	15	15a	10	29b	15c	21	23d	29e	34	48g	59h	49	1.31j	.92
200 *Bromus*/m^2	15	12a	7	23b	11c	4	22d	30e	17	55f	53h	24	.89j	.39
400 *Bromus*/m^2	15	13a	7	33b	9c	5	22d	17e	9	45g	38h	19	1.35j	.53

Bromus competition also had a significantly greater percentage of biomass in roots and crown (Figure 21). Also, the root-shoot ratio of control seedlings was approximately .7, but seedlings in competition had a significantly greater ratio of 1.1. Although the root and aerial percentages were not significantly different between *Bromus* competition levels, seedling root, aerial and total biomass weights were significantly heavier in *B* 50 than the three higher densities.

Agropyron control seedlings in the native species mixture were significantly heavier in all biomass categories than seedlings that competed with *Bromus* (Figure 22, Table 29). However, there were no significant differences in seedling biomass parameters between *Bromus* competition levels. Compared to control, seedlings in *Bromus* competition had significantly greater root percentage and combined root and crown percentage (Figure 22). Seedlings in *Bromus* competition also had a significantly greater root-shoot ratio (2.09) than control seedlings (.86).

Sitanion seedlings grown in *Bromus* competition were significantly lighter than control seedlings in all biomass categories (Figure 23, Table 30). Seedlings in *Bromus* competition had significantly greater root percentages, combined root and crown percentages (Figure 23) and also a greater root-shoot ratio (2.4) than control seedlings (1.06). Although roots, crown and aerial percentages and root-shoot ratios were not significantly different between competition levels, seedlings in *B* 50 and 100 were significantly heavier than seedlings in the two higher competition levels.

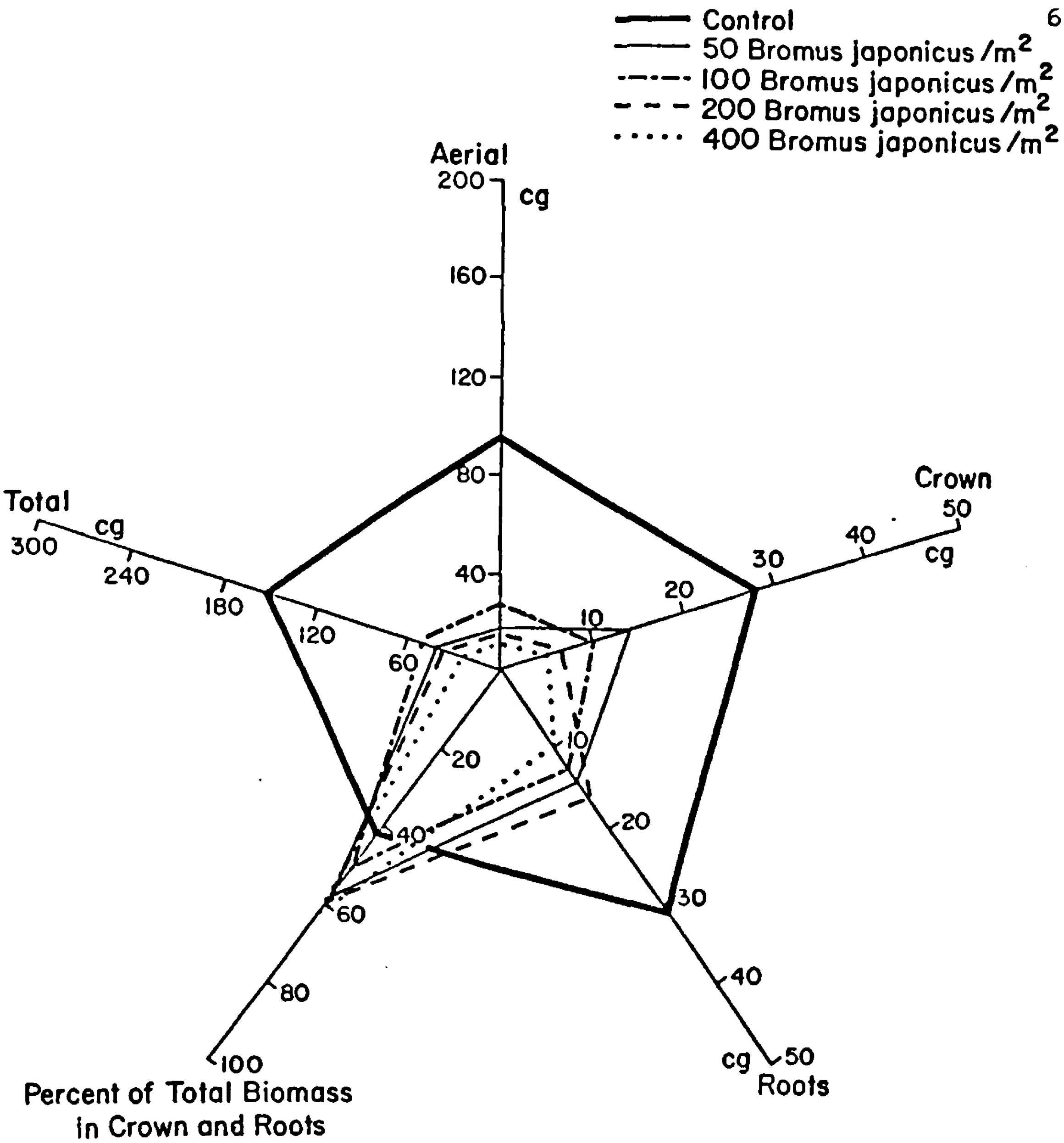

Figure 22. Biomass of *Agropyron spicatum* seedlings grown in the indigenous species mixture after 20 weeks in *Bromus* competition.

Table 29. Summary of *Agropyron spicatum* biomass data presented in Figure 22. A similar letter within groups indicates non-significant differences. α=.05.

Treatment	n	Roots cg			Crown cg			Aerial cg			Total cg		Root-Shoot Ratio	
		$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	$\bar{x}$	s
Mixture Control	30	31	18	22	28	19	19d	95	54	59	154	67	.86	.79
50 *Bromus*/m²	15	14a	11	32b	11c	14	23d	19e	15	44f	44g	33	1.86h	1.57
100 *Bromus*/m²	15	12a	8	31b	10c	8	20d	29e	27	49f	50g	31	1.72h	1.77
200 *Bromus*/m²	15	16a	23	37b	6c	5	20d	17e	21	43f	39g	27	2.62h	2.7
400 *Bromus*/m²	14	10a	8	37b	5c	3	22d	10e	8	41f	26g	11	2.16h	1.78

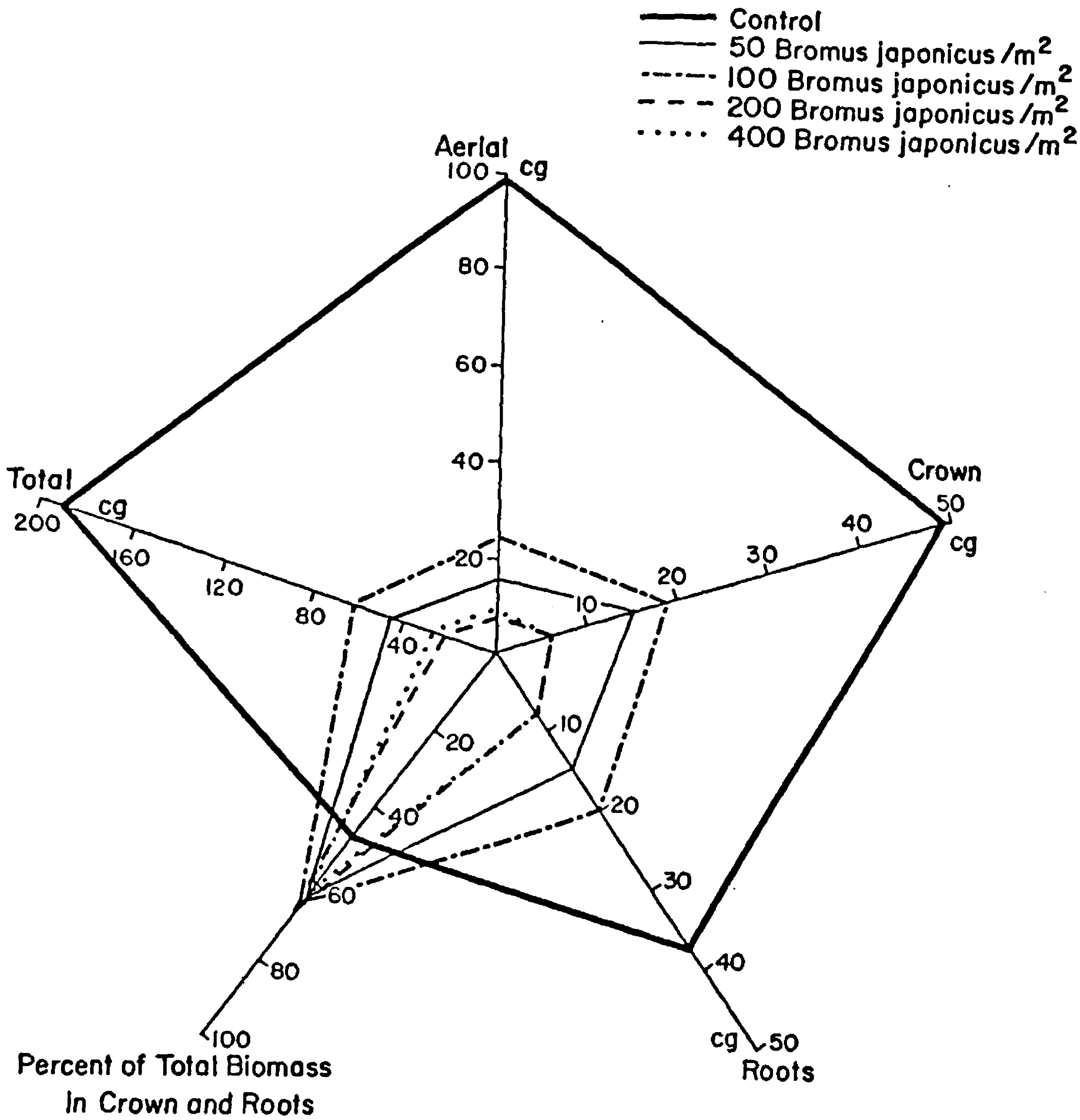

Figure 23. Biomass of *Sitanion hystrix* seedlings after 20 weeks in *Bromus* competition.

Table 30. Summary of *Sitanion hystrix* biomass data presented in Figure 23. A similar letter within groups indicates non-significant differences. $\alpha = .05$.

Treatment	n	Roots cg			Crown cg			Aerial cg			Total cg		Root-Shoot Ratio	
		$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	$\bar{x}$	s
Control	30	38	27	20	51	29	27f	104	69	53	193	111	1.06	.73
50 *Bromus*/m^2	15	15a	10	31c	16d	9	34	17gh	11	36i	47jk	29	1.96l	.76
100 *Bromus*/m^2	15	20a	18	36c	18d	18	29f	25g	36	35i	63j	71	1.97l	.62
200 *Bromus*/m^2	15	8b	6	38c	6e	3	29f	7h	5	33i	21k	13	2.18l	.77
400 *Bromus*/m^2	15	8b	6	35c	6e	4	28f	8h	5	37i	22k	14	1.76l	.52

Control *Sitanion* seedlings grown in the native species mixture were significantly heavier than seedlings that competed with *Bromus* (Figure 24, Table 31). However, there were no significant differences in biomass apportionment or root-shoot ratios. Between levels of *Bromus* competition, root weights were not significantly different, but seedlings in *B* 50 and 100 were significantly heavier in crown, aerial and total biomass than seedlings in 200 and 400.

Koeleria control seedlings were significantly heavier than seedlings in *Bromus* competition (Figure 25, Table 32). Seedlings in competition had significantly greater root and combined root and crown percentages than control, but root-shoot ratios were not significantly different. Root, crown and aerial biomass weights were not significantly different between levels of *Bromus* competition, however, total biomass of seedlings from *B* 50 and 100 was significantly heavier than *B* 200 and 400.

When grown in the native species mixture, only total biomass of *Koeleria* control was significantly heavier than seedlings in *Bromus* competition (Figure 26, Table 33). Biomass apportionment and root-shoot ratios showed no differential response between control and seedlings from *Bromus* competition.

Kochia Competition

Agropyron control seedlings were significantly heavier than seedlings that competed with *Kochia* (Figure 27, Table 34). Root-shoot ratios and root biomass percentages were not significantly different, but the combined root and crown percentage was significantly greater in *Kochia* competition. Among levels of *Kochia* competition, root, aerial and total biomass were not significantly different, but crown weight was significantly he[illegible] her competition levels.

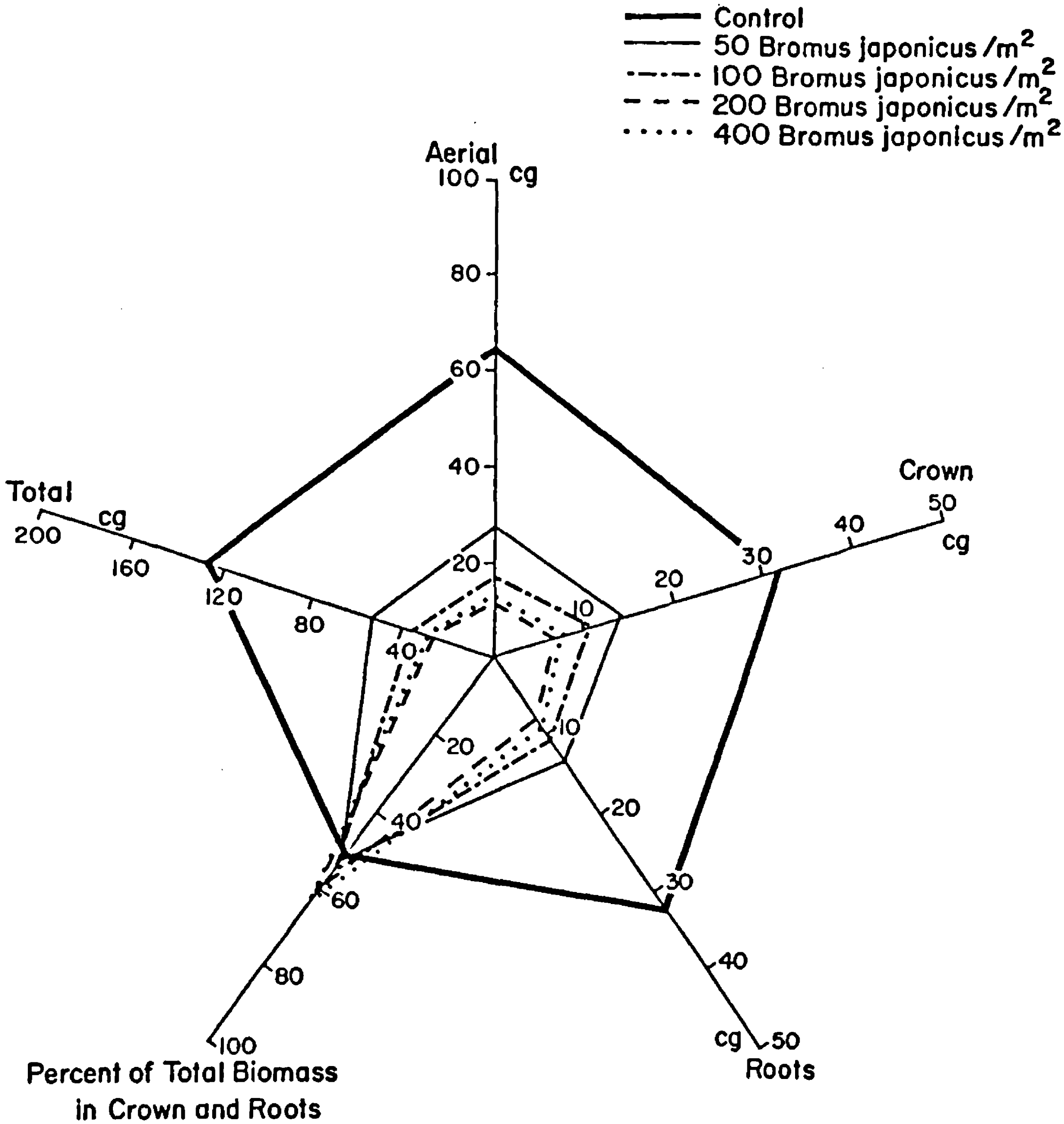

Figure 24. Biomass of *Sitanion hystrix* seedlings grown in the indigenous species mixture after 20 weeks in *Bromus* competition.

Table 31. Summary of *Sitanion hystrix* biomass data presented in Figure 24. A similar letter within groups indicates non-significant differences. α=.05.

Treatment	n	Roots cg			Crown cg			Aerial cg			Total cg		Root-Shoot Ratio	
		$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	$\bar{x}$	s
Mixture Control	30	32	27	25b	32	24	26e	64	46	49h	127	58	1.73k	1.86
50 *Bromus*/m^2	15	13a	7	25b	14c	7	29e	27f	21	47h	53i	25	1.53k	1.09
100 *Bromus*/m^2	15	11a	8	28b	11cd	10	28e	17fg	13	44h	39ij	16	3.56k	5.74
200 *Bromus*/m^2	15	8a	5	33b	7d	6	26e	11g	11	40h	26j	12	2.60k	2.27
400 *Bromus*/m^2	15	10a	9	38b	7d	4	24e	12g	9	38h	29j	14	3.32k	4.58

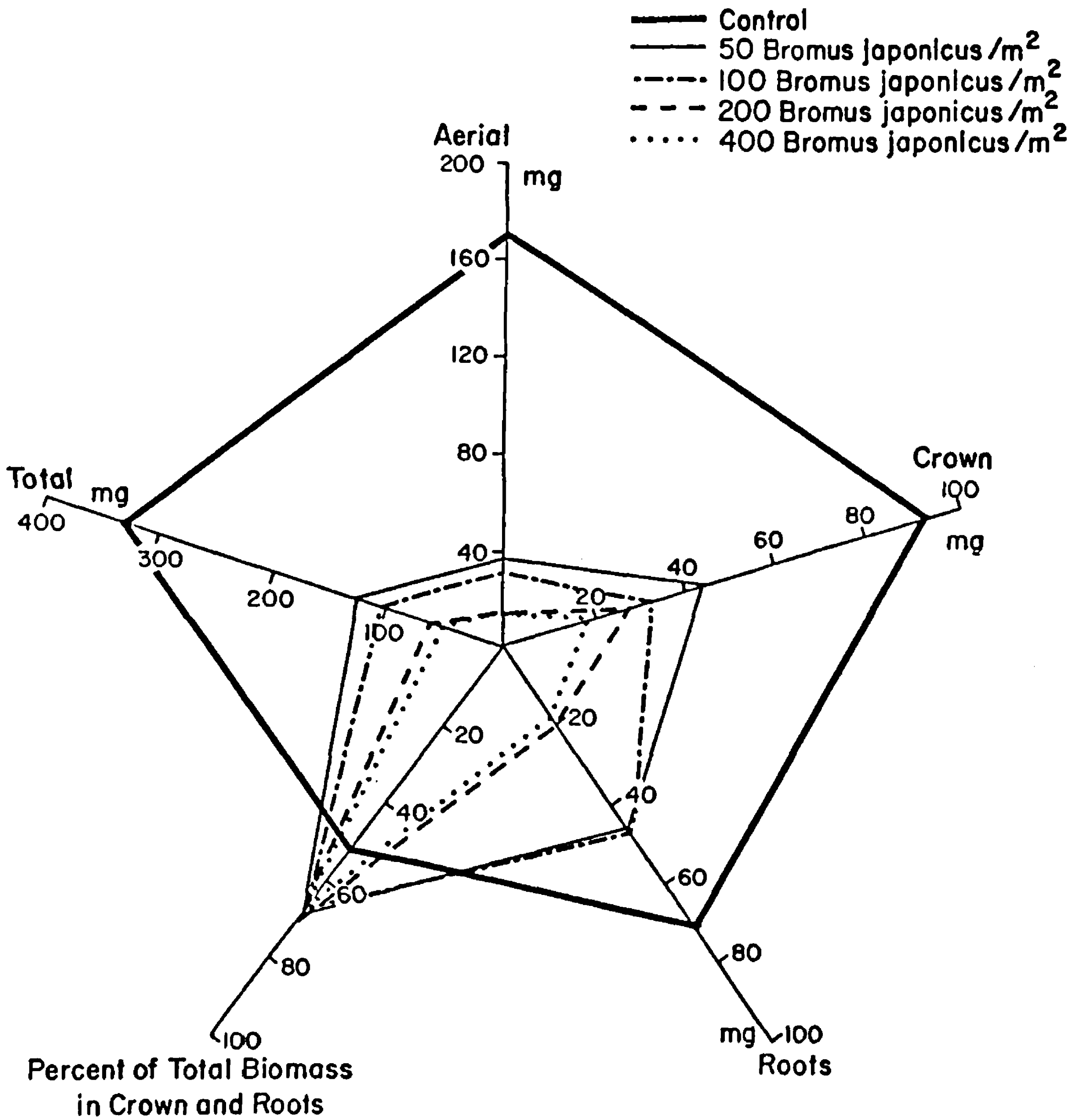

Figure 25. Biomass of *Koeleria gracilis* seedlings after 20 weeks in *Bromus* competition.

Table 32. Summary of *Koeleria gracilis* biomass data presented in Figure 25. A similar letter within groups indicates non-significant differences. α=.05.

Treatment	n	Roots mg			Crown mg			Aerial mg			Total mg		Root-Shoot Ratio	
		$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	$\bar{x}$	s
Control	30	71.1	51.6	22	93.6	72.5	31d	172.6	132.7	47	337	149	1.94i	1.9
50 *Bromus*/m^2	14	46.6a	37.0	36b	44.7c	32.4	34d	39.0e	30.8	30f	130g	72	2.98i	2.04
100 *Bromus*/m^2	10	48.2a	51.1	39b	32.6c	28.9	29d	31.2e	25.2	32f	112g	76	5.45i	8.66
200 *Bromus*/m^2	7	20.7a	23.5	33b	27.7c	37.1	39d	17.1e	17.9	28f	66h	56	3.35i	2.33
400 *Bromus*/m^2	8	19.3a	13.5	38b	18.0c	15.3	31d	16.1e	11.9	31f	53h	40	2.41i	.66

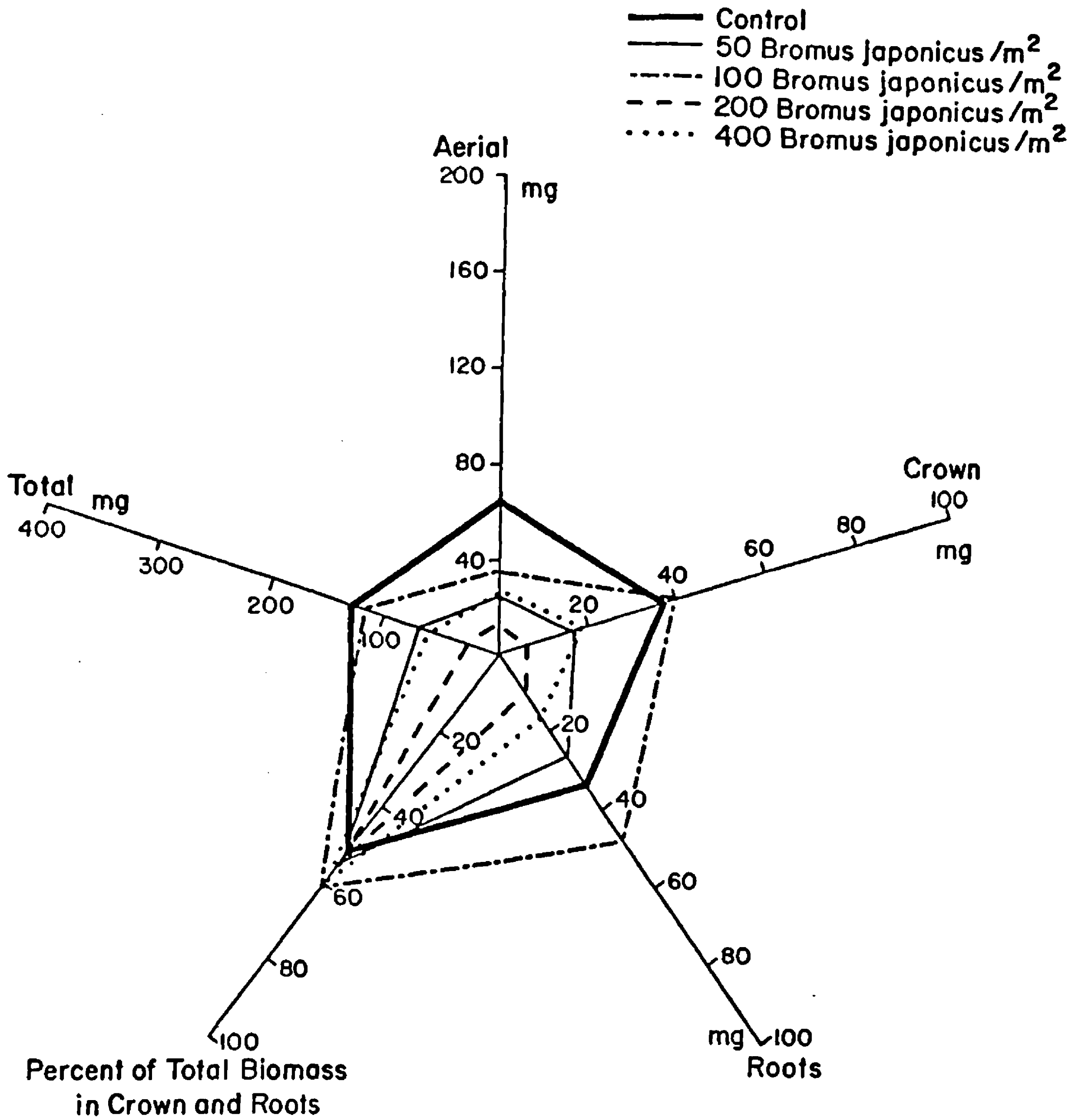

Figure 26. Biomass of *Koeleria gracilis* seedlings grown in the indigenous species mixture after 20 weeks in *Bromus* competition.

Table 33. Summary of *Koeleria gracilis* biomass data presented in Figure 26. A similar letter within groups indicates non-significant differences. α=.05.

Treatment	n	Roots mg			Crown mg			Aerial mg			Total mg		Root-Shoot Ratio	
		$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	$\bar{x}$	s
Mixture Control	20	33.6a	30.0	24b	35.6c	27.6	29d	64.5e	47.8	48f	134	89	1.47h	1.36
50 *Bromus*/m²	10	26.0a	30.1	33b	17.1c	16.9	22d	28.7e	23.2	45f	72g	48	3.02h	4.01
100 *Bromus*/m²	8	46.3a	75.6	34b	37.1c	71.0	28d	36.8e	57.4	38f	120g	111	9.86h	19.3
200 *Bromus*/m²	6	9.7a	6.4	33b	6.5c	1.8	23d	12.0e	3.2	44f	28g	3.0	1.63h	1.29
400 *Bromus*/m²	3	16.7a	11.4	28b	18.7c	13.4	32d	28.0e	29.6	39f	63g	48	1.76h	.96

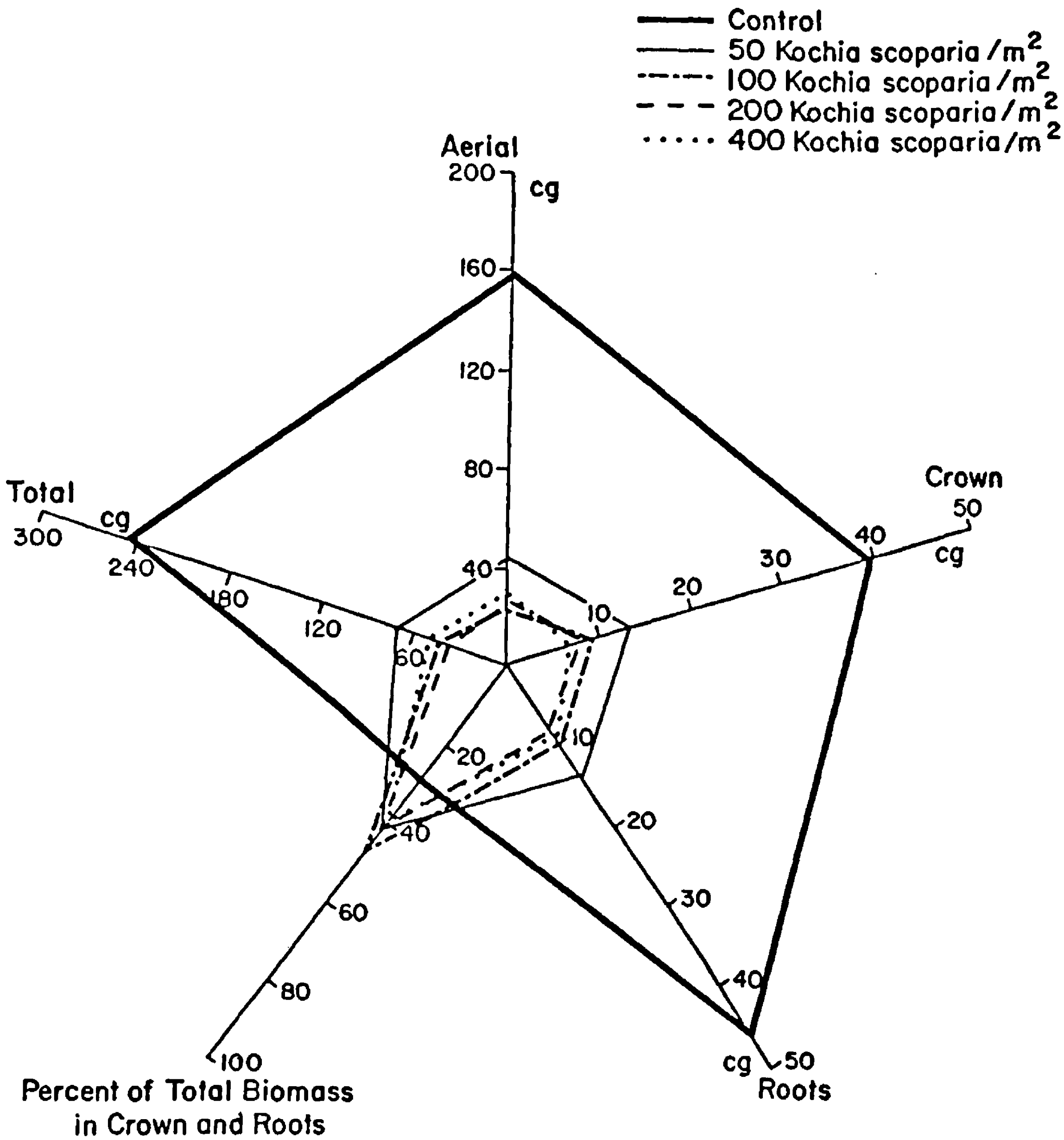

Figure 27. Biomass of *Agropyron spicatum* seedlings after 20 weeks in *Kochia* competition.

Tale 34. Summary of *Agropyron spicatum* biomass data presented in Figure 27. A similar letter within groups indicates non-significant differences. α=.05.

Treatment	n	Roots cg			Crown cg			Aerial cg			Total cg		Root-Shoot Ratio	
		$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	$\bar{x}$	s
Control	30	46	31	19b	40	29	9d	161	93	72	247	135	.72h	.81
50 *Kochia*/m^2	14	13a	6	21b	13	7	21d	44e	40	58f	70g	52	.81h	.45
100 *Kochia*/m^2	15	10a	6	25b	9c	5	23d	22e	11	53f	41g	18	1.04h	.76
200 *Kochia*/m^2	14	8a	4	21b	9c	5	21d	23e	14	58f	39g	22	.74h	.21
400 *Kochia*/m^2	15	9a	5	23b	8c	4	18d	29e	24	59f	46g	31	.74h	.34

In the native species mixture, *Agropyron* control seedlings were significantly heavier than seedlings in *Kochia* competition (Figure 28, Table 35). However, there were no significant differences in biomass apportionment or root-shoot ratios. Seedlings from *K* 50 were significantly heavier in root and total biomass than seedlings from the higher *Kochia* competition levels.

Sitanion seedlings grown in *Kochia* competition were significantly lighter than control seedlings (Figure 29, Table 36), but there were no significant differences in biomass apportionment or root-shoot ratios. Crown weight and total biomass were significantly lighter in *K* 400 than the lower *Kochia* competition levels.

When grown in the native species mixture, *Sitanion* control seedlings were significantly heavier than seedlings that competed with *Kochia* (Figure 30, Table 27). However, root-shoot ratios and biomass apportionment were not significantly different. Among levels of *Kochia* competition, total biomass was significantly heavier in *K* 50 than the higher competition levels.

Within all biomass categories, control *Koeleria* seedlings were significantly heavier than seedlings that competed with *Kochia* (Figure 31, Table 38), but biomass apportionment and root-shoot ratios were not significantly different. There were no differential biomass responses among *Kochia* competition levels.

When grown in the native species mixture, *Koeleria* control seedlings were significantly heavier than seedlings in *Kochia* competition in all biomass categories except root weight (Figure 32, Table 39). Biomass apportionment and root-shoot ratios were not significantly

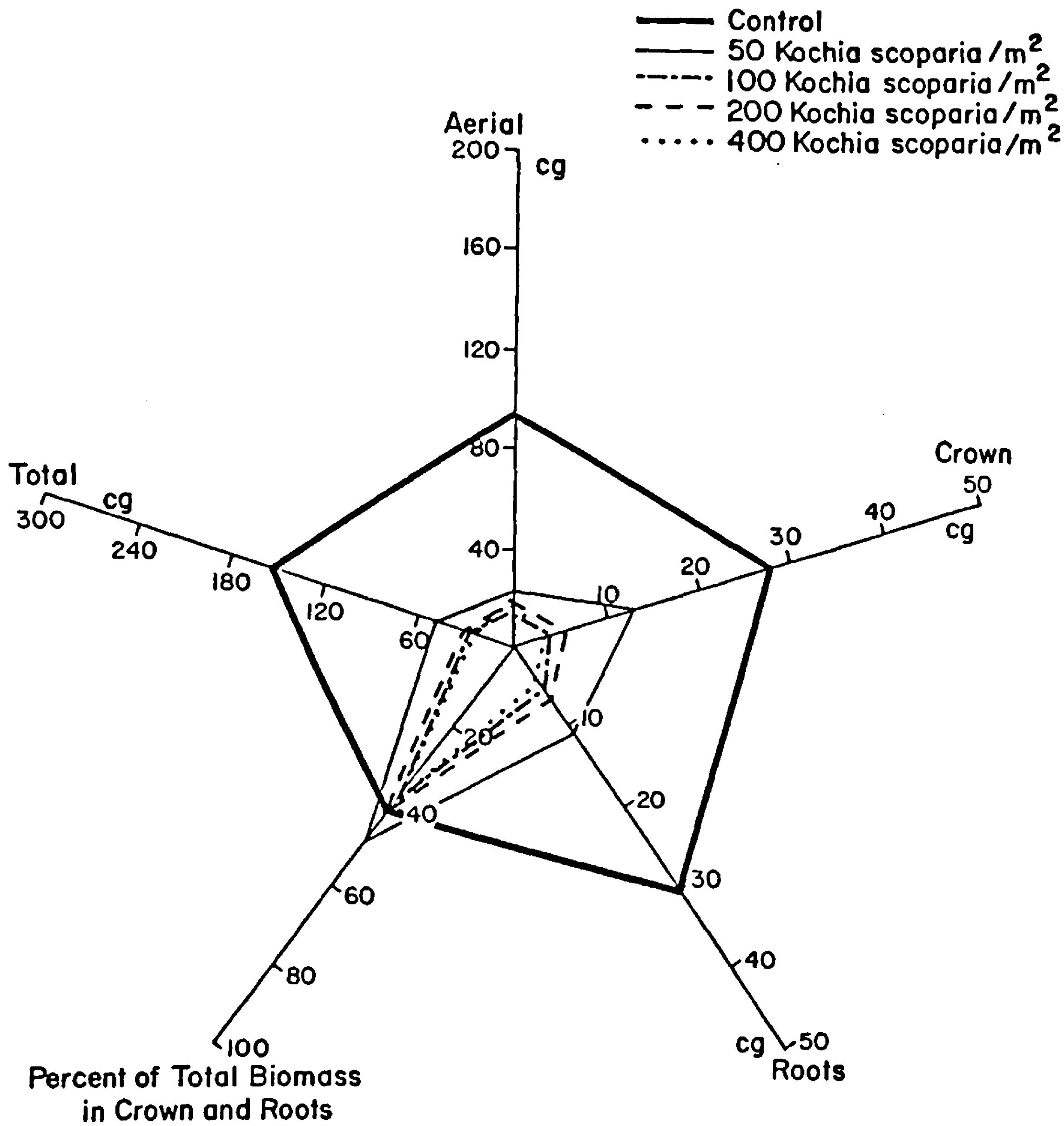

Figure 28. Biomass of *Agropyron spicatum* seedlings grown in the indigenous species mixture after 20 weeks in *Kochia* competition.

Table 35. Summary of *Agropyron spicatum* biomass data presented in Figure 28. A similar letter within groups indicates non-significant differences. α=.05.

Treatment	n	Roots cg			Crown cg			Aerial cg			Total cg		Root-Shoot Ratio	
		$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	$\bar{x}$	s
Mixture Control	30	31	18	22b	28	19	19d	95	54	59f	154	67	.87h	.79
50 *Kochia*/m²	15	11	7	28b	13c	24	20d	24e	12	52f	47	27	2.07h	3.6
100 *Kochia*/m²	14	5a	4	22b	4c	3	19d	15e	8	60f	25g	9	.92h	.91
200 *Kochia*/m²	15	7a	3	27b	5c	3	18d	19e	17	56f	30g	16	1.78h	2.87
400 *Kochia*/m²	16	5a	5	28b	4c	2	16d	17e	9	62f	26g	10	.91h	1.02

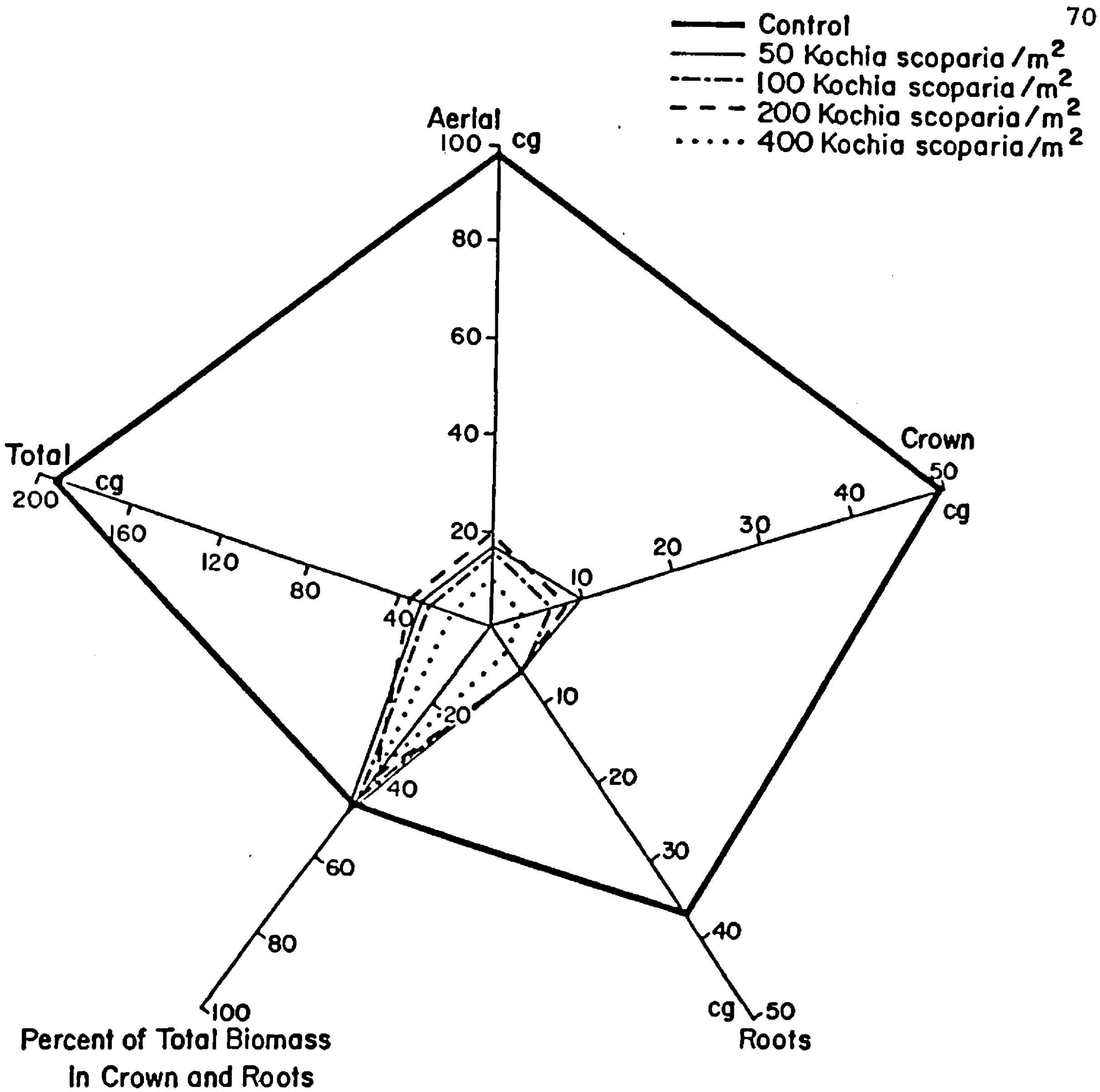

Figure 29. Biomass of *Sitanion hystrix* seedlings after 20 weeks in *Kochia* competition.

Table 36. Summary of *Sitanion hystrix* biomass data presented in Figure 29. A similar letter within groups indicates non-significant differences. $\alpha=.05$.

Treatment	n	Roots cg			Crown cg			Aerial cg			Total cg		Root-Shoot Ratio	
		$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	$\bar{x}$	s
Control	30	38	27	20b	51	29	27e	104	69	53h	193	111	1.06j	.73
50 *Kochia*/m^2	15	6a	4	20b	10c	6	30e	17g	10	50	321	17	1.16j	.71
100 *Kochia*/m^2	15	6a	4	20b	7c	4	25e	16g	12	55h	291	18	.91j	.55
200 *Kochia*/m^2	15	6a	4	19b	8c	4	23e	20g	12	58h	341	18	.78j	.35
400 *Kochia*/m^2	15	3a	2	20b	3d	2	22f	10g	7	59h	17	11	.81j	.58

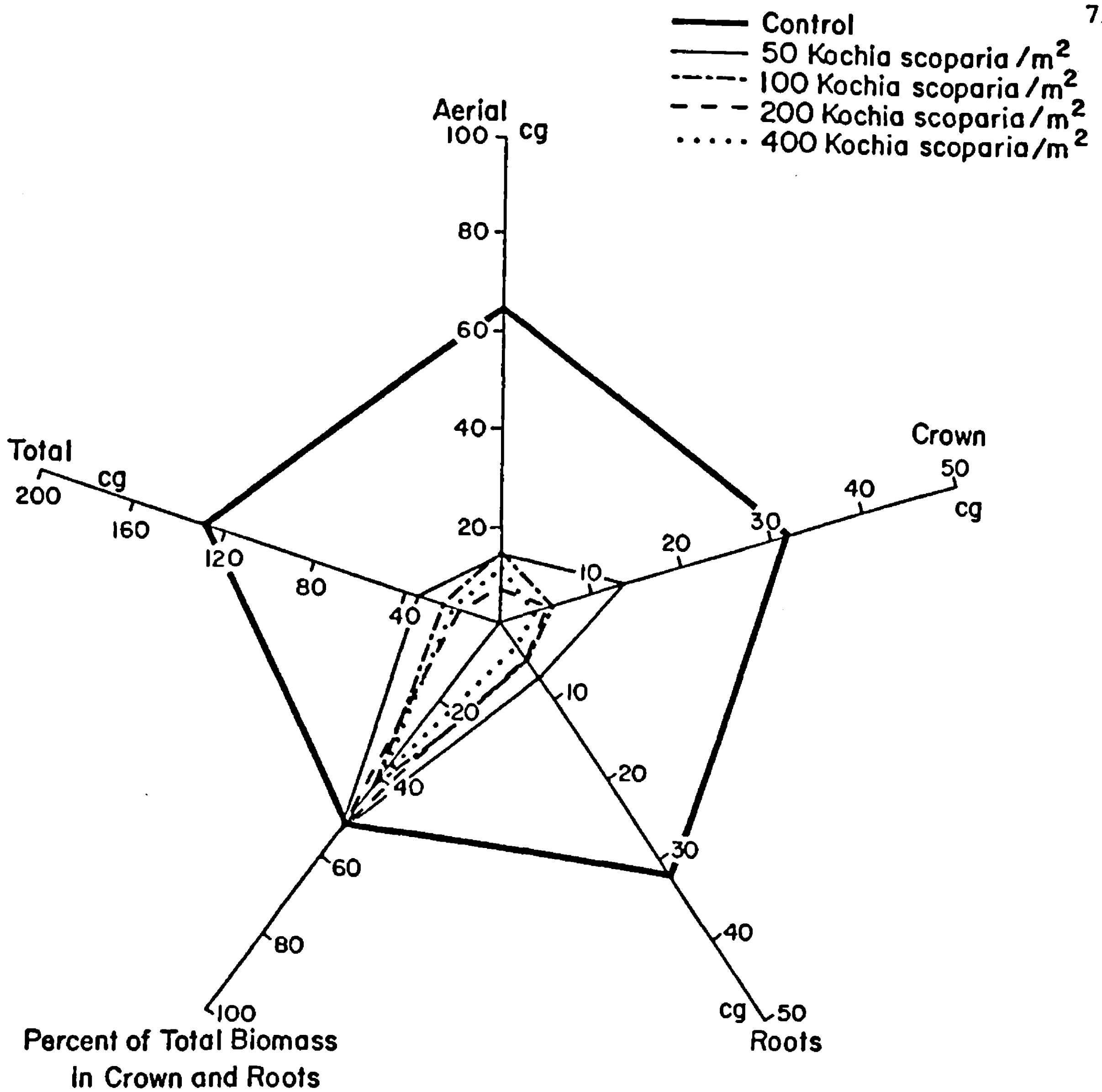

Figure 30. Biomass of *Sitanion hystrix* seedlings grown in the indigenous species mixture after 20 weeks in *Kochia* competition.

Table 37. Summary of *Sitanion hystrix* biomass data presented in Figure 30. A similar letter within groups indicates non-significant differences. α=.05.

Treatment	n	Roots cg			Crown cg			Aerial cg			Total cg		Root-Shoot Ratio	
		$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	$\bar{x}$	s
Mixture Control	30	32	27	25b	32	24	26d	64	46	49g	127	58	1.73j	1.86
50 *Kochia*/m²	15	7a	3	24b	14c	25	30d	15e	3	46g	36h	6	2.67j	5.36
100 *Kochia*/m²	15	5a	2	21b	6c	2	24d	15e	8	56g	25i	8	.93j	.64
200 *Kochia*/m²	15	5a	3	25b	5c	2	28d	8f	5	46g	18i	6	1.46j	.99
400 *Kochia*/m²	15	3	2	18b	4c	2	24d	11ef	4	58g	19i	5	.89j	.63

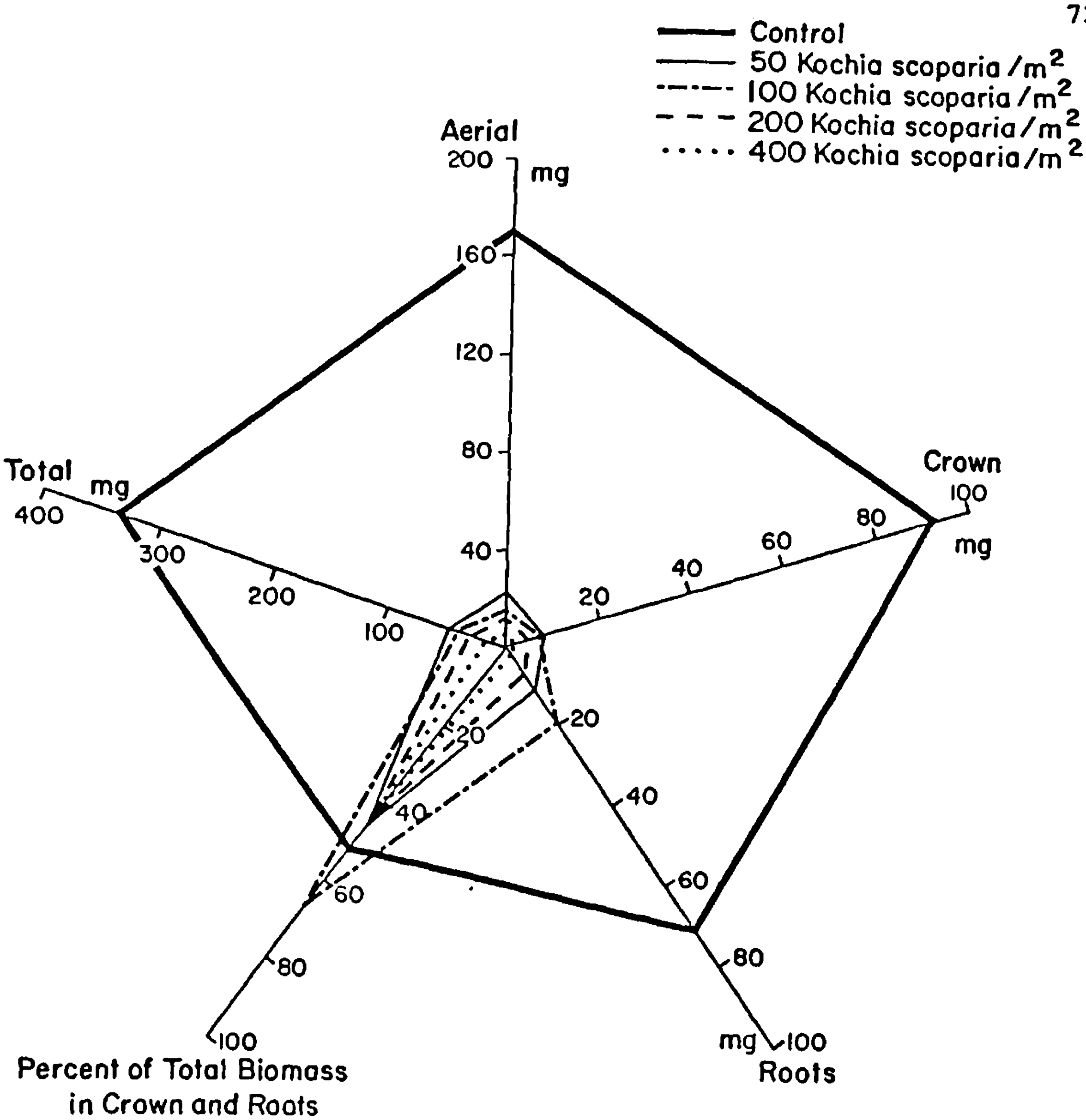

Figure 31. Biomass of *Koeleria gracilis* seedlings after 20 weeks in *Kochia* competition.

Table 38. Summary of *Koeleria gracilis* biomass data presented in Figure 31. A similar letter within groups indicates non-significant differences. α=.05.

Treatment	n	Roots mg			Crown mg			Aerial mg			Total mg		Root-Shoot Ratio	
		x̄	s	%	x̄	s	%	x̄	s	%	x̄	s	x̄	s
Control	30	71.1	51.6	22b	93.6	72.5	31d	172.6	132.7	47f	337	149	1.94h	1.9
50 *Koohia*/m²	9	12.6a	16.6	27b	9.4c	9.1	19d	22.13	20.2	54f	44g	34	1.8h	2.61
100 *Koohia*/m²	10	19.0a	26.3	42	9.2c	11.0	26d	14.9e	20.5	33f	43g	55	2.51h	1.76
200 *Koohia*/m²	7	8.4a	13.3	22b	5.9c	2.9	26d	12.4e	7.5	52f	27g	22	1.01h	.47
400 *Koohia*/m²	8	1.8a	1.4	21b	2.1c	2.2	23d	5.3e	317	55f	9g	7	1.02h	.73

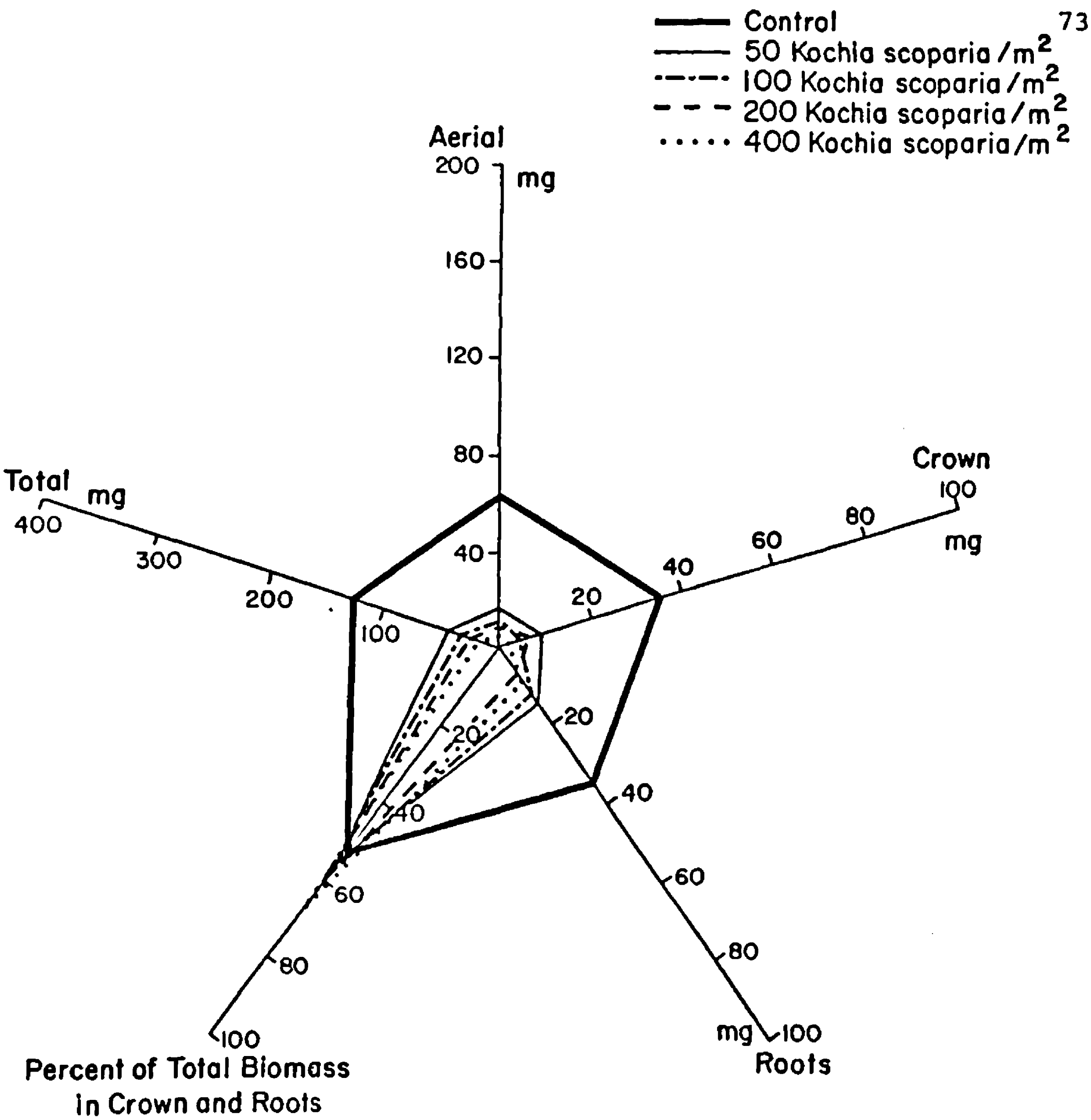

Figure 32. Biomass of *Koeleria gracilis* seedlings grown in the indigenous species mixture after 20 weeks in *Kochia* competition.

Table 39. Summary of *Koeleria gracilis* biomass data presented in Figure 32. A similar letter within groups indicates non-significant differences. a=.05.

Treatment	n	Roots mg			Crown mg			Aerial mg			Total mg		Root-Shoot Ratio	
		$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	%	$\bar{x}$	s	$\bar{x}$	s
Mixture Control	20	33.6a	30	24b	35.6	27.6	29d	24.5	47.8	48f	134	89	1.47h	1.36
50 *Kochia*/m²	7	13.1a	15.6	29b	9.9c	10.0	25d	17.9e	17.5	47f	41g	42	1.34h	.71
100 *Kochia*/m²	14	12.5a	28.2	26b	8.6c	9.8	27d	13.4e	14.6	46f	35g	9	6.21h	12.33
200 *Kochia*/m²	5	7.2a	5.5	27b	10.2c	6.1	31d	13.0e	9.7	41f	31g	13	5.98h	11.19
400 *Kochia*/m²	3	9.3a	11.9	37b	5.0c	4.6	29d	8.0e	9.6	34f	23g	26	1.91h	.15

different between control and competition levels. Among *Kochia* competition levels there were no differential responses in biomass weights.

Response of Native Species Grown Monospecifically Versus Native Species Mixture

Bromus Competition

Agropyron seedlings grown in *Bromus* competition and the native species mixture had significantly lighter crown weight, aerial weight and total biomass than when grown monospecifically. Root weights were not significantly different, but the root percentage of total biomass was significantly greater for seedlings grown in the native species mixture. Also, *Agropyron* root-shoot ratios were significantly greater in the native species mixture (2.09) than when grown monospecifically (1.1).

Sitanion and *Koeleria* weights and root-shoot ratios were not significantly different when grown monospecifically or in the native species mixture. However, the aerial biomass percentage of both was significantly greater in the native species mixture.

Kochia Competition

Agropyron seedlings grown monospecifically in *Kochia* competition were significantly heavier in root, aerial and total biomass than seedlings in the native species mixture. Crown weight, root-shoot ratios and biomass apportionment were not significantly different.

In *Kochia* competition, *Sitanion* aerial biomass was significantly heavier when grown monospecifically than in the native species mixture. Root-shoot ratios and biomass apportionment were not significantly different.

There were no significant differences in *Koeleria* biomass weights, root-shoot ratios or biomass apportionment when grown monospecifically or in the native species mixture in *Kochia* competition.

Responses in *Bromus* versus *Kochia* Competition

Differential responses of native species to *Bromus* and *Kochia* competition were determined by testing only total biomass and root-shoot ratios. Comparisons were made within the native species mixture and when grown monospecifically in competition.

There were no significant differences in total biomass of *Agropyron* seedlings grown monospecifically in *Kochia* or *Bromus* competition. However, the root-shoot ratio was significantly greater in *Bromus* competition (1.11) than in *Kochia* (.84). When grown in the native species mixture, neither root-shoot ratios or total biomass of *Agropyron* were significantly different between *Kochia* or *Bromus* competition.

Total biomass of monospecifically grown *Sitanion* was not significantly different between *Bromus* and *Kochia*competition. The root-shoot ratio was significantly greater in *Bromus* competition (1.02) than in *Kochia* (.56). The same relationships held for *Sitanion* seedlings grown in the native species mixture. The root-shoot ratios of *Sitanion* competing with *Bromus* and *Kochia* were 1.37 and .98, respectively.

Monospecifically grown *Koeleria* root-shoot ratios and total biomass were significantly greater in *Bromus* competition than *Kochia*. *Koeleria*'s root-shoot ratio was 3.56 in *Bromus* competition and 1.66 in *Kochia*. In the native species mixture, *Koeleria* was significantly heavier in *Bromus* competition than in *Kochia*, but the root-shoot ratios were not significantly different.

Stress Germination Study

All statistical differences in stress germination were determined using analysis of variance and two-sample T-tests within and between species. Parameters tested were germination rate (GR), coefficient of rate of germination (CRG) and germination total (GT). Seedling survival was to be tested, but *Kochia* seedlings died in PEG before the end of the germination test. The rapidly growing *Kochia* seedlings may have succumbed because of nutrient deficiences.

Responses Within Species

Polyethylene Glycol

CRG and GR of *Bromus* showed a direct relationship with decreasing PEG induced water potential (Table 40). Significant reductions of CRG and GR resulted with each increment of stress. GT was significantly reduced at water potentials lower than -6 ψ's (Table 40, Figure 33), but no significant differences were found between -9 and -12 ψ's.

Kochia's CRG's and GR's were significantly reduced in water potentials less than -6 ψ's (Table 40). Significant reductions also occurred between -9 and -12 ψ's. GT was significantly reduced only at -12 ψ's (Table 40, Figure 34).

Sodium Chloride

Bromus CRG's showed a direct relationship with decreasing osmotic potential (Table 40). GR was directly related to decreasing osmotic potentials lower than -3 ψ's. GT was significantly reduced under all stress levels, but there were no differences between -3, -6 and -9 ψ's. At -12 ψ's GT was significantly less than at higher osmotic potentials (Table 40, Figure 35).

Table 40. Mean coefficient of rate of germination, germination rate, and total germination of *Kochia scoparia* and *Bromus japonicus* germinated in osmotic solutions 0, -3, -9 and -12 bars.

<, =, >, indicate superior or equal responses between species for a given treatment and parameter. A similar letter within a species and parameter indicates non-significant differences. α = 0.05.

Treatment	*Bromus japonicus* $\bar{x}$	s		*Kochia scoparia* $\bar{x}$	s	Electrical Conductivity MMHOS/cc
			Coefficient of Rate of Germination			
Control (0 Ψ's)	11.99	.54	=	12.4a	.22	
-3 Ψ's PEG	10.7	.78	<	12.5ab	0	
-6 Ψ's PEG	8.4	1.1	<	11.99ab	1.01	
-9 Ψ's PEG	4.9	.88	<	10.1	..98	
-12 Ψ's PEG	2.7	.54	<	5.3	2.08	
Control	11.99	.54	=	12.4a	.22	< .001
-3 Ψ's NaCl	10.7	.8	<	12.3a	.24	4.4
-6 Ψ's NaCl	7.5	1.7	<	11.2ab	1.42	9.5
-9 Ψ's NaCl	5.3	.6	<	9.6bc	1.42	13.0
-12 Ψ's NaCl	2.7	.35	<	7.3c	2.52	17.0
			Germination Rate			
Control	.48	.02	=	.5a	0	
-3 Ψ's PEG	.44	.03	<	.5ab	0	
-6 Ψ's PEG	.36	.04	<	.49abc	.02	
-9 Ψ's PEG	.29	.03	<	.43c	.03	
-12 Ψ's PEG	.18	.01	<	.30	.1	
Control	.48a	.02	=	.5a	0	
-3 Ψ's NaCl	.45a	.03	<	.49a	.01	
-6 Ψ's NaCl	.34	.06	<	.46ab	.04	
-9 Ψ's NaCl	.25	.04	<	.47bc	.02	
-12 Ψ's NaCl	.18	.02	<	.39bc	.11	
			Germination Total			
Control	24.8a	.45	=	24.8a	.45	
-3 Ψ's PEG	24.2ab	.45	<	25.0a	0	
-6 Ψ's PEG	23.4ab	1.34	=	24.4a	1.34	
-9 Ψ's PEG	17.0c	6.0	<	23.6a	1.67	
-12 Ψ's PEG	14.0bc	2.61	=	18.0	3.39	
Control	24.8a	.45	=	24.8a	.45	
-3 Ψ's NaCl	23.8a	.84	<	24.8ab	.45	
-6 Ψ's NaCl	21.8ab	1.79	=	24.0ab	1.22	
-9 Ψ's NaCl	21.8ab	2.17	=	20.4bc	2.30	
-12 Ψ's NaCl	15.2	3.56	=	18.8c	1.92	

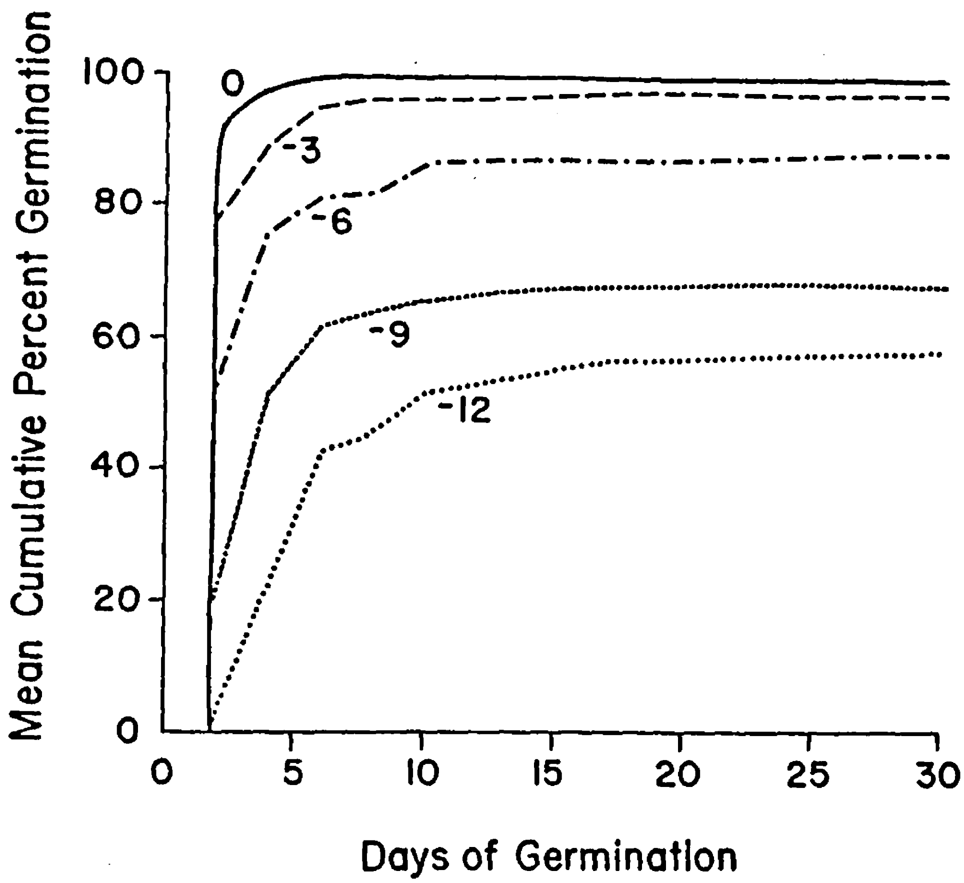

Figure 33. Mean cumulative percent germination of *Bromus japonicus* seeds at 0, -3, -6, -9 and -12 bars of PEG induced stress.

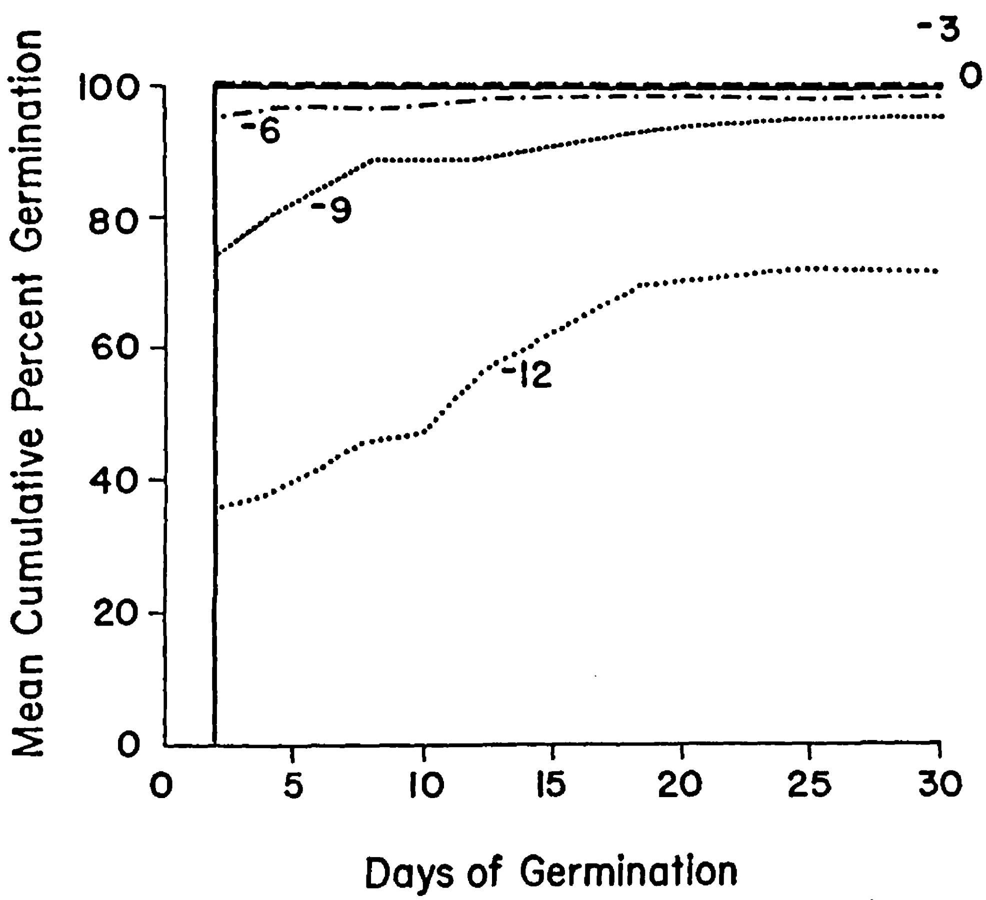

Figure 34. Mean cumulative percent germination of *Kochia scoparia* seeds at 0, -3, -6, -9 and -12 bars of PEG induced stress.

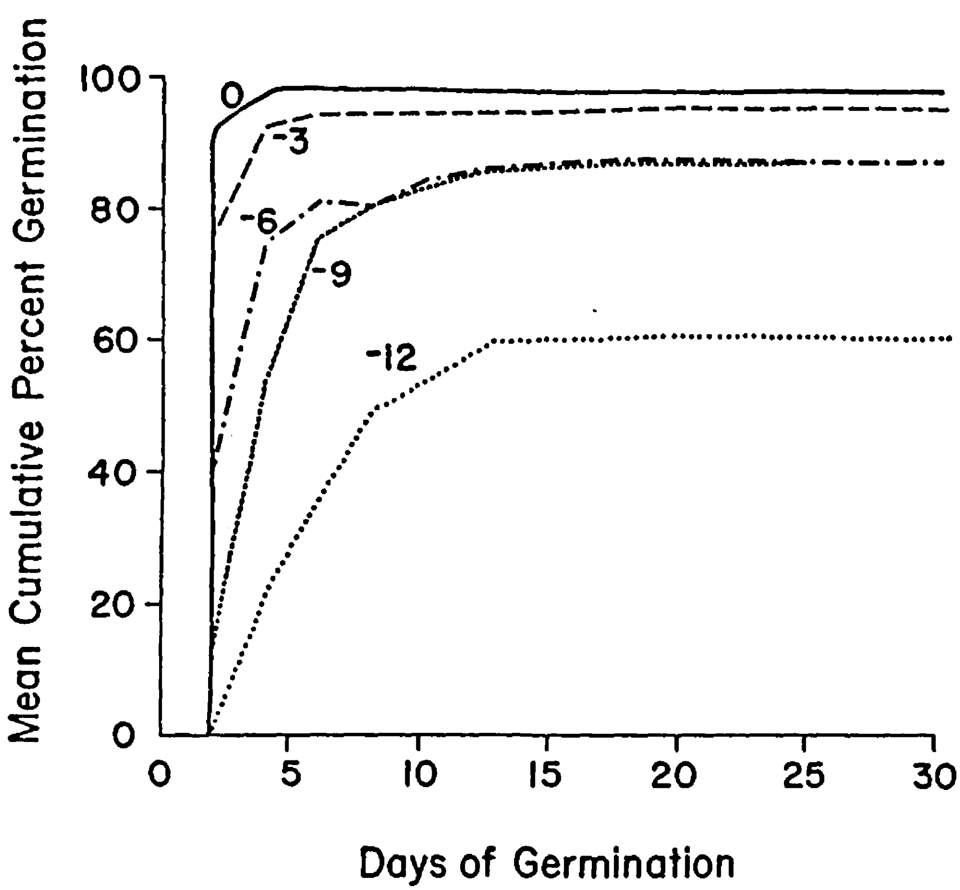

Figure 35. Mean cumulative percent germination of *Bromus japonicus* seeds at 0, -3, -6, -9 and -12 bars of NaCl induced stress.

Kochia's CRG's, GR's and GT's were significantly reduced by osmotic potentials lower than -6 ψ's (Table 40, Figure 36), although germination responses were not significantly different between -9 and -12 ψ's.

Between Species

Kochia consistently expressed greater GR's and CRG's than *Bromus* at stress levels lower than 0 ψ's (Table 40). In PEG *Kochia* GT's were significantly greater than *Bromus* at -3 and -9 ψ's, but GT of *Kochia* was significantly higher in sodium chloride only at -3 ψ's (Table 40).

Seedling Growth Response in Sodium Chloride Stress Germination

Bromus seedling growth was limited at osmotic potentials lower than 0 ψ's, but -9 ψ's appeared to be the threshold for radical and plumule elongation (Figure 37). Roots were brittle at -9 and -12 ψ's but they did not appear severely affected at higher osmotic potentials. Root browning occurred at -6 and -9 ψ's but they apparently remained functional.

Lateral root development of *Kochia*was noted earlier at -9 and -12 ψ's than at higher stress levels. Roots of seedlings in stress germination were finer, but nearly the same length as control seedlings. Seedlings were vigorous in all levels of stress (Figure 38).

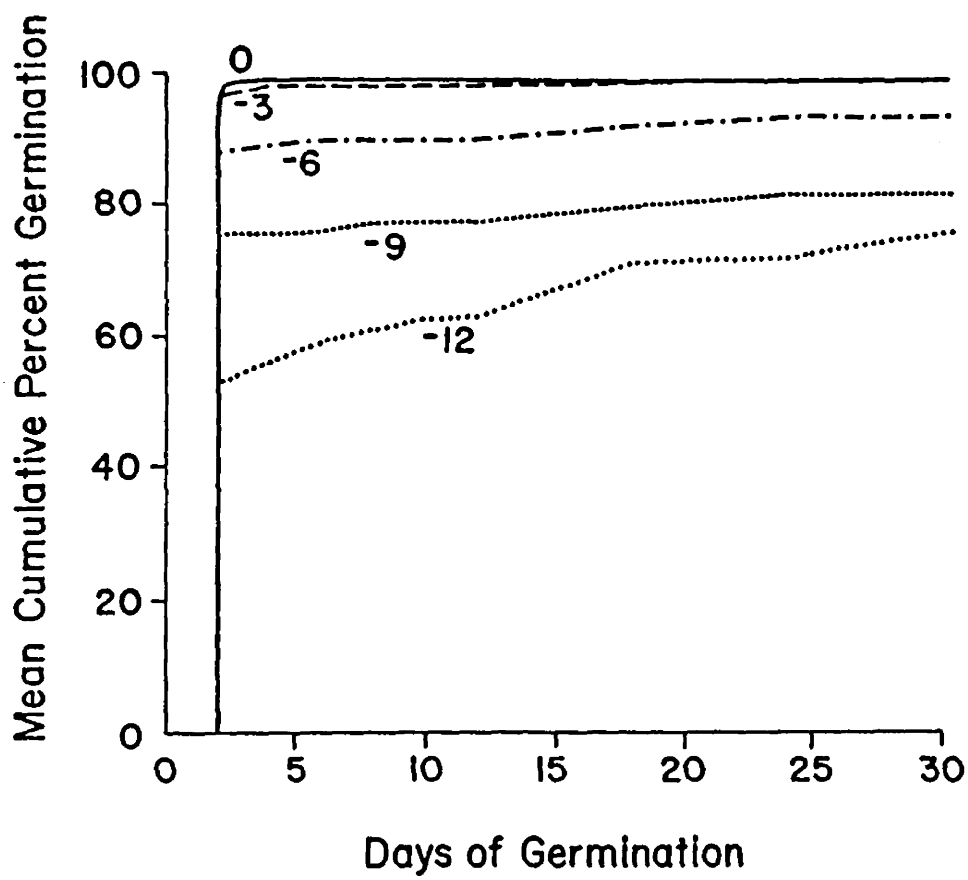

Figure 36. Mean cumulative percent germination of *Kochia scoparia* seeds at 0, -3, -6, -9 and -12 bars of NaCl induced stress.

Figure 37. *Bromus japonicus*. Twenty day old seedlings germinated and grown in sodium chloride. From left to right osmotic potentials are 0, -3, -6, -9, and -12 bars.

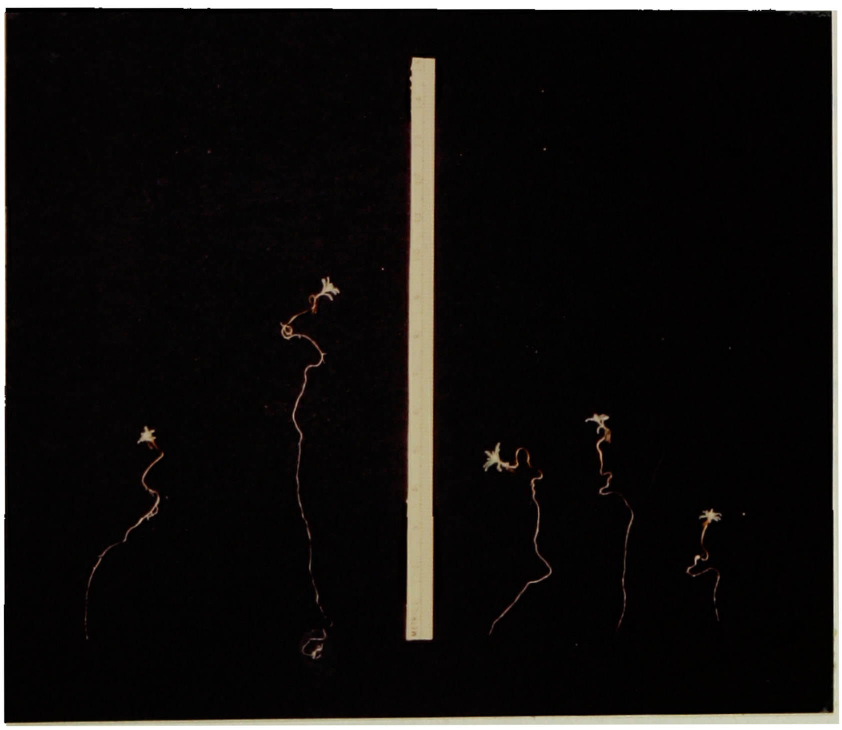

Figure 38. *Kochia scoparia*. Twenty day old seedlings germinated and grown in sodium chloride. From left to right osmotic potentials are 0, -3, -6, -9, and -12 bars.

CHAPTER VII

DISCUSSION

During mined land reclamation weeds are inadvertently given the competitive advantage during the spread of topsoil. Weed seeds have been preconditioned while lying in the soil, hence when conditions are favorable, they germinate and seedlings gain dominance of the site. In western stripmine reclamation the magnitude of the competitive advantage of weeds is determined by the length of time elapsed between topsoil spreading, seeding, seed preconditioning, germination and emergence of desirable species. This time sequence relationship of weeds and seeded species is critical because species which germinate earliest gain a competitive advantage over slower emerging seedlings. Of utmost importance in alien annual competition is their plastic germination response. The wide range of environmental conditions that weed seeds can germinate in allows early emergence, site dominance and suppression of species with more restrictive germination requirements. If exotic weeds are not effectively controlled in the initial revegetation efforts, slow developing or closed communities may result.

The temporal and spatial relationships of seeds and seedlings with their environment are the most important factors governing plant establishment in semiarid environments. The success of a given seed producing an established plant is determined mainly by the time of germination and emergence, the rate of seedling growth and the amount of space occupied, particularly by roots. In semiarid environments such as southeastern Montana, species which germinate earliest can occupy available space, exploit moisture reserves and gain a competitive advantage over later emerging species. The major consequence of late germination is the abbreviation of the effective growth period. Later germinating seeds and emergent seedlings are usually confronted with seasonal moisture deficiencies or moisture depletion by competing seedlings and unfavorable temperature conditions. This may prohibit advanced seedling development which is essential for seedling establishment. Species which can utilize moisture as seedlings rather than for germination have a competitive advantage.

In southeastern Montana, early spring or fall planting will probably yield most consistent establishment success of seeded species because moisture is most consistently available (Table 41). Considering the sporadic late spring and early summer precipitation pattern, germination at cool temperatures and variable moisture stress are important for seedling establishment. In southeastern Montana, inconsistent success can be expected of species with restricted moisture and temperature requirements for germination. Seeds must germinate quickly after planting to minimize the magnitude of the competitive advantage of invader species so that desirable seedlings develop sufficiently before encountering competition induced or seasonal moisture stress. Given the seasonal climatic conditions of southeastern Montana, germination at warm temperatures is an ecological disadvantage for reestablishment on mined lands. For instance, species which require warm germination temperatures will likely have limited establishment success because of increasingly inconsistent precipitation and less moisture availability associated with higher temperatures (Table 41). Seedlings emerging in warm conditions will also be subjected to temperature stress. However, evidence suggests that seedlings subjected to cold or hot temperatures are more resistant to moisture stress than seedlings grown at intermediate temperatures (Schlatterer and Hironaka 1972). Therefore, selection of species or genotypes which germinate under cold temperatures may also promote seedling drought preconditioning and create an overall ecological superiority. Also, germination over a range of moisture and temperature conditions may yield an array of plants suited to diverse environmental conditions.

Table 41. Mean Monthly Temperatures and Mean Monthly Precipitation at Colstrip, Montana (U.S. Weather Bureau 1952 and 1961).

	Temp. ^{o}C	Precipitation cm	Coefficient of Variation (%) Precip.
January	-5	1.4	66
February	-4	1.5	58
March	0	2.5	55
April	7	4.1	65
May	13	5.7	55
June	18	7.4	66
July	23	3.1	67
August	21	3.1	80
September	16	3.0	79
October	10	3.1	102
November	1	1.7	62
December	-3	1.5	75

The consequences of fall planting must be thoroughly evaluated. If germination is not timed properly to allow adequate seedling development before quiescence, seedlings emerging in the autumn may succumb to frost heaving or winter mortality. On the other hand, fall planted species emerging in the spring may be at a competitive disadvantage if they do not germinate early. Many alien annuals germinate in the autumn and overwinter or germinate under the snow or just following snowmelt, thereby giving them a competitive advantage. Also, the expectation of fall germination of seeded species is optimistic because precipitation is not as abundant or consistent as during the spring.

In dry environments, the response of seedling root development and carbohydrate storage capacity are critical. The tenacity of perennial seedlings under moisture stress is best expressed by rapid and extensive root development for moisture extraction and root and crown development for carbohydrate reserves. Species or ecotypes which do not respond to moisture depletion by developing more extensive root systems and carbohydrate reserves render themselves susceptible to death during seasonal drought dormancy, prematurely (competition) induced quiescence, or winter dormancy. Synopses of studies by Weaver (1954, 1968) describe a close relationship between root depth and extent and drought resistance of mature plants. Similarly, Plummer (1943) associated root development prior to drought with the initial establishment success or failure of seedlings. Plants which increase root depth during moisture depletion also encounter moister conditions necessary for additional root development and rootlet initiation. Extensive root development also aids soil development, increases site stability and closes the community to invasion by alien annuals. Seeding mixtures of species with varied rooting habits and periods of phenological activity promotes efficient soil utilization and increases the probability that desirable species persist over a range of environmental conditions.

Species which have the potential to reproduce in the early stages of their life cycle should be included in revegetation plans. Early reproduction should accelerate community stability and reduce the overall success of undesirable species. If desirable species establishment is not accomplished early, annual weed infestations may be most serious with time because of prolific seed production and formation of favorable microenvironments through the yearly accumulation of litter (Evans and Young 1970, 1972). Competitive perennials that reproduce early in their life cycle should increase the probability that desirable species occupy sites voided by nonsurviving perennials or annuals by interrupting the potential perpetual cycle of alien annuals. Species with varied reproduction requirements and phenology insure continual dispersal of propagules thereby further increasing the likelihood of desirable species establishing and dominating the site. Species with effective dispersal mechanisms also increase the probability that desirable species are introduced throughout the community and occupy sites not tolerable by species with restricted habitat requirements. Asexual reproduction is also a desirable competitive characteristic for occupying disturbed sites. In reseeding efforts on sagebrush dominated rangelands, Robertson and coworkers (1966) noted that sodforming *Agropyrons* were aggressive and tended to close the community to shrub reinvasion. Vegetative reproduction may also promote species regeneration in years of poor seed production and/or seedling establishment.

Species or ecotypes can be selected on the basis of the aforementioned criteria to maximize competitive abilities and establishment potential for a given environment. However, with all factors considered, the best measure of species or ecotypic competitive abilities is the ability of plants to establish and quickly dominate the site.

Although statistical confirmation is not available, apparently a good relationship exists between germination and seedling emergence under field conditions and in vitro germination using PEG 6000 to simulate water stress. Because moisture is the most limiting and undependable variable in the southeastern Montana ecosystem, a systematic approach for preliminary selection of species and genotypes based on in vitro germination over a range of PEG induced moisture stress appears desirable. In laboratory moisture stress germination, *Sitanion* and *Agropyron* had superior germination responses over *Koeleria*(Eddleman and Doescher 1977). Likewise, under field conditions *Agropyron* and *Sitanion* emerged faster and had higher seedling survival than *Koeleria*. The more restrictive moisture and temperature requirements of *Koeleria* were partially exhibited by the aggregation of emergent seedlings around stones on the soil surface. Stones may create a moister microsite by functioning as a condensation and moisture collection surface and mitigating environmental extremes. However, this relationship may have interferred with seedling establishment by creating severe intraspecific competition.

All native species had peak population numbers eight weeks following sowing which was one week subsequent to the maximum amount of precipitation received during the study. Effective precipitation (nearly 30% of the total received during the study) and moderate temperatures the seventh and eighth weeks of study may have induced germination in the portion of the seed population requiring warm temperatures and minimal moisture stress. However, these seedlings may not have been sufficiently phenológically advanced to survive dessication that followed (Figures 39 and 40).

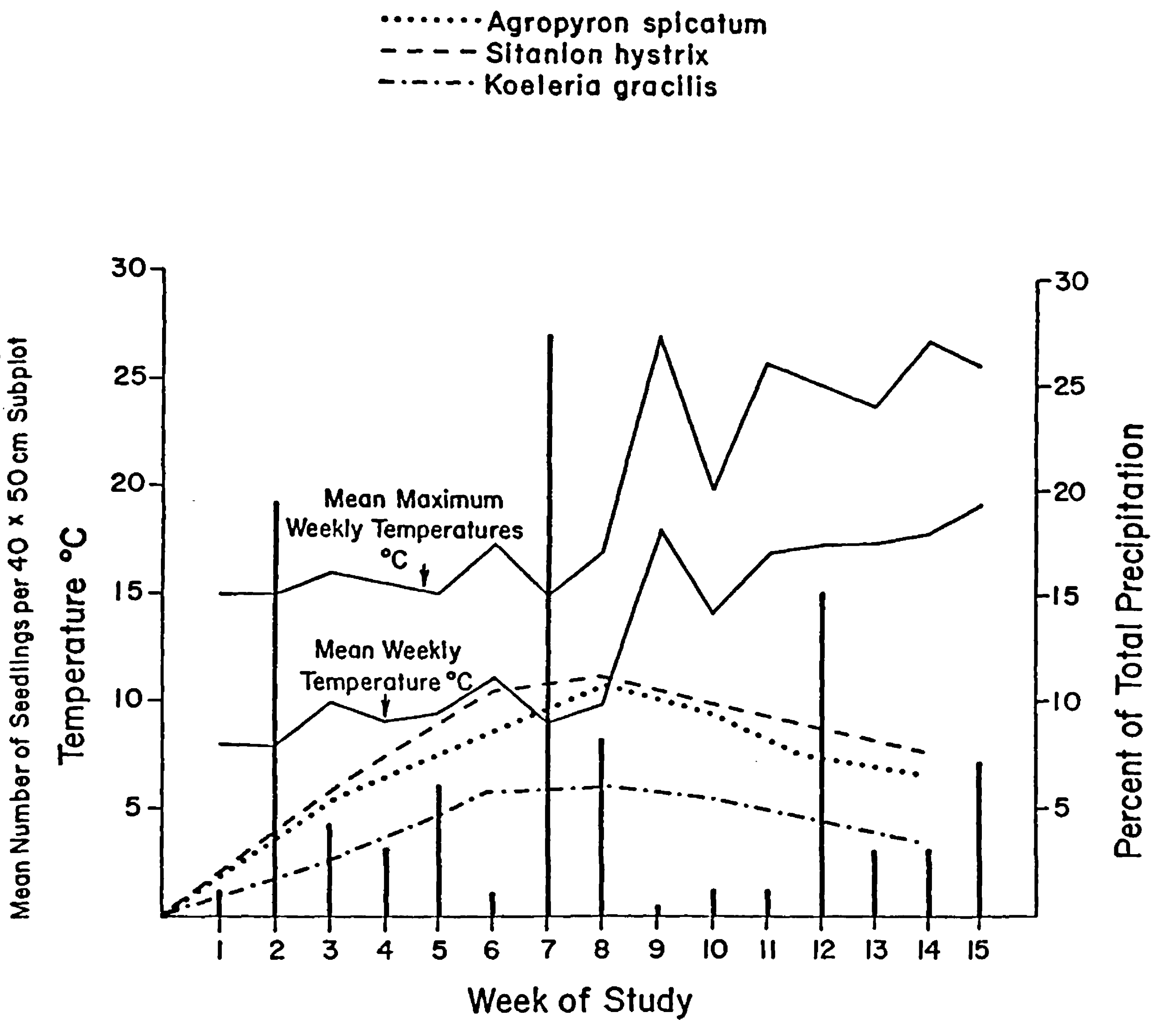

Figure 39. Climatic conditions through study and indigenous species population trends in *Bromus japonicus* competition. Vertical bars indicate the percent of total precipitation received per week.

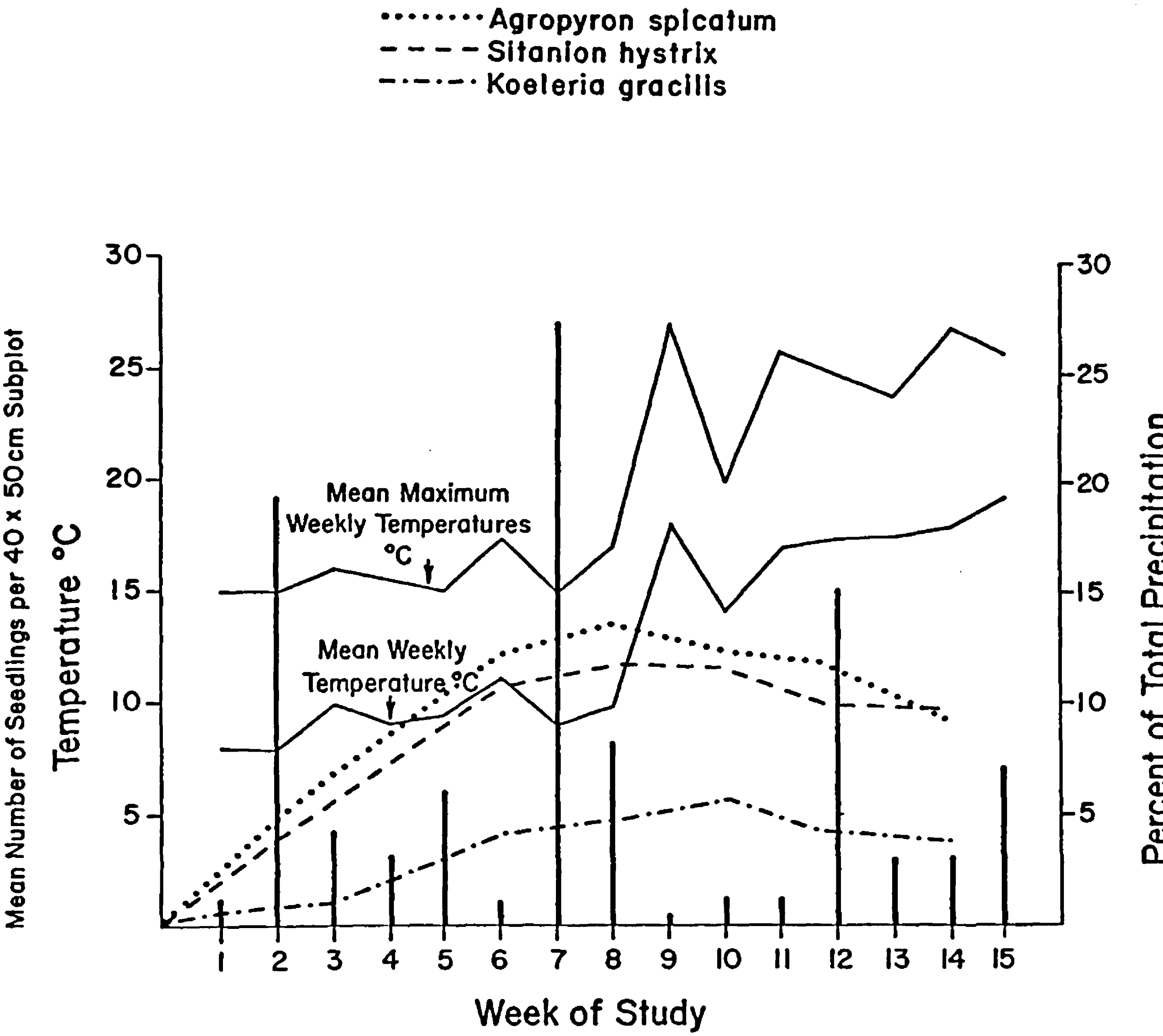

Figure 40. Climatic conditions through study and indigenous species population trends in *Kochia scoparia* competition. Vertical bars indicate the percent of total precipitation received per week.

Populations declined significantly the ensuing two weeks. Seasonal drought as indicated by increasing mean weekly temperatures and decreasing precipitation (Table 42) is credited for declines (based on weekly temperatures and precipitation at Johnson Bell Field during April, May, June and July; National Weather Service 1978).

Table 42. Weekly precipitation, mean weekly temperatures and mean and maximum temperatures received during study (National Weather Service 1978, Missoula, Montana).

Week	Percent of Precipitation Received	Mean Weekly Temperatures °C	Mean Maximum Weekly Temperatures °C
1	.7	8	15
2	18.7	8	15
3	3.6	11	16
4	3.0	9	14
5	6.1	9	15
6	.7	12	17
7	27.3	9	15
8	8.0	10	17
9	0	18	27
10	1	13	20
11	1	16	26
12	15	17	25
13	3	17	24
14	3	18	27
15	7	19	26

Field response of *Kochia* and *Bromus* closely parallels in vitro moisture stress germination. In the field study *Kochia* seedlings emerged faster and in greater numbers than *Bromus*. *Kochia* seedlings were first observed twelve days after planting, but *Bromus* emergence did not begin until eighteen days. The smaller seeds of *Kochia* may provide better soil contact, quicker seed hydration and more rapid germination than *Bromus*. Also, the embryo of *Kochia* appears nearly fully differentiated in the seed and this precocious seedling may be a competitive advantage for rapid germination, emergence and early occupation of available sites. The germination responses of *Bromus* in moisture and salinity stress may mask an ecological asset. The reduction and delay of germination of *Bromus* may be important for limiting germination to near optimal environmental conditions which would prevent decimation of the seed population. Moisture stress germination provides partial explanation of extreme year to year population fluctuations of *Bromus* and also its greatest success on moist, litter laden, depleted range sites in southeastern Montana.

Evans and Young (1970) concluded that plant litter on the soil surface moderates temperatures and moisture conditions thereby creating favorable microsites for germination and the establishment of annual weeds. Moisture stress germination indicates that mulching or irrigating seedbeds will enhance *Kochia* and *Bromus* infestations. Damper conditions should increase germination rates and seedling numbers while simultaneously directing the competitive advantage to weeds. Further research is required, but perhaps before seeding desirable species an application of moisture to the seedbed followed by drying and mechanical scarification could significantly reduce *Kochia* or *Bromus* competition by inducing germination and reducing seed populations.

In the field competition study, *Kochia* plants consistently extended lateral roots (up to 1.5m) into buffer zones. Also moisture stress germination seedlings growing in lower stress levels initiated lateral roots earlier than seedlings in higher osmotic potentials. Therefore in reclamation it is important to fully saturate the site with desirable competitors to reduce vigor and success of *Kochia*. Seeding mixtures of species should assure that desirable species occupy the diverse microenvironments otherwise available to weeds.

Bromus seedlings had two morphologically distinct growth forms. Approximately 50-60 percent of the seedlings tillered extensively, remained vegetative, overwintered and reproduced in 1979 (Figure 41). The remaining 40-50 percent did not tiller as abundantly but developed sexually and flowered (Figure 42); however, seed fill was nearly nil. Requirements for floral initiation in *Bromus* merit further research.

First year *Agropyron* and *Sitanion* produced seeds in all levels and types of competition (Figures 43, 44, 45), but *Koeleria* remained vegetative (Figure 46). This is in agreement with Looman (1978) who reported that floral initials of *Koeleria* are formed in the autumn following the first frost. In 1979 *Koeleria* produced abundant seed in control, but seed production was limited in competition plots. *Agropyron* and *Sitanion* produced abundant seeds in all levels of competition in 1979.

Of the more than 300 *Agropyron* seedlings examined, two had short rhizomes. Dodd (1970) studied *Agropyron spicatum* in western North Dakota and concluded that rhizomatous forms do not occur that far east. It may be desirable to select rhizomatous southeastern Montana ecotypes to increase competitive abilities.

Figure 41. A representative *Bromus japonicus* seedling which tillered extensively and overwintered.

Figure 42. A representative *Bromus japonicus* seedling which completed its life cycle during the study.

Figure 43. *Agropyron spicatum*. Seedlings grown in control conditions photographed approximately 90 days following planting.

Figure 44. *Sitanion hystrix*. Seedlings grown in Control conditions, photographed approximately 90 days following planting.

Figure 45. Indigenous species mixture. Seedlings grown in control conditions, photographed approximately 90 days following planting.

Figure 46. *Koeleria gracilis*. Seedlings grown in Control conditions, photographed approximately 90 days following planting.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

This study was designed to evaluate the impacts of alien annual competition on seedling population dynamics and the response of three indigenous perennial grasses. The objectives of this research were: 1) evaluate the relationship of in vitro moisture stress germination and seedling emergence under field conditions; 2) identify the responses of certain indigenous perennial grass seedlings when grown in weed densities likely to be encountered in spoil bank reclamation; 3) determine the relationship of seral position and establishment potential in alien annual competition; 4) determine the effects of moisture and salinity stress on germination and on early seedling development of alien annuals; and 5) from this research and a literature review, identify critical ecological assets which should increase desirable seedling establishment on mined lands in southeastern Montana.

Agropyron spicatum, *Koeleria gracilis* and *Sitanion hystrix* were grown monospecifically and in a mixture in competition with 0, 50, 100, 200 and 400 *Kochia scoparia* and *Bromus japonicus* plants per square meter. Native species seedling emergence rates and amount, seedling survival, plant height, tiller and leaf development and inflorescence numbers were recorded periodically to 97 days following planting. Approximately 130 days following planting, native seedling biomass productivity was determined for each species and treatment.

Species which had high germination rate and amount over a range of PEG 6000 induced moisture stress also had the fastest seedling emergence rate and highest seedling survival under field conditions. Compared to control, competition had no effect on seedling emergence rate, amount or survival of native species. *Agropyron* and *Sitanion* seedling mortality was significantly higher in *Bromus* competition than *Kochia* competition. *Koeleria* seedling establishment was not significantly different between *Kochia* and *Bromus*, but *Koeleria* had significantly lower seedling establishment in the native species mixture than when grown monospecifically.

The rate of indigenous seedling growth in *Bromus* and *Kochia* was significantly slower than control and the response was species specific. In *Bromus* competition all native species ceased tillering earlier than control. *Agropyron* and *Koeleria* produced leaves throughout the study, but *Sitanion* leaf initiation and development ceased earlier in *Bromus* competition than control. Also, native species had significant reductions of height and seedhead production in *Bromus* competition.

Seedlings of all native species competing with *Kochia* produced new leaves through the entire study. *Agropyron* seedlings in *Kochia* competition ceased tillering earlier but *Sitanion* seedlings increased tiller numbers through the study. *Koeleria* initiated tillering later in *Kochia* competition, but additional tillers were formed through the end of the study. In *Kochia* competition all native species had significantly more leaves per tiller and significantly fewer seedheads than control, but seedling height was not significantly affected. Experimental design did not allow for a satisfactory explanation of leaf differences per tiller.

The biomass of native seedlings grown in *Kochia* or *Bromus* was significantly less than control. All native species grown with *Bromus* had a greater percentage of biomass in the roots and crown than control. *Agropyron* and *Sitanion* also had greater root-shoot ratios in *Bromus* competition but *Koeleria* was not significantly altered. There were no significant differences in seedling root-shoot ratios between control and *Kochia* competition. *Agropyron* did however have a significantly greater root and crown percentage in *Kochia* competition than control.

Agropyron seedlings were significantly lighter in the indigenous species mixture than when grown monospecifically although *Koeleria* and *Sitanion* seedling weights did not differ significantly. Native seedlings grown in the native species mixture and in *Bromus* competition had significantly greater root-shoot ratios than seedlings that competed with *Kochia*. Total biomass of *Sitanion* and *Agropyron* was not significantly different between *Kochia* and *Bromus*, but *Koeleria* seedlings were significantly heavier in *Bromus* than in *Kochia* competition. This may be resultant of a greater competitive advantage of *Kochia* gained by more rapid germination than *Bromus* and/or higher *Koeleria* mortality in *Bromus* competition may have skewed biomass values because slower emerging and presumably smaller seedlings may have been eliminated from the populations.

Similar responses of native species between levels of exotic annual competition indicate that varied competition levels may have been negated by release or suppression of weeds at low or high levels, respectively. That is, because of the plastic response of annuals, competition in the densities studied presumably was not a linear relationship as designed. Also, the genetic variability of the native species populations may have abridged the competitive effects.

Laboratory moisture and salinity stress germination indicates that *Kochia* infestations should be expected over a wide range of environmental conditions and *Kochia* infestations should also be more serious than *Bromus* on saline sites. Cultural practices such as irrigation, mulching or hydroseeding may also create more serious weed infestations.

Field observations, the literature review and results of this research suggest criteria which may be important for selecting competitive ecotypes and increasing reestablishment potential on severely disturbed land in southeastern Montana. These are: 1) high germination rate and amount at cool temperatures (5 - 15^{o} C) and a wide range of moisture stress; 2) rapid growth rate of seminal roots and the capacity to develop adventitious roots early; 3) seedlings should direct growth to roots and crown under moisture depletion thereby increasing drought and dormancy survival; 4) seedlings must have high survival under high temperatures and severe moisture stress; and 5) it is desirable to include species which have the potential to produce propagules early in their life cycle.

Based on the results of this research, southeastern Montana ecotypes of *Agropyron spicatum*, *Koeleria gracilis* and *Sitanion hystrix* should establish well in the face of *Bromus japonicus* or *Kochia scoparia* competition but the combination of *Bromus* and *Kochia* may create a synergistic effect. Evidence does not link establishment potential with seral position, but establishment appears to be more related to the diversity of sites occupied in natural conditions and the species germination response to moisture stress. The great variation in the data collected suggests that erratic responses can be expected until superior and uniform genotypes are selected. Also, variability implies that selection for desirable characteristics may be achieved. Seedlots which conform to the above criteria should give most consistent results in reestablishing native species on severely disturbed land in southeastern Montana.

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Appendix 1. Growth parameters of *Agropyron spicatum* seedlings in *Bromus japonicus* competition.

Treatment	Sample Number		Leaf Number		Stem Number		Number of leaves/stem		Height cm	
		n	x	s	x	s	x	s	x	s
Control	1	54	1.2	.4	1.0	0	1.2	.4	2.8	1.0
	2	97	2.8	.8	1.1	.2	2.7	.6	4.7	1.1
	3	111	5.7	2.5	1.9	.9	2.7	.7	5.0	1.3
	4	74	14.0	6.0	5.2	2.5	2.8	.6	8.3	2.3
	5	42	20.7	8.3	8.1	3.0	2.6	.5	12.9	4.3
	6	20	41.6	18.6	16.5	6.9	2.5	.4	23.4	7.7
50 *Bromus*/m^2	1	19	1.1	.2	1.0	0	1.1	.2	2.9	.8
	2	32	2.6	.6	1.0	0	2.6	.6	4.4	.9
	3	35	5.4	2.4	2.0	1.0	3.0	.9	5.3	1.4
	4	32	10.9	4.6	4.2	2.5	2.9	.8	7.6	2.7
	5	19	14.0	8.3	5.5	2.7	2.6	.8	10.6	3.4
	6	10	19.8	11.4	7.5	3.9	2.7	1.0	16.9	9.0
100 *Bromus*/m^2	1	31	1.2	.4	1.0	1	1.2	.4	2.9	1.0
	2	48	2.9	.7	1.0	0	2.9	.7	4.4	1.1
	3	52	5.3	2.5	1.9	.9	3.0	.9	4.8	1.2
	4	37	8.4	4.4	3.1	2.1	3.2	1.3	6.8	1.8
	5	14	8.4	3.9	2.8	1.4	3.2	.9	10.3	4.0
	6	10	10.4	4.5	4.5	1.4	2.5	.6	13.3	5.2
200 *Bromus*/m^2	1	35	2.0	1.3	1.2	1.4	1.2	.4	3.1	1.1
	2	65	2.6	.7	1.0	.4	2.6	.7	4.4	.9
	3	67	4.5	1.8	1.4	.7	3.4	1.0	5.1	1.1
	4	45	6.7	3.2	2.3	1.4	3.3	1.2	6.8	3.8
	5	12	9.5	5.5	3.1	1.8	3.2	.8	8.4	2.6
	6	10	16.6	11.5	4.3	1.7	4.0	2.7	13.6	4.9
400 *Bromus*/m^2	1	28	1.1	.3	1.0	0	1.1	.3	2.7	1.0
	2	44	2.5	.5	1.0	0	2.5	.5	4.7	1.1
	3	50	4.2	2.1	1.3	.6	3.2	.9	4.8	1.5
	4	38	6.4	3.4	1.9	1.2	3.6	1.1	6.2	2.0
	5	12	8.3	4.9	2.8	1.5	3.1	.8	8.5	2.9
	6	10	10.0	2.9	3.7	1.1	2.8	.7	12.2	3.6

Appendix 2. Growth parameters of *Agropyron spicatum* seedlings in *Kochia scoparia* competition.

Treatment	Sample Number		Leaf Number		Stem Number		Number of leaves/stem		Height cm	
		n	x	s	x	s	x	s	x	s
Control	1	54	1.2	.4	1.0	0	1.2	.4	2.8	1.0
	2	97	2.8	.8	1.1	.2	2.7	.6	4.7	1.1
	3	111	5.7	2.5	1.9	.9	2.7	.7	5.0	1.3
	4	74	14.0	6.0	5.2	2.5	2.8	.6	8.3	2.3
	5	42	20.7	8.3	8.1	3.0	2.6	.5	12.9	4.3
	6	20	41.6	18.6	16.5	6.9	2.5	.4	23.4	7.7
50 *Kochia*/m^2	1	36	1.1	.3	1.0	0	1.1	.3	3.1	.8
	2	67	2.7	.6	1.0	0.1	2.7	.6	5.2	1.2
	3	71	5.3	2.2	2.0	.8	2.8	.9	5.3	1.4
	4	50	10.1	3.6	3.3	1.3	3.2	1.4	7.9	2.7
	5	10	12.5	4.3	4.3	1.5	3.0	.8	12.8	3.9
	6	10	13.8	3.5	4.7	.9	2.9	.3	26.3	11.4
100 *Kochia*/m^2	1	29	1.2	.4	1.0	0	1.2	.4	3.3	1.0
	2	56	2.5	.7	1.0	.1	2.5	.7	4.6	1.0
	3	61	4.9	2.6	1.6	.9	3.2	1.0	5.0	1.4
	4	47	9.3	4.2	3.1	1.5	3.0	.6	7.0	2.3
	5	10	11.3	4.2	3.6	1.4	3.3	.7	11.1	4.0
	6	10	16.6	5.4	5.0	1.6	3.5	.9	18.8	5.2
200 *Kochia*/m^2	1	49	1.3	.6	1.1	.4	1.2	.4	3.3	1.1
	2	70	2.7	.8	1.0	.2	2.6	.7	4.6	1.2
	3	76	5.5	5.0	2.3	4.8	3.2	1.1	4.6	1.3
	4	49	8.4	3.8	2.6	1.1	3.1	.9	6.4	2.1
	5	10	12.0	2.5	3.4	.8	3.7	1.1	10.9	3.0
	6	10	18.9	9.0	5.1	1.7	4.0	1.9	18.4	3.2
400 *Kochia*/m^2	1	32	1.3	.4	1.0	0	1.3	.4	3.3	1.2
	2	58	2.6	.8	1.0	.2	2.6	.7	4.7	.9
	3	59	4.4	2.2	1.4	.8	3.2	1.0	4.8	1.3
	4	45	7.6	3.5	2.2	1.2	3.7	1.4	7.2	2.6
	5	10	10.0	4.1	2.6	1.3	3.5	.8	11.4	2.2
	6	10	12.1	4.2	3.5	1.1	3.5	.7	21.0	3.9

Appendix 3. Growth parameters of *Sitanion hystrix* seedlings in *Kochia scoparia* competition.

Treatment	Sample Number		Leaf Number		Stem Number		Number of leaves/stem		Height cm	
		n	x	s	x	s	x	s	x	s
Control	1	55	1.0	.2	1.0	0	1.0	.2	3.1	1.1
	2	121	2.5	.8	1.0	.2	2.4	.7	4.3	1.2
	3	132	5.3	2.3	1.9	.9	2.8	.9	4.7	1.3
	4	91	12.9	5.5	5.0	2.5	2.8	.7	7.2	2.0
	5	41	24.0	9.5	9.5	4.2	2.6	.6	10.0	4.0
	6	20	36.5	16.6	13.1	5.8	2.8	.4	15.5	4.4
50 *Kochia*/m^2	1	35	1.0	.2	1.3	1.5	1.0	.2	3.1	1.0
	2	62	2.3	.6	1.0	.1	2.3	.5	4.7	1.0
	3	64	5.3	1.9	1.8	.8	3.1	1.0	4.8	.9
	4	44	10.0	3.3	3.3	1.4	3.2	.8	6.8	1.6
	5	10	15.6	6.1	5.2	2.4	3.0	.6	7.5	2.5
	6	10	23.9	7.1	6.8	2.3	3.6	.4	13.3	4.9
100 *Kochia*/m^2	1	20	1.1	.2	1.0	0	1.1	.2	3.1	1.0
	2	44	2.0	.9	1.0	0	2.2	.6	4.4	1.2
	3	43	4.6	1.3	1.6	.7	3.2	1.1	4.3	.8
	4	30	9.3	3.5	2.6	1.1	3.7	.9	5.6	1.6
	5	10	15.6	4.2	5.8	4.5	3.3	1.1	7.7	2.6
	6	10	24.1	8.5	7.2	3.0	3.4	.5	13.9	4.6
200 *Kochia*/m^2	1	25	1.0	0	1.0	0	1.0	0	2.9	1.5
	2	52	2.1	.6	1.0	0	2.1	.6	4.0	1.2
	3	47	4.6	1.7	1.6	.7	3.1	.9	4.3	.9
	4	35	8.7	3.2	2.6	1.0	3.5	.9	5.4	1.4
	5	10	11.3	2.9	3.2	1.0	3.6	.6	7.5	1.4
	6	10	17.9	5.3	5.2	1.6	3.5	.5	13.9	4.0
400 *Kochia*/m^2	1	33	1.1	.2	1.0	0	1.1	.2	3.2	1.2
	2	64	2.3	.6	1.0	0	2.3	.6	4.1	.7
	3	67	4.3	1.5	1.5	.8	3.1	.8	4.3	.9
	4	40	7.8	4.5	2.6	1.7	3.2	1.2	5.6	1.7
	5	10	9.6	5.1	3.0	1.4	3.1	.4	9.4	3.6
	6	10	13.0	4.4	4.0	1.1	3.2	.5	13.8	3.9

Appendix 4. Growth parameters of *Sitanion hystrix* seedlings in *Bromus japonicus* competition.

Treatment	Sample Number		Leaf Number		Stem Number		Number of leaves/stem		Height cm	
		n	x	s	x	s	x	s	x	s
Control	1	55	1.0	.2	1.0	0	1.0	.2	3.1	1.1
	2	121	2.5	.8	1.0	.2	2.4	.7	4.3	1.2
	3	132	5.3	2.3	1.9	.9	2.8	.9	4.7	1.3
	4	91	12.9	5.5	5.0	2.5	2.8	.7	7.2	2.0
	5	41	24.0	9.5	9.5	4.2	2.6	.6	10.0	4.0
	6	20	36.5	16.6	13.1	5.8	2.8	.4	15.5	4.4
50 *Bromus*/m^2	1	29	1.0	0	1.2	1.1	1.0	0	3.1	.9
	2	57	2.5	.7	1.0	.1	2.4	.6	4.2	.9
	3	61	4.7	2.0	1.7	.8	3.1	1.2	4.5	1.0
	4	40	9.8	3.8	3.4	1.5	3.1	.8	6.5	1.6
	5	11	13.8	4.3	5.5	1.9	2.6	.5	8.1	3.0
	6	10	14.7	5.8	5.6	2.0	2.6	.6	10.2	3.6
100 *Bromus*/m^2	1	25	1.0	.2	1.0	0	1.0	.2	3.0	1.1
	2	47	2.8	2.9	1.0	0	2.8	2.9	4.1	1.0
	3	49	4.6	1.8	1.4	.7	3.4	1.1	4.6	1.0
	4	35	8.6	2.7	2.7	1.1	3.4	.8	5.7	1.3
	5	10	12.4	4.8	3.8	2.0	3.6	.8	5.9	2.5
	6	10	18.6	8.9	6.7	3.5	2.8	.6	9.6	4.2
200 *Bromus*/m^2	1	37	1.1	.3	1.0	0	1.1	.3	3.3	1.1
	2	51	2.5	.7	1.0	.1	2.4	.6	4.5	1.1
	3	55	4.5	2.0	1.6	.8	2.9	.8	4.6	1.1
	4	38	8.1	4.2	2.8	1.7	3.2	1.0	5.8	1.8
	5	10	11.0	4.2	3.7	1.9	3.3	.9	6.1	2.4
	6	10	11.4	6.1	3.8	2.3	3.1	.5	7.3	2.4
400 *Bromus*/m^2	1	23	1.1	.3	1.0	0	1.1	.3	3.4	.9
	2	43	2.4	.5	1.0	0	2.4	.1	4.3	1.1
	3	47	4.4	1.4	1.4	.6	3.4	1.2	4.6	1.1
	4	35	8.0	2.8	2.3	1.1	3.8	1.1	5.2	1.3
	5	10	9.2	4.3	2.8	1.5	3.5	.8	6.0	1.2
	6	10	11.1	5.5	4.0	1.9	2.8	.6	8.7	3.3

Appendix 5. Growth parameters of *Koeleria gracilis* seedlings grown in *Bromus japonicus* competition.

Treatment	Sample Number		Leaf Number		Stem Number		Number of leaves/stem		Height mm	
		n	x	s	x	s	x	s	x	s
Control	1	20	1.0	0	1.0	0	1.0	0	8.3	2.9
	2	56	2.3	.6	1.0	0	2.3	.6	15.5	4.9
	3	47	4.4	2.6	1.3	.5	3.1	.7	18.5	6.9
	4	55	11.5	7.8	3.3	2.0	3.4	.9	24.8	9.2
	5	48	21.9	14.5	7.1	4.7	3.2	.6	27.6	8.9
	6	20	38.9	30.2	12.5	10.6	3.4	.7	37.8	13.7
50 *Bromus*/m^2	1	10	1.2	.4	1.0	0	1.2	.4	12.5	3.5
	2	29	2.3	.8	1.0	0	2.3	.8	14.8	6.5
	3	31	3.6	1.7	1.1	.4	3.3	1.2	19.7	8.2
	4	27	8.9	5.7	2.6	1.9	3.6	.9	26.3	8.3
	5	26	12.3	9.0	3.9	2.9	3.0	1.1	27.5	9.3
	6	10	16.1	9.4	4.5	3.1	4.1	.9	34.0	11.7
100 *Bromus*/m^2	1	15	1.1	.3	1.0	0	1.1	.3	9.3	4.6
	2	35	2.3	.7	1.0	0	2.3	.7	15.4	5.9
	3	32	3.6	2.0	1.1	.3	3.1	1.5	19.4	6.4
	4	27	7.3	5.1	2.1	1.3	3.5	.8	22.6	8.2
	5	26	10.5	7.2	3.4	2.4	3.2	.7	26.3	7.8
	6	10	13.3	9.1	4.3	2.6	3.0	.6	29.0	9.1
200 *Bromus*/m^2	1	15	1.0	0	1.0	0	1.0	0	10.0	3.3
	2	29	2.2	.6	1.0	0	2.2	.6	17.2	4.7
	3	30	3.3	1.1	1.1	.3	3.1	.8	21.5	6.8
	4	31	5.0	2.9	1.5	.9	3.3	.9	21.9	5.3
	5	24	6.9	4.0	1.9	1.2	3.7	.9	26.0	5.1
	6	7	8.3	3.6	3.0	1.1	3.5	.7	27.1	7.0
400 *Bromus*/m^2	1	9	1.0	0	1.0	0	1.0	0	7.8	4.4
	2	20	2.1	.8	1.0	0	2.1	.8	16.5	5.9
	3	23	3.2	2.0	1.2	.4	2.7	1.2	16.3	6.9
	4	22	6.1	4.8	1.9	1.2	2.9	1.1	18.6	8.6
	5	15	7.8	5.1	2.3	1.4	3.4	.8	23.0	8.8
	6	8	11.8	5.1	3.0	1.5	4.0	.8	24.4	7.3

Appendix 6. Growth parameters of *Koeleria gracilis* seedlings grown in *Kochia scoparia* competition.

Treatment	Sample Number		Leaf Number		Stem Number		Number of leaves/stem		Height mm	
		n	x	s	x	s	x	s	x	s
Control	1	20	1.0	0	1.0	0	1.0	0	8.3	2.9
	2	56	2.3	.6	1.0	0	2.3	.6	15.5	4.9
	3	47	4.4	2.6	1.3	.5	3.1	.7	18.5	6.9
	4	55	11.5	7.8	3.3	2.0	3.4	.9	24.8	9.2
	5	48	21.9	14.5	7.1	4.7	3.2	.6	27.6	8.9
	6	20	38.9	30.2	12.5	10.6	3.4	.7	37.8	13.7
50 *Kochia*/m^2	1	3	1.0	0	1.0	0	1.0	0	13.3	14.4
	2	14	1.7	.6	1.0	0	1.7	.6	13.2	4.2
	3	20	2.8	1.1	1.0	0	2.8	1.1	16.5	4.9
	4	25	3.6	2.2	1.2	.5	2.9	1.1	16.8	8.0
	5	23	5.3	3.9	1.5	1.0	3.3	1.0	18.5	9.5
	6	10	10.1	7.0	2.5	1.8	4.1	1.1	35.0	19.6
100 *Kochia*/m^2	1	7	1.3	.5	1.0	0	1.3	.5	15	8.2
	2	28	1.9	.6	1.0	0	1.9	.6	15.4	5.3
	3	31	3.2	1.4	1.0	.2	3.1	1.2	15.8	5.6
	4	35	5.3	3.7	1.6	.9	3.0	1.1	17.6	8.3
	5	28	7.3	5.0	2.2	1.4	3.2	.8	21.6	8.8
	6	9	13.2	10.3	3.4	2.4	3.5	.5	30.0	14.8
200 *Kochia*/m^2	1	8	1.0	0	1.0	0	1.0	0	10.6	5.0
	2	19	1.9	.7	1.0	0	1.9	.7	14.7	5.9
	3	22	2.9	1.5	1.0	.0	2.9	1.5	17.5	7.0
	4	23	4.8	3.2	1.4	8	3.3	1.0	19.8	8.6
	5	17	8.2	5.0	2.2	1.3	3.7	.9	22.1	8.5
	6	10	14.8	9.2	3.6	2.4	4.3	.6	37.0	11.4
400 *Kochia*/m^2	1	4	1.3	.5	1.0	0	1.3	.5	11.3	4.8
	2	15	1.7	.7	1.0	0	1.7	.7	13	4.9
	3	18	2.9	2.3	1.1	.3	2.5	1.1	13.9	5.3
	4	26	3.5	2.9	1.3	.6	2.5	1.4	16.2	8.9
	5	15	5.9	6.6	1.7	1.6	3.2	1.0	18.3	9.8
	6	9	8.4	2.1	2.2	1.6	4.0	.9	30.6	14.2

Appendix 7. Growth parameters of *Koeleria gracilis* seedlings in the indigenous species mixture grown in *Kochia scoparia* competition.

Treatment	Sample Number		Leaf Number		Stem Number		Number of leaves/stem		Height(mm)	
		n	x	s	x	s	x	s	x	s
Control	1	33	1.1	.3	1.0	0	1.1	.3	11.7	6.3
	2	40	2.1	.6	1.0	0	2.1	.6	15.0	4.9
	3	39	3.6	1.6	1.2	.5	3.1	.9	18.3	4.6
	4	40	6.1	4.0	2.0	1.2	3.0	1.0	22.9	7.3
	5	31	16.9	12.4	6.1	5.1	3.2	.8	31.3	9.1
	6	18	31.2	31.1	10.1	10.6	3.5	1.0	40.8	12.0
50 *Kochia*/m^2	1	22	1.0	0	1.0	0	1.0	0	12.0	4.8
	2	23	2.3	.8	1.0	0	2.3	.8	20.7	5.1
	3	21	3.7	1.2	1.1	.4	3.3	.9	20.0	6.9
	4	33	4.3	2.8	1.4	.8	3.0	1.0	19.3	8.0
	5	24	8.3	5.7	2.3	1.6	3.6	.8	26.7	10.4
	6	6	10.3	4.8	3.3	2.1	3.6	1.0	37.5	17.2
100 *Kochia*/m^2	1	6	1.2	.4	1.0	0	1.2	.4	8.3	4.1
	2	9	2.0	0	1.0	0	2.0	0	13.3	3.5
	3	11	2.9	1.6	1.1	.3	2.6	.9	16.4	3.9
	4	10	5.3	2.9	1.5	1.0	3.7	1.2	19.0	7.0
	5	14	5.9	4.2	1.6	.9	3.6	.8	20.0	7.2
	6	6	9.8	5.3	2.7	1.4	3.6	.4	40.0	7.1
200 *Kochia*/m^2	1	13	1.2	.4	1.0	0	1.2	.4	13.5	3.8
	2	14	2.6	.9	1.0	0	2.6	.9	19.3	6.5
	3	14	3.9	1.0	1.2	.4	3.2	1.1	19.0	4.9
	4	19	5.5	4.2	1.5	.8	3.4	1.5	20.0	5.9
	5	11	11.1	6.3	3.5	2.2	3.3	.8	24.5	6.1
	6	6	11.3	5.5	3.5	2.2	3.7	1.0	42.5	14.1
400 *Kochia*/m^2	1	9	1.0	0	1.0	0	1.0	0	11.7	5.6
	2	14	1.7	.5	1.0	0	1.7	.5	14.3	5.1
	3	14	3.1	.9	1.1	.3	2.9	.9	19.6	6.6
	4	24	3.5	2.0	1.2	.4	2.9	.9	19.8	6.0
	5	16	5.5	2.5	1.5	.7	3.8	.8	25	7.1
	6	5	6.6	3.3	1.5	.5	4.6	1.0	35	13.2

Appendix 8. Growth parameters of *Koeleria gracilis* seedlings in the indigenous species mixture grown in *Bromus japonicus* competition.

Treatment	Sample Number		Leaf Number		Stem Number		Number of leaves/stem		Height mm	
		n	x	s	x	s	x	s	x	s
Control	1	33	1.1	.3	1.0	0	1.1	.3	11.7	6.3
	2	40	2.1	.6	1.0	0	2.1	.6	15.0	4.9
	3	39	3.6	1.6	1.2	.5	3.1	.9	18.3	4.9
	4	40	6.1	4.0	2.0	1.2	3.0	1.0	22.9	7.3
	5	31	16.9	12.4	6.1	5.1	3.2	.8	31.3	9.1
	6	18	31.2	31.1	10.1	10.6	3.5	1.0	40.8	12.0
50 *Bromus*/m^2	1	22	1.0	0	1.0	0	1.0	0	9.3	4.2
	2	24	2.0	.7	1.0	0	2.0	.7	16.5	5.4
	3	30	3.3	1.4	1.2	.5	2.7	.8	20.8	5.9
	4	29	6.0	3.5	1.8	1.2	3.6	.9	24.3	6.5
	5	14	9.1	5.4	3.0	2.0	3.3	.9	32.1	9.1
	6	8	14.5	16.8	4.6	4.7	3.2	.9	35	10.4
100 *Bromus*/m^2	1	15	1.2	.4	1.0	0	1.2	.4	13.7	6.9
	2	20	2.1	.7	1.0	0	2.1	.7	16.5	5.2
	3	19	3.4	1.5	1.2	.4	3.0	1.1	20.7	7.7
	4	23	4.7	2.7	1.4	.7	3.4	.8	18.7	5.3
	5	16	5.6	3.1	1.4	1.0	4.1	.9	27.2	12.6
	6	7	5.9	3.1	1.7	1.5	3.9	.8	24.3	6.7
200 *Bromus*/m^2	1	12	1.1	.3	1.0	0	1.1	.3	8.3	3.9
	2	20	2.1	.6	1.0	0	2.1	.6	15.5	4.6
	3	17	2.9	.7	1.0	0	2.9	.7	19.4	3.9
	4	17	4.8	2.2	1.5	.9	3.3	1.1	20.3	5.4
	5	15	5.7	2.1	1.5	.7	4.0	.9	25.6	8.2
	6	9	5.2	2.4	1.7	.9	3.3	.8	26.1	8.2
400 *Bromus*/m^2	1	14	1.1	.4	1.0	0	1.1	.4	10.4	5.0
	2	15	2.1	.7	1.0	0	2.1	.7	15.3	7.4
	3	15	2.9	1.5	1.1	.3	2.7	1.0	18.3	5.9
	4	15	4.5	3.4	1.5	1.0	3.1	1.5	21.7	5.9
	5	12	8.4	3.4	2.8	1.3	3.2	.8	33.3	12.7
	6	8	11.8	5.1	3.1	1.5	3.8	.9	24.4	7.3

Appendix 9. Soils of the Fort Missoula Research Area

JOCKO SERIES

Typic, Haploxeroll, Sandy-Skeletal, Mixed, Frigid

The Jocko series consists of deep, well drained soils formed in coarse-textured alluvial materials from quartzite and argillite. These soils are on terraces in intermountain valleys.

Drainage and Permeability: Well drained; slow runoff; moderately rapid permeability through the solum and rapid in the underlying material.

Ap 0 to 7 inches; grayish brown (10 yr 5/2) gravelly silt loam, very dark grayish brown (10 yr 3/2) moist; moderate very fine granular and cloddy structure; slightly hard, firm, slightly sticky and slightly plastic; few fine and very fine roots; 20 percent gravel; slightly acid; abrupt smooth boundary.

A12 7 to 10 inches; grayish brown (10 yr 5/2) gravelly silt loam, very dark grayish brown (10 yr 3/2) moist; moderate medium and fine subangular blocky structure; slightly hard, firm, slightly sticky and slightly plastic; few fine and very fine roots; 20 percent gravel; slightly acid; abrupt smooth boundary.

B2 10 to 19 inches; brown (10 yr 5/3) very gravelly silt loam, dark grayish brown (10 yr 4/2) moist; moderate medium prismatic breaking to strong coarse and medium angular blocky structure; slightly hard, firm, slightly sticky and slightly plastic; common fine and very fine roots; 45 percent gravel; neutral; clear smooth boundary.

Appendix 9 continued. Soils of the Fort Missoula Research Area

C 19 to 35 inches; pale brown (10 yr 6/3) very gravelly loamy sand, grayish brown (10 yr 5/2) moist; single grain structure; loose, nonsticky and nonplastic; few fine and very fine roots; 50 percent gravel; lime casts on rock bottoms; mildly alkaline.

Pedon number 2 is similar in horizonation and soil morphology except that the C horizon is slightly effervescent in places and has a pH of 7.8 - 8.0 (moderately alkaline). Some blue-green crystals were found within the prisms in the B2 horizon, suggesting the presence of some salt.