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"Oh God, to reach the point of death
only to find that you never really lived at all"

- Henry David Thoreau

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Revegetation Assessment of a Twelve-Year-Old Pipeline on Native Rangeland in Southern Alberta

by

Deborah Kelly Ostermann ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Land Reclamation and Remediation

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Revegetation Assessment of a Twelve-Year-Old Pipeline on Native Rangeland in Southern Alberta submitted by Deborah Kelly Ostermann in partial fulfillment of the requirements for the degree of Master of Science in Land Reclamation and Remediation.

Date

This thesis is dedicated to friends,

Bryce Heartwell
(June 19, 1954 – June 29, 2000)

and

Laura Heartwell

Bryce, you showed me how to live well and yes
I'm still scraping my pegs. We miss you very much.
Laura, you are my hero.

ABSTRACT

The long-term (11 to 12 years) impact of grazing and pipeline right-of-way (ROW) zone on plant community development was assessed in Dry Mixed Grass, Mixed Grass (Milo) and Fescue Grassland (Porcupine Hills) Ecoregions. Native and non-native seed mix influences on plant community development were assessed in Dry Mixed Grass Ecoregion.

Grazed plots had significantly higher bare ground and lower crested wheatgrass cover than ungrazed plots. Grazing did not significantly impact plant community or soil properties. Trenching significantly increased rhizomatous grasses and ROW disturbance and generally reduced tufted grasses. Work zone soil had significantly higher penetration resistance than other zones. Bare ground was higher on disturbed zones than undisturbed prairie. At Milo, the trench had significantly higher biomass than other zones. Right-of-way did not affect animal use. Native seed mix established more successfully than dryland pasture mix. Seed mix did not significantly affect cover, animal use or productivity.

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What would you do if someone asked you to spend a summer in southern Alberta looking at native rangelands? At some sites, I have an endless view of prairie landscape, needle and thread grass waving with the wind. Heat waves make the grass come alive. And storm clouds! I see them coming for miles, dark blue against the golden of mature native grass and I wonder if I have time to do one more plot before rains make the trail impassable for my vehicle. At Waldren, surrounding me is fescue grassland. To the east as far as the eye can see is prairie, to the west Rocky Mountains. On the first trip to Pincher Creek, I walk through aspen with an understory of glacier lilies. The most beautiful place on earth is here, in front of me. Did I mention the medicine circle, grizzly bears or wild turkeys? Now you tell me I'm being paid! Okay, so it's not a lot. So when does the hell of being a graduate student start? If only I knew then what I know now….

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I. INTRODUCTION TO DISTURBANCE AND REVEGETATION ON RANGELAND ECOSYSTEMS

1.0 BACKGROUND

Gas pipelines cross much of Alberta, many of them constructed on native rangelands. Establishment and persistence of acceptable vegetation on these rangelands can be a challenge due to soil characteristics, disturbance effects, climate and grazing. Revegetation of native rangelands can be viewed as managed plant succession. Attempts are made to establish late seral stage plant communities in a relatively short time by planting specific species. Re-establishment of native plant species is becoming more important as native range is seen as an important resource for humans, wildlife and domestic animals. Often disturbances are seeded with non-native species, which differ from native species in their palatability, productivity, competitive ability and longevity. These differences can make reclaiming the pipeline rights-of-way (ROW) and managing the adjacent native rangeland difficult.

In 1986, a long-term project was initiated by NOVA Gas Transmission Ltd. to monitor pipeline revegetation on native rangelands in southern Alberta. Two pipeline laterals crossing Dry Mixed Grass, Mixed Grass and Fescue Grassland Ecoregions were studied. The primary purpose of the research was to determine the impacts of native and non-native seeded pipeline zones on plant species composition, succession, biomass production and animal utilization. The seeded zones of the pipeline ROW were compared to native prairie. The study also determined impact of grazing on species composition and successional changes.

In this chapter rangeland ecosystems in southern Alberta and successional theories are examined through a review of the effects of grazing and pipeline disturbance on grassland communities. Plant characteristics, role of propagule supply and functional groups potentially necessary in successful revegetation of rangeland communities are considered. This information helps explain why changes in rangeland ecosystems occur after pipeline construction and makes it possible to recommend more appropriate ways to construct and reclaim pipeline ROW on native rangelands in southern Alberta.

2.0 RANGELAND ECOSYSTEMS IN SOUTHERN ALBERTA

Rangeland is land unsuitable for cultivation because of physical limitations such as topography, climate or soils but provides forage or browse for animals (Holochek

1998). Rangelands include grasslands, forested areas, desert and tundra. Attempts to reconstruct native rangelands are often based on agronomic rather than ecological concepts. Allan (1988) states agronomic concepts are often inappropriate when the goal is to establish a stable, self-sustaining ecosystem that requires minimal inputs on arid or semi-arid lands. Seeding in rows, fertilizing or irrigating to re-establish vegetation on native rangelands are not representative of natural processes and may inhibit successful establishment of desirable plants (Allan 1988).

Most grasslands in southern Alberta are defined by the dominance of herbaceous vegetation, since insufficient moisture can not support tree growth (Coupland and van Dyne 1979). Warm summers and cold winters characterize Alberta grasslands. Maximum precipitation occurs early in the growing season in June. Winter precipitation varies within the grassland ecoprovince (Strong and Leggat 1992). The driest (88 to 233 mm of annual precipitation) and warmest region (mean summer temperature of 16.2 °C) of the province, the Dry Mixed Grass Ecoregion, occurs in the southeast (Strong and Leggat 1992). Soil development and plant species reflect severe summer moisture deficits. Topsoils are shallow, with low organic matter due to diminished vegetation production and slow root turnover. Wind erosion is common. The primary range types are *Stipa-Bouteloua* (needle grass-blue grama grass), *Bouteloua-Stipa-Agropyron* (blue grama grass-needle grass-wheat grass) and *Stipa-Agropyron* (needle grass-wheat grass) (Strong and Leggat 1992).

North and west, the climate becomes less extreme in the Mixed Grass Ecoregion. Total summer precipitation is approximately 20 mm greater and summer temperature is approximately 1 °C lower than the Dry Mixed Grass. Winter temperatures are not as severe and there is deeper snow cover (Strong and Leggat 1992). These climatic differences, which decrease evapotranspiration and increase precipitation, result in more moisture for plant growth. Plant biomass (Smoliak 1956, Wroe et al. 1979) and soil organic matter (Canada Soil Survey Committee 1978) tends to be greater on Mixed Grass than Dry Mixed Grass. *Stipa-Agropyron* dominates much of the area, but xeric locations have vegetation more characteristic of the Dry Mixed Grass Ecoregion. Many of these grasslands are cultivated and are in permanent cereal crop or forage production. Those that remain native are due to limitations other than climate. Soils or topographical limitations are common and can cause problems with revegetation after disturbance.

The Fescue Grassland Ecoregion lies west and north of the Mixed Grass Ecoregion. Climate is more moderate, with cooler summer temperatures and more summer and winter precipitation than both the Mixed and Dry Mixed Grass Ecoregions. Subhumid conditions created by the overlap of grassland and cordilleran climate

promotes the development of graminoid vegetation (Strong and Leggat 1992). These moist conditions encourage development of a *Festuca-Danthonia* (fescue-oatgrass) vegetation type (Moss and Campbell 1947, Strong and Leggat 1992). Topsoils are rich in organic matter due to high vegetation production and rapid root decomposition. Due to the fertile soils that developed in the Fescue Grassland, crops and forages cover areas suitable for cultivation. Native rangelands exist in areas of high elevation or topographical limitations. Moisture deficits are less severe and revegetation concerns are establishing suitable vegetation. *Festuca-Danthonia* range offers high protein, late season grazing for many ranchers. Invasion by non-native species is common and a concern in native areas since many non-native species (e.g. soft grasses) do not cure on the stem as well as the native hard grasses. Because of the high effective moisture found in this ecoregion, lack of disturbance results in an increase of woody vegetation.

3.0 SUCCESSIONAL THEORIES

Succession is the process of community change at a single location over time in the absence of disturbance (Luken 1990). Clements (1916) proposed vegetation was constantly changing, and like an organism, it reproduced, grew, matured and died. He postulated the most stable association is never in complete equilibrium nor is it free from disturbed areas in which secondary succession is occurring. Clements (1916) separated the successional process into nudation, migration, ecesis, competition, reaction and stabilization. His theory rested on the assumption that vegetation could be classified into formations representing a group of plant species acting as an organic entity. He believed all successional units within a region developed along a single linear path toward a single formation determined by climate. This is the monoclimax theory.

While Clements theorized climate-controlled succession and plant communities were organic entities, other scientists questioned the narrowness of the monoclimax theory. By 1920, Gleason criticized the concept that a unit of vegetation was an organic unit and others did not accept the assumption that edaphic factors could not determine climax (Joyce 1993). Braun-Blanquet (1932) criticized Clements for not allowing adequate provision for a graduated scale for designating vegetation units of different degrees. He further commented the climax formation described by Clements and Weaver (1924) embraces several climax communities to which the term association is applied. Braun-Blanquet (1932) thought this term was poorly circumscribed, large and difficult to grasp.

By the mid 1950s, ecologists were beginning to test alternative theories (Joyce 1993). Odum (1969) defined succession as an orderly and predictable process of community development that results from modifying the physical environment and culminates in a stabilized ecosystem in which maximum biomass and symbiotic function are maintained. Odum focused on succession involving a fundamental shift in energy flow as more energy is relegated to maintenance. He also identified biogeochemical cycling of major nutrients as important. Compared to developing ones, mature systems have a greater capacity to entrap and hold nutrients for cycling within the system (Odum 1969).

Connell and Slatyer (1977) proposed three mechanisms of succession. The facilitation model assumes that only certain early succession species are able to colonize a site in the conditions that occur immediately following a disturbance. This follows Clement's theory that each successive wave of vegetation alters the environment to make it fit for the next plant community but unfit for the current one (Clements 1928). The tolerance model suggests species establish that can tolerate lower levels of resources than in the first model. The inhibition model relies on the theory that once species secure resources; they inhibit invasion of subsequent species or suppress growth of those already present.

Grime (1977) classified external factors that limit plant biomass as stress or disturbance. He suggested succession be based on level of stress and disturbance. Of the four permutations of high/low stress and disturbance, only three present viable plant habitats for competitive plants (low stress and low disturbance), stress tolerant plants (high stress and low disturbance) and ruderal plants (low stress and high disturbance) leading to the intermediate disturbance hypothesis (IDH).

Traditional successional theory supports the concept of community as an organism and the individuals and species within a community interact to increase one another's potential for survival. Alternative theories indicate there are no discontinuities in vegetation, and plant communities exist on a continuum. Greig-Smith (1983) stated acceptance of the continuum theory does not lead to entire rejection of the organism concept of community. Plants could be grouped according to their ranges of tolerances, so total number of species could be arranged in a considerably smaller number of groups, with each group having more or less well-defined boundaries. Comparing the three succession models by Gitay and Wilson (1995) indicates that the three-phase model (pioneer, building and mature) suggested by Greig-Smith, fits better than the gradient-in-time model and the competitive-sorting model, in post-fire changes in tall tussock

grassland. There is still ample debate on the reason for and direction of succession after a disturbance.

4.0 DISTURBANCE

Disturbance is defined as a variation in some factor in an ecosystem beyond the normal range of variation, resulting in a change in the ecosystem (Kaufman and Franz 1993). While Kaufman and Franz do not indicate what constitutes change, Smith (1996) indicates disturbance is any physical force, such as fire, wind, flood, extremely cold temperature or epidemic, that damages natural systems and results in the mortality of organisms or loss of biomass. The most important disturbances affecting species composition on grasslands are fire, climate and herbivory (Coupland et al. 1960).

4.1 Grazing

Grazing is a biotic disturbance. Palatability, morphology, phenological stage, grazing history, intensity of grazing and competition from other plants all affect individual plant response (Holochek 1998, Kerr et al. 1993). Plant recovery from grazing depends on its ability to re-establish photosynthetic tissue and retain its competitive position in the plant community (Kerr et al. 1993). Light to moderate grazing can increase tillering and photosynthesis as well as help disperse seed (Holochek 1998). It aids in the removal of older tissue thus increasing available light to lower, young tissue. Removal of excess litter also aids in establishing seedlings. Gross (1984) determined dense litter was detrimental to the establishment of small seeded species with spreading growth forms. There is also the added benefit of recycling nutrients contained in animal wastes and accelerating decadent forage breakdown by trampling (Kerr et al. 1993).

While there are many benefits to grazing, overgrazing can decrease plant vigour and density and carbohydrate reserves (Holochek 1998). Vallentine (1990) and Crider (1955) state overgrazing can reduce root mass. Root reduction leads to susceptibility to environmental stresses, such as temperature extremes and lack of soil moisture. Naeth et al. (1990) concluded heavy grazing increases soil surface bulk density and penetration resistance, which in turn, decreases soil water in the root zone in Mixed Grass Prairie (Naeth et al. 1991). Grazing affects soil water; treading alters infiltration rates and defoliation reduces evapotranspiration (Naeth and Chanasyk 1995). While Naeth and Chanasyk (1995) found little difference between type of grazing regime (i.e. heavy

rotational vs. heavy continuous), they concluded that maintenance of vegetation cover allows snowmelt infiltration, which is critical for soil water recharge in Fescue Grassland.

Generally, as grazing pressure increases, less palatable species in the plant community increase and species composition shifts from taller to shorter plants. Moss and Campbell (1947), Looman (1969) and Willms et al. (1985, 1986) all noted shifts in Fescue Grassland away from rough fescue and oat grass to less palatable forbs, sedges and invader species. Puerto et al. (1990) noted the great diversity in oligotrophic and very oligotrophic pastures; these pastures also marked the transition between high and low grazing pressure. Green and Kaufmann (1995) showed similar results in riparian grassland: ungrazed dry and moist meadows had significantly lower species richness and diversity compared to grazed counterparts. In heavily grazed communities, competitive ruderal species were favored while in exclosures, competitive or competitive stress-tolerant species dominated (Green and Kaufmann 1995).

Puerto et al. (1990) found palatability of initial species did not affect plant diversity. Increased diversity, resulting from preferential consumption of palatable, dominant species, was usually limited to conditions of moderate grazing. Gibson and Brown (1991) found sheep grazing for short periods enhanced appearances of both short-lived and perennial plants early in a six-year study. Perennial species' disappearances were relatively constant with time and grazing and stocking rate, but perennials disappeared more from spring and autumn grazed areas than from other treatments. The spring and fall grazed areas had the highest species richness, suggesting that grazing treatment had relatively little effect on the relationship between species number and diversity. Samuel and Hart (1994) found little difference in diversity between moderately grazed and ungrazed areas 10 to 20 years after cultivation on Wyoming High Plains. They also noted soils and precipitation affected species composition.

4.2 Pipeline Disturbance

Plant communities subjected to small size anthropogenic disturbances can return to an equilibrium state similar to predisturbed conditions (Zink et al. 1995). Unfortunately, larger disturbances have a profound effect on existing and future plant communities. The obvious effect is the physical absence of vegetation after disturbance. In appearance, this is the most dramatic, but lack of vegetation can be rectified by planting new plant species. Zink et al. (1995) indicate pipeline disturbance may provide an invasion pathway for non-native species that have established elsewhere in the community. Thus, successional progression towards predisturbed conditions may not

necessarily occur. In a southern California ecological reserve, Zink et al. (1995) found that 10 years after disturbance, the pipeline ROW was still dominated by non-native annuals commonly found in the adjoining urban and agricultural areas.

The most significant changes affecting pipeline revegetation occur in soils and hydrology (Naeth 1985). Pipeline construction commonly decreases topsoil thickness and organic matter and increases soil bulk density in the work and spoil zones due to mixing of topsoil and subsoil (Naeth 1985). Naeth, in a study of pipelines constructed from 1957 to 1981 in southeastern Alberta, noted the increase in density was most pronounced in surface soil; changes in density with depth persisted over time but surface bulk densities decreased within ten years. Naeth et al. (1987) observed there was greater amelioration of chemical than physical changes over time. The time needed for a soil to return to a physical and chemical state similar to predisturbed conditions is unknown. Dormaar and Smoliak (1985) and Whitman et al. (1943) estimated it to be 50 years, while Naeth et al. (1987) estimated 50 years would only restore half the lost organic matter.

The pipeline ROW can disrupt hydrological processes. Ditching may enhance infiltration over the trench area, though water-holding capacity and hydraulic conductivity tends to decrease after pipeline construction (Culley et al. 1981, Naeth 1985). Work done by Naeth et al. (1988) in the Mixed Grass Prairie, indicates soil water regimes tend toward undisturbed conditions in pipelines that are ten years or older. In severe cases of soil compaction, groundwater flow regimes may be altered (Kerr et al. 1993). Compaction will also reduce infiltration, which can lead to an increase in surface runoff and reduction of soil moisture. Loss of litter in the disturbed area will also affect soil-water interactions. Litter helps conserve moisture by insulating the soil against solar radiation, thus reducing temperature, light and evaporation at the soil surface (Naeth 1988, Willms et al. 1986).

5.0 REVEGETION

Plant characteristics affect revegetation success. Understanding how plants compete, grow and reproduce allows predictions about what will happen after a disturbance. What grows depends heavily on available seeds and vegetative propagules. The following is a discussion on the role of niches, competition, functional groups and propagule supply on revegetation of disturbed areas.

5.1 Plant Characteristics: Importance of Niche and Competition

While all autotrophic terrestrial plants use the same resources: sunlight, soil water, carbon dioxide and mineral nutrients in the soil, not all of them are successful at long-term establishment. Some species are able to establish and maintain their existence more effectively than others. Is it due to an inherent quality they have or just by chance they were in the right place at the right time? A number of individuals have studied why species differ in their ability to become established after disturbance.

Connell (1978) stated community diversity is a result of equilibrial or nonequilibrial processes. Equilibrium theories assume plants order themselves according to inherent attributes or niches. Species differ in their optimal and tolerable responses to factors important to survival and hence, have different niches. Plants survive and prosper at sites where they are competitively superior to other species in the acquisition of one or more resources (Burton et al. 1988). Competition for resources, between two or more species, is defined by the amount of niche overlap. Species sharing the same niche will likely be interacting in the same space and time.

Equilibrial theory predicts the best competitor for a single limiting resource will displace all other species from a habitat despite their initial densities. Many long-term garden experiments strongly support this theory (Tilman 1994). If this is the case, then why do many species co-exist with competitive plants? An example of this is the presence of little bluestem (*Schizachyrium scoparium* (Michx.) Nees), a fierce nitrogen competitor, with more than 100 species in native prairie (Tilman 1994). Building on models developed by Levins, Hastings and Nee and May, Tilman (1994) theorized species can co-exist if appropriate two-way or three-way trade-offs occur among competitive ability, colonization ability and longevity. Using spatial competition models, Tilman concluded there is no limit to species richness in a spatially subdivided habitat with a single limiting resource.

This is contrary to research by Epp and Aarssen (1989) and Grime (1973). They developed the competitive index, which is made up of measured plant attributes that include seed weight, emergence time, plant height and lateral spread. Both concluded species with higher competitive indices may cause local suppression or exclusion of species with lower competitive indices. Epp and Aarssen found patterns were most noticeable at the smallest spatial scale of 1 m^2 and early stage attributes, such as seed weight, affected the relationship in recently established communities. In older communities, late stage attributes related to competitive ability affected the relationship.

Nonequilibrial theory places importance on randomness of interactions among

species and on disturbance at different scales (Hubbell 1979, Pickett and White 1985). According to this theory, persistence of a species in a community depends on its ability either to resist displacement by disturbance or to take advantage of space vacated by disturbance. Once established, plants are difficult to displace and squatter's rights (i.e. ecological inertia) of site occupancy often prevail over competitive ability.

Work done by Coffin et al. (1996), on old-field Shortgrass Prairie, indicates establishment of grasses is highly variable depending on disturbance conditions, management practices over time and fine-scale climate. Walker and Koen (1995) found total plant cover as high or higher on a pipeline ROW, compared to adjacent undisturbed areas four years after construction. This cover was mostly due to increased forbs. They also noted yearly variation in precipitation and competition from previously established plants greatly affected species composition. A study in Grand Teton National Park showed that sites heavily disturbed by cultivation were virtually covered with non-native aggressive grass species (McArthur et al. 1995). The researchers concluded movement towards the predisturbed vegetation could take centuries or could not occur at all without human intervention.

5.2 Functional Groups

Several researchers (Naeem and Li 1997, Tilman et al. 1996, Sankaran and McNaughton 1999) state biodiversity influences ecosystem productivity, sustainability and stability (the diversity-stability hypothesis). Other studies indicate ecosystems with high species richness are not always the most productive. Grime (1997) points out species-poor communities, such as the boreal forest and bogs, have high productivity. Tilman et al. (1997) concluded functional diversity has a greater impact on ecosystem processes than does species diversity. Friedel et al. (1988) hypothesized each species may not have an essential role in a community and groups of species may have similar functions. These groups of species are defined as functional groups and species within a group could be considered redundant (Walker 1995). Tilman and Downing (1994) indicate the effects of biodiversity level off at ten species, while others have determined little is gained from more than five species in an agronomic plant community (Baskin 1994). Research in the Aspen Parkland of Alberta could neither support nor refute that diverse plant communities have better cover or are more resistant to weed invasion (Bush 1998). Bush's work emphasizes the importance of site heterogeneity, seeding rates and influence of individual species on community development.

In moving from a community defined by species diversity to functional diversity, classifying species according to functional group has to assume a relationship between function and plant form such as physiology, life history or reproductive strategy. Determining characteristics necessary for the movement of energy and matter and for growth and change is difficult (Solbrig 1993). On Tallgrass Prairie, Jackson (1980) determined the plant community had at least one species from each of four functional groups: warm season grass, cool season grass, legume and composite. He concluded a stable ecosystem should have at minimum, these four components. Tilman et al. (1997) defined five functional groups, the same four as Jackson, but added woody plants. Hooper and Vitousek (1997) only used four groups, but defined them differently than Jackson and Tilman, using early and late season annuals, perennial bunchgrasses and nitrogen fixers. Solbrig (1993) cautions use of functional diversity, stating criteria for determination is arbitrarily set and plants may not stay within the same functional group, making determination of functional groups subjective.

Laycock (1991) suggested methods of reproduction of species affect revegetation of disturbed shortgrass steppe vegetation. Laycock concluded blue grama had not re-established in an area surrounded by blue grama because there was insufficient precipitation for plants to reproduce. Blue grama reproduces primarily by vegetative means, and restrictive moisture and temperature conditions can decrease germination and adventitious root development (Laycock 1991). Clonal growth makes it possible for a species to rapidly colonize available space. A ten-year study by Prach and Pysek (1994) studied clonal plant development and its relationship to soil conditions at 15 different sites. They found total cover of clonal plants increased from the onset of succession to a maximum value and then decreased in the majority of environments. Cover of clonal plants increased with soil moisture conditions, but was not significantly affected by soil nitrogen. Clonal plants had slower and less successful performance on drier sites due to annuals and biennials dominating dry sites early. While they found clonal plants did not do well under water stress conditions, Callaghan et al. (1992) observed that parent plants can support young ramets, thus buffering spatial heterogeneity of habitat and localized disturbance.

5.3 The Role of Propagule Supply

After pipeline disturbance, the vegetation that develops depends to a considerable extent on which species are represented in the seed bank and on their germination requirements. Gibson and Brown (1991) found most differences between species and

rate at which they appeared were due to composition of the seed bank formed after abandoning cultivation of the field. In long-term studies on the Wyoming High Plains, Samuel and Hart (1994) concluded many species, regardless of seral stage in which they occur naturally, establish early on disturbed sites provided an adequate supply of seed or vegetative propagules were present.

Levassor et al. (1990) found the number of species and the density of buried seeds increased with successional age from zero to four years, then decreased until a constant was reached after nine years. The greatest seed diversity was found at intermediate levels of disturbance, and there was a dramatic decrease in seed diversity at high disturbance levels. Research on long-term, grazed fescue grassland found an increase in seeds in the seed bank from ungrazed to heavily grazed areas (Willms and Quinton 1995). Willms and Quinton also concluded from seed bank analysis, that increasing grazing disturbance in the fescue prairie will likely lead to a seral community dominated by annual forbs and invasive perennials (e.g. bluegrass) rather than a rough fescue dominated grassland.

Primary succession of lake islands in Sweden found similarity between seed bank and vegetation decreased with an increase in successional age (Grandin 1998). The same research showed 100 years of primary succession was not long enough for exhaustion of early successional species from the seed bank. Kotanen (1996) indicated soil disturbances differ spatially or temporally from one another, with recolonization by different propagule pools leading to initially different successional paths.

There is limited information published on external seed supply and its effect on plant community development. Research in the Aspen Parkland of central Alberta indicates seeded species, specifically slender wheat grass (*Agropyron trachycaulum* (Link) Malte) and awned wheat grass (*Agropyron trachycaulum* var. *unilaterale* (Cassidy) Malte), can be aggressive and establish quickly in the first two years after seeding (Bush 1998). In the same research, wild buckwheat (*Polygonum convolvulus* L.), which was a seed bank species, had a tremendous effect on the plant community by out-competing seeded species in the first year. Many of the seeded species that initially germinated, died due to lack of sunlight getting through the thick wild buckwheat canopy. In the following year, wild buckwheat cover was greatly diminished and seeded species that had been able to survive and ones that germinated in the second year were able to establish. However, even though seeded species were starting to establish, the dominant plant in the second year was pasture sage (*Artemisia frigida* Willd.), an unseeded species. Bush (1998) concluded that what you seed is not what you get. Site heterogeneity, community composition and interactions, disturbance and individual species are all factors that influence the development of the plant community.

6.0 RESEARCH OBJECTIVES

Little work is published on early succession in grasslands of the Mixed Grass, Dry Mixed Grass and the Fescue Grasslands of Alberta. The uniqueness of pipeline disturbance makes application of successional changes caused by grazing or agricultural practices impractical. Presently, most of the literature focuses on changes with grazing and on areas of agricultural disturbance. Linearity of a pipeline also makes invasion by native species more probable, depending on the type of species seeded. Research on effectiveness of seeding species to advance successional stages is sparse. Comparison of seeded species and desired endpoint is not addressed adequately in the literature. The long-term nature of this project makes it possible to determine changes in species composition over time. The objectives of this research were:

- To determine the impact of grazing and pipeline ROW zone on the vegetation and soil components of native rangeland 11 to 12 years after construction,
- To determine plant community development over a 12-year period on pipeline ROW zones and grazing treatments, and
- To determine the long-term influence of seed mix on plant community development and reclamation success after pipeline construction.

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II. IMPACT OF GRAZING AND RIGHT-OF-WAY ZONE ON NATIVE RANGELAND 11 TO 12 YEARS AFTER PIPELINE CONSTRUCTION IN SOUTHERN ALBERTA

1.0 INTRODUCTION

There are over 276,000 km of pipeline in Alberta (Alberta Ministry of Resource Development 2000). A number of these are located in southern Alberta, many on native rangelands. In the last decade, there has been a shift from using non-native to native species for maintaining the long-term integrity of these rangelands after disturbance. Reclaiming the pipeline rights-of-way (ROW) to a functional plant community can be a challenge. Because of construction techniques, each ROW zone has its own unique characteristics. Grazing after disturbance and during the reclamation process can further affect revegetation.

Moss and Campbell (1947), Looman (1969) and Willms et al. (1985, 1986) found shifts in fescue grassland away from rough fescue and oat grass to less palatable forbs, sedges and invaders with grazing. In Dry Mixed Grass Prairie, grass and forb yield decreased with increased years of litter removal (Willms et al. 1986). Blue grama grass (*Bouteloua gracilis* (HBK) Lag.) decreased viable seed production and increased vegetative spread with grazing in semi-arid rangeland (Coffin et al. 1998). Naeth et al. (1991a) found grazing did not affect amount of live vegetation in Mixed Grass Prairie, and was highest in light to moderate grazing in fescue grassland. Grass yield remained constant while forb yield increased with number of years of litter removal (Willms et al. 1986). Puerto et al. (1990) concluded the highest diversity occurred in oligotrophic and very oligotrophic pastures that also marked the transition between high and low grazing pressure. Green and Kaufmann (1995) found similar results in riparian grassland. In heavily grazed communities ruderal species were favored while in exclosures, competitive and competitive stress-tolerant species dominated (Green and Kaufmann 1995). While much research indicates a shift away from native, non-ruderal species, grazing response was not always consistent. Stohlgren et al. (1999) found few plant species with consistent directional response to grazing and grazing had little effect on native species richness at landscape scales in Rocky Mountain grasslands.

Plant recovery from grazing depends on its ability to re-establish photosynthetic tissue and retain its competitive position in the plant community (Kerr et al. 1993). Light to moderate grazing can increase tillering and photosynthesis and help disperse seed (Archer and Pyke 1991, Belsky 1986, Willms et al. 1986). It aids in the removal of older

tissue thus increasing available light to lower, younger tissue. Removal of excess litter aids in the establishment of seedlings (Gross 1984). There is also the added benefit of recycling nutrients contained in animal wastes and accelerating decadent forage breakdown by trampling (Kerr et al. 1993).

Overgrazing can decrease plant vigour, density, carbohydrate reserve and root mass (Coffin et al. 1998, Crider 1955). Naeth et al. (1990, 1991b) concluded heavy grazing increased surface soil bulk density and penetration resistance, which decreased soil water in the root zone in Mixed Grass Prairie andFescue Grassland. Treading altered infiltration and defoliation reduced evapotranspiration rates, which in turn affected the soil (Naeth and Chanasyk 1995).

The most significant changes affecting revegetation after pipeline construction occur in soil and hydrologic properties (Naeth 1985). The type of disturbance in each ROW zone is also unique in its effect on soil characteristics. In the Mixed Grass Ecoregion in southern Alberta, soil bulk density was higher on work and spoil areas and lower on trench areas of the ROW (Naeth 1985). Topsoil thickness and organic matter decreased (Naeth 1985). Hydrologic processes were disrupted in the construction zone. Ditching enhanced infiltration over the trench area, though water holding capacity and hydraulic conductivity decreased after pipeline construction (Culley et al. 1981, Naeth 1985). Compaction in the construction zone reduced infiltration, which increased surface runoff and reduced soil moisture (Kerr et al. 1993). Loss of litter in the disturbed area increased surface soil temperature and evaporation at the soil surface (Naeth 1988, Willms et al. 1986). Soils are predicted to take in excess of 50 years to return to predisturbed conditions (Dormaar and Smoliak 1985, Naeth et al. 1987, Whitman et al. 1943). Thus, grazing and pipeline ROW construction itself have the potential to cause problems when revegetating.

Large anthropogenic disturbances have a profound effect on existing and future plant communities. Zink et al. (1995) indicated pipeline corridor disturbances provide an invasion pathway for non-native species that have established elsewhere in the community thus, succession towards predisturbed conditions may not occur. While some research has focused on soil characteristics of pipeline disturbance, not as much has been done on plant community development. Work completed by Naeth was limited to the Mixed Grass Ecoregion. This research encompasses plant communities located in the Mixed Grass, Dry Mixed Grass and Fescue Grasslands Ecoregions of southern Alberta.

2.0 OBJECTIVES

The objectives of this study were to assess impacts of grazing and ROW zone on revegetation (plant density, cover, community composition, ground cover), to assess soil factors affecting revegetation (water holding capacity, texture, surface bulk density, penetration resistance, organic matter, pH, electrical conductivity) and to assess impacts of ROW zone on cattle utilization and litter biomass accumulation on a pipeline ROW in native rangeland.

3.0 MATERIALS AND METHODS

3.1 History of the Project

In 1986, a long-term project was initiated by NOVA Gas Transmission Ltd. to monitor revegetation of pipeline ROW on native rangelands in southern Alberta. Two natural gas pipeline laterals (Milo and Porcupine Hills) were studied with four sites on each lateral (Figure A.1). The ROWs were 18 m wide, with a 2 m wide trench. Pipeline diameters were 40 cm at Milo and 15 cm at Porcupine Hills. Ditchline stripping conserved topsoil, with the stripped topsoil stockpiled on the work side and the subsoil stockpiled on the spoil side of the ROW.

The ROW was seeded in 1986 at Milo and 1987 at Porcupine Hills, using a rangeland seed drill with 15 cm spacing. Milo sites were seeded at a rate of approximately 8 kg ha^{-1}. High soil moisture and compaction caused poor penetration of the seed drills at two of the Milo sites, consequently, these sites were seeded with two passes of the seed drill. Seeding rate on the Porcupine Hills lateral was not recorded. Both laterals were seeded with grass-dominated mixes (Table 2.1). At each site, 0.25 to 0.90 ha exclosures were constructed after completion of seeding and prior to cattle grazing.

3.2 Site Description for Milo and Porcupine Hills

The Milo lateral (SW 31-18-19-W4M to NE 13-16-17-W4M) is 39 km long and crosses the Dry Mixed Grass and Mixed Grass Ecoregions (Figure A.1). The area is characterized by severe summer and winter temperatures and low precipitation (Table 2.2). Climate data for the years of study are provided in Table 2.3. Sites M1 and M2 soils are predominately Brown Solods with occurrences of Brown Solodized Solonetz

and Solonetzic Brown and Orthic Brown Chernozems. Sites M3 and M4 are predominately Orthic Dark Brown and Solonetzic Dark Brown Chernozems. Parent material is fine to coarse loamy till, moderately to well-drained. Alkaline soils are common, with occurrences of saline soils at M1 and M2. Soil organic matter ranges from 1.7 to 2.8%. Range type is *Stipa-Bouteloua* (needle grass-grama grass) at M1 and M2, *Stipa-Bouteloua-Agropyron* (needle grass-grama grass-wheat grass) at M3 and *Stipa-Agropyron* (needle grass-wheat grass) at M4. All plant names are according to Moss (1994) unless otherwise specified.

The Porcupine Hills lateral (NE 24-18-3 W4M to NE 36-4-1-W5M) is 160 km long and traverses the Aspen Parkland, Fescue Grassland and Montane Ecoregions of southwestern Alberta (Figure A.1). The climate is moderate, with cooler summer temperatures and more summer and winter precipitation than the Mixed and Dry Mixed Grass Ecoregions (Tables 2.2 and 2.3). Orthic Black, Rego Black or Calcareous Black Chernozem soils dominate. Sites are well-drained and located on fine- to medium-textured till or glacio-fluvial deposits. Topsoil depths range from 12 to 30 cm. Topsoil organic carbon ranges from 2.1 to 8.7%. Soil pH varies from slightly acidic to slightly basic. Soils are generally non-saline and non-sodic. Range type varies, being *Festuca-Danthonia* (fescue-oatgrass) at P1 and P4, an invasive *Phleum-Poa* (timothy-blue grass) community at P2 and *Festuca-Agropyron* (fescue-wheat grass) at P3.

Plants for both laterals were visually estimated and summarized (Smith 1986). Complete species lists and detailed site descriptions are available (Naeth et al. 1997) and are summarized in Tables A.1 and A.2.

3.3 Experimental Design

The experimental design was a split-block (Peterson 1994) with levels of ROW (work, trench, spoil, undisturbed) assigned to strips of plots running through the block in one direction. Levels of grazing (grazed, ungrazed) were applied to strips of plots perpendicular to the ROW strips (Figure A.2). The experiment was a 4 x 2 factorial; each experimental unit was subjected to one of four ROW treatments and one of two grazing treatments. Milo and Porcupine Hills data were analyzed separately so there were four blocks (site is equivalent to block) per design, with one treatment replicate in each block.

3.4 Field Measurements

3.4.1 Vegetation Characteristics

In June and August 1998, species composition in each treatment was assessed using one, 30 m long, permanent transect established in 1986/1987. On each transect ten, 0.10 m^2 quadrats at a 3 m spacing were measured for density and % cover. Densities of rhizomatous species was difficult to determine due to vegetative growth form. Each tiller was tugged gently (but not pulled out of the ground) to determine if it was an individual . Cover is the estimated volume each plant contributes to the total volume of vegetation in the quadrat.

Plant biomass within exclosures was determined by clipping current year's growth to 2.5 cm in ten 0.25 m^2 quadrats. Litter, using 0.1 m^2 quadrats, was sampled in the same locations as biomass, after current year's growth was removed. Any dead, partially decomposed or decomposed plant material was considered litter. To sample, litter only had to fall within the sample frame but did not have to be rooted within the frame. Litter was sampled as close to the mineral soil as possible with small hand-held rakes used to separate decomposed litter from mineral soil. All biomass and litter samples were taken on the west side of the transect, at the end of the growing season following peak growth. Samples were oven dried at 65 ^{o}C and weighed to 0.01 grams.

In June 1998, ground cover was assessed visually in ten 0.1 m^2 quadrats per treatment. Ground cover categories were live (excluding little club moss), little club moss (*Selaginella densa* Rydb.), lichen, litter (including manure), bare ground and rock.

3.4.2 Animal Utilization

In May 1998, eight grazing cages were set in grazed treatments in each ROW zone. Due to a limited number of cages, not all sites had grazing cages. Sites M1 and M2 were selected because two seed mixes were used at these sites (see Chapter 4) and P1, P3 and P4 were selected because they were most similar in species composition. Cages at M1 and M2 were approximately 70 cm high with a 0.6 m^2 basal area; those at P1, P3 and P4 were approximately 150 cm high with a 1.3 m^2 basal area. At the end of the grazing season, one 0.25 m^2 sample was clipped inside each cage and two 0.25 m^2 samples per cage were clipped on an adjacent grazed area. Clipping height was 2.5 cm. Animal utilization was calculated as the difference between biomass inside and outside the cage.

3.4.3 Soil Characteristics

In July 1998, three, 5 cm soil cores were taken in each treatment. Cores were divided into 0-5, 5-15, 15-30 cm increments on work and spoil, and 0-5, 5-15, 15-30, 30-45, 45-60 and below 60 cm increments on trench and undisturbed treatments. The three samples were composited and analyzed for pH, electrical conductivity (EC), total carbon, particle size and water holding capacity (McKeague 1978). Electrical conductivity and pH were determined using a 1:2 soil:water ratio. Total carbon was determined by combustion. Particle size was determined by hydrometer method; when necessary, pretreating removed carbonates and organic matter. Pressure chambers determined wilting point (1500 kPa) and field capacity (33 kPa).

Surface bulk density and soil penetration resistance (PR) were measured at ten locations in each treatment. Soil density to a 10 cm depth was measured with a Campbell Pacific Nuclear Soil Moisture/Density Probe, model MC1. PR was measured using a proving ring penetrometer, with a 30° circular cone of 13 mm diameter at the surface, and at 2.5, 5.0, 10, 15, 22.5 and 30 cm depths. PR data were used to determine cone index values (CI, highest PR measurement) for depth increments of 0-5, 5-15 and 15-30 cm.

3.5 Statistical Analyses

Analysis of variance (Tables B.2 and B.3) determined differences between main effects for plant density and cover, community diversity and similarity, ground cover, animal utilization, litter, plant biomass and soil parameters. Plant density and cover categories tested were: total plants, total grass, sedge, native grass, non-native grass, native and non-native rhizomatous grass, native and non-native tufted grass, total forbs, native and non-native forbs, legumes and shrubs (Table D.1). Forbs and shrubs were analyzed using June data and grasses and sedges were analyzed using August data. Most forbs were easily identified and were at peak growth in early June, while the grasses and sedges did not flower till later in the season and were at the peak of their growth in August. If results from ANOVA indicated significant differences ($P < 0.10$) among main effects, Scheffe's test for multiple comparisons determined treatment differences. SAS version 6.12 was used for all statistical analyses.

The Czekanowski coefficient was used to calculate plant community similarity indices (Table B.4). Diversity was calculated using Shannon diversity index (Table B.5). Ten 0.10 m^2 quadrats in each treatment were measured and averaged for number and

abundance of species. Averaged number and abundance values were used to evaluate treatment differences.

4.0 RESULTS AND DISCUSSION

4.1 Effect of Grazing

4.1.1 Species Composition

Grazing had little significant effect on species composition, as measured by density and cover, at Milo and Porcupine Hills (Tables 2.4 and 2.5). Density generally increased with grazing at Milo, but at Porcupine Hills response varied with plant group with no clear trend across groups. Some data warrant further discussion regardless of statistical significance.

The rhizomatous grasses dominating the plant communities at Milo and Porcupine Hills were increasers and/or invaders (Smoliak et al. 1976) but there were no significant differences between grazing treatments on either lateral (Tables 2.4 and 2.5). Native rhizomatous grasses at Milo, dominated by northern (*Agropyron dasystachyum* (Hook.) Scribn.) and western wheat grass (*Agropyron smithii* Rydb.) contributed approximately 45% of plant density and 50% cover on both grazed and ungrazed treatments. At Porcupine Hills, non-native rhizomatous grasses dominated by Kentucky blue grass (*Poa pratensis* L.), an invader, decreased in cover with grazing (35 vs. 31%), likely due to direct utilization.

Competition and grazing favor development of rhizomatous species (Belsky 1992, Coffin et al. 1996, Callaghan et al. 1992, Epp and Aarssen 1989, Grime 1973). However, the lack of significant differences between grazed and ungrazed treatments may be due to equilibrial and/or non-equilibrial forces. Rhizomatous species can have superior colonization ability and as such got a foot-hold in the community regardless of grazing treatment (Tilman 1994). They have maintained their position in the ungrazed plant community because they are competitively superior to other species (Burton et al. 1988). If we follow non-equilibrial theory (Hubbell 1979, Pickett and White 1985) persistence of these species is due to randomness and interaction among species. They resisted displacement and/or took advantage of space vacated by disturbance. Stocking rate and time of grazing can also affect species composition. For the first four years after pipeline construction, animals utilized less than 50% each year and in year 12, animals utilized 41% at Porcupine Hills and 62% at Milo. At Porcupine Hills, three of the sites were fall

grazed; late season grazing favors native tufted grasses, which may help to explain the decrease in Kentucky bluegrass cover with grazing. Rhizomatous species' competitive advantage may not have been realized with rate or timing of grazing. As well, there was a significant interaction between grazing and ROW at Milo for native rhizomatous grass density. These grasses increased significantly with grazing on the trench, but decreased (not significant) on the work (Table 2.5).

Grazing almost doubled the density and cover of tufted grasses at Porcupine Hills, but at Milo it decreased cover and did not affect density (Tables 2.4 and 2.5). At Porcupine Hills animal utilization in grazed areas averaged 41% in year 12 and 46% in each of the first four years (utilization between years 5 and 12 is unknown). Climate is more temperate than at Milo with more precipitation and less severe summer and winter temperatures, so plants recover more quickly from grazing. Grazing removed a potentially detrimental layer of excessive litter. The closed canopy and thick litter layer in the ungrazed treatment would inhibit tufted grasses dependent on seed dispersal to colonize and establish (Grime 1973, 1984). At Milo, dominant native tufted grasses were needle and thread grass (*Stipa comata* Trin.&Rupr.) and western porcupine grass (*Stipa curtiseta* (A.S. Hitchc.) Barkworth) so decreased cover with grazing was expected (Smoliak et al. 1976). Animal utilization in year 12 was 62%. Even when species are tolerant of defoliation, they may be disadvantaged when competing with species that are defoliated less frequently or intensely (Archer and Pyke 1991). These authors suggested mixing of grazing tolerant and grazing avoidance species will inevitably lead to dominance by species that avoid grazing.

At Porcupine Hills grazing was beneficial to all tufted grasses but more beneficial to non-native tufted grasses (Tables 2.4 and 2.5). Grazing increased native tufted grass density by 36% but increased non-native tufted grass density by 117%. Results are similar for tufted cover, with increases of 43% for native and 108% for non-native species. A number of factors could be responsible for this. The dominant non-native tufted grasses, timothy (*Phleum pratense* L.) and sheep fescue (*Festuca ovina* L.), are an invader and increaser, respectively, while the dominant native tufted grasses, foothills rough fescue (*Festuca campestris* Rydb.) and needle grass (*Stipa* sp.) are decreasers (Smoliak et al. 1976). Previous research in the fescue grassland all noted shifts away from rough fescue to less palatable species with an increase in grazing pressure (Moss and Campbell 1947, Looman 1969, Willms et al. 1985, 1986).

At Porcupine Hills, there was a significant interaction between grazing and ROW for non-native grass cover (Table 2.6). Grazing increased non-native grass cover on undisturbed prairie and work treatments but decreased it on the trench and had no effect

on the spoil. The increase on undisturbed and work treatments was expected due to colonization of timothy, Kentucky blue grass and sheep fescue. However, constancy in spoil and decrease in the trench is not easy to explain. Likely, successful native wheat grass (slender (*Agropyron trachycaulum* L.), western and northern) establishment on trench and spoil zones competed with non-native grass establishment.

Grazing significantly increased sedge density at Milo with a significant interaction of grazing and ROW (Table 2.6). This is discussed further in Section 4.2.1. At Milo, there were no significant differences between grazed and ungrazed forb density or cover, but total forb and legume cover increased with grazing (Tables 2.4 and 2.5). At Porcupine Hills, grazing decreased total forb, native forb and legume cover but increased non-native forb and significantly decreased shrub cover (Table 2.5).

4.1.2 Plant Community Composition

Plant community composition, as measured by similarity, diversity and evenness, was not significantly affected by grazing at either site (Table 2.7). This supports work done by Gibson and Brown (1991) who found season and amount of grazing had little impact on species diversity. Samuel and Hart (1994) reported little difference in diversity between moderately grazed and ungrazed areas 10 to 20 years after disturbance in the Wyoming High Plains. At Milo, diversity and evenness were highest on grazed treatments; at Porcupine Hills ungrazed treatments had higher diversity than grazed, but when taking into account evenness, grazed treatments were more diverse. Moderate grazing can increase community diversity but heavy grazing can decrease it (Belsky 1992, Green and Kaufmann 1995, Puerto et al. 1990, Willms et al. 1985).

4.1.3 Ground Cover

Grazing significantly increased bare ground and decreased litter at both Milo and Porcupine Hills (Table 2.8). At Milo, grazed treatments had 17% bare ground 12 years after reclamation. Government of Alberta wellsite criteria indicate more than 20% bare ground is not suitable for reclamation certification (Alberta Environment 1995). Although pipelines are not covered under these criteria, use of 20% bare ground as an acceptable reclamation standard is widespread. While 17% meets the standard, bare ground could easily increase under drought.

Grazing had no significant effect on live ground cover at Milo, but was significant at Porcupine Hills. Willms et al. (1986) found litter removal caused a decrease in

herbage production in Mixed Prairie and an increase in Fescue Prairie. They attributed the decrease in Mixed Prairie was attributed to loss of soil moisture. Removing the insulating litter layer in xeric sites leads to moisture deficits since infiltration is reduced and roots are near the soil surface (Naeth 1988, Willms et al. 1986). Litter accumulation benefited plant growth during establishment by providing a protective layer to the soil but by year 12 it may have been detrimental as evidenced by higher live cover in the grazed treatment.

Increase of live ground cover in the Porcupine Hills supports previous work where litter accumulation inhibited tillering of grasses in Fescue Prairie (Willms et al. 1986). Litter build up in ungrazed treatments by year 11 was approximately 8500 kg ha^{-1} and responsible for 95% ground cover. This thick thatch would be detrimental to plant growth (Holochek 1998) and inhibitseedling establishment (Belsky 1992, Gross 1984). Interpreting Porcupine Hills results is complex due to significant interactions between main effects (Table 2.6). Grazing significantly decreased litter and increased live cover on the trench but not on other zones.

Grazing increased club moss in undisturbed prairie, but caused a sharp decline in the work treatment (Table 2.6). In areas of low precipitation little club moss may inhibit growth of larger species by absorbing rainfall, but it also protects the soil from wind and/or rain erosion. Grazing tends to increase its cover, but the ungrazed work treatment had over 11% cover by year 12, compared to less than 2% for the grazed work. Because the work zone was not cleared of vegetation (only driven on), club moss may not have died and protecting it from grazing allowed it to recover.

4.1.4 Soil Properties

Grazing did not significantly affect soil carbon, pH or texture (predominantly loam to clay loam) (Table C.1). Grazing had some statistical, but little ecological, effect on soil EC and available water at Milo and Porcupine Hills. For example, at Porcupine Hills, grazing significantly increased EC by 0.03 mS cm^{-1} and similarly, at Milo grazing significantly increased available water in the top 5 cm by 1.6% but neither of these increases are considered ecologically significant (Table C.1).

Grazing significantly increased soil surface bulk density at Milo and Porcupine Hills (Table 2.9) but the increase would not influence plant development since the highest density recorded (1.11 Mg m^{-3}) was well below what is considered inhibitory to plant growth and hydrologic processes (Naeth et al. 1991b). As well, grazing led to a significant increase in CI at both Milo and Porcupine Hills (Table 2.9). Cone index of

both grazed and ungrazed treatments at Milo and grazed at Porcupine Hills were above 2.0 MPa, which be can inhibitory to root development but are very dependent on soil bulk density and soil moisture (Thompson et al. 1987, Lowery and Schuler 1994). Soil moisture in the top 10 cm, was low at Milo (14%) and high at Porcupine Hills (36%) (data not shown). The high surface bulk density and CI values agree with previous work done by Naeth et al. (1990). Cone index at Porcupine Hills also showed a significant interaction between grazing and ROW in the 0-5 cm depth interval. The ungrazed trench had the second lowest CI value while the grazed trench had the highest (Table 2.6). Cattle use in 1998 was not significantly different among ROW treatments, however this interaction would indicate cattle utilize the trench preferentially or the trench is more susceptible to compaction, since work and spoil zones did not have large differences if grazed or ungrazed.

4.2 Effect of Right-of-Way

4.2.1 Species Composition

Right-of-way treatments significantly affected plant species composition, as measured by density and cover (Tables 2.10 and 2.11). Cover was generally higher on disturbed areas compared to undisturbed. While there were changes to sedges, forbs and shrubs, the most significant ecological changes occurred in the grass community.

Disturbance at Milo favored rhizomatous grasses. The trench had almost twice as many rhizomatous grasses (native and non-native) as undisturbed prairie (Table 2.10). Rhizomatous species on the trench (northern and western wheat grass at Milo and Kentucky bluegrass at Porcupine Hills) may have established early. A long-term study of secondary succession in the Wyoming High Plains indicates species that establish first, may be the ones to persist (Samuel and Hart 1994). Species vegetatively reproducing, can colonize available space more rapidly and effectively than sexually reproducing species (O'Connor 1991, Prach and Pysek 1994). Rhizomatous species may persist in areas unfavorable to tufted species (i.e., seed producing), since the ramet can fill gaps in closed vegetation cover (Grime 1979). Clonal species also dominate longer than non-clonal species (Prach and Pysek 1994). High rhizomatous grass cover on the trench could also be a result of grazing. There were no significant differences in animal utilization of the ROW, but the trench appeared to be utilized more than other zones (see Section 4.2.5). The dominant rhizomatous species on the trench were all increasers. At Milo, there was a significant interaction between grazing and ROW treatment for native rhizomatous

grass density (Table 2.6, see Section 4.1.1).

Native tufted grass density on undisturbed prairie was significantly higher than on the trench at Milo and on trench and work zones at Porcupine Hills (Table 2.10). Milo also had significant differences among treatments for native tufted cover, with undisturbed having the highest, trench the lowest. Grass covers at Porcupine Hills were not significantly influenced by ROW but followed a trend similar to Milo. There was significant interaction between grazing and ROW for cover of native tufted grasses (Table 2.6, see Section 4.1.1).

Many tufted grasses in the disturbed zones were not present in the seed mix nor would they have been a major component of the seed bank. Correlation of existing mid- to late-succesional vegetation to seed bank is generally poor (D'Angela et al. 1988, Grandin 1998, Levassor et al. 1990). Tufted species would have to rely on seed rain to establish. Seed set in many of Alberta's native species does not occur annually (Tannas n.d.). Belsky (1992) concluded rhizomatous species were replacing caespitose species. The caespitose species were not replacing themselves because their seeds did not germinate and their seedlings did not survive due to competition from other plants.

Sedge density and cover were significantly influenced by ROW at Milo (Tables 2.10 and 2.11). The work zone had highest density and cover, the trench the lowest. It appears while sedges are tolerant of mild to moderate disturbance, they are not tolerant to severe or intense disturbance. It also appears that viable seed does not persist in the seed bank because after 12 years, few were growing on the trench. Sedges were present on the spoil zone but not as dense as on undisturbed prairie, possibly due to scalping at sites M1 and M2 during pipeline construction. There was a significant interaction between grazing and ROW treatments for sedge density (Table 2.6). Grazed work zones had the highest bulk density and highest sedge values. Sedges at M1 and M2 were the dominant species growing in vehicle wheel tracks or under mild to moderate disturbance. Thus, sedges could be better competitors than other species in high density soils.

At Milo and Porcupine Hills, forb density was highest on the spoil zone. Cover of native forbs was highest on the spoil and undisturbed zones and non-native forbs were highest on the spoil and trench zones. Trends in legumes and shrubs at Milo and Porcupine Hills were difficult to determine due to high variability among sites (Tables 2.10 and 2.11).

4.2.2 Plant Community Composition

Right-of-way significantly affected plant community composition, as measured by similarity and diversity at Milo and Porcupine Hills (Table 2.12). Eleven to twelve years after revegetation, disturbed zones were still significantly dissimilar to undisturbed. The trench was most dissimilar to undisturbed prairie on both laterals. At Milo and Porcupine Hills, work and spoil zones had the highest diversity, undisturbed and trench zones had the lowest. These results support other research. Both Grime (1973) and Connell (1978) proposed intermediate levels and/or rates of disturbance produce maximum diversity. Field studies found highest diversity occurred three years after disturbance then declined to year six, which was the end of the study (Gibson and Brown 1991). Right-of-way did not affect evenness on either lateral (Table 2.12).

4.2.3 Ground Cover

Right-of-way significantly impacted ground cover at Milo and Porcupine Hills (Table 2.13). Bare ground was not significantly affected at Milo, but was at Porcupine Hills. At Milo, ecologically there was a difference between spoil bare ground at 17.0% and undisturbed at 3.2%, especially given the harsh climate and susceptibility of soils to wind erosion in the Dry Mixed and Mixed Grass Ecoregions. Bare ground on spoil could exceed the 20% standard for reclamation (Alberta Environment 1995) given adverse grazing or environmental conditions. Conversely, Porcupine Hills had significant differences (4.9 vs. 0.1%) in bare ground that were not ecologically significant. There was a significant interaction of main effects at Porcupine Hills; the grazed trench treatment had 9.9% bare ground compared to 0.0% in the ungrazed trench (Table 2.6, see discussion in Section 4.1.3). While the interaction should not be ignored, these two treatments would not have to be managed differently to protect the soil surface.

At Milo live cover was significantly lower on disturbed ROW versus adjacent undisturbed prairie whereas at Porcupine Hills, there were no differences among ROW zones (Table 2.13). Higher live cover on undisturbed prairie at Milo can be attributed to native tufted grass. Litter was significantly lower on undisturbed than disturbed zones at Milo. At Porcupine Hills, statistically there was a significant difference in litter among the ROW zones, but ecologically, differences were not significant.

Little club moss at Milo was heavily impacted by ROW zone (Table 2.13) with a significant interaction between main effects (Table 2.6). See discussion in Section 4.1.3.

4.2.4 Productivity

Right-of-way significantly affected litter and live biomass at Milo but not at Porcupine Hills (Table 2.14). At Milo, ungrazed litter biomass was significantly higher on trench than work zones. Ungrazed live biomass was high with significant differences between trench, work and undisturbed zones. This high biomass is partially due to growth of slender wheat grass and alfalfa. Because of the large amount of litter in the exclosures, it is possible litter and live components were not completely separated. Ungrazed live biomass was higher than grazed at both Milo and Porcupine Hills.

While there have been numerous studies to indicate grazing increases production (Cook and Stoddart 1953, Puerto et al. 1990, Wikeem and Pitt 1991, Willms et al. 1986), overgrazing can also decrease production (Crider 1955). Not grazing can increase snow and litter accumulation providing more moisture and a protective insulating layer, thus improving conditions for plant growth. Higher production in ungrazed treatments at Milo is likely due to increased moisture retention versus overgrazing.

4.2.5 Animal Utilization

Right-of-way did not significantly affect animal use at either Milo or Porcupine Hills (Table 2.14). At Milo utilization on the trench and work zones was similar (68%) and spoil and undisturbed zones were similar (55%). In October, P3 had not been grazed so animal use was not determined for that site. For the other Porcupine Hills sites, use was highest on trench and lowest on spoil zones. Differences among treatments may not be expressed due to experimental design limitations of having only two replicates on each lateral. As well, we used caged and uncaged subplots. Unless subplot size can accommodate local heterogeneity, measurements may be inaccurate (Bork and Werner 1999). Bork and Werner recommended above-ground net primary production be used when focusing on the herbivore and relative utilization be used if the focus is on the plant community. While the there were no significant differences in animal use among ROW zones, CI indicates cattle preferentially graze the trench.

4.2.6 Soil Properties

ROW had some statistical, but little ecological, effect on soil characteristics at Milo or Porcupine Hills (Table C.2). For example, undisturbed prairie at Milo had significantly lower pH than the trench. There were significant differences in EC at both

Milo and Porcupine Hills. Soil carbon at Porcupine Hills was significantly lower on trench and spoil zones compared to undisturbed prairie. Similarly, the amount of sand, silt and clay were affected by ROW treatment at Milo, but it did not equate to a difference in textural class. All treatments, for all depths were loam to clay loam texture. For most species these differences would not be ecologically significant (Carter 1993). However, at Milo ROW influenced soil carbon and available water in the top 5 cm. Soil carbon was 2% less in the trench compared to undisturbed prairie. While a difference in soil carbon between 4.67 and 2.66% may not seem significant, it could lead to the lower available water measured in the trench compared to the undisturbed prairie in the top 5 cm of soil. Available water in the trench was 4% less than in undisturbed prairie. Where moisture is not limiting, this difference would not be ecologically significant, but in the Dry Mixed Grass and areas of the Mixed Grass Ecoregions, 4% could be significant.

Surface bulk densities were higher on the disturbed areas of the ROW, supporting work by Naeth (1985), but the increase would not be detrimental to plant growth (Table 2.15). ROW had a significant impact on CI at Milo and Porcupine Hills (Table 2.15). Milo and Porcupine Hills work zones had high values of 3.25 and 2.57 MPa, respectively. In the Porcupine Hills, there was significant interaction between grazing and ROW in the 0-5 cm depth (see discussion in Section 4.1.4). At Milo, CI in the work zone would have been detrimental to root growth. Since dominant grasses at Milo reproduced vegetatively, a reduction in plant density could be expected but the work zone did not have a significantly lower number of rhizomatous grasses. The work zone had a significantly higher density of sedges, which were also rhizomatous.

5.0 CONCLUSIONS

- Grazing had little effect on plant species composition. Density generally increased with grazing at Milo, but at Porcupine Hills response varied with plant group. Generalizations for grazing management over different ecoregions may not be appropriate. For example, not grazing at Porcupine Hills decreased tufted grass growth while at Milo it increased it.
- Right-of-way zone significantly affected plant species composition. Affected species did not respond similarly between Milo and Porcupine Hills. Plant densities decreased as level of right-of-way disturbance increased, whereas cover was generally higher on disturbed versus undisturbed areas. The more intense the disturbance, the higher the rhizomatous grasses, the fewer tufted grasses.
- Plant community composition was not significantly affected by grazing but was

affected by right-of-way. Eleven to twelve years after revegetation, disturbed zones were significantly dissimilar to undisturbed adjacent prairie. Intermediate levels of disturbance (work and spoil) had the highest diversity.

- Grazing and right-of-way zone significantly impacted ground cover by increasing bare ground and decreasing litter. Reducing litter at Porcupine Hills may be beneficial considering biomass produced and potential fire hazard. At Milo biomass was lower and fuel build up is not an issue. In fact, litter at Milo protects soil against wind and water erosion. Grazed areas at Milo had almost 20% bare ground 12 years after construction so a potential for soil erosion exists with reduced plant cover.
- Grazing and right-of-way zone had some statistical, but little ecological, effect on measured soil characteristics. In some circumstances, grazing and right-of-way treatment had high enough CI values to potentially inhibit root development. While there was no significant differences in the density of rhizomatous species, a high CI could affect spread of rhizomes.
- Right-of-way significantly affected litter and live biomass at Milo.
- Right-of-way did not significantly affect relative animal utilization of herbage at either Milo or Porcupine Hills.

Table 2.1. Milo and Porcupine Hills seed mixes.

Species	Common Name	Variety	% by Weight
Milo			
Agropyron smithii	Western wheat grass	Walsh	25
Agropyron dasystachyum	Northern wheat grass	Elbee	25
Agropyron trachycaulum	Slender wheat grass	Revenue	17
Poa compressa	Canada bluegrass	Ruebens	8
Puccinellia nuttalliana	Alkali grass	Nuttall's	25
Porcupine Hills			
Poa compressa	Canada bluegrass	Ruebens	2
Festuca ovina duriuscula	Hard fescue	Durar	3
Festuca campestris	Rough fescue	Common	14
Festuca ovina	Sheep fescue	Covar	3
Koeleria macrantha	June grass	Common	3
Agropyron dasystachyum	Northern wheat grass	Elbee	15
Agropyron trachycaulum	Slender wheat grass	Revenue	10
Agropyron riparian	Streambank wheat grass	Sodar	45
Medicago sativa	Alfalfa	Rangelander	5

Table 2.2. Thirty year average climate data for Milo and Porcupine Hills (Environment Canada 1994).

Climate Data	Milo[1]	Porcupine Hills[2]	
		Turner Valley	Pincher Creek
Annual air temperature (°C)	4.5	2.3	4.6
Average summer temperature[3] (°C)	15.9	12.1	14.0
Hottest months – July (°C)	18.4	14.3	16.7
– August (°C)	17.6	14.2	16.2
Coldest month – January (°C)	-11.5	-11.8	-9.0
Annual precipitation (mm)	338	573	552
Wettest months – May (mm)	39.5	71.2	68.7
– June (mm)	62.5	111.3	87.6
Winter precipitation[4] (mm)	53.6	91.8	123.4
Spring precipitation[5] (mm)	85.8	169.4	163.9
Fall precipitation[6] (mm)	54.0	85.1	81.0

[1] Milo is averaged data from Vauxhaul and Brooks weather stations.
[2] Turner Valley weather station is closest to north site; Pincher Creek is close to most southerly site.
[3] Summer is June, July and August, inclusive.
[4] Winter is November, December, January and February, inclusive.
[5] Spring is March, April and May, inclusive.
[6] Fall is September and October.

Table 2.3. Climate data for Milo (1986 to 1998) and Porcupine Hills (1987 to 1998) (Environment Canada 1994, 2001).

	Temperature (°C)						Precipitation (mm)						
Year	Annual	Summer[1]	July	August	Winter	January	Annual	Spring	Summer	Fall	Winter	May	June
Milo[2]													
30 year average	**4.5**	**15.9**	**18.4**	**17.6**	**-6.2**	**-11.5**	**338**	**85.8**	**144.6**	**54.0**	**53.6**	**39.5**	**62.5**
1986	6.2	17.5	16.5	18.4	-4.5	-0.3	492	98.8	151.4	191.0	50.9	70.4	66.8
1987	I[3]	16.3	17.4	13.9	-0.3	I	I	I	122.8	5.8	32.6	I	39.6
1988	I	17.7	17.9	17.1	-5.7	-9.6	243	10.4	190.2	12.4	30.0	7.0	150.4
1989	4.5	17.3	18.9	16.4	-7.1	-8.6	I	71.8	I	30.5	69.0	40.8	59.4
1990	5.3	17.3	17.8	18.8	-6.5	-4.8	339	142.4	59.0	17.0	91.0	76.4	25.4
1991	I	17.2	17.5	19.5	-3.6	-10.3	I	I	149.8	21.1	36.2	I	93.0
1992	6.0	15.9	15.7	15.7	-4.0	-0.6	312	52.8	162.3	66.4	30.6	32.6	73.7
1993	4.4	14.7	14.7	15.2	-7.4	-13.8	335	60.2	161.4	69.4	43.8	19.6	63.6
1994	4.8	16.9	18.6	17.6	-8.7	-11.9	I	I	103.4	66.0	55.0	62.8	82.0
1995	3.5	15.7	17.0	15.2	-8.5	-10.4	325	96.7	123.2	44.4	61.0	50.4	25.8
1996	2.7	17.8	18.4	18.8	-11.9	-16.8	207	49.4	36.6	54.4	66.4	19.6	20.4
1997	5.3	17.2	17.7	18.0	-5.3	-15.5	236	74.6	122.0	17.0	22.0	48.2	51.2
1998	5.7	17.9	19.8	19.5	-6.0	-13.8	370	134.4	175.6	16.0	44.0	44.8	123.2
Porcupine Hills[4]													
30 year average	**3.5**	**13.0**	**15.5**	**15.2**	**-4.3**	**-10.4**	**563**	**166.5**	**205.8**	**83.1**	**107.6**	**70.0**	**99.5**
1987	6.3	14.2	15.0	12.4	-0.9	-2.5	457	89.2	257.5	43.9	66.1	9.9	44.4
1988	5.5	15.5	16.1	15.2	-4.1	-7.7	363	98.3	153.2	44.8	66.9	37.9	51.0
1989	3.9	14.9	16.6	14.6	-5.4	-5.9	577	152.2	189.8	74.9	159.9	60.1	52.7
1990	4.4	14.6	15.4	15.8	-5.5	-3.6	644	216.7	197.9	55.1	174.0	120.9	37.2
1991	4.9	14.6	15.4	16.9	-2.3	-9.2	541	143.8	214.3	89.6	93.2	83.2	159.5
1992	5.2	13.5	13.3	13.5	-3.0	-0.1	688	100.0	383.8	89.8	114.6	45.2	205.7
1993	4.0	12.1	11.8	12.8	-5.3	-10.1	729	159.4	364.7	93.4	111.2	62.4	129.5
1994	4.7	15.3	16.9	15.8	-6.3	-5.7	459	127.0	154.9	50.1	127.1	83.7	59.6
1995	3.8	13.4	14.8	13.2	-4.8	-5.1	750	244.8	285.7	96.9	122.8	149.1	132.1
1996	2.2	15.0	15.7	16.4	-9.4	-13.0	658	221.9	107.1	98.8	230.4	141.1	75.3
1997	4.7	14.5	15.2	15.4	-3.4	-9.8	514	190.6	162.7	88.6	75.1	121.0	86.6
1998	5.1	15.4	17.5	17.1	-4.7	-9.9	678	285.9	223.5	40.7	127.6	162.4	156.1

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[1] Summer is June, July and August; fall is September and October; winter is November, December, January and February; Spring is March, April and May.

[2] Milo lateral 30 year average data collected from Vauxhall and Brooks; yearly data from Vauxhall

[3] I = incomplete data set due to missing values.

[4] Porcupine Hills 30 year average data collected from Turner Valley and Pincher Creek; yearly data collected from High River and Connelly Creek.

Table 2.4. Plant density (plants per 0.1 m^2) for grazing treatments at Milo and Porcupine Hills in 1998.

Variable		Milo			Porcupine Hills		
		Grazed	Ungrazed	P ≥ F	Grazed	Ungrazed	P ≥ F
Total Plants	Mean	23.8 a[1]	18.6 b	0.0106	26.8	30.0	0.4201
	SD	4.3	5.2		8.5	6.1	
Total Grass		12.9	10.7	0.1671	19.7	20.0	0.9172
		3.5	3.1		8.3	6.1	
Sedge[2,3]		7.6 a	5.8 b	0.0903			
		5.8	4.5				
Native Grass		12.9	10.7	0.1556	3.9	2.2	0.2837
		3.5	3.1		3.2	1.9	
Non-native Grass[2]					14.9	17.3	0.4900
					7.3	7.5	
Native Rhizomatous Grass		10.0	8.0	0.2638	2.4	1.2	0.3382
		4.5	2.6		2.8	1.1	
Non-native Rhizomatous Grass[2]					12.8	16.5	0.3402
					8.1	8.3	
Native Tufted Grass		2.8	2.6	0.6050	1.5	1.1	0.1064
		1.7	1.4		1.3	1.1	
Non-native Tufted Grass[2]					2.6 a	1.2 b	0.0941
					2.4	1.6	
Total Forb		4.7	2.7	0.3540	8.2	7.8	0.8554
		3.5	2.4		5.9	3.7	
Total Legume		0.5	0.3	0.6111	1.0	0.6	0.5073
		1.0	0.4		2.1	0.7	
Shrub		0.2	0.0	0.5443	0.3	0.6	0.1289
		0.5	0.2		0.6	0.6	
Native Forb		4.4	1.9	0.1980	5.9	7.0	0.5969
		3.1	1.4		5.2	4.0	
Non-native Forb		0.3	0.3	0.7511	2.3	0.8	0.1681
		0.6	0.5		2.4	0.7	

[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[2] Sedges at Porcupine Hills and non-native grasses at Milo were either not present or too few to include in analysis.

[3] Shading of a variable indicates a significant interaction between grazing and ROW zone ($P < 0.10$).

Table 2.5. Plant cover (%) for grazing treatments at Milo and Porcupine Hills in 1998.

			Milo			Porcupine Hills	
Variable		Grazed	Ungrazed	$P \geq F$	Grazed	Ungrazed	$P \geq F$
Total Grass	Mean	75.1	81.1	0.5072	75.6 a[1]	58.3 b	0.0205
	SD	13.4	15.4		15.8	12.3	
Sedge[2]		7.5	6.2	0.3350			
		7.1	6.6				
Native Grass		75.1	80.1	0.5595	22.2	13.5	0.2080
		13.4	14.8		18.4	14.7	
Non-native Grass[2, 3]					51.0 a	44.6	0.0307
					18.1	21.2	
Native Rhizomatous Grass		51.7	46.9	0.4108	7.0	2.9	0.2869
		19.7	17.7		8.5	3.0	
Non-native Rhizomatous Grass[2]					31.4	35.3	0.2198
					17.7	20.4	
Native Tufted Grass		23.4 b	33.2 a	0.0648	15.2	10.6	0.1556
		13.0	18.1		13.0	12.4	
Non-native Tufted Grass[2]					19.6 a	9.4 b	0.0765
					16.0	9.5	
Total Forb		18.3	12.0	0.4782	20.2	25.7	0.3469
		14.9	12.1		13.2	11.7	
Total Legume		5.5	4.1	0.7767	1.6	2.0	0.5588
		13.4	9.3		2.5	2.9	
Shrub		1.8	2.0	0.9103	2.8 b	8.7 a	0.0480
		0.5	0.2		5.6	10.1	
Native Forb		13.4	7.8	0.2970	13.1	21.4	0.1830
		8.8	9.2		11.2	12.1	
Non-native Forb		4.8	3.8	0.7920	7.1	4.3	0.5262
		12.3	9.1		5.5	6.3	

[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[2] Sedges at Porcupine Hills and non-native grasses at Milo were either not present or too few to include in analysis.

[3] Shading of a variable indicates a significant interaction between grazing and ROW zone ($P < 0.10$).

Table 2.6. Measured variables that showed significant grazing by ROW interaction at Milo and Porcupine Hills in 1998.

		Grazed				Ungrazed				
Variable		Spoil	Trench	Work	Undisturbed	Spoil	Trench	Work	Undisturbed	P ≥ F
Milo										
Native Rhizomatous	Mean	9.5 ab	15.8 a	7.1 b	7.8 b	6.9 b	10.2 ab	8.1 b	7.0 b	0.0127
Grass Density	SD	2.0	3.6	3.4	2.9	2.7	2.2	1.5	3.3	
Native Tufted		22.1 b	12.5 c	25.0 b	33.9 ab	27.4 b	21.3 b	32.0 b	52.2 a	0.0222
Cover		8.7	6.6	15.1	13.8	17.3	6.7	16.8	17.4	
Sedge Density		6.3 b	0.2 c	12.2 a	11.7 a	6.9 b	0.1 c	9.5 ab	6.5 b	0.0386
		4.3	0.3	2.6	4.3	2.8	0.2	2.3	5.0	
Club Moss Ground		3.6 bc	0.0 c	1.8 c	44.8 a	1.3 c	0.0 c	10.7 b	37.5 a	0.0435
Cover		6.1	0.1	2.3	27.4	2.4	0.0	8.1	30.8	
Porcupine Hills										
Non-native Grass		44.7 a	49.1 a	58.4 a	51.8 a	44.9 a	58.5 a	47.8 a	27.6 b	0.0487
Cover		11.8	9.2	27.7	22.7	19.6	20.3	20.6	19.0	
Live Ground		7.7 ab	11.0 a	7.7 b	9.5 ab	4.2 b	3.8 b	4.4 b	7.5 b	0.0816
Cover		2.2	4.5	1.9	1.5	0.7	0.9	1.1	3.1	
Litter Ground		89.7 a	79.0 b	87.4 a	90.4 a	95.3 a	96.2 a	94.9 a	92.6 a	0.0043
Cover		5.1	5.3	5.0	1.5	0.6	0.9	0.9	3.1	
Bare Ground		2.5 b	9.9 a	4.9 ab	0.2 b	0.4 b	0.0 b	0.7 b	0.0 b	0.0536
		4.9	6.9	5.0	0.2	0.8	0.0	1.4	0.0	
Cone Index		2.30 a	2.36 a	1.87 ab	1.74 ab	1.38 ab	1.25 b	1.46 ab	1.19 b	0.0261
		1.02	0.87	0.72	0.50	0.76	0.45	0.28	0.10	

Table 2.7. Similarity, diversity and evenness for grazing treatments at Milo and Porcupine Hills in 1998.

Variable		Milo Grazed	Milo Ungrazed	Milo P ≥ F	Porcupine Hills Grazed	Porcupine Hills Ungrazed	Porcupine Hills P ≥ F
Similarity[1]	Mean	0.64	0.62	0.7770	0.53	0.55	0.6350
	SD	0.29	0.32		0.32	0.31	
Diversity		2.11	1.82	0.2855	2.07	2.11	0.8270
		0.35	0.28		0.39	0.60	
Evenness		0.77	0.69	0.3201	0.73	0.70	0.2740
		0.07	0.10		0.09	0.15	

[1] Disturbed zones (spoil, trench, work) were combined and compared to undisturbed prairie; the closer to 1.0 the more similar to undisturbed.

Table 2.8. Ground cover (%) for grazing treatments at Milo and Porcupine Hills in 1998.

Variable		Milo Grazed	Milo Ungrazed	Milo P ≥ F	Porcupine Hills Grazed	Porcupine Hills Ungrazed	Porcupine Hills P ≥ F
Live[1]	Mean	22.8	20.6	0.4663	9.0 a[2]	5.0 b	0.0418
	SD	24.3	22.7		2.9	2.2	
Litter		59.8 b	75.4 a	0.0448	86.6 b	94.8 a	0.0239
		21.9	22.3		6.2	2.1	
Bare ground		17.4 a	3.9 b	0.0246	4.3 a	0.3 b	0.0963
		14.1	5.2		5.7	0.8	
Club Moss[3]		12.6	12.4	0.9139			
		23.0	21.2				

[1] Shading of a variable indicates a significant interaction between grazing and ROW zone ($P < 0.10$).

[2] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[3] There was no club moss (*Selaginella densa*) in the Porcupine Hills.

Table 2.9. Surface bulk density (Mg m^{-3}) and cone index (MPa) for grazing treatments at Milo and Porcupine Hills in 1998.

Variable		Milo			Porcupine Hills		
		Grazed	Ungrazed	P ≥ F	Grazed	Ungrazed	P ≥ F
Bulk Density	Mean	1.11 a[1]	1.02 b	0.0972	0.89	0.78	0.0083
	SD	0.11	0.09		0.13	0.09	
Cone Index (0-5 cm)[2]		2.69 a	2.35 b	0.0691	2.07 a	1.32 b	0.0312
		0.62	0.61		0.77	0.43	
Cone Index (5-15 cm)		2.69	2.74	0.6002	2.08 a	1.69 b	0.0078
		0.61	0.58		0.64	0.66	
Cone Index (15-30 cm)		2.67	2.74	0.5319	2.42	2.25	0.3490
		0.35	0.43		0.56	0.59	

[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[2] Shading of a variable indicates significant interaction between main effects of grazing and ROW zone ($P < 0.10$).

Table 2.10. Plant density (plants per 0.1 m^2) for ROW treatments at Milo and Porcupine Hills in 1998.

		Milo					Porcupine Hills				
Variable		Spoil	Trench	Work	Undisturbed	$P \geq F$	Spoil	Trench	Work	Undisturbed	$P \geq F$
Total Plants	Mean	20.8 b[1]	16.3 c	24.9 a	22.8 ab	0.0196	31.5	26.3	30.6	24.9	0.3151
	SD	4.4	4.7	3.1	5.6		6.9	7.3	4.4	9.4	
Total Grass		10.6 b	14.2 a	10.6 b	11.6 b	0.0042	21.8	20.3	22.1	15.1	0.3405
		3.0	4.2	2.0	3.1		7.6	3.7	5.8	9.3	
Sedge[2, 3]		6.6 b	0.2 c	10.9 a	9.1 ab	0.0007					
		3.4	0.3	2.7	5.1						
Native Grass		10.6 b	14.2 a	10.6 b	11.6 ab	0.0046	3.2	1.9	3.4	3.9	0.4222
		3.1	4.3	2.0	3.1		2.7	2.8	3.2	2.6	
Non-native Grass[2]							18.3	18.0	18.8	11.1	0.2375
							7.8	3.6	6.0	8.4	
Native Rhizomatous Grass		8.2 b	13.0 a	7.6 b	7.4 b	0.0005	1.8	1.3	2.3	1.8	0.7531
		2.6	4.1	2.4	2.9		2.1	2.3	2.7	1.7	
Non-native Rhizomatous[2] Grass[2]							16.4	16.4	16.6	9.2	0.2973
							9.6	3.6	8.1	9.4	
Native Tufted Grass		2.4 ab	1.2 b	3.0 ab	4.2 a	0.0004	3.1 ab	1.0 b	2.1 b	4.1 a	0.0621
		0.9	0.5	1.5	1.5		3.1	0.9	2.2	3.4	
Non-native Tufted Grass[2]							1.4	0.7	1.2	2.2	0.7977
							1.4	0.6	0.7	1.4	
Total Forb		4.5	3.5	3.2	3.6	0.5017	9.9	5.9	6.8	9.5	0.3522
		2.6	4.2	2.9	3.0		5.0	4.8	5.5	3.4	
Total Legume		0.7	0.6	0.3	0.1	0.2817	0.8	1.3	0.7	0.4	0.6757
		0.7	1.3	0.3	0.3		1.0	2.8	0.4	1.1	
Shrub		0.2	0.0	0.2	0.1	0.2670	0.7	0.1	0.4	0.5	0.2754
		0.4	0.1	0.5	0.2		0.8	0.1	0.6	0.6	
Native Forb		4.0 a	2.1 b	3.0 ab	3.4 ab	0.0668	8.1	3.4	5.3	9.0	0.1073
		2.2	2.7	2.8	3.1		4.2	4.1	4.9	3.4	
Non-native Forb		0.5	0.5	0.1	0.1	0.1274	1.8	2.5	1.5	0.4	0.1382
		0.6	0.9	0.2	0.1		1.6	2.9	1.7	0.3	

[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[2] Sedges at Porcupine Hills and non-native grasses at Milo were either not present or too few to include in analysis.

[3] Shading of a variable indicates significant interaction between main effects of grazing and ROW zone ($P < 0.10$).

Table 2.11. Plant cover (%) for ROW treatments at Milo and Porcupine Hills in 1998.

Variable		Milo					Porcupine Hills				
		Spoil	Trench	Work	Undisturbed	$P \geq F$	Spoil	Trench	Work	Undisturbed	$P \geq F$
Total Grass	Mean	68.8 b[1]	85.2 a	74.9 ab	83.5 a	0.0496	61.6	69.0	70.4	66.9	0.1057
	SD	19.0	14.2	8.6	8.9		11.3	19.1	19.9	16.0	
Sedge[2]		8.4 ab	0.3 b	11.4 a	7.4 ab	0.0037					
		7.5	0.4	6.0	6.0						
Native Grass		68.0 b	84.0 a	74.9 ab	83.5 a	0.0422	14.6	12.8	17.3	26.0	0.2720
		18.7	13.2	8.6	9.0		13.8	19.8	17.8	15.6	
Non-native Grass[2, 3]							44.7	53.8	53.1	39.7	0.2320
							15.0	15.5	23.3	23.4	
Native Rhizomatous Grass		43.2 b	67.1 a	46.4 b	40.5 b	0.0053	3.5	5.0	6.7	4.4	0.5334
		18.5	9.5	18.6	15.7		3.6	8.1	9.8	3.7	
Non-native Rhizomatous Grass[2]							32.2	39.7	36.7	24.9	0.3973
							16.8	16.0	18.7	23.4	
Native Tufted Grass		24.7 a	16.9 c	28.5 b	43.0 a	0.0140	11.2	7.8	10.6	22.2	0.1344
		13.0	7.7	15.3	17.5		12.0	11.8	10.5	13.6	
Non-native Tufted Grass[2]							12.5	14.1	16.4	14.8	0.8688
							11.2	11.3	18.6	16.0	
Total Forb		27.4 a	11.4 b	19.7 b	12.1 b	0.0301	27.9	18.5	18.5	27.0	0.2728
		16.0	13.1	8.2	10.3		13.9	12.1	14.1	8.3	
Total Legume		13.3	4.6	1.0	0.3	0.1632	2.4	1.4	1.9	1.5	0.8794
		18.3	10.4	0.7	1.2		3.6	2.5	2.6	2.0	
Shrub		1.3	0.5	3.8	2.0	0.1149	10.0	0.7	4.4	7.2	0.2015
		2.5	1.4	5.2	3.5		11.3	1.4	6.7	9.6	
Native Forb		14.7	7.0	9.4	11.4	0.2016	22.1 a	9.1 b	13.5 ab	24.4 a	0.0421
		6.6	7.4	8.0	10.2		13.5	9.1	11.9	9.0	
Non-nativeForb		12.7	3.7	0.3	0.6	0.1485	5.8	9.3	5.0	2.6	0.1125
		17.6	8.7	0.4	1.2		3.4	8.5	6.2	3.0	

[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[2] Sedges at Porcupine Hills and non-native grasses at Milo were either not present or too few to include in analysis.

[3] Shading of a variable indicates there was significant interaction between the main effects of grazing and ROW zone ($P < 0.10$).

Table 2.12. Similarity, diversity and evenness for ROW treatments at Milo and Porcupine Hills in 1998.

		Milo					Porcupine Hills				
Variable		Spoil	Trench	Work	Undisturbed	P ≥ F	Spoil	Trench	Work	Undisturbed	P ≥ F
Similarity[1]	Mean	0.59 b[2]	0.27 c	0.66 b	1.00 a	0.0001	0.41 b	0.31 b	0.43 b	1.00 a	0.0001
	SD	0.23	0.12	0.15	0.00		0.18	0.16	0.16	0.00	
Diversity		2.09 a	1.73 b	2.02 ab	2.02 ab	0.0489	2.33 a	1.83 b	2.35 a	1.86 b	0.0873
		0.25	0.33	0.38	0.36		0.10	0.07	0.10	0.11	
Evenness		0.76	0.70	0.73	0.74	0.3297	0.75	0.72	0.75	0.66	0.3376
		0.10	0.07	0.10	0.11		0.10	0.15	0.06	0.15	

[1] Each disturbed zone was compared to undisturbed prairie; the closer to 1.0 the more similar to undisturbed

[2] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

Table 2.13. Ground cover (%) for ROW treatments at Milo and Porcupine Hills in 1998.

		Milo					Porcupine Hills				
Variable		Spoil	Trench	Work	Undisturbed	P ≥ F	Spoil	Trench	Work	Undisturbed	P ≥ F
Live[1]	Mean	10.3 b[2]	9.5 b	14.1 b	52.9 a	0.0075	6.0	7.3	6.0	8.5	0.1467
	SD	4.6	4.7	7.3	28.1		2.4	4.9	2.3	2.5	
Litter		72.7 a	77.3 a	76.6 a	43.9 b	0.0538	92.5 a	87.6 b	91.2 ab	91.5 ab	0.0162
		12.9	20.2	7.6	29.5		4.5	9.9	5.2	2.5	
Bare Ground		17.0	13.2	9.1	3.2	0.1049	1.5 ab	4.9 a	2.8 ab	0.1 b	0.0616
		10.3	20.0	7.0	3.5		3.4	6.9	4.1	0.1	
Little Club Moss[3]		2.5 b	0.0 b	6.2 b	41.1 a	0.0080					
		4.4	0.0	7.7	27.3						

[1] Shading of a variable indicates there was significant interaction between the main effects of grazing and ROW zone ($P < 0.10$).

[2] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[3] Little club moss is *Selaginella densa*.

Table 2.14. Exclosure litter (kg ha^{-1}), exclosure biomass (kg ha^{-1}), biomass on grazed areas (kg ha^{-1}) and animal utilization (%) for ROW treatments at Milo and Porcupine Hills in 1998.

				Milo					Porcupine Hills		
Variable		Spoil	Trench	Work	Undisturbed	P ≥ F	Spoil	Trench	Work	Undisturbed	P ≥ F
Exclosure Litter	Mean	4124 ab[1]	5879 a	2907 b	3498 ab	0.0723	7924	8443	8019	9634	0.9002
	SD	1200	3402	931	1423		1412	5687	1614	2921	
Exclosure Live Biomass		4348 ab	7409 a	4039 b	2388 b	0.0039	5304	6219	5699	5959	0.7628
		2307	2011	2527	904		780	1657	1055	1500	
Grazed Biomass		829	1042	708	520	0.5751	1713	1919	1546	1754	0.1997
		265	258	111	475		240	84	258	94	
Animal Utilization		56	69	67	54	0.4692	29	54	41	39	0.1453
		19	37	34	44		3	5	12	19	

[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

Table 2.15. Surface (0-10 cm) bulk density (Mg m^{-3}) and cone index (MPa) for ROW treatments at Milo and Porcupine Hills in 1998.

				Milo					Porcupine Hills		
Variable		Spoil	Trench	Work	Undisturbed	P ≥ F	Spoil	Trench	Work	Undisturbed	P ≥ F
Bulk Density	Mean	1.11 a[1]	1.06 ab	1.08 ab	1.01 b	0.0028	0.90 a	0.90 a	0.80 ab	0.75 b	0.0018
	SD	0.13	0.10	0.08	0.08		0..13	0.12	0.10	0.06	
Cone Index (0-5 cm)[2]		2.38 b	2.35 b	3.23 a	2.08 b	0.0001	1.84	1.81	1.67	1.46	0.3864
		0.44	0.45	0.62	0.27		0.97	0.87	0.55	0.45	
Cone Index (5-15 cm)		2.52 b	2.70 b	3.25 a	2.37 b	0.0068	1.90	1.91	1.87	1.86	0.9747
		0.36	0.46	0.73	0.33		0.72	0.82	0.48	0.76	
Cone Index (15-30 cm)		2.63 b	2.92 a	2.81 a	2.45 b	0.0122	2.19 b	2.22 b	2.57 a	2.36 ab	0.0308
		0.27	0.36	0.48	0.27		0.56	0.61	0.55	0.60	

[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[2] Shading of a variable indicates there was significant interaction between the main effects of grazing and ROW zone ($P < 0.10$).

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III. PLANT COMMUNITY DEVELOPMENT OVER TWELVE YEARS AFTER PIPELINE CONSTRUCTION ON NATIVE RANGELAND IN SOUTHERN ALBERTA

1.0 INTRODUCTION

Plant community change - succession, can involve species replacements, shifts in population structure and changes in resource availability. Clements (1916) first described succession as a process involving stages of component processes, an approach used by many to explain succession under a variety of environmental conditions. The theory behind relay floristics, developed from his work, is that one group of species establishes and then is replaced by another group until a stable state is reached. But this theory may not adequately describe the process of succession (Luken 1990). Egler (1954) determined initial floristics was an important factor in plant community development. Absence of a species in the original propagule pool means it will not be part of succession or it will become a part only slowly. If the propagule pool can be manipulated early in succession, the mix of plant species participating in succession can be modified. Succession as a process, such as plant species sorting along a gradient of resources was popularized by Drury and Nisbet (1973). Because each species has a unique optimum for growth or reproduction and because resource availability changes, species replacement occurs with time. Pickett (1976) expanded this argument by incorporating competition into the resource-time gradient. Connell and Slatyer (1977) further developed explanations of succession by proposing three models: facilitation, tolerance and inhibition. Inhibition appears to have the most supportive evidence (Luken 1990).

Three general components of succession are site availability, differential species availability and differential species performance (Pickett et al. 1987). Humans have modified all three to direct succession. Designed disturbances alter site availability; controlled colonization, such as use of seed bank or seeding, can enhance differential species availability or establishment of certain species. Controlling species performance by decreasing or enhancing growth will influence what persists in the plant community.

This study addressed all three components of succession. The right-of-way (ROW) is a designed disturbance. Site availability can be different on all three disturbed zones (trench, work and spoil). The trench is characterized by low soil bulk density and high % bare ground. The work zone is often compacted. The spoil zone does not undergo the compacting effects of the work zone, but storage of soil, with subsequent replacement can cause compaction and scalping. Species colonization was modified by

conserving the natural seed bank by saving topsoil and augmenting the species pool by seeding the ROW. Availability of species at a site is ultimately controlled by propagules present or by propagules that arrive quickly from other sites.

After plant species are established, processes or conditions giving rise to differential species performance include life history, intra- and interspecific competition, allelopathy, predation and herbivory. Grazing was initiated immediately after pipeline construction and seeding. A species' response to grazing will affect its life span and dominance within the plant community. Niering (1987) indicated there are no stable plant communities and all communities are experiencing successional processes at all times. Since the three components of succession were modified, it should be possible to determine the successional pathway. Disturbances contribute to long-term maintenance of ecological diversity but can also disrupt dynamic cycles and lead to dramatic and irreversible changes. Understanding the response of communities to both repeated and new disturbance regimes is necessary to predict potential changes that could occur.

Plant functional classifications can be used to explain these changes. Functional groups are commonly based on morphological, physical or ecological traits not necessarily linked to taxonomic attributes (Harris 1995, Montalva et al. 1991). Several non-taxonomic classes have been developed including growth form, phenology or germination behaviour. Keystone and critical link species have been identified as species significant to understanding complex patterns of diversity in the plant community. Although many scientists believe universal classification of functional groups is irrelevant since function may be specific to a region or set of conditions (Noble and Gitay 1996, Woodward and Cramer 1996) they are widely used in vegetation ecology studies (McIntyre et al. 1999). Dyksterhuis (1949) grouped plants as decreasers, increasers or invaders in their response to herbivory; we still use these groups as an indicator of range condition. Models for land management strategies, such as fire or grazing, use functional groups to address vegetation response to specific disturbances (Noble and Slatyer 1980, Noble and Gitay 1996). Plants are generally divided based on growth form (for example, grasses/sedges, forbs and shrubs) with further subdivisions into annual and perennial life cycles (McIntyre et al. 1999). Researchers have grouped species according to morphology: height, lateral spread or position of dormant buds as developed by Raunkiaer (1934). Grazing-related traits, such as secondary compounds, hairiness, position of active buds, or plasticity in response to defoliation have been used as classification criteria (McIntyre et al. 1999). Characteristics such as seed size, seed dispersal method, fecundity or vegetative reproduction are also functionally relevant as well as their contribution to ecological process (e.g. nitrogen fixation).

For this research, species were grouped according to growth form and life cycle, with grasses further subdivided by reproductive method. Legumes were identified as being functionally important because of their ability to fix nitrogen and contribute to community advancement through nutrient cycling. Because the study was on native rangelands where invasion of non-native species is a hazard, grasses, forbs and legumes were separated into native and non-native.

2.0 OBJECTIVE

The objective of this study was to determine if the plant community, as defined by functional groups, would develop similarly regardless of grazing by ROW treatment over an 11 to 12 year period.

3.0 MATERIALS AND METHODS

3.1 Background

In 1986, a long-term project was initiated by NOVA Gas Transmission Ltd. to monitor revegetation of pipeline ROWs on native rangelands in southern Alberta. Two natural gas pipeline laterals (Milo and Porcupine Hills) were studied with four sites on each lateral (Figure A.1). The Milo lateral crosses the Dry Mixed Grass and Mixed Grass Ecoregions. The Porcupine Hills lateral traverses the Aspen Parkland, Fescue Grassland and Montane Ecoregions of southwestern Alberta. Experimental design was split-block (Peterson 1994) with four levels of ROW (work, trench, spoil, undisturbed) assigned to strips of plots running through the block in one direction across the breadth of the ROW. Levels of grazing (grazed, ungrazed) were applied to strips of plots perpendicular to the ROW strips (Figure A.2). A complete history of the project, site descriptions for Milo and Porcupine Hills laterals and experimental design are discussed in detail in Chapter 2, Sections 3.1 to 3.3.

3.2 Field Measurement of Species and Ground Cover

Thirty meter line transects, parallel with the ROW, were established in each treatment after pipeline construction in 1986 at Milo and 1987 at Porcupine Hills. Thirty permanent quadrat locations along each transect were randomly selected prior to initiation of the study (Naeth et al. 1997). From 1988 to 1991, vegetation was assessed

within the 30, 0.1 m^2 quadrats, using cover classes and associated midpoints (Table 3.1). Species and associated cover classes for each quadrat were recorded during peak growing season, generally late July or early August.

Vegetation data collected from 1988 to 1991 were converted from cover class to midpoint for each quadrat and averaged so there was one data set (multiple species) for each plot. Individual species canopy covers were added together to determine total percent vegetation cover for each plot. Relative cover for each species was calculated as its cover divided by total cover because total cover varied from below 50 to over 140%. For this research relative cover of species to each other within a plot was more important than its absolute cover. Cove data was collected once again 1998 To be consistent with data collected in previous years, the data were converted to cover classes then transformed into midpoint values, and total cover and relative cover were calculated as previously stated.

Ground cover was visually assessed in each treatment using 30 0.1 m^2 quadrats from 1988 to 1991 and ten 0.1 m^2 quadrats in 1998. Ground cover was divided into live plant (excluding little club moss), little club moss (*Selaginella densa* Rydb.), lichen, litter (including manure), bare ground and rocks.

3.3 Species Grouping into Functional Groups

Species were grouped into functional group categories: native grass, non-native grass, native rhizomatous grass, non-native rhizomatous grass, native tufted grass, non-native tufted grass, sedge, native forb, non-native forb, annual forb, perennial forb, native legume, non-native legume and shrub. A list of species within each group is given in Appendix D.1. Taxonomic nomenclature is from Moss (1994).

3.4 Statistical Analyses

Regression analysis (with a factor) was used to test for significant differences in slope and intercept among grazing by ROW treatments (grazed spoil, grazed trench, grazed work, grazed undisturbed, ungrazed spoil, ungrazed trench, ungrazed work, ungrazed undisturbed). Vegetation cover was the dependent variable, while year was the independent variable. During analysis, three questions were asked. The first question was whether variables were best described by a distinct or parallel line model. Regression analysis was used to calculate R-squared and sum of squares for both the distinct and parallel line models. With that statistical output, the pairs of models were

compared. Comparison of the models is equivalent to testing to accept or reject Ho (slope = slope 1 = slope 2...). The second question was if Ho is accepted (i.e., data are best described by the parallel line model) then are the intercepts different? If Ho is rejected (data are best described by the distinct line model) then the third question was which treatments have different slopes? Treatments with common slopes and/or intercepts were grouped together for discussion purposes. SAS 6.12 was used to determine regression models and to perform contrasts.

4.0 RESULTS AND DISCUSSION

4.1 Species Composition

4.1.1 Grasses

4.1.1.1 Rhizomatous Grasses

Grazing by ROW treatments significantly impacted native rhizomatous cover at both Milo and Porcupine Hills as well as non-native rhizomatous cover at Porcupine Hills (Table 3.2). Trenching was beneficial to development of rhizomatous grasses, they increased at a greater rate on the grazed and ungrazed trenches compared to other zones. The increase at Porcupine Hills was due to northern wheat grass (*Agropyron dasystachyum* (Hook.) Scribn.), an increaser, comprising 15% of the seed mix used on the lateral. Dominant native rhizomatous grasses at Milo were northern and western wheat grass (*Agropyron smithii* Rydb.). Both grasses are present in undisturbed prairie, are increasers and made up 50% of the seed mix (Table 2.1). Non-native rhizomatous grasses at Porcupine Hills, dominated by Kentucky bluegrass (*Poa pratensis* L.) showed a similar trend as native rhizomatous grasses. Non-native rhizomatous grasses at Milo were too few to measure. This difference between laterals is likely due to the higher moisture at Porcupine Hills, which facilitates rapid invasion by opportunistic species like Kentucky bluegrass.

Rhizomatous species encroachment is often important in revegetation of small grassland disturbances (Bullock et al. 1995, Kotanen 1996). The role of clonal dispersal in succession is evidenced in early and late stages due to rapid capture of space following disturbance (Waller 1988) and rapid filling of gaps in relatively closed vegetation cover. On both laterals, the trench had a steady increase in rhizomatous grasses. Movement of clonal species such as western and northern wheat grass at Milo and Kentucky bluegrass

at Porcupine Hills onto the trench would be anticipated since available space is high and soil density low (Table 2.14) allowing unimpeded rhizome movement.

Clonal species can play an important role as mid-successional species (Grime 1979, Gray et al. 1984) but the high number of rhizomatous grasses from the beginning of the project supports the theory that clonal species play an important role from the onset of succession (Prach and Pysek 1994, Walker and Chapin 1987, Waller 1988). In secondary succession, plants having the ability to survive disturbance by means of vegetative propagules are favoured in early stages (Walker and Chapin 1987). Localized disturbance and spatial heterogeneity of habitat can be buffered by young ramets of clonal species because they are supported by parent plants (Callaghan et al. 1992). Non-clonal species can obtain peak cover sooner than clonal species but clonal species are likely to dominate and maintain dominance after disturbance (Prach and Pysek 1994). While clonal species may dominate, Prach and Pysek (1994) concluded there was no simple and unambiguous pattern of succession displayed by clonal plants.

4.1.1.2 Tufted Grasses

Treatments impacted native and non-native tufted grasses similarly (Table 3.2). ROW negatively impacted tufted grasses at Milo and Porcupine Hills. Disturbed zones at Milo had significantly lower initial cover of native tufted grass and did not change with time, whereas at Porcupine Hills there was no initial impact but there were significant differences over time (Table 3.2). Initial cover at Porcupine Hills for all treatments ranged from 25 to 35%.

The reason no significant differences occurred with native tufted grasses was the presence of slender wheat grass (*Agropyron trachycaulum* (Link) Malte) in the seed mix. Slender wheat grass made up 10% of the seed mix and was the dominant grass in disturbed zones at the beginning of the study, with the trench having the highest cover followed by spoil and work zones then undisturbed prairie (Table 3.3). Slender wheat grass cover declined in all disturbed zones and by year 11 there was little left on any treatments. These results support research indicating this grass is aggressive (Bush 1998) and short-lived. Other tufted species (June grass (*Koeleria macrantha* (Ledeb. J.A. Schultes f.)) and rough fescue (*Festuca campestris* Rydb.)) were seeded on the ROW, but did not establish in the community. June grass and rough fescue had low colonizing ability and/or lacked early competitive ability. While there was no significant difference in initial cover of native tufted grasses, both fescue (*Festuca* L.) and needle grass (*Stipa*

L.) had significantly lower cover on disturbed zones than on undisturbed prairie (Table 3.3).

Seeding native tufted grasses had no influence on species composition at Milo. Slender wheat grass and alkali grass (*Puccinellia nuttalliana* (Schult.) A.S. Hitchc.) made up 42% of the seed mix at Milo (Table 2.1) but were not successful at establishing and surviving. This does not appear to be that unusual; research in the Aspen Parkland, Mixed Grass and Dry Mixed Grass Ecoregions found many seeded species did not establish (Bush 1998, Petherbridge 2000, Pitchford 2000). This would appear to contradict work done by Samuel and Hart (1994) who concluded many species are adapted to early establishment on disturbed sites if an adequate seed supply is provided. Only slender wheat grass on the ungrazed trench contributed substantially to cover where they constituted half the tufted grass cover. The trench was uncolonized initially and thus, would have facilitated the larger initial increase in slender wheatgrass. Persistence of native tufted plants into year 12 was dependent upon their ability to survive construction and/or establish quickly from the seed bank or seed rain since seeded species did not contribute. Dominant native tufted grasses at Milo were needle and thread grass (*Stipa comata* Trin. & Rupr.) and western porcupine grass (*Stipa curtiseta* (A.S. Hitchc.) Barkworth). Also persistent were Sandberg bluegrass (*Poa sandbergii* Vasey) and June grass.

While grazing is an important factor affecting species composition in grasslands (Coupland et al. 1960), it did not play an important role in this study. Work done by Gibson and Brown (1991) found the effects of grazing on colonization was concentrated in the first few years after disturbance. ROW disturbance could have masked effects of grazing early in the study, when grazing effects had the greatest differences. Though dominant tufted grasses on the ROW at Milo could be classified as decreasers (Smoliak et al. 1976), grazing did not negatively impact their development. This could be due to proper grazing management of the sites. Grazing at two of the four sites occurred in the fall, which encourages survival of needle grasses. The other two sites were subjected to various grazing regimes, but stocking rates were generally low. Only relatively heavy grazing can have the ability to substantially change succession as it increases both establishment and extinction (Gibson and Brown 1991). There were similar results with fescue and needle grass and non-native tufted grasses (timothy (*Phleum pratense* L.) and sheep fescue (*Festuca ovina* L.)) at Porcupine Hills. Non-native tufted species increased prominently at Porcupine Hiils initially, but didn't change thereafter, indicating they are persistent once established.

Lack of grazing in the Porcupine Hills can result in litter accumulation. After 12 years, ungrazed treatments had an average of 8500 kg ha^{-1} of litter (Table 2.13). Gross (1984) determined excess litter was detrimental to small-seeded species establishing. Similarly, Green and Kaufmann (1995) concluded competitive or competitive stress-tolerant species were favored in ungrazed moist meadows. Species reproducing by seed would be disadvantaged by a thick litter layer that would impair seed/soil contact and increase potential for seed predation and disease.

4.1.2 Sedges

Treatments affected the sedge community at Milo (Table 3.4). Treatments subjected to the most physical disruption had fewer sedges. Initial cover of sedges in the grazed/ungrazed trench and the grazed spoil zone was significantly lower than in other zones, which indicated that sedges are intolerant of severe disturbance and do not readily colonize bare soil. The initial cover in the grazed spoil zone was similar to the trench due to scalping at sites M1 and M2. Sedge cover remained low on these three treatments for the duration of the project. The high initial cover of sedges on the work zone compared to spoil zones could be from increased surface soil density but it could be that sedges on the spoil zone were disadvantaged. Even ungrazed spoil treatments (which had no scalping) had less than half the cover of work zones. Covering sedges with topsoil and subsoil may have been detrimental to growth.

4.1.3 Forbs

Treatments significantly impacted forb cover at Milo and Porcupine Hills (Table 3.5). ROW affected forb cover more than grazing as indicated by treatments being grouped according to ROW zone and not by grazing. Generally, for both Milo and Porcupine Hills, the more severe the disturbance the higher the initial cover of forbs. For example, the trench had the highest cover of non-native and annual forbs at Milo and Porcupine Hills. Similarly, native and perennial forbs at Milo were highest on the trench. However, this trend was not observed with native or perennial forbs at Porcupine Hills where there was equal cover by native or perennial forbs on all ROW zones. Generally, forbs decreased in cover over the course of the project.

Native forb cover at Milo was impacted by grazing by ROW treatment, whereas at Porcupine Hills it was not (Table 3.5). At Milo, the trench had the highest native forb cover intially, followed by spoil, work, then undisturbed zones. Forbs that dominated

early (pasture sage (*Artemisia frigida* Willd.) and scarlet mallow (*Sphaeralcea coccinea* (Pursh) Rydb.)) tended to persist into year 12, but cover decreased in all treatments with the greatest decrease at the trench regardless of grazing treatment. At Porcupine Hills, there were no significant differences among treatments in initial cover or change over time of native forbs. Thus severity of disturbance (trench vs. work vs. spoil) did not impact native forbs. Trends for perennial forbs at Milo and Porcupine Hills followed native forb trends.

Grazing by ROW treatments impacted non-native forbs differently at Milo than Porcupine Hills (Table 3.5). The patterns for non-native forb are similiar between laterals though, with the exception that spoil and work zone at Milo weren't encroached as they were at Porcupine Hills; this is likely due to the more mesic environment at Milo. Milo vegetation on spoil and work areas is more resistent to forb increasers, however at Milo forbs on the spoil did increase after 1988 indicating resistance is lower in the long term. At Milo, initially the trench had significantly more non-native forbs than other zones of the ROW and the spoil and work zones were not significantly different from undisturbed prairie. At Porcupine Hills, there were no significant differences among disturbed treatments with all three disturbed zones significantly different than undisturbed prairie. Thus, statistically all disturbances had the same initial impact. However, there were ecological differences with the trench having the highest cover, and spoil and work zones having similar, lower cover. At Milo, non-native forbs increased with time on grazed and ungrazed spoil treatments. The increase was due to alfalfa (*Medicago sativa* L.) growth between years 5 and 12 on sites M1 and M3. It is unclear why alfalfa increased on both grazed and ungrazed treatments, and why it would increase on the spoil zone, while on other ROW zones it was stable or decreasing. Stocking rates and grazing times at the four Milo sites did not explain differences among sites. On the other six treatments, non-native forbs decreased and cover on those treatments was similar by year 12. At Porcupine Hills, non-native forbs decreased at similar rates on all treatments. Preventing establishment of non-native forbs at time of disturbance would be a benefit that would carry through to subsequent years in the Porcupine Hills.

Annual forbs behaved similarly at Milo and Porcupine Hills and decreased over time. At the beginning of the study, annuals (most notably lamb's quarters (*Chenopodium album* L.) at Milo and stinkweed and common knotweed (*Thlaspi arvense* L. and *Polygonum aviculare* L., respectively) at Porcupine Hills), comprised most of the total forb cover on grazed/ungrazed trenches. Annuals often play an important role in community development. Some research indicates an increase in annual species often comes at the expense of perennials (Bush 1998, McGinley and Tilman 1992, Kotanen

1997) but Crawley (1987) concluded coexistence of annuals and perennials is possible. Continuance of both annual and perennial forbs at both Milo and Porcupine Hills would support Crawley's conclusion. Annuals can colonize a site early after disturbance because they generally are prolific seed producers and constitute a high percentage of seed bank species (Donelan and Thompson 1980, Grandin 1998, Kotanen 1997, Zink et al. 1995). While they can colonize a site quickly, their competitive ability is poor. At both Milo and Porcupine Hills, annual species declined quickly and by the end of the study had reached predisturbance levels in all disturbed treatments.

Many forbs at Milo and Porcupine Hills developed from the seed bank and/or seed rain since they were not in the seed mix. Though disturbance was severe, topsoil was salvaged and replaced thus allowing seed bank species to germinate. At Milo, pasture sage contributed less than 5% cover in undisturbed prairie, but in the first year after disturbance made up almost 25% cover on the trench. There were similar results at Porcupine Hills. Early dominance and then a decline of pasture sage on the ROW at Milo was also noted by Naeth (1988). Research conducted on the same plots showed a significant increase in forbs on disturbed zones versus undisturbed prairie the first four years after construction (Naeth et al. 1997). Species recruitment on disturbed zones was likely due to seed rain since studies of perennial grasslands found low similarity between seed bank and vegetation (Levassor et al. 1990, D'Angela et al. 1988), especially with an increase in successional age (Grandin 1998). Pasture sage, may be an exception to this, and could have persisted in the soil.

4.1.4 Legumes

Management of legumes could be difficult because there was no clear legume response to grazing by ROW treatments (Table 3.6). On both laterals, native legumes did not recover quickly, and in the Porcupine Hills they tended to decrease over time. Treatments did not impact initial cover of native legumes with the exception of the grazed work treatment at Milo. Although initial cover of native legume was statistically higher on the grazed work treatment (4.30% vs. average of 0.60%), the difference was small and likely not ecologically significant.

Non-native legume cover tended to increase with grazing by ROW treatment at both Milo and Porcupine Hills (Table 3.6). At Milo, the ungrazed trench treatment and undisturbed prairie stayed constant, whereas the grazed spoil and trench and ungrazed spoil treatments increased in cover. At Porcupine Hills, the ungrazed spoil treatment had higher initial cover of non-native legumes (non significant) but it decreased with time, so

by year 11, there were few differences among treatments. On the Porcupine Hills lateral, alfalfa (*Medicago sativa* L.), which had been seeded on the ROW, was the dominant non-native legume in the first few years of study. By year three alfalfa was almost eliminated and between years 4 and 11, clover (*Trifolium* L.) became dominant and was increasing in all treatments except the ungrazed spoil. Clover is a classic an increaser/invader in the fescue grassland and the Aspen Parkland.

4.1.5 Shrubs

At Porcupine Hills, protection from grazing numerically increased shrub cover (Table 3.7). Trench and work zones started with few shrubs and recovery was slow. Those zones could have been too disturbed to re-establish shrubs in the time frame of this study. Grass cover on the trench could also have hindered re-establishment of shrubs. In the absence of grazing and fire, it has long been recognized that fescue grassland would revert "back" to shrub/tree community on mesic sites. At Milo there were too few shrubs to test for treatment differences.

4.2 Ground Cover

Grazing by ROW treatments significantly affected ground cover at Milo and Porcupine Hills (Table 3.8). ROW had more of an impact on bare ground as differences were grouped according to ROW zone and not by grazing. At the beginning of the study, spoil and trench zones had the most bare ground, while undisturbed had the least. Bare ground decreased with time for all treatments and by years 11 and 12 approached zero at both Milo and Porcupine Hills. At Milo, bare ground on work zones increased before it decreased (significant quadratic equation).

Initial low bare ground on work zones was due in part to more little club moss on the work zones at the onset of the study. Little club moss on the work zone would not have been removed as it was on the trench, or scalped or buried as was possible on the spoil zone. While it did not survive into the following seasons, it was present and so reduced the bare ground cover. When little club moss started to die, bare ground increased until other plants grew and contributed to live and litter cover. Little club moss cover on all disturbed zones remained low throughout the duration of the study (Table 3.8).

Grazing by ROW treatment affected litter cover (Table 3.8). Treatments sorted themselves according to ROW zone with grazed/ungrazed spoil, trench and work

treatments being different from grazed/ungrazed undisturbed treatments. Disturbed portions of the ROW increased in litter more quickly than undisturbed prairie due to the large tufted slender wheat grass plants that quickly became established after construction.

4.3 General Climatic Considerations

There were few non-native species at Milo. Non-native annuals present early in the study had been almost eliminated by year 12 and there were few non-native plants in the surrounding plant community. Lack of invasion of non-native species at Milo could be attributed to inability of most non-native species to adapt to the harsh growing conditions. Many parts of the fescue grassland are dominated by non-native species, most notably Kentucky blue grass, timothy and smooth brome (*Bromus inermis* Leyss.) and clover. Invasion of these species into rough fescue-dominated areas is of concern.

Vegetation at Milo often undergoes moisture stress whereas at Porcupine Hills, moisture is not limiting. Vegetative and sexual reproduction can be greatly affected by soil moisture. Laycock (1991) concluded blue grama grass could not reproduce due to insufficient precipitation. Coffin et al. (1996) indicated establishment of vegetation was not only dependent on disturbance conditions but also on micro-scale climate.

5.0 CONCLUSIONS

- Trenching was beneficial to the development of rhizomatous grasses.
- Right-of-way disturbance negatively impacted tufted grasses at both Milo and Porcupine Hills. Initial cover of native tufted grasses at Milo was higher than on undisturbed prairie, but change over time of native tufted grasses was not impacted at Milo. At Porcupine Hills, there was no difference in initial coverage, but ungrazed spoil and trench decreased coverage more rapidly than the other treatments.
- Treatments subjected to the most physical disruption had fewest sedges at the onset of the project and all treatments had similar recovery rates.
- Right-of-way impacted forb cover as indicated by treatments being grouped according to ROW zone. Generally, for both Milo and Porcupine Hills, the more severe the disturbance, the higher the initial cover of forbs.
- Native legumes did not recover quickly from ROW disturbance and in the Porcupine Hills, they tended to decrease with time.

- At Porcupine Hills, not grazing increased shrub cover.
- Right-of-way impacted bare ground as differences were grouped according to ROW zone and not by grazing. Amount of bare ground decreased with time for all treatments and by years 11 and 12 bare ground approached zero at both Milo and Porcupine Hills.

Table 3.1 Midpoint and cover classes for species composition data collected from 1988 to 1991 at Milo and Porcupine Hills.

Cover Class	Midpoint
1	0.5
2	2.5
3	15.0
4	37.5
5	62.5
6	85.0
7	97.5

Table 3.2. Regression analyses results for grasses at Milo and Porcupine Hills from 1986 to 1998.

Treatment	Intercept	Linear	Quadratic	R	$P \geq F$	Intercept	Linear	Quadratic	R	$P \geq F$
Native Rhizomatous	Milo					Porcupine Hills				
Grazed Spoil	35.21 a[1]	1.04 b	-	0.3306	0.1667	5.86 a	0.03 b	-	-0.0151	0.9495
Grazed Trench	23.58 a	3.99 a	-	0.5248	0.0211	0.41 b	0.80 a	-	0.4900	0.0283
Grazed Work	31.39 a	1.27 b	-	0.3124	0.1928	3.48 a	0.78 a	-	0.3418	0.1402
Grazed Undisturbed	20.45 a	1.61 b	-	0.3888	0.0999	4.54 a	0.01 b	-	0.0077	0.9743
Ungrazed Spoil	49.30 a	-0.93 b	-	-0.3167	0.1737	3.72 a	0.09 b	-	0.0965	0.6857
Ungrazed Trench	17.77 a	4.42 a	-	0.6120	0.0041	6.52 a	-0.24 b	-	-0.0984	0.6886
Ungrazed Work	39.10 a	0.75 b	-	0.2768	0.2374	7.26 a	-0.30 b	-	-0.2086	0.3774
Ungrazed Undisturbed	26.42 a	0.95 b	-	0.2593	0.2697	6.44 a	-0.05 b	-	-0.0294	0.9051
Non-Native Rhizomatous	Milo[2]					Porcupine Hills				
Grazed Spoil						20.75 a	0.93 b	-	0.1978	0.4023
Grazed Trench						13.16 b	2.35 a	-	0.4071	0.0748
Grazed Work						25.83 a	1.02 b	-	0.1540	0.5168
Grazed Undisturbed						32.02 a	-0.61 b	-	-0.0820	0.7311
Ungrazed Spoil						18.56 a	1.44 b	-	0.3529	0.1269
Ungrazed Trench						8.94 b	4.18 a	-	0.7032	0.0008
Ungrazed Work						22.94 a	1.81 b	-	0.3461	0.1350
Ungrazed Undisturbed						20.02 a	-0.35 b	-	-0.0532	0.8288
Native Tufted	Milo					Porcupine Hills				
Grazed Spoil	22.12 b	-0.11 a	-	-0.0619	0.8012	27.10 a	-1.38 a	-	-0.3564	0.1230
Grazed Trench	10.97 b	0.13 a	-	0.0985	0.6883	27.08 a	-1.43 a	-	-0.3554	0.1241
Grazed Work	22.81 b	0.17 a	-	0.0678	0.7825	24.74 a	-1.12 a	-	-0.2318	0.3254
Grazed Undisturbed	43.86 a	0.89 a	-	0.2735	0.2571	26.17 a	-0.53 a	-	-0.1185	0.6187
Ungrazed Spoil	18.03 b	0.51 a	-	0.1953	0.4093	31.80 a	-2.16 b	-	-0.6283	0.0030
Ungrazed Trench	10.34 b	0.92 a	-	0.2773	0.2366	33.42 a	-2.80 b	-	-0.5208	0.0222
Ungrazed Work	27.94 b	0.60 a	-	0.1890	0.4249	27.16 a	-1.39 a	-	-0.2795	0.2326
Ungrazed Undisturbed	46.87 a	0.31 a	-	0.0895	0.7075	33.84 a	-0.67 a	-	-0.1298	0.5963

[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[2] Milo had no measurable amounts of non-native rhizomatous or tufted grass.

Table 3.2 (continued). Regression analyses results for grasses at Milo and Porcupine Hills from 1986 to 1998.

Treatment	Intercept	Linear	Quadratic	R	P ≥ F	Intercept	Linear	Quadratic	R	P ≥ F
Non-Native Tufted	Milo[2]					Porcupine Hills				
Grazed Spoil						6.58 b[1]	0.50 a	-	0.1720	0.4685
Grazed Trench						15.96 a	-0.42 a	-	-0.0747	0.7544
Grazed Work						11.91 a	0.50 a	-	0.1138	0.6327
Grazed Undisturbed						5.81 b	0.66 a	-	0.2254	0.3392
Ungrazed Spoil						5.32 b	-0.32 a	-	-0.2197	0.3662
Ungrazed Trench						19.09 a	-1.38 a	-	-0.2433	0.3154
Ungrazed Work						10.64 a	-0.74 a	-	-0.2843	0.2245
Ungrazed Undisturbed						6.25 b	-0.53 a	-	-0.3755	0.1131

[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[2] Milo had no measurable amounts of non-native tufted or tufted grass.

Table 3.3. Regression analyses for slender wheat grass, fescue and needle grass at Porcupine Hills from 1986 to 1998.

Treatment	Intercept	Linear	Quadratic	R	P ≥ F
Slender Wheatgrass (*Agropyron trachycaulum*)					
Grazed Spoil	14.09 b[1]	-1.26 b	-	-0.3004	0.1981
Grazed Trench	25.27 a	-2.40 b	-	-0.5447	0.0130
Grazed Work	14.09 b	-1.32 b	-	-0.2834	0.2260
Grazed Undisturbed	0.03 c	0.00 a	-	-0.0130	0.9568
Ungrazed Spoil	10.48 b	-0.89 b	-	-0.2351	0.3183
Ungrazed Trench	29.38 a	-2.69 b	-	-0.5226	0 0217
Ungrazed Work	16.86 b	-1.50 b	-	-0.2548	0.2783
Ungrazed Undisturbed	0.07 c	-0.00 a	-	-0.0872	0.7226
Fescue (*Festuca* sp.)					
Grazed Spoil	2.15 b	0.51 a	-	0.3268	0.1592
Grazed Trench	0.44 b	0.37 a	-	0.3078	0.1867
Grazed Work	2.10 b	-0.12 a	-	-0.1760	0.4579
Grazed Undisturbed	12.90 a	-0.35 a	-	-0.1399	0.5564
Ungrazed Spoil	4.58 b	-0.09 a	-	-0.0660	0.7803
Ungrazed Trench	-0.27 b	0.20 a	-	0.4178	0.0751
Ungrazed Work	2.03 b	0.24 a	-	0.1889	0.4250
Ungrazed Undisturbed	16.94 a	-0.44 a	-	-0.1304	0.5947
Needle Grass (*Stipa* sp.)					
Grazed Spoil	2.71 b	0.08 b	-	0.0953	0.6894
Grazed Trench	-2.59 c	1.25 a	-	0.5833	0.0069
Grazed Work	0.07 b	0.66 b	-	0.4924	0.0274
Grazed Undisturbed	5.00 a	0.24 b	-	0.1507	0.5260
Ungrazed Spoil	3.91 ab	-0.03 b	-	-0.0253	0.9155
Ungrazed Trench	0.66 b	-0.03 b	-	-0.1238	0.6136
Ungrazed Work	1.64 b	0.13 b	-	0.1390	0.5589
Ungrazed Undisturbed	5.86 a	0.31 b	-	0.2139	0.3793

[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

Table 3.4. Regression analyses results for sedges at Milo and Porcupine Hills from 1986 to 1998.

Treatment	Intercept	Linear	Quadratic	R	P ≥ F	Intercept	Linear	Quadratic	R	P ≥ F
Sedges	Milo					Porcupine Hills[1]				
Grazed Spoil	3.06 b[2]	0.04 a	-	0.0360	0.8836					
Grazed Trench	-0.03 b	0.02 a	-	0.4621	0.0463					
Grazed Work	16.81 a	-0.42 a	-	-0.1820	0.4557					
Grazed Undisturbed	17.59 a	-0.61 a	-	-0.2383	0.3258					
Ungrazed Spoil	8.48 a	0.31 a	-	0.1814	0.4440					
Ungrazed Trench	1.73 b	-0.15 a	-	-0.1585	0.5045					
Ungrazed Work	14.79 a	-0.59 a	-	-0.3722	0.1060					
Ungrazed Undisturbed	13.17 a	-0.87 a	-	-0.5074	0.0224					

[1] Porcupine Hills had no measurable amounts of sedges.

[2] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

Table 3.5. Regression analyses results for forbs at Milo and Porcupine Hills from 1986 to 1998.

Treatment	Intercept	Linear	Quadratic	R	P ≥ F	Intercept	Linear	Quadratic	R	P ≥ F
Native Forbs	Milo					Porcupine Hills				
Grazed Spoil	32.93 b[1]	-1.52 b	-	-0.5765	0.0098	18.01 a	-0.19 a	-	-0.0550	0.8178
Grazed Trench	54.21 a	-3.89 a	-	-0.4353	0.0624	20.46 a	-1.39 a	-	-0.2956	0.2057
Grazed Work	27.21 b	-1.17 b	-	-0.4112	0.0803	21.52 a	-0.89 a	-	-0.2127	0.3679
Grazed Undisturbed	17.36 bc	-0.30 b	-	-0.1641	0.5019	27.16 a	-0.65 a	-	-0.2089	0.3767
Ungrazed Spoil	28.12 b	-1.35 b	-	-0.5947	0.0057	22.77 a	0.50 a	-	0.1483	0.5326
Ungrazed Trench	51.82 a	-4.11 a	-	-0.5401	0.0140	19.53 a	-0.79 a	-	-0.1872	0.4429
Ungrazed Work	18.01 bc	-1.10 b	-	-0.5812	0.0072	22.00 a	-0.21 a	-	-0.0623	0.7943
Ungrazed Undisturbed	9.41 c	-0.27 b	-	-0.2173	0.3416	24.87 a	0.72 a	-	0.2980	0.2153
Non-Native Forbs	Milo					Porcupine Hills				
Grazed Spoil	0.72 b	0.81 a	-	0.3041	0.2052	13.44 a	-0.75 a	-	-0.2203	0.3506
Grazed Trench	10.71 a	-0.27 b	-	-0.0949	0.6991	24.40 a	-1.14 a	-	-0.2064	0.3827
Grazed Work	1.46 b	-0.08 b	-	-0.1279	0.6019	8.78 a	-0.37 a	-	-0.1278	0.5912
Grazed Undisturbed	0.15 b	0.07 b	-	0.2542	0.2936	0.04 b	0.32 a	-	0.5344	0.0152
Ungrazed Spoil	-3.15 b	1.15 a	-	0.6039	0.0048	8.90 a	-0.42 a	-	-0.1227	0.6064
Ungrazed Trench	19.42 a	-1.52 b	-	-0.2705	0.2488	14.63 a	-0.34 a	-	-0.0838	0.7331
Ungrazed Work	1.13 b	-0.09 b	-	-0.1883	0.4267	8.87 a	-0.68 a	-	-0.1944	0.4115
Ungrazed Undisturbed	0.44 b	0.00 b	-	0.0124	0.9587	1.76 b	-0.01 a	-	-0.0115	0.9629
Annual Forbs	Milo					Porcupine Hills				
Grazed Spoil	1.64 b	-0.05 a	-	-0.0648	0.7922	7.81 b	-0.75 a	-	-0.2796	0.2325
Grazed Trench	23.59 a	-1.77 b	-	-0.4116	0.0799	21.00 a	-1.89 b	-	-0.3223	0.1658
Grazed Work	1.79 b	-0.10 a	-	-0.1499	0.5400	3.74 b	-0.40 a	-	-0.2851	0.2232
Grazed Undisturbed	0.23 b	0.07 a	-	0.2093	0.3898	0.11 b	0.01 a	-	0.1770	0.4555
Ungrazed Spoil	0.85 b	-0.07 a	-	-0.1975	0.4039	1.34 b	-0.13 a	-	-0.2186	0.3545
Ungrazed Trench	27.62 a	-2.35 b	-	-0.3612	0.1177	17.09 a	-1.78 b	-	-0.4555	0.0500
Ungrazed Work	1.15 b	-0.09 a	-	-0.1943	0.4116	4.50 b	-0.54 a	-	-0.2069	0.3814
Ungrazed Undisturbed	0.41 b	-0.00 a	-	0.0049	0.9836	0.13 b	-0.00 a	-	-0.0275	0.9109

Table 3.5 (continued). Regression analyses results for forbs at Milo and Porcupine Hills from 1986 to 1998

Treatment	Intercept	Linear	Quadratic	R	P ≥ F	Intercept	Linear	Quadratic	R	P ≥ F
Perennial Forb	Milo					Porcupine Hills				
Grazed Spoil	32.26 a	-0.69 a	-	-0.2336	0.3358	23.76 a	-0.24 a	-	-0.0690	0.7726
Grazed Trench	41.35 a	-2.40 b	-	-0.3309	0.1665	23.86 a	-0.64 a	-	-0.1796	0.4485
Grazed Work	26.86 ab	-1.15 a	-	-0.4194	0.0739	26.56 a	-0.86 a	-	-0.2243	0.3417
Grazed Undisturbed	17.28 b	-0.30 a	-	-0.1627	0.5059	27.09 a	-0.32 a	-	-0.1098	0.6448
Ungrazed Spoil	24.14 b	-0.14 a	-	-0.0657	0.7831	30.37 a	0.21 a	-	0.0892	0.7083
Ungrazed Trench	43.63 a	-3.28 b	-	-0.4958	0.0262	17.03 a	0.67 a	-	0.2502	0.3015
Ungrazed Work	17.99 b	-1.09 a	-	-0.5798	0.0074	26.37 a	-0.36 a	-	-0.1492	0.5302
Ungrazed Undisturbed	9.77 b	-0.27 a	-	-0.2187	0.3684	26.56 a	0.67 a	-	0.3289	0.1692

[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

Table 3.6. Regression analyses results for legumes at Milo and Porcupine Hills from 1986 to 1998.

Treatment	Intercept	Linear	Quadratic	R	$P \geq F$	Intercept	Linear	Quadratic	R	$P \geq F$
Native Legume	Milo					Porcupine Hills				
Grazed Spoil	1.61 b[1]	0.00 a	-	0.0029	0.9905	1.00 a	-0.09 a	-	-0.2312	0.3267
Grazed Trench	-0.36 b	0.14 a	-	0.4245	0.0701	0.95 a	-0.10 a	-	-0.2648	0.2593
Grazed Work	4.30 a	-0.28 a	-	-0.2253	0.3536	2.71 a	-0.05 a	-	-0.0739	0.7568
Grazed Undisturbed	0.27 b	0.01 a	-	0.0663	0.7873	2.87 a	-0.12 a	-	-0.1538	0.5173
Ungrazed Spoil	1.68 b	-0.10 a	-	-0.2463	0.2951	2.70 a	0.12 a	-	0.1406	0.5542
Ungrazed Trench	-0.31 b	0.10 a	-	0.4448	0.0494	0.19 a	0.09 a	-	0.2540	0.2940
Ungrazed Work	0.56 b	0.02 a	-	0.0998	0.6756	1.76 a	-0.10 a	-	-0.2155	0.3615
Ungrazed Undisturbed	0.69 b	0.05 a	-	0.2528	0.2822	2.95 a	-0.09 a	-	-0.0796	0.7461
Non-Native Legume	Milo					Porcupine Hills				
Grazed Spoil	-0.44 a	0.82 a	-	0.3286	0.1696	0.39 a	0.05 a	-	0.1196	0.6154
Grazed Trench	-1.83 a	0.62 a	-	0.4269	0.0683	0.50 a	0.12 a	-	0.1817	0.4432
Grazed Work[1]						0.28 a	0.00 a	-	0.0165	0.9451
Grazed Undisturbed[2]										
Ungrazed Spoil	-3.91 a	1.21 a	-	0.6356	0.0026	2.24 a	-0.23 a	-	-0.2709	0.2481
Ungrazed Trench	0.78 a	-0.02 b	-	-0.0355	0.8817	0.09 a	0.00 a	-	0.0191	0.9383
Ungrazed Work[1]						-0.30 a	0.19 a	-	0.4027	0.0784
Ungrazed Undisturbed	0.03 a	0.00 b	-	0.1424	0.5492	-0.00 a	0.03 a	-	0.3389	0.1557

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[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[2] Non-native legumes were not measurable at Milo on grazed work or grazed undisturbed and at Porcupine Hills on grazed undisturbed.

Table 3.7. Regression analyses results for shrubs at Milo and Porcupine Hills from 1986 to 1998.

Treatment	Intercept	Linear	Quadratic	R	$P \geq F$	Intercept	Linear	Quadratic	R	$P \geq F$
Shrubs	Milo[1]					Porcupine Hills[2]				
Grazed Spoil						5.53 a	0.10 b	-	0.0547	0.8186
Grazed Trench						1.11 a	-0.10 b	-	-0.3135	0.1783
Grazed Work						2.85 a	-0.15 b	-	-0.2634	0.2618
Grazed Undisturbed						2.71 a	-0.11 b	-	-0.1644	0.4886
Ungrazed Spoil						3.91 a	0.69 a	-	0.3429	0.1389
Ungrazed Trench						0.52 b	0.10 b	-	0.2876	0.2325
Ungrazed Work						2.85 a	0.35 b	-	0.2582	0.2718
Ungrazed Undisturbed						3.93 a	0.69 a	-	0.3604	0.1296

[1] Milo had no measurable amounts of shrubs.

[2] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

Table 3.8. Regression analyses results for bare ground, litter and club moss at Milo and Porcupine Hills from 1986 to 1998.

Treatment	Intercept	Linear	Quadratic	R	$P \geq F$	Intercept	Linear	Quadratic	R	$P \geq F$
Bare Ground	Milo					Porcupine Hills				
Grazed Spoil	87.96 a	-5.27 c	-	-0.8127	<0.0001	56.14 b	-5.29 b	-	-0.6314	0.0028
Grazed Trench	77.21 a	-4.51 c	-	-0.5967	0.0070	70.81 a	-6.17 b	-	-0.6232	0.0033
Grazed Work	42.29 b	8.64 a	-0.91	0.6609 (R^2)	0.0003	50.89 b	-4.47 b	-	-0.5162	0.0198
Grazed Undisturbed	33.41 c	-2.06 b	-	-0.4169	0.0758	10.51 c	-0.96 a	-	-0.4399	0.0523
Ungrazed Spoil	84.41 a	-6.38 c	-	-0.8819	<0.0001	46.92 b	-4.78 b	-	-0.6033	0.0062
Ungrazed Trench	87.71 a	-7.61 c	-	-0.8790	<0.0001	71.11 a	-7.48 b	-	-0.6746	0.0015
Ungrazed Work	58.34 b	4.34 c	-0.01	0.5663 (R^2)	0.0008	35.64 b	-3.69 b	-	-0.4841	0.0306
Ungrazed Undisturbed	32.39 c	-2.43 b	-	-0.5157	0.0120	8.78 c	-0.83 a	-	-0.3735	0.1152
Litter	Milo					Porcupine Hills				
Grazed Spoil	9.70 b	5.11 a	-	0.8581	<0.0001	40.84 b	5.59 a	-	0.6740	0.0011
Grazed Trench	22.81 b	4.50 a	-	0.5959	0.0071	29.19 c	6.17 a	-	0.6232	0.0033
Grazed Work	15.65 b	5.35 a	-	0.8586	<0.0001	74.16 a	2.29 ab	-	0.3316	0.1532
Grazed Undisturbed	30.86 a	0.85 b	-	0.1633	0.5042	55.21 b	3.72 a	-	0.4876	0.0342
Ungrazed Spoil	16.01 b	6.23 a	-	0.8753	<0.0001	60.01 ab	3.95 a	-	0.6097	0.0072
Ungrazed Trench	12.31 b	7.61 a	-	0.8797	<0.0001	28.89 c	7.48 a	-	0.6746	0.0015
Ungrazed Work	36.52 a	3.98 ab	-	0.7424	0.0002	72.11 a	2.74 ab	-	0.4778	0.0385
Ungrazed Undisturbed	37.31 a	1.46 b	-	0.2820	0.2284	88.90 a	1.01 b	-	0.3410	0.1530
Little Club Moss[2]	Milo					Porcupine Hills[3]				
Grazed Spoil	2.34 b	0.15 a	-	0.1050	0.6688					
Grazed Trench	0.00 b	0.00 a	-	0.1643	0.5014					
Grazed Work[1]	7.78 b	-0.55 a	-	-0.2389	0.3399					
Grazed Undisturbed[1]	35.70 a	1.21 a	-	0.1451	0.5535					
Ungrazed Spoil	-0.42 b	0.15 a	-	0.4687	0.0371					
Ungrazed Trench	-0.01 b	0.00 a	-	0.4402	0.0521					
Ungrazed Work[1]	4.66 b	0.55 a	-	0.1988	0.4007					
Ungrazed Undisturbed	30.31 a	0.97 a	-	0.1361	0.5674					

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[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[2] Latin name for little club moss is *Selaginella densa* Rydb. (Moss 1994).

[3] There was no measurable little club moss in the Porcupine Hills.

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IV. IMPACT OF NATIVE AND NON-NATIVE SEED MIXES ON REVEGETATION AFTER PIPELINE CONSTRUCTION IN SOUTHEASTERN ALBERTA

1.0 INTRODUCTION

Activities associated with agriculture, grazing and the energy industry have altered large tracts of native rangeland in southeastern Alberta. Pipelining causes intense local disturbance by removal of vegetation and disturbance to soil strata. Following disturbance, efforts are often undertaken to attempt to speed up the revegetation process; these often involve seeding of native and/or agronomic species. Revegetation of these areas by species selected for specific characteristics (i.e. high biomass) are often used in revegetation, but they may not be the most effective. As well, reclamation of disturbed lands in southeastern Alberta is limited by low rainfall, severe summer and winter temperatures, soil characteristics and grazing practices.

Native plants occur naturally within a region and are adapted to local climates and habitats. Linhart (1995) indicated the term native is ambiguous and suggested the use of scientific names as criteria for native determination is incorrect. The same species can come from many different parts of the world. Just because two plants have the same scientific name, does not make them "equal under the laws of revegetation" (Linhart 1995). Cooper (1957) observed that ecotypes can be moved 400 to 480 km north or 160 to 240 km south of their point of origin, and assuming similar soil and climatic conditions, still give satisfactory performance. Linhart (1995) was much more conservative and suggested a move of no more than 100 meters for herbaceous plants.

It is not uncommon to hear native species are more adapted to poor soil conditions or require fewer management inputs than agronomic species. Their ability to grow in compacted or nutrient-poor soils is often touted. The ability for seed to germinate and then establish is the first step in a long process of survival. In a semi-arid climate, Franklin (1981) found most seeds either failed to germinate or failed to survive the establishment year if they did germinate on a disturbed site. A plant native to a disturbed area has adapted its life strategy to survive and as such, should be more suited for revegetation in that area.

Many agronomic species used in revegetation have been selected and bred for specific characteristics such as quick germination, competitiveness or high biomass production. Agronomic species are quicker to establish than native species (Naidu and

Harwood 1997, Pelech 1998). Does this ultimately result in a different plant community? Studies of the role of agronomic species on community development indicate a common problem: these species can dominate the community even if they constitute only a small portion of the seed mix (Depuit and Coenenberg 1979). If the objective of reclamation is to restore a native plant community, planting of non-native species to rapidly provide cover may not be conducive to re-establishment of native species (Munshower 1994). There is also concern that communities dominated by a few species are not stable in the long-term.

Much work has been done on the number of species necessary to maintain a healthy ecosystem. The connection between ecosystem stability and biodiversity was first made by Elton (1958). He observed there was greater frequency of pest outbreaks in a monoculture cropland than the surrounding diverse grasslands. Since then, there has been debate on the issue. Mathematical modeling (May 1974) indicates the greater the number of species, the more complex the interactions and hence the greater chance of instability. As in any research, relating one study to real life is often difficult especially if it involves extrapolation of mathematical equations to ecologically-based events. Tilman et al. (1996) suggested biodiversity influences ecosystem productivity, sustainability and stability. Tilman and Downing (1994) found the effects of biodiversity level off at ten species, while others determined little is gained from more than five species in an agronomic plant community (Baskin 1994).

If functional diversity is the key to ecosystem stability, the question in reclamation is how is that diversity achieved. In the past, the goal of revegetation was not long-term stability but short-term cover and erosion control. Success was establishment of any plant cover. Knowledge of ecosystems has changed revegetation goals; there is a desire not only to protect the soil, but to reclaim the disturbed area back to predisturbance vegetation. With these new objectives, came the demand for more native species to be planted. Unfortunately, seed for many native species was and still is commercially unavailable so seed choice has been extremely limited.

There are important questions to be answered in determining the influence of seed mix on revegetation success. Grazing has long been known to alter species composition. When considering much of the revegetation efforts on rangelands, a question when designing seed mixes, is will cattle utilize the mixes differently? This is important to answer, especially when having to manage disturbed areas within larger rangelands. A broad question often asked is whether native species are better than non-native for reclamation. Of course, the idea of "better" depends upon what the end goal is. Another question, and one that is often the most difficult to answer with out long-term data, is

does seed mix alter the plant community in the long term. This study was of long-term (12 years) effects of seed mix, grazing and right-of-way (ROW) zones on revegetation of native rangeland in southeastern Alberta.

2.0 OBJECTIVES

The objective of the study was to determine if two seed mixes used in the Dry Mixed Grass Ecoregion had different success in long-term establishment of plant cover, reduction of weedy species and protection against soil erosion. Differences between seed mixes for animal utilization and biomass production were also assessed.

3.0 MATERIALS AND METHODS

3.1 History of the Project

In 1986, a long-term project was initiated by NOVA Gas Transmission Ltd. to monitor revegetation of a pipeline ROW on native rangelands in southern Alberta. A natural gas pipeline lateral at Milo was studied at two sites (M1 and M2 on Figure A.1). The ROW was 18 m wide, with a 2 m wide trench. Pipe diameter was 40 cm. Ditchline stripping conserved topsoil, with the stripped topsoil stockpiled on the work side and the subsoil stockpiled on the spoil side of the ROW. The ROW was seeded in 1986 using a rangeland seed drill with a 15 cm spacing at a rate of approximately 8 kg ha^{-1}. High soil moisture and compaction caused poor penetration of the seed drills at the sites, consequently, they were seeded with two passes of the seed drill. The sites were seeded with either a grass-dominated native or dryland pasture mix (Table 4.1). At each site, 0.50 ha exclosures were constructed after completion of seeding and prior to cattle grazing.

3.2 Site Description

The Milo lateral (SW 31-18-19-W4M to NE 13-16-17-W4M) is 39 km long and crosses the Dry Mixed Grass and Mixed Grass Ecoregions (Figure A.1). Sites M1 and M2 are located in the Dry Mixed Grass Ecoregion and are characterized by severe summer and winter temperatures and low precipitation (Table 2.2). Soils are predominately Brown Solods with occurrences of Brown Solodized Solonetz and Solonetzic Brown and Orthic Brown Chernozems. Alkaline soils are common, with

occurrences of saline soils. Soil organic matter ranges from 1.0 to 3.7%. Parent material is fine to coarse loamy till, moderately to well-drained. Range type is *Stipa-Bouteloua* (needle grass-grama grass). All plant names are according to Moss (1994) unless otherwise specified. Plant cover was visually estimated and summarized (Smith 1986). Complete species list and detailed site descriptions are available (Naeth et al. 1997) and summarized in Table A.1.

3.3 Experimental Design

Experimental design was a split-block, split-plot (Peterson 1994) with levels of ROW (work, trench, spoil) assigned to strips of plots running through the block in one direction. Levels of seed mix (native, non-native) are applied to strips of plots perpendicular to the ROW strips. The experimental unit of ROW by seed mix is then split into levels of grazing (grazed, ungrazed) (Figure A.3). Because the objective of the study was to determine differences in seed mix, only the seeded portion of the ROW was included for analysis, making it a 3 x 2 x 2 factorial experiment. Each plot was subjected to one of three ROW treatments, one of two seed mix treatments and one of two grazing treatments.

3.4 Field Measurements

Species composition was determined using permanent transects that were established in each treatment at the beginning of the study. From 1988 to 1991, vegetation, was assessed within 30 0.1 m^2 quadrats, using cover classes and their midpoints (Table 3.1). In 1998, ten of the original 30 were again assessed for % cover. Species in each quadrat were recorded in the field and sampling was done during the of the peak growing season. Ground cover was visually assessed in each treatment using 30 0.1 m^2 quadrats from 1988 to 1991 and ten 0.1 m^2 quadrats in 1998. Ground cover was divided into live plant (excluding little club moss), little club moss (*Selaginella densa* Rydb.), lichen, litter (including manure), bare ground and rocks. Detailed methods are given in Chapter 2, Sections 3.4.1 and 3.4.2 and Chapter 3, Section 3.2.

In May 1998, eight grazing cages were set in grazed treatments in each ROW zone in each seed mix. Cages were approximately 70 cm high with a 0.6 m^2 basal area. At the end of the grazing season, one 0.25 m^2 sample was clipped inside each cage and two 0.25 m^2 samples were clipped on an adjacent grazed area. Clipping height was 2.5

cm. Animal utilization was calculated as the difference between biomass inside and outside the cage.

3.5 Statistical Analyses

Analysis of variance (Table B.6) was used to assess differences between main effects for plant cover, ground cover, animal utilization and plant biomass. Categories tested for plant cover were: seeded species, native and non-native rhizomatous grass, total forbs, non-native forbs and annual forbs (Table D.1). If results from ANOVA indicated significant differences ($P < 0.10$) among main effects, Scheffe's test for multiple comparisons determined specific treatment differences. SAS version 6.12 was used for all statistical analyses.

4.0 RESULTS AND DISCUSSION

4.1 Establishment of Seeded and Non-seeded Grasses

The native mix was more successful than the dryland pasture mix at establishing seeded vegetation cover (Table 4.2). Dominant grasses that established in the native mix with approximately 98% of the total cover, were northern (*Agropyron dasystachyum* (Hook.) Scribn.) and western (*Agropyron smithii* Rydb.) wheat grass. While these two species were part of the native mix, it is improbable all their cover is due to the seed mix. Table 4.3 includes the combined cover of these two wheat grasses occurring in both seed mixes. Since western and northern wheat grass were growing in the dryland pasture mix treatments as well, where they were not seeded, the presence of these species is partly due to survival and establishment of propagules or species success at invading from adjacent undisturbed prairie. This documented success of native seeded species, even when taking into account residual propagules, is contrary to previous work (Redente et al. 1984, Pelech 1998). Pelech found in the first two years after planting, non-native seed mixes were more successful at establishing cover than native seed mixes in the Aspen Parkland. The difference is likely a result of growing conditions and adaptability of species planted. In 1998, there was also a significant interaction between seed mix and grazing; not grazing the dryland pasture mix caused a significant increase in the cover of crested wheat grass (*Agropyron pectiniforme* R. & S.), a seeded species (Table 4.2).

Grazing had a significant impact on development of non-native grasses included in the dryland pasture mix (Table 4.4). In the first four years, cover of non-native species

increased slowly whether grazed or ungrazed, but from 1991 to 1998 non-native species increased from 9 to 37% in ungrazed treatments. This increase in cover was strictly due to growth of crested wheat grass plants. Crested wheat grass is an agronomic species that can be invasive if not managed properly. It matures early and becomes coarse and unpalatable as it senesces. The leaves and stems have a high content of structural components. There was visual evidence of crested wheat grass invasion off the ROW and into native prairie. This is reflected in the significant seed mix by grazing interactions in 1990, 1991 and 1998. Interestingly, grazing decreased non-natives and appeared to inhibit their invasion into the native mix (Table 4.4).

Recovery of native prairie depends on the plant community's ability to inhibit invasion of undesirable species as well as allow immigration of desirable species. The native mix did not have a high number of non-native grasses, which indicates invasion of non-native grasses into native seeded areas is not a concern (Table D.2). As well, native grasses had high cover in both mixes indicating an equal ability of both mixes to have desirable species move into the community (Table D.2). While significant differences occurred between seed mixes in coverage of native and non-native grass, there was a significant interaction between seed mix and ROW (Table 4.5). Native grass remained low in the dryland pasture mix trench and only in year 12 was it beginning to approach values similar to spoil and work zones. Due to the severity of the disturbance on the trench, there were fewer surviving propagules there than on spoil or work zones forcing establishment from off site. Establishment of native grass on the trench was influenced by seed mix (Table 4.5). For non-native grasses, both mixes had similar cover on spoil and work from 1988 through to 1991 but by 1998 there were large differences. The dryland pasture mix trench had significantly higher cover of non-native grasses than either the spoil or work by 1991. By 1990, crested wheat grass had started to establish and by 1998 it composed almost 40% of the cover. The increase in crested wheat grass would have increased competition for other species, thus the inverse relationship between native and non-native species on native and dryland pasture mix trenches.

Seeded wheat grasses did well; slender (*Agropyron trachycaulum* (Link) Malte), crested, northern and western wheat grasses all remained into year 12. They are large seeded species, which have higher survivability than small-seeded species. They can produce abundant seed, which can rejuvenate the stand. Performance of wheat grasses supports recent research in seed mix establishment (Bush 1998, Pelech 1997, Pitchford 2000). Slender wheat grass, which is supposedly a short-lived species, still had 21% cover in the native trench 12 years after seeding. These results have been noted in other studies where grasses (creeping red fescue (*Festuca rubra* L), orchard grass (*Dactylis*

glomerata L) and timothy (*Phleum pratense* L)) that were thought to be short-lived due to environmental conditions were still present ten years after seeding (Lamb 1998).

4.2 Continuance and Invasion of Weedy Species

Seed mix did not significantly affect total, native, non-native, annual or perennial forb cover in the years measured (Table D.3). Results from this study support recent research indicating seed mix has no effect on the early plant community (Bush 1998, Howat 1998, Pitchford 2000). Forb cover was high at the beginning of the study, but declined steadily and by 1998, was near undisturbed levels. There were also significant interactions between seed mix and ROW that need to be considered in detail.

Total forb cover was significantly higher on the dryland pasture mix trench than all other treatments prior to 1998 (Table 4.6). For both mixes, the trench started out with the highest forb cover, but by 1998 had the lowest cover. Often, large numbers of forbs are present in disturbed landscapes because of their efficiency in secondary succession. They can be more efficient than grasses in using environmental resources such as nutrients, water and sunlight. Many are not palatable giving them an advantage in grazed environments as well. The majority of forbs on the dryland pasture mix trench were non-native; in 1991 there was over 33% non-native forb cover (Table 4.6). The native mix trench had 17% non-native forbs. The dramatic increase in non-native forbs between 1990 and 1991 was due to an increase in non-native annuals (blue bur (*Lappula* Moench) and lamb's quarters (*Chenopodium album* L)) (Table 4.7). Annuals can grow and mature quickly. A well-timed rainfall can cause of flush of annuals because they can make up the majority of the seed bank species. June and July 1991 had normal precipitation amounts, but when and how this rain fell is unknown. One or two rainfall events can enhance annual forb growth. While annuals contributed substantially to cover in the first few years after disturbance, by 1998 they composed less than 1% to the total cover.

Perennials dominated the forb component, contributing over 75% of the cover early in the study to nearly 100% by year 12 (Table D.3). Other research indicates annuals are often the first to establish after disturbance. Pasture sage (*Artemisia frigida* Willd.) was the dominant perennial in the first few years. Other pipeline work in the Mixed Grass Prairie listed pasture sage as an early dominant perennial (Naeth 1985).

Initial establishment can play a role in plant community development. If certain species are aggressive early in the establishment period, they dominate the vegetation. Although they may not survive long-term, they may have eliminated other plants due to early competition. An example would be quick establishment of wild buckwheat

(*Polygonum convolvulus* L), a non-native weedy annual, that would inhibit growth of seeded species because of its mat-like growth (Bush 1998). By year two the buckwheat was gone, but seeded species that germinated in year one had died from lack of sunlight which could not make it through the thick, dense canopy.

The seed bank played an important role in the establishment of non-native and annual species. Neither non-natives nor annuals were abundant in undisturbed prairie. Levassor et al. (1990) concluded the greatest seed diversity was found at intermediate levels of disturbance and that there was a dramatic decrease in seed diversity at high disturbance. Similarly, research on long-term, grazed fescue grassland showed a steady increase in seed bank seeds from ungrazed to heavily grazed (Willms and Quinton 1995). These authors also concluded from seed bank analysis that increasing grazing disturbance in Fescue Prairie will likely lead to a seral community dominated by annual forbs rather than a rough fescue dominated grassland. Successional work in Sweden found 100 years of primary succession was not long enough for exhaustion of early successional species from the seed bank (Grandin 1998). Flixweed (*Descurainia sophia*), a non-native annual, though not abundant in the undisturbed Mixed Grass Prairie, was ubiquitous in the seed bank (Naeth 1985). The probability of seed being carried to a particular spot on a disturbed site where the species micro and macro environmental requirements will be met is reduced as disturbance size and distance downwind from seed source increases (Munshower 1994). Species with light, highly mobile seeds often invade highly disturbed situations while species with large, heavy seeds often require animal dissemination and enter the ecosystem at a later stage of development.

4.3 Ground Cover

Seed mix did not affect ground cover (Table D.4). Bare ground decreased with time for both mixes. Dryland pasture mix spoil zones had significantly higher bare ground than other treatments in 1998 (Table 4.8). High bare ground was caused by scalping during construction and potential overuse by cattle. It was observed in 1998 that the cattle would spend much of their ruminating time on certain areas of the ROW and these areas were heavily trampled. Litter in both seed mixes increased with time. Cover of little club moss stayed low for the duration of the project. There was a significant interaction between seed mix and zone and seed mix and grazing, but high variability within treatments and low values make interpretation of the interactions difficult (Table 4.9). Little club moss increases with grazing pressure, but over the 12-year-period of this study, that trend was not evident in either mix. In previous pipeline work, club moss was

still not present in appreciable amounts 25 years after pipeline construction (Naeth 1985). Conditions for re-establishment of little club moss are unknown.

4.4 Animal Utilization and Biomass Production

Seed mix did not significantly affect animal utilization or biomass (data not shown). Dryland pasture mix was 70% utilized, native mix 64% and adjoining undisturbed prairie 54%. Native seeded treatments had higher biomass (3241 kg ha^{-1}) than dryland pasture seeded treatments (2377 kg ha^{-1}) in the exclosures (12 years without grazing), but differences were non-significant due to high variability between replicates. Biomass production in adjacent undisturbed prairie was 1614 kg ha^{-1}. The reliability of these data is limited due to only having two replicates and high variability among treatments. Biomass in grazed treatments was 860 kg ha^{-1} in native seeded and 839 kg ha^{-1} in dryland pasture mix treatments. Even though utilization of the undisturbed prairie would be considered moderate at 54%, the production value ratio of grazed:ungrazed (860 and 839 kg: 1614 kg) would indicate that this range is in poor health and utilization may have been high in the past. As well, clipping height of 2.5 cm in the grazed treatments may have been too high. Blue grama grass, a common grass in the Dry Mixed Grass Prairie is a low growing plant and may not have included in the biomass. If this was the case, then the ratio of grazed:ungrazed would be higher and discrepancy between utilization and range health would not be as great. Biomass data were not available for years prior to 1998. Several researchers have concluded non-native species are advantaged in the first few years of establishment, but by the third or fourth year, there are no significant differences in biomass between non-native and native grasses (Doerr et al. 1983, Redente et al. 1984). Work done by Pelech (1998) in the Aspen Parkland found similar results; native species started out with lower productivity but by the second year there were no significant differences between native and non-native species.

5.0 CONCLUSIONS

- The native mix was more successful at establishing seeded vegetation cover than the dryland pasture mix.
- Grazing had a significant impact on the survival of non-native grasses.
- Seeded wheat grasses established easily and were the most productive grasses.
- Seed mix did not significantly affect total, native, non-native, annual or perennial forb cover, but there were significant seed mix by ROW interactions.

- Total forb cover was significantly higher on the dryland pasture mix trench than all other treatments.
- Perennials were the dominant forbs.
- The seed bank appeared to played an important role in the establishment of non-native and annual species.
- Seed mix did not affect ground cover.
- Seed mix did not significantly affect animal utilization or biomass but this conclusion is questionable in terms of data reliability.

Table 4.1 Native and dryland pasture mix used at Milo.

Species	Common Name	Variety	% by Weight
Native Mix			
Agropyron dasystachyum	Northern wheat grass	Elbee	25
Agropyron smithii	Western wheat grass	Walsh	25
Agropyron trachycaulum	Slender wheat grass	Revenue	17
Poa compressa	Canada bluegrass	Ruebens	8
Puccinellia nuttalliana	Alkali grass	Nuttall’s	25
Dryland Pasture Mix			
Agropyron elongatum	Tall wheat grass	Orbit	7
Agropyron pectiniforme	Crested wheat grass	Parkway	3
Agropyron riparium	Streambank wheat grass	Sodar	6
Agropyron trachycaulum	Slender wheat grass	Revenue	3
Agropyron trichophorum	Pubescent wheat grass	Greenleaf	6
Elymus angustus	Altai wild rye	Prairieland	12
Elymus junceus	Russian wild rye	Swift	3
Astragalus cicer	Cicer milk vetch	Oxley	17
Medicago sativa	Alfalfa	Rambler	12
Onobrychis viciaefolia	Sanfoin	Common	33

Table 4.2. Percent cover of seeded species and the interaction of seed mix by grazing at Milo from 1988 to 1998.

			Dryland		Native Mix		Dryland Pasture Mix		
Year		Native	Pasture	P ≥ F	Grazed	Ungrazed	Grazed	Ungrazed	P ≥ F
1988	Mean	31.2 a[1]	1.1 b	0.0117	30.0	32.3	0.2	2.1	0.9820
	SD	29.9	3.5		32.3	30.4	0.4	5.0	
1989[1]		34.5 a	0.9 b	0.0001	34.5	34.5	0.3	1.6	0.5867
		5.3	1.7		3.2	7.2	0.5	2.2	
1990		37.8 a	2.8 b	0.0001	32.4	41.7	1.0	4.7	0.4376
		14.8	3.9		16.3	12.8	1.3	4.9	
1991		49.2 a	5.3 b	0.0585	43.3	55.0	1.9	8.7	0.4679
		5.3	9.4		7.9	19.2	2.7	12.6	
1998[2]		44.9 a	21.8 b	0.0928	48.7	41.0	3.2	40.5	0.0002
		24.4	27.4		23.2	27.2	3.2	28.4	

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[1] Means within a row with different letters are significantly different at $p < 0.10$.

[2] Shading of a variable indicates there was significant interaction between the main effects of seed mix and grazing or RoW ($p < 0.10$); significant differences between main effects should be ignored.

Table 4.3. Percent cover of wheat grass[1] at Milo from 1988 to 1998.

Year		Native	Dryland Pasture
1988	Mean	31.1	18.8
	SD	29.9	13.8
1989[1]		34.4	23.2
		5.3	14.7
1990		36.2	20.5
		14.6	15.3
1991		48.9	31.0
		15.0	14.7
1998[3]		44.0	22.8
		23.5	20.0

[1] Wheat grass only includes *Agropyron smithii* and *A. dasystachyum.*

Table 4.4. Interaction of seed mix by grazing for percent cover of non-native grass at Milo from 1988 to 1998.

		Native Mix		Dryland Pasture Mix		
Year		Grazed	Ungrazed	Grazed	Ungrazed	P ≥ F
1988	Mean	0.0	0.0	0.0	0.0	0.4372
	SD	0.1	0.6	0.0	0.0	
1989		0.0	0.2	0.3	1.1	0.3905
		0.0	0.2	0.5	1.3	
1990		0.0	0.2	0.4	3.7	0.0007
		0.0	0.4	0.5	4.9	
1991		0.0	0.5	1.9	8.7	0.0750
		0.0	0.4	2.7	12.6	
1998		0.0	1.1	3.2	37.0	0.0001
		0.0	2.7	3.2	31.2	

Table 4.5 Seed mix by ROW interaction for percent cover of native grass and non-native grass at Milo from 1988 to 1998.

		Native Grass							Non-Native Grass						
		Native Mix			Dryland Pasture Mix				Native Mix			Dryland Pasture Mix			
Year		Spoil	Trench	Work	Spoil	Trench	Work	P ≥ F	Spoil	Trench	Work	Spoil	Trench	Work	P ≥ F
1988	Mean	58.9	28.7	63.0	54.3	12.0	55.7	0.5657	0.0	0.5	0.0	0.0	0.0	0.0	0.4073
		10.1	11.5	7.3	11.8	8.7	6.9		0.0	0.8	0.0	0.0	0.0	0.0	
1989		59.0	53.5	66.3	59.2	15.7	63.3	0.0662	0.1	0.2	0.0	0.7	1.5	0.0	0.1442
		5.4	15.1	6.4	9.1	13.1	6.3		0.2	0.3	0.1	1.0	1.2	0.0	
1990		67.5	52.2	64.3	62.5	29.7	59.3	0.1591	0.2	0.0	0.0	1.2	5.0	0.0	0.0397
		11.5	26.2	9.3	17.0	14.3	12.3		0.5	0.0	0.1	0.3	5.7	0.0	
1991		68.4	73.7	81.3	62.9	36.4	71.5	0.0155	0.3	0.3	0.2	3.6	12.3	0.0	0.0219
		10.4	19.4	2.6	13.5	3.4	6.3		0.4	0.3	0.5	2.2	14.6	0.0	
1998		65.7	89.4	76.6	49.8	41.9	62.2	0.0415	0.0	1.7	0.0	19.1	39.1	2.1	0.0347
		21.7	7.6	7.6	10.8	22.4	9.0		0.0	3.4	0.0	17.1	39.5	4.2	

Table 4.6. Seed mix by ROW interaction for percent cover of total forb and non-native forb at Milo from 1988 to 1998.

		Total Forb							Non-Native Forb						
		Native Mix			Dryland Pasture Mix				Native Mix			Dryland Pasture Mix			
Year		Spoil	Trench	Work	Spoil	Trench	Work	P ≥ F	Spoil	Trench	Work	Spoil	Trench	Work	P ≥ F
1988	Mean	33.3	66.8	20.3	36.3	87.9	17.0	0.0284	0.8	9.8	0.4	4.5	19.2	0.0	0.1726
		10.8	5.7	7.2	10.3	8.6	8.8		1.1	6.4	0.5	2.9	9.9	0.1	
1989		32.0	46.3	23.6	27.8	82.9	15.0	0.0220	0.1	7.9	0.3	1.4	11.8	0.2	0.1170
		7.2	15.1	4.4	9.1	14.3	4.5		0.1	5.5	0.7	1.2	14.3	0.3	
1990		23.6	47.8	17.9	24.5	65.4	14.2	0.2869	0.2	2.4	0.0	0.5	4.3	0.3	0.4553
		10.2	26.2	3.9	11.5	14.1	6.7		0.4	3.9	0.1	0.8	5.9	0.1	
1991		21.5	25.9	10.4	24.1	49.3	14.9	0.0434	0.9	17.2	1.5	3.7	33.6	1.4	0.0077
		6.6	19.6	3.4	11.6	11.7	9.0		1.0	13.3	1.5	3.6	15.0	0.7	
1998		25.9	4.5	8.0	19.1	2.4	13.1	0.0865	7.5	1.2	0.0	0.9	0.2	0.4	0.5026
		13.8	6.4	6.4	5.7	2.6	8.1		13.0	2.5	0.1	1.3	0.2	0.4	

Table 4.7. Seed mix by ROW interaction for percent cover of annual forb at Milo from 1988 to 1998.

		Annual Forb						
		Native Mix			Dryland Pasture Mix			
Year		Spoil	Trench	Work	Spoil	Trench	Work	$P \geq F$
1988	Mean	0.7	22.6	0.4	9.5	34.1	0.0	0.5568
		1.2	18.2	0.5	9.7	18.4	0.0	
1989		0.8	8.2	0.3	2.4	16.7	0.2	0.4215
		1.0	5.6	0.7	1.7	17.2	0.3	
1990		0.0	6.5	0.0	0.5	4.6	0.0	0.8708
		0.0	12.3	0.1	0.8	5.7	0.1	
1991		0.6	17.4	1.6	3.7	35.5	1.4	0.0705
		1/0	13.6	1.5	3.6	13.7	0.7	
1998		0.8	0.0	0.0	0.2	0.2	0.4	0.3392
		1.6	0.0	0.1	0.2	0.1	0.4	

Table 4.8. Seed mix by ROW interaction for percent cover of bare ground and litter at Milo from 1988 to 1998.

		Bare Ground							Litter						
		Native Mix			Dryland Pasture Mix				Native Mix			Dryland Pasture Mix			
Year		Spoil	Trench	Work	Spoil	Trench	Work	$P \geq F$	Spoil	Trench	Work	Spoil	Trench	Work	$P \geq F$
1988	Mean	75.6	69.8	44.8	82.3	77.7	38.1	0.8240	24.0	30.2	47.1	17.8	22.2	46.7	0.7761
	SD	8.2	19.9	6.1	7.2	3.2	18.0		7.7	19.9	6.0	7.2	3.2	4.7	
1989		71.0	71.8	73.0	68.9	71.3	69.4	0.9503	28.6	28.2	26.3	31.1	28.8	30.6	0.9260
		14.0	13.3	10.2	8.6	10.7	11.6		14.4	13.3	10.5	8.6	17.6	7.6	
1990		70.1	40.8	43.5	69.4	65.7	28.5	0.0024	28.2	59.3	48.3	30.5	34.3	47.5	0.0829
		12.9	20.5	12.7	14.7	17.6	18.8		12.3	20.5	9.0	14.8	17.6	7.6	
1991		53.8	43.4	58.6	55.0	55.9	48.8	0.3666	45.2	56.6	39.4	45.0	44.1	45.8	0.4732
		19.4	19.1	11.9	12.7	19.9	8.9		19.6	19.1	10.4	12.7	19.9	13.3	
1998		10.5	7.4	13.5	34.8	7.9	5.2	0.0218	71.2	92.6	80.1	64.6	92.1	91.5	0.3523
		9.0	8.2	7.3	9.4	8.5	4.4		28.5	8.2	2.3	9.6	8.5	6.5	

Table 4.9. Seed mix by ROW and seed mix and grazing interaction for percent cover of little club moss at Milo from 1988 to 1998.

Year		Native Mix			Dryland Pasture Mix				Native Mix		Dryland Pasture Mix		
		Spoil	Trench	Work	Spoil	Trench	Work[1]	P ≥ F	Grazed	Ungrazed[1]	Grazed[1]	Ungrazed[1]	P ≥ F
1988	Mean	0.4	0.0	8.1	0.0	0.2	15.2	0.9509	0.6	3.8	5.0	5.3	0.4956
		0.9	0.1	11.9	0.0	0.3	16.0		0.8	8.8	12.0	11.5	
1989		0.5	0.0	0.7	0.0	0.0	-	0.4195	0.6	-	-	-	0.1816
		0.9	0.0	1.0	0.0	0.0	-		1.0	-	-	-	
1990		1.7	0.0	8.2	0.1	0.0	24.0	0.4579	2.8	3.8	9.6	6.4	0.0165
		3.5	0.0	4.4	0.1	0.1	21.8		3.3	6.1	18.4	15.6	
1991		1.0	0.0	2.0	0.0	0.0	5.4	0.0400	0.8	1.2	3.0	0.7	0.0576
		2.0	0.0	2.1	0.0	0.0	4.9		1.6	1.9	5.1	1.1	
1998		0.6	0.0	6.4	0.6	0.0	3.4	0.4911	0.7	4.0	2.1	0.6	0.5627
		1.0	0.1	6.9	0.3	0.1	3.0		0.9	6.4	2.9	0.9	

[1] In 1989, the data for grazed and ungrazed work in the dryland pasture mix were all entered in as zeros. This data was considered incorrect as it was somewhat different than the other grazed/ungrazed ROW zones and was not included in this data set.

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V. SYNTHESIS

1.0 SUMMARY OF RESEARCH IN THIS THESIS

This research was undertaken to evaluate the influence of grazing, right-of-way (ROW) zone and seed mix on long-term revegetation of disturbed native rangelands. It was established as a long-term study to evaluate the accumulative responses over a number of years. The following summary highlights the results from this research.

Grazing Response

- Grazing had little impact on development of the plant community.
- Functional group response did not vary significantly with grazing. Certain plant variables showed a grazing effect in year 12, but effects were not consistent between laterals (e.g., locations).
- Plant community diversity was not affected by grazing in year 12.
- Grazing did affect changes in litter and bare ground over the 12 year period.
- Grazing increased soil surface bulk density and cone index values on both laterals although the increases did not result in differences in plant density.

Right-of-Way

- Rhizomatous grasses did extremely well on both laterals and were most advantaged on the trench.
- The greater the disturbance the fewer native tufted grasses.
- The trench had high numbers of exotic and weedy species and could serve as an invasion corridor.
- Highest overall diversity occurred on zones of intermediate disturbance, i.e., the work and spoil.
- Animal utilization was not affected by ROW zone.
- Soil bulk density in year 12 was lowest on the trench and highest on the work zone.

Seed Mix

- The native seed mix was more successful at establishing and maintaining vegetation.
- There was no significant difference between dryland pasture and native mixes in the amount of native species present.
- Significant interactions occurred with seed mix and ROW for annual and exotic forbs. The dryland pasture mix trench treatment had the highest cover for both of these.

- Animal utilization was not affected by seed mix, but conclusions are based on a very limited data set.
- Seed mix did not affect bare ground, litter or amount of little club moss present.

2.0 PRACTICAL APPLICATIONS OF THE RESEARCH RESULTS

The two laterals need to be managed differently. At Milo, non-native species are not a serious threat to native rangelands. Grazing did not help nor hinder invasion of non-native species. If non-native species are already present or seeded they could spread (as in the case of crested wheat grass at Milo). Grazing has been proposed as a means to control the invasion or spread of non-native species into native rangelands but this research did not support that claim. Considering that grazing was beneficial to certain native grasses, grazing should begin after pipeline construction in the Dry Mixed Grass Prairie. However, in more mesic environments such as the Porcupine Hills, exotic species are more prevalent and they increased with grazing, most notably exotic rhizomatous grasses.

Caution is required in interpreting grazing results from this study. Timing of grazing varied among sites and even changed between years for individual sites. Because there were significant interactions between grazing and ROW, management decisions should not be based solely on grazing or ROW and each plant group would have to be assessed separately in the context of management priorities and objectives.

Animals did not utilize one mix more than another. These results are not conclusive because of differences in grazing times between sites, duration of grazing and limited sample size. It would be inappropriate to make recommendations based solely on these results.

Size of disturbance needs to be minimized. Zones of highest disturbance, the trench and work, had the highest number and sharpest increase of non-native species and the trench was always the least similar to the undisturbed prairie. When possible, minimize trench and work widths.

Grazing exclusion is not necessary for soil protection, but caution is needed when determining grazing managment plans in Dry Mixed Grass where percent bare ground remained high after 12 years.

Native rhizomatous wheat grasses already present on the ROW do not need to be seeded. Even the seeding of slender wheatgrass is not necessary if the area remains ungrazed; an annual cereal crop could be seeded to provide adequate short-term soil protection. If the area is to be grazed, slender wheat grass could be seeded to provide soil

protection. With grazing, this grass would not persist. Seeding crested wheat grass in the vicinity of any native prairie is not recommended, as it could mature and produce seed.

3.0 FUTURE RESEARCH

There are over 276,000 km of pipeline in this province, with no sign that development is decreasing. We know what the impacts are, but we do not know all the reasons why the plant communities respond the way they do to these impacts. Until we have a better understanding of ecological processes, plant community development is not predictable. In the interim, we must minimize disturbance whenever possible.

The two laterals responded differently to treatments so more research is needed in these ecoregions and in others. We need to continue to monitor these sites to see whether revegetation is moving towards restoration of the native range. More conclusive results need to be gathered on animal preferences for different plants at a variety of times during the year. Some rangelands are grazed continuously over the season, while others are grazed at specific times. This study did not determine if animals preferentially graze the ROW, and that could be an important question to answer to better understand how the community is developing.

We need to learn more about non-native species spread in the fescue grassland. Kentucky bluegrass, timothy and smooth brome are ubiquitous in some areas of this grassland. If we are to preserve what is left of this native prairie, we need to understand how these species respond to specific types of disturbance. It is not sufficient to say that it is an increaser or decreaser. Shifts in species composition also need to be considered at the community level. Our focus has to move away from the quadrat and into the landscape.

More research needs to be done on natural recovery. When a disturbance is small, the native prairie may be able to restore itself. This research showed that there was ample propagule supply in the soil to establish vegetation on the ROW.

As the use of native species becomes more prevalent, we need information on their growth and reproductive strategies. It is wrong to conclude that native species do not perform well. In this research, certain native species did exceptionally well, while others did not even germinate; was it the fault of the seed, timing of seeding, seeding method, or was it just a bad year? There are many questions that have not been answered about native species and to have successful reclamation of native rangelands, we need to find answer to these.

APPENDIX A

SITE INFORMATION

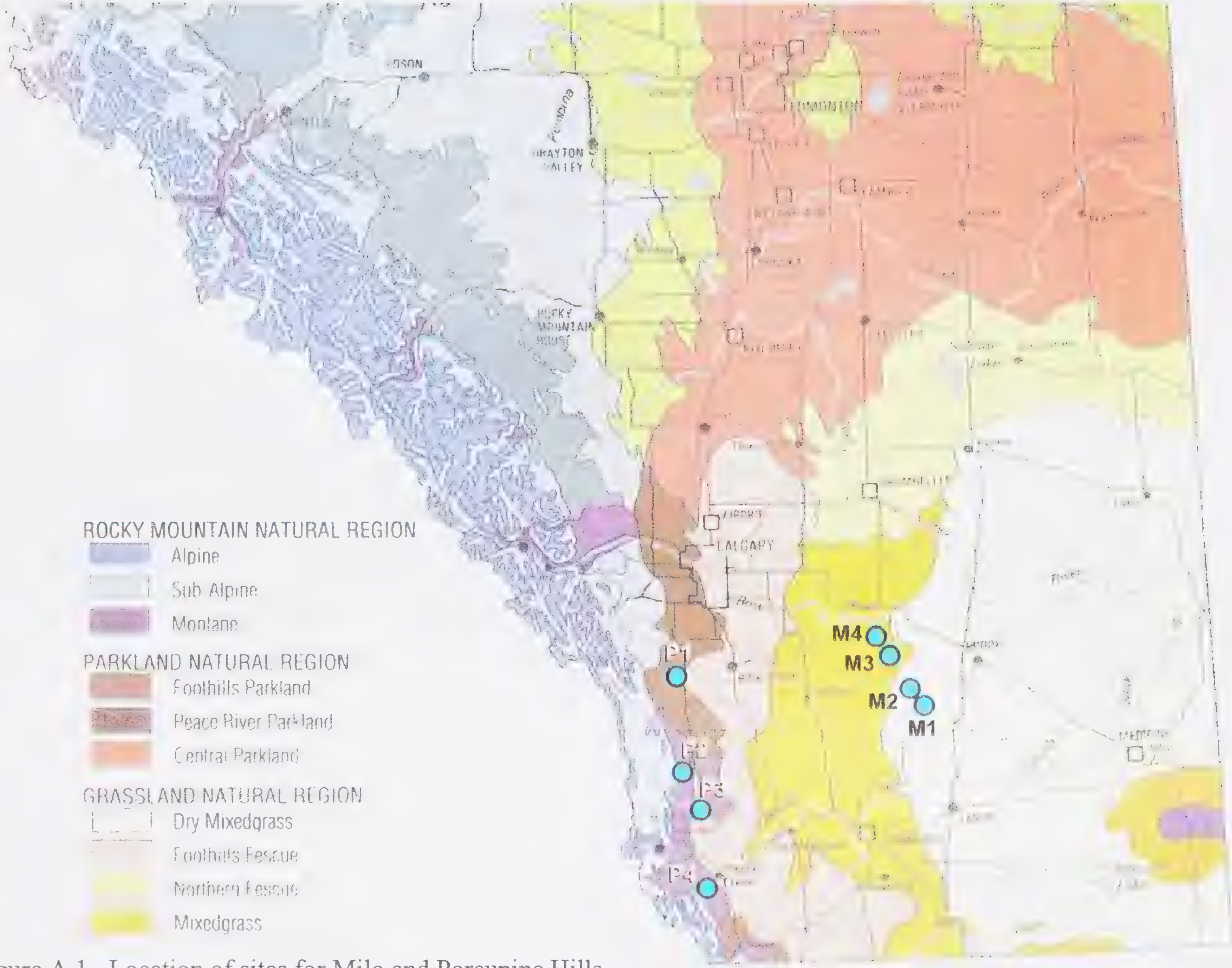

Figure A.1. Location of sites for Milo and Porcupine Hills.

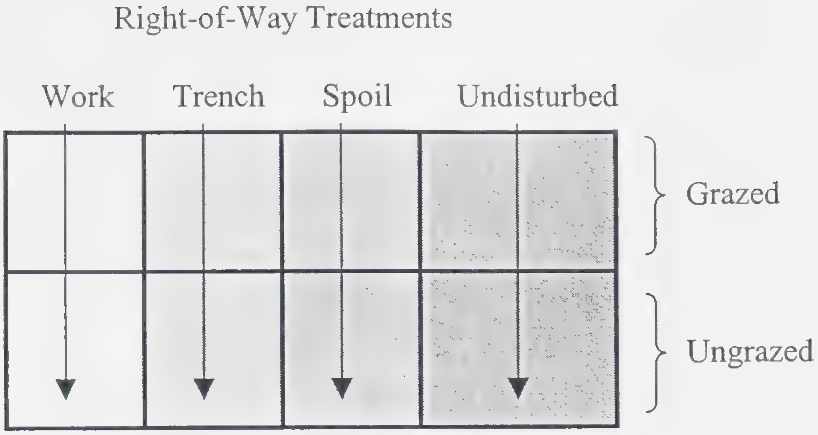

Figure A.2. Plot layout at Milo and Porcupine Hills

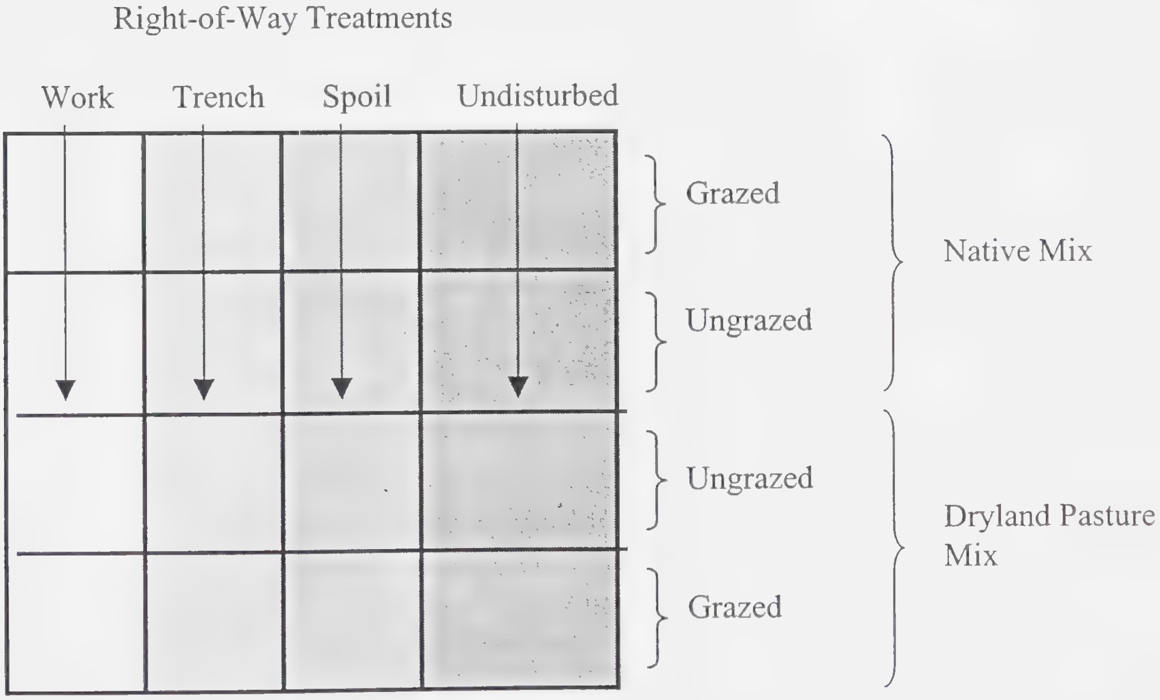

Figure A.3. Plot layout at Milo for seed mix treatments

Table A.1. Milo lateral site characteristics.

Description[1, 2]	Site 1 (M1)	Site 2 (M2)	Site 3 (M3)	Site 4 (M4)
Legal Land Description	NW 23-16-17-W4M	SE 27-16-17-W4M	NW 14-18-19-W4M	NE 21-18-19-W4M
Topography	Very gently to gently undulating	Very gently undulating	Depressional to strongly undulating	Very gently to gently undulating or depressional
Dominant Soil	Brown Solod	Brown Solod	Orthic Brown Chernozem	Solonetzic Dark Brown Chernozem
Other Soils	Solonetzic Brown Chernozem, Brown and Gleyed Solodized Solonetz	Brown Solodized Solonetz, Solonetzic Brown and Orthic Brown Chernozem	Eluviated, Rego and Calcareous Dark Brown Chernozem	Orthic, Rego and Calcareous Dark Brown Chernozem
Parent Material	Fine loamy till	Fine loamy till	Coarse loamy to fine loamy till	Fine loamy till
Drainage	Moderately well to well	Moderately well to well	Moderately well to rapid	Well to imperfectly
% Topsoil Organic Carbon	2.1 – 3.7	1.0 – 1.68	1.7 – 2.6	1.9 – 3.0
Profile pH	6.2 – 9.0	6.2 – 8.7	5.8 – 8.4	6.5 – 8.4
Topsoil EC (mS cm^{-1})	0.28 - 3.31	0.27 – 0.80	0.23 – 0.55	0.41 – 0.93
Subsoil EC (mS cm^{-1})	0.43 – 20.10 (saline and alkaline)	0.96 – 8.73 (saline and alkaline)	0.18 – 0.58 (slightly alkaline, non-saline)	0.51 – 0.92 (slightly alkaline, non-saline)
Dominant Plants[3]	*Koeleria macrantha, Bouteloua gracilis, Stipa comata, Agropyron smithii*	*Bouteloua gracilis, Stipa comata, Selaginella densa*	*Stipa comata, Koeleria macrantha, Bouteloua gracilis*	*Agropyron dasystachyum, Stipa comata, Koeleria macrantha*
Common Plants	*Selaginella densa, Agropyron* sp., *Poa* sp., *Sporobolus cryptandrus, Artemisia frigida, Phlox hoodii, Carex* sp.	*Koeleria macrantha, Agropyron* sp., *Poa* sp., *Sporobolus cryptandrus, Artemisia frigida, Phlox hoodii, Carex* sp.	*Agropyron dasystachyum, Agropyron smithii, Selaginella densa, Artemisia frigida, Phlox hoodii*	*Bouteloua gracilis, Poa* sp., *Selaginella densa, Artemisia frigida, Antennaria* sp.

[1] All soil descriptions are from McNeil and Finlayson 1988.
[2] Vegetation description is from Naeth et al. 1997.
[3] Method of differentiation between dominant and common is not known.

Table A.2. Site characteristics on the Porcupine Hills lateral.

Description[1, 2]	Site 1 (P1)	Site 2 (P2)	Site 3 (P3)	Site 4 (P4)
Legal Land Description	NE 24-18-3-W5M	NW 36-12-2-W5M	SW 24-10-2-W5M	NE 36-4-1-W5M
Topography	Undulating to gently rolling	Undulating to gently rolling	Gently undulating to gently rolling	Gently undulating
Dominant Soils	Calcareous Black Chernozem	Orthic and Rego Black Chernozem	Orthic and Rego Black Chernozem	Orthic Black Chernozem
Other Soils	Orthic Black Chernozem			Eluviated Black Chernozem
Parent Material	Medium to moderately fine till	Fine loamy till	Medium textured till and glacio-fluvial	Medium textured, gravelly glacio-fluvial
Drainage	Moderately well to well	Moderately well to well	Moderately well to well	Moderately well to well
% Topsoil Organic Carbon	3.3 – 5.4	3.6 – 4.9	2.0 – 3.9	6.7 – 8.7
Profile pH	7.3 – 8.0	6.2 – 8.0	7.1 – 8.4	5.3 – 7.1
Topsoil EC (mS cm^{-1})	0.67 – 1.02	0.44 – 0.91	0.51 – 1.08	0.15 – 0.50
Subsoil EC (mS cm^{-1})	0.43 – 0.50	0.35 – 0.71	0.39 – 0.81	0.21 – 0.59
Dominant Plants[3]	*Festuca campestris, Danthonia parryi, Agropyron dasystachyum*	*Poa pratensis, Phleum pratense, Festuca campestris*	*Festuca campestris, Agropyron dasytachyum, Festuca idahoensis*	*Danthonia parryi, Festuca campestris, Festuca idahoensis*
Common Plants	*Geum triflorum, Poa pratensis, Agropyron* sp. *Stipa* sp. *Koeleria macrantha*	*Trifolium repens, Trifolium hybridum, Fragaria virginia*	*Stipa curtiseta, Artemisia frigida, Selaginella densa, Aster ericoides*	*Hedysarum* sp. , *Penstemon* sp.

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[1] All soil descriptions are from Finlayson 1988.
[2] Vegetation description is from Naeth et al. 1997.
[3] Method of differentiation between dominant and common is not known.

APPENDIX B

STATISTICAL INFORMATION

STATISTICAL OVERVIEW

Data Type

Variables can be classified into two groups: continuous or discrete. If the variable can assume any numerical value over an interval or over different intervals, the variable is continuous. In contrast, a discrete variable is one whose possible values consist of breaks between successive values (Khazanie 1979). When a discrete variable can be assigned a large number of potential values, the discrete variable can be considered a continuous variable (Myers and Well 1995). For example, if the number of plants in a quadrat can be from 0 to 100, there is a large enough spread that the data could be considered continuous. This would not be the case if that range in values were from 0 to 10. The way in which data can be related to each other is called measurements of scale (Jongman et al 1987). The most common scales are nominal, ordinal, interval and ratio. Nominal and ordinal scales are qualitative in nature; interval and ratio are quantitative. All data presented in this chapter is quantitative. The interval scale possesses a constant unit of measurement and differences between values can be compared. In the interval scale the position of the zero value is arbitrary. Ratio scale is the same as interval, but has a fixed zero point (Kent and Coker 1992). Table B.1 categorizes all the data presented in chapter 2.

Distributions and Sampling

Many statistical analyses of data require knowledge of how the data are distributed. From a known probability distribution of a test statistic it is possible to calculate the probability with which any value of the test statistic will occur. The normal distribution is a distribution for continuous variables; its major feature is that the relative frequency of observing a particular value is symmetric around the mean. The normal distribution is described by two parameters, the mean (μ) and standard deviation (σ). Approximately 67% of measured values should fall between μ-σ and μ+σ and 95% of the values should fall between μ-2σ and μ+2σ (Jongman et al. 1987). An assumption of many statistical tests is that the data are normally distributed.

To test for normality it is necessary to have an adequate sample size. In this experiment, the number of replicates per treatment was four. Four is not enough to measure normality. It is often necessary to assume normality when dealing with small sample size. In field-based experiments, time and monetary constraints often limit the number of replicates possible. Another concern is the inability to get an accurate

measurement for the sample. For example, in this study, to get an exact value for the vegetation parameters, the entire plot would have to be measured. Again, this is not possible for reasons listed earlier. Rather than sample the entire plot, subsamples are taken to get an accurate assessment of the treatment value. If subsampling procedures are correct, then mean values calculated from subsamples will be representative of the plot.

Data Analyses

For pipeline research where treatments are in strips, the split-block is a useful design for statistical analyses. Ideally, a separate randomization is used in each block. Due to the nature of pipeline construction, it was not possible to randomize the work, trench, spoil or undisturbed strips. Due to the inability to make these random and the size of each of the work, trench, spoil and undisturbed areas, the presence of one is not expected to influence the other (Blenis 1998). As complexity of design increases, so does the amount of restriction imposed on randomization of treatments. As randomization is restricted, degrees of freedom are lost from the experimental error. Unless the restriction reduces the error sum of squares (reduced variation among plots treated alike), the error mean square will increase; this results in a loss of precision for the experiment (Peterson 1994). Split-block has the disadvantage of differential precision in estimating the interaction and main effects. Error used for analyzing grazing and ROW is grazing by block and ROW by block, respectively. The error term for the interaction is the residual error. Interactions are measured with greater precision than are main effects. Table B.2 partitions sources of variation and degrees of freedom for this experiment.

To have the correct model for analysis, it is necessary to determine which factors are random or fixed. A random factor is defined as one that was chosen from a number of possibilities. A fixed factor is not chosen from a number of possibilities. In this experiment, both grazing and ROW zone are fixed factors. Site, which is equivalent to block, is random.

A measure of the degree to which the species compositions of quadrats or sample matches is alike is called a similarity index. Dunn and Everitt (1982) and Sneath and Sokal (1973) advise the most simple coefficient should be used since this will make interpretation of results much more easy. The Czekanowski coefficient is used widely on quantitative data and is considered the most useful similarity coefficient (Kent and Coker 1992). It takes into account presence or absence and differences in abundance of common species. Shannon diversity index makes two assumptions: 1) individuals are randomly sampled from an infinitely large population and 2) all species from a

community are included in the sample (Kent and Coker 1992). The index is made up of two components, species richness and relative abundance of species.

Table B.1. Data type and classification for data presented in Chapter 2.

Data	Variable	Data
Species density	Discrete	Ratio
Species cover	Continuous	Ratio
Ground cover	Continuous	Ratio
Productivity	Continuous	Ratio
Litter	Continuous	Ratio
Animal utilization	Continuous	Ratio
Soil moisture/density	Continuous	Ratio
Penetration resistance	Continuous	Ratio
Soil particle size	Continuous	Ratio
Soil pH	Continuous	Interval
Soil EC	Continuous	Ratio
Soil total carbon	Continuous	Ratio

Table B.2. Sources of variation and degrees of freedom for data presented in Chapter 2.

Source of Variation	Degrees of Freedom (df = n-1)
Site[1]	3 = 4-1
Grazing (A)	1 = 2-1
Site*Grazing (error a)	3 = (4-1)(2-1)
RoW (B)	3 = 4-1
Site*RoW (error b)	9 = (4-1)(4-1)
Grazing*RoW (A*B)	3 = (2-1)(4-1)
Residual error (error c)	9 = (4-1)(2-1)(4-1)
Total	31 =(4*2*4)-1

[1] Site is equivalent to block.

Table B.3. Model statement for statistical analysis in Chapter 2.

$X_{ijk} = \mu + \beta_i + \alpha_j + (\beta\alpha)_{ij} + \gamma_k + (\beta\gamma)_{ik} + (\alpha\gamma)_{jk} + \varepsilon_{ijk}$

Where:

X_{ijk} = observation

μ = population mean

β_i = block, i = 1-4,

α_j = grazing, j = 1-2,

$(\beta\alpha)_{ij}$ = block by grazing interaction, error term for grazing,

γ_{κ} = ROW, k = 1-4,

$(\beta\gamma)_{ik}$ = block by ROW interaction, error term for ROW,

$(\alpha\gamma)_{jk}$ = grazing by ROW interaction,

ε_{ijkl} = residual error, error term for grazing by ROW

Table B.4. Determination of similarity index (Sc) using Czekanowski coefficient.

$$Sc = \frac{2 \sum_{i=1}^{m} \min(X_i, Y_i)}{\sum_{i=1}^{m} X_i + \sum_{i=1}^{m} Y_i}$$

where X_i and Y_i = the abundance of species i (measured as % cover),

$\sum_{i=1}^{m} \min(X_i, Y_i)$ = sum of lesser scores of species i where it occurs in both quadrats

m = number of species

Table B.5. Determination of Shannon diversity index.

$$\text{Diversity } H' = \sum_{i=1}^{s} p_i \ln p_i$$

where s = the number of species

p_i = proportion of individuals or the abundance (measured as % cover) of the i^{th} species expressed as a proportion of total % cover

ln = log base_n ($\log_{10}$ was used for all diversity calculations)

Table B.6. Sources of variation and degrees of freedom for comparison of seed mix treatments at sites M1 and M2, Milo for Chapter 4.

Source of Variation	Degrees of Freedom (df = n-1)
Site[1]	1 = 2-1
RoW	2 = 3-1
Site*RoW (error a)	2 = (2-1)(3-1)
Seed Mix	1 = 2-1
Site*Seed Mix (error b)	1 = (2-1)(2-1)
RoW*Seed Mix	2 = (3-1)(2-1)
Site*RoW*Seed Mix (error c)	2 = (2-1)(3-1)(2-1)
Grazing	1 = 2-1
Grazing*Seed Mix	1 = (2-1)(2-1)
Grazing*RoW	2 = (2-1)(3-1)
Grazing*RoW*Seed Mix	2 = (2-1)(3-1)(2-1)
Residual (error d)	6
Total	23 =(2*3*2*2)-1

[1] Site is equivalent to block.

APPENDIX C

SOIL INFORMATION

Table C.1. Soil characteristics for grazing treatments at Milo and Porcupine Hills, 1998.

Variable		Milo Grazed	Milo Ungrazed	Milo P ≥ F	Porcupine Hills Grazed	Porcupine Hills Ungrazed	Porcupine Hills P ≥ F
Soil Carbon (%)							
0-5 cm	Mean	3.72	3.54	0.5965	6.88	7.32	0.6427
	SD	0.97	1.28		1.83	2.59	
5-15 cm		2.16	2.18	0.7229	4.95	5.14	0.6291
		0.66	0.66		0.84	1.16	
15-30 cm		1.73	1.77	0.7141	3.97	4.03	0.7861
		0.66	0.89		0.90	0.81	
30-45 cm		1.55			2.98		
		0.41			1.29		
45-60 cm		1.56			2.94		
		0.48			1.52		
60+ cm		1.63			2.82		
		0.60			1.72		
pH							
0-5 cm	Mean	7.1	7.0	0.6661	6.9	6.9	0.7049
	SD	0.7	0.7		1.0	0.9	
5-15 cm		7.4	7.2	0.4288	7.0	6.9	0.6016
		0.5	0.6		1.1	1.1	
15-30 cm		7.8	7.6	0.3313	7.1	7.1	0.3105
		0.5	0.6		1.1	1.1	
30-45 cm		8.3			7.1		
		0.5			1.3		
45-60 cm		8.3			7.1		
		0.4			1.4		
60+ cm		8.3			7.2		
		0.4			1.4		

Table C.1 (continued). Soil characteristics for grazing treatments at Milo and Porcupine Hills, 1998.

Variable		Milo Grazed	Milo Ungrazed	Milo P ≥ F	Porcupine Hills Grazed	Porcupine Hills Ungrazed	Porcupine Hills P ≥ F
EC (mS cm^{-1})							
0-5 cm	Mean	0.21	0.19	0.1283	0.34	0.27	0.1758
	SD	0.08	0.06		0.22	0.11	
5-15 cm		0.18	0.14	0.2149	0.21 a[1]	0.18 b	0.0419
		0.09	0.06		0.05	0.05	
15-30 cm		0.24	0.21	0.3050	0.17 a	0.15 b	0.0803
		0.20	0.16		0.06	0.05	
3-45 cm		0.26			0.14		
		0.11			0.07		
45-60 cm		0.43			0.12		
		0.34			0.07		
60+ cm		0.64			0.11		
		0.62			0.06		
Available Water (% gravimetric)							
0-5 cm	Mean	17.9 a	16.3 b	0.0790	14.5	13.9	0.5348
	SD	3.4	3.5		3.3	3.1	
5-15 cm		15.0	14.4	0.4102	14.0	14.5	0.6512
		3.0	3.9		2.1	3.0	
15-30 cm		15.0	14.4	0.3566	13.3	13.9	0.5212
		3.0	3.1		2.6	2.1	
30-45 cm		15.4			13.7		
		3.2			2.5		
45-60 cm		14.7			13.2		
		3.1			2.7		
60+ cm		14.6			13.1		
		3.5			4.0		

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[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[2] Sedges at Porcupine Hills and introduced rhizomatous grasses at Milo were either not present or too few to include in analysis.

[3] Shading of a variable indicates there was significant interaction between the main effects of grazing and RoW zone ($P < 0.10$); significant differences between main effects should be ignored.

Table C.2. Soil characteristics for right-of-way treatments at Milo and Porcupine Hills, 1998.

		Milo					Porcupine Hills				
Variable		Spoil	Trench	Work	Undist'd	P ≥ F	Spoil	Trench	Work	Undist'd	P ≥ F
Soil Carbon (%)											
0-5 cm	Mean	3.66 ab[1]	2.66 bc	3.41 b	4.67 a	0.0142	6.40 bc	5.37 c	7.82 ab	8.84 a	0.0001
	SD	1.35	0.33	0.77	0.78		2.05	1.18	1.92	2.11	
5-15 cm		2.13	2.44	2.05	2.09	0.5641	5.23	4.47	5.01	5.47	0.2027
		0.69	0.31	0.95	0.54		1.03	1.04	0.82	1.00	
15-30 cm		1.71 b	2.17 a	1.82 b	1.83 b	0.0836	4.06	3.77	4.16	4.00	0.6852
		0.64	0.82	0.97	0.41		0.62	1.08	0.69	1.01	
30-45 cm			1.43		1.67	0.5175		2.72		3.24	0.2264
			0.39		0.46			1.21		1.51	
45-60 cm			1.75		1.38	0.2171		2.83		3.06	0.5769
			0.58		0.34			1.60		1.68	
60+ cm			1.81		1.44	0.1001		2.71		2.97	0.8149
			0.67		0.54			1.78		2.03	
pH											
0-5 cm	Mean	7.2 ab	7.7 a	6.7 b	6.6 b	0.0077	7.0	7.0	6.9	6.7	0.1219
	SD	0.7	0.3	0.7	0.2		1.0	1.1	1.0	0.9	
5-15 cm		7.4 ab	7.7 a	7.1 b	7.0 b	0.0295	7.1	7.1	6.9	6.8	0.1416
		0.6	0.5	0.6	0.5		1.1	1.2	1.1	1.1	
15-30 cm		7.6	7.8	7.7	7.5	0.3077	7.2	7.1	7.1	6.9	0.1979
		0.6	0.3	0.6	0.6		1.1	1.2	1.1	1.1	
30-45 cm			8.1		8.0	0.7758		7.0		7.2	0.3079
			0.2		0.7			1.5		1.3	
45-60 cm			8.2		8.4	0.5965		7.0		7.1	0.7727
			0.3		0.5			1.5		1.5	
60+ cm			8.3		8.4	0.2041		7.0		7.5	0.5811
			0.4		0.4			1.4		1.7	

Table C.2 (continued). Soil characteristics for right-of-way treatments at Milo and Porcupine Hills, 1998.

		Milo					Porcupine Hills				
Variable		Spoil	Trench	Work	Undist'd	P ≥ F	Spoil	Trench	Work	Undist'd	P ≥ F
EC (mS cm^{-1})											
0-5 cm	Mean	0.23	0.22	0.17	0.17	0.1671	0.23 b	0.21 b	0.44 a	0.34 ab	0.0469
	SD	0.10	0.06	0.05	0.04		0.06	0.07	0.27	0.14	
5-15 cm		0.17	0.20	0.16	0.12	0.1624	0.19 ab	0.16 b	0.20 ab	0.23 a	0.0055
		0.11	0.04	0.08	0.06		0.04	0.06	0.05	0.05	
15-30 cm		0.33	0.20	0.21	0.18	0.2271	0.15	0.14	0.17	0.14	0.1896
		0.33	0.05	0.08	0.13		0.05	0.07	0.06	0.05	
30-45 cm			0.32 a		0.19 b	0.0129		0.13		0.14	0.1117
			0.11		0.07			0.07		0.07	
45-60 cm			0.53		0.33	0.2206		0.12		0.13	0.4784
			0.45		0.19			0.08		0.06	
60+ cm			0.59		0.67	0.5100		0.11		0.12	0.8806
			0.58		0.74			0.07		0.07	
Available Water (% gravimetric)											
0-5 cm	Mean	17.6 ab	15.3 b	16.2 ab	19.3 a	0.0061	13.4	14.5	14.3	14.5	0.7342
	SD	3.0	3.9	3.1	3.4		2.0	2.9	3.0	4.6	
5-15 cm		15.9	15.1	14.2	13.6	0.2073	13.5	15.2	13.9	15.0	0.5141
		4.1	3.5	3.0	3.3		1.6	3.9	1.7	2.6	
15-30 cm		15.6	14.3	14.1	14.8	0.7037	13.4	13.4	13.1	14.5	0.5597
		2.6	3.5	3.3	2.9		2.5	2.2	1.8	2.7	
30-45 cm			14.9		16.0	0.8537		13.8		13.5	0.7308
			3.7		3.1			2.8		2.5	
45-60 cm			15.0		14.1	0.4452		13.5		13.0	0.6713
			2.3		4.4			3.2		2.5	
60+ cm			14.4		14.8	0.7781		13.4		12.6	0.6777
			2.9		4.8			3.5		5.3	

Table C.2 (continued). Soil characteristics for right-of-way treatments at Milo and Porcupine Hills, 1998.

	Milo				Porcupine Hills			
Variable	Spoil	Trench	Work	Undist'd	Spoil	Trench	Work	Undist'd
Soil Texture[2]								
0-5 cm	L	L	L	L	L	L	L→CL	L
5-15 cm	L	L	L	L	L	L	L→CL	L
15-30 cm	CL	L	L→CL	L→CL	L	L	L→CL	L→CL
30-45 cm		L→CL		CL		L→CL		L→CL
45-60 cm		CL		CL		CL		CL
60+ cm		CL		CL		SCL		SCL

[1] Within a lateral, means within a row with different letters are significantly different at $P < 0.10$.

[2] Determined by hydrometer method (McKeague 1978).

APPENDIX D

VEGETATION INFORMATION

Table D.1. Species contained within each category/functional group. Not all species were found in all treatments

Scientific Name	Common Name
Native Rhizomatous Grasses	
Agropyron albicans	Awned northern wheat grass
Agropyron dasystachyum	Northern wheat grass
Agropyron smithii	Western wheat grass
Calamagrostis montanensis	Plains reed grass
Hierochloe odorata	Sweet grass
Muhlenbergia richardsonis	Mat muhly
Native Tufted Grasses	
Agropyron trachycaulum var. *glaucum*	
Agropyron spicatum	Bluebunch wheat grass
Agropyron trachycaulum var. *unilaterale*	Awned wheat grass
Agropyron trachycaulum	Slender wheat grass
Agrostis scabra	Hair grass, tickle grass
Bouteloua gracilis	Blue grama
Calamagrostis purpurascens	Purple reed grass
Calamagrostis rubescens	Pine grass
Danthonia californica	Intermediate oat grass
Danthonia parryi	Parry oat grass
Deschampsia cespitosa	Tufted hair grass
Elymus innovatus	Hairy wild rye
Festuca campestris	Foothills rough fescue
Festuca idahoensis	Bluebunch fescue
Helictotrichon hookeri	Hooker's oat grass
Hordeum jubatum	Foxtail barley
Koeleria macrantha	June grass
Poa alpina	Alpine bluegrass
Poa canbyi	Canby bluegrass
Poa interior	Wood bluegrass
Poa juncifolia	Alkali bluegrass
Poa sandbergii	Sandberg bluegrass
Puccinellia nuttalliana	Nuttall's alkali grass
Schedonnardus paniculatus	Tumble grass
Schizachne pupurascens	False melic
Stipa columbiana	Columbia needle grass
Stipa comata	Needle and thread grass
Stipa curtiseta	Western porcupine grass
Stipa richardsonii	Richardson needle grass
Stipa spartea	Porcupine grass
Stipa viridula	Green needle grass

Non-native Rhizomatous Grasses	
Bromus inermis	Smooth brome
Bromus pumpellianus	Northern awnless brome
Festuca rubra	Creeping red fescue
Poa compressa	Canada bluegrass
Poa pratensis	Kentucky bluegrass
Non-native Tufted Grasses	
Agropyron pectiniforme	Crested wheat grass
Bromus carinatus	Mountain brome
Dactylis glomerata	Orchard grass
Elymus junceus	Russian wild rye
Festuca ovina	Sheep fescue
Phleum pratense	Timothy
Poa cusickii	Cusick bluegrass
Sedges and Sedge-like	
Carex atrosquama	
Carex filifolia	Thread leaf sedge
Carex obtusata	Blunt sedge
Carex pensylvanica	Sun loving sedge
Carex praticola	
Carex rossii	Ross's sedge
Carex scirpoidea	Rush-like sedge
Carex siccata	Hay sedge
Carex stenophylla	Low sedge
Eleocharis sp.	Spike rush
Juncus balticus	Wire rush
Native Perennial Forbs	
Achillea millefolium	Yarrow
Agoseris glauca	False dandelion
Allium cernuum	Nodding onion
Anemone canadensis	Canada anemone
Anemone cylindrica	Long-fruited anemone
Anemone multifida	Cut-leaved anemone
Anemone patens	Prairie crocus
Antennaria aprica	Pussy-toes
Antennaria neglecta	Pussy-toes
Antennaria nitida	Pussy-toes
Antennaria parvifolia	Pussy-toes
Antennaria pulcherrima	Showy everlasting
Antennaria rosea	Pussy toes

Native Perennial Forbs (continued)

Aquilegia sp.	Columbine
Arabis drummondii	Rock cress
Arabis sp.	Rock cress
Arnica sp.	Arnica
Artemisia campestris	Sage
Artemisia frigida	Fringed sage, pasture sagewort
Artemisia ludoviciana	Prairie sagewort
Aster ascendens	Western aster
Aster ciliolatus	Lindley's aster
Aster conspicuus	Showy aster
Aster ericoides	Tufted white prairie aster
Aster falcatus	Creeping white prairie aster
Aster laevis	Smooth aster
Astragalus flexuosus	Slender milk vetch
Astragalus missouriensis	Missouri milk vetch
Astragalus pectinatus	Narrow-leaved milk vetch
Balsamorhiza sagittata	Arrow-leaf balsam-root
Campanula rotundifolia	Harebell, bluebell
Castilleja miniata	Common red paint-brush
Cerastium arvense	Mouse-ear chickweed
Cirsium flodmanni	Flodman's thistle
Cirsium undulatum	Thistle
Comandra umbellata	Bastard toadflax
Coryphantha vivipara	Ball cactus
Delphinium glaucum	Tall larkspur
Epilobium angustifolium	Fireweed
Erigeron caespitosus	Fleabane
Erigeron glabellus	Fleabane
Erysimum inconspicuum	Small flowered rocket
Fragaria virginiana	Wild strawberry
Gaillardia aristata	Gaillardia
Galium boreale	Northern bedstraw
Gaura coccinea	Scarlet butterfly-weed
Geranium richardsonii	Geranium
Geranium viscosissimum	Sticky purple geranium
Geum aleppicum	Yellow avens
Geum macrophyllum	Yellow avens
Geum triflorum	Old man’s whiskers, three-flowered avens
Grindelia squarrosa	Gumweed
Gutierrezia sarothrae	Broom snake-weed
Hackelia americana	Stick-seed

Native Perennial Forbs (continued)	
Hackelia sp.	Stick-seed
Hedysarum alpinum	Alpine sweet broom
Hedysarum sulphurescens	Yellow sweet broom
Heterotheca villosa	Hairy golden aster
Heuchera sp.	Alum-root
Hieracium umbellatum	Narrow-leaved hawkweed
Lathyrus ochroleucus	Yellow pea vine
Lathyrus venosus	Purple pea vine
Liatris punctata	Blazing star
Linum lewisii	Wild blue flax
Lithospermum ruderale	Puccoon
Lomatium triternatum	Prairie parsley
Lupinus sericeus	Perennial lupine
Lygodesmia juncea	Skeleton-weed
Minuartia rubella	Sandwort
Monarda fistulosa	Wild bergamot, horse mint
Opuntia polyacantha	Prickly pear cactus
Oxytropis cusickii	Alpine loco-weed
Oxytropis deflexa	Reflexed loco-weed
Oxytropis monticola	Late yellow loco-weed
Oxytropis splendens	Showy loco-weed
Penstemon confertus	Yellow beard-tongue
Penstemon nitidus	Smooth blue beard-tongue
Penstemon procerus	Slender blue beard-tongue
Perideridia gairdneri	Squaw-root, yampa
Phlox hoodii	Hood's phlox, moss phlox
Polygonum bistortoides	Bistort
Potentilla arguta	White cinquefoil
Potentilla gracilis	Graceful cinquefoil
Potentilla hippiana	Cinquefoil
Potentilla pensylvanica	Cinquefoil
Ranunculus cardiophyllus	Heart-leaved buttercup
Rhinanthus minor	Yellow rattle
Rumex triangulivalis	Narrow-leaved dock
Senecio canus	Prairie groundsel
Senecio pauperculus	Ragwort
Senecio sp.	Ragwort
Silene parryi	Catchfly, campion
Sisymbrium altissimum	Tumbling mustard
Sisyrinchium montanum	Blue-eyed grass
Smilacina stellata	Star-flowered Solomon's-seal

Native Perennial Forbs (continued)	
Solidago canadensis	Canada goldenrod
Solidago missouriensis	Missouri goldenrod
Solidago spathulata	Goldenrod
Solidago sp.	Goldenrod
Sphaeralcea coccinea	Scarlet mallow
Thalictrum venulosum	Veiny meadow rue
Thermopsis rhombifolia	Golden bean
Urtica dioica	Stinging nettle
Vicia americana	Wild vetch
Viola adunca	Early blue velvet
Viola sp.	Violet
Zigadenus elegans	White camus
Zigadenus venenosus	Death camas
Zizia aptera	Meadow parsnip
Native Annual Forbs	
Amaranthus albus	Tumbleweed
Androsace septentrionalis	Fairy candelabra
Descurainia richardsonii	Grey tansy mustard
Draba nemorosa	Yellow whitlow-grass
Equisetum laevigatum	Horsetail
Gentianella amarella	Felwort
Lappula occidentalis	Blue bur
Lepidium sp.	Peppergrass
Monolepis nuttalliana	Spear-leaved goosefoot
Orthocarpus luteus	Owl-clover
Polygonum douglasii	Knotweed, smartweed
Potentilla norvegica	Rough cinquefoil
Potentilla rivularis	Cinquefoil
Solanum triflorum	Wild tomato
Non-native Perennial Forbs	
Artemisia absinthium	Absinthe, wormwood
Astragalus cicer	Cicer mild vetch
Cirsium arvense	Canada thistle
Medicago sativa	Alfalfa
Plantago sp.	Plantain
Taraxacum officinale	Common dandelion
Tragopogon pratensis	Goat's-beard
Trifolium hybridum	Alsike clover
Trifolium pratense	Red clover

Non-native Perennial Forbs (continued)	
Trifolium repens	White clover
Soncus sp.	Sow thistle
Silene pratensis	White cockle
Non-native Annual Forbs	
Capsella bursa-pastoris	Shepherd's purse
Chenopodium album	Lamb's-quarters
Cirsium vulgare	Bull thistle
Cynoglossum officinale	Hound's-tongue
Descurainia sophia	Flixweed, tansy mustard
Lappula squarrosa	Blue bur
Medicago lupulina	Black medick
Melilotus sp.	Sweet clover
Polygonum aviculare	Common knotweed
Salsola kali	Russian thistle
Thlaspi arvense	Stinkweed
Native Legumes	
Astragalus flexuosus	Slender milk vetch
Astragalus missouriensis	Missouri milk vetch
Astragalus pectinatus	Narrow-leaved milk vetch
Astragalus sp.	Milk vetch
Hedysarum alpinum	Alpine sweet broom
Hedysarum sulphurescens	Yellow sweet broom
Lathyrus ochroleucus	Yellow pea vine
Lathyrus venosus	Purple pea vine
Lupinus sericeus	Perennial lupine
Oxytropis campestris	Alpine loco-weed
Oxytropis deflexa	Reflexed loco-weed
Oxytropis monticola	Late yellow loco-weed
Oxytropis splendens	Showy loco-weed
Thermopsis rhombifolia	Golden bean
Vicia americana	Wild vetch
Vicia sparsifolia	Wild vetch
Non-native Legumes	
Medicago lupulina	Black medick
Melilotus sp.	Sweet clover
Astragalus cicer	Cicer mild vetch
Medicago sativa	Alfalfa
Trifolium hybridum	Alsike clover
Trifolium pratense	Red clover

Non-native Legumes (continued)	
Trifolium repens	White/Dutch clover
Shrubs and Trees	
Amelanchier alnifolia	Saskatoon
Arctostaphylos uva-ursi	Common bearberry, kinnikinnick
Artemisia cana	Sagebrush
Atriplex nuttallii	Salt sage
Betula glandualosa	Bog birch, dwarf birch
Elaeagnus commutata	Silver-berry, wolf willow
Eurotia lanata	Winter fat
Haplopappus spinulosus	Spiny iron plant
Juniperus horizontalis	Creeping juniper
Picea glauca	White spruce
Populus tremuloides	Trembling aspen
Potentilla fruticosa	Shrubby cinquefoil
Ribes oxycanthoides	Wild gooseberry
Rosa acicularis	Prickly rose
Rosa arkansana	Prairie rose
Rosa woodsii	Common wild rose
Rubus idaeus	Wild red raspberry
Salix bebbiana	Beaked legume
Salix pseudomonticola	
Salix sp.	Willow
Shepherdia canadensis	Canadian buffalo-berry
Symphoricarpos albus	Snowberry
Symphoricarpos occidentalis	Buckbrush, Wolfberry

Table D.2. Percent cover of total, native and inon-native grass in each native seed mix (NM) and dryland pasture seed mix (DPM) treatments at Milo from 1988 to 1998.

		Total Grass				Native Grass				Non-native Grass			
Year		NM	DPM	P ≥ F	Undisturbed	NM	DPM	P ≥ F	Undisturbed	NM	DPM	P ≥ F	Undisturbed
1988	Mean	50.4	40.7	0.1780	74.1	50.2	26.3	0.1874	74.1	0.2	0.00	0.3820	0.0
	SD	17.9	22.8		2.3	18.2	22.8		2.3	0.5	0.0		0.0
1989[1]		59.7 a[2]	46.8 b	0.0781	73.4	59.6 a	46.1 b	0.0841	73.4	0.1	0.7	0.1994	0.0
		10.5	24.0		4.2	10.6	24.3		4.2	0.2	1.0		0.0
1990		61.4	52.5	0.3086	67.3	61.3	50.5	0.2478	67.3	0.1 b	2.1 a	0.0699	0.0
		17.1	18.8		15.6	17.1	20.4		15.6	0.3	3.7		0.0
1991		74.7	62.3	0.3090	87.1	74.4	56.9	0.1490	87.1	0.2	5.3	0.2816	0.0
		12.8	14.5		5.4	12.8	17.5		5.4	0.4	9.4		0.0
1998		77.8	75.8	0.7233	81.7	77.2	51.2	0.1490	81.7	0.6 b	20.1 a	0.0744	0.0
		16.8	17.1		8.8	16.2	16.3		8.8	1.9	27.6		0.0

[1] Shading of a variable indicates there was significant interaction between the main effects of seed mix and grazing or ROW ($P < 0.10$); significant differences between main effects should be ignored.

[2] Means within a row (within total, native or introduced grass) with different letters are significantly different at $P < 0.10$.

Table D.3. Percent cover of total, annual and perennial forbs in each native seed mix (NM) and dryland pasture seed mix (DPM) treatments at Milo from 1988 to 1998.

		Total Forb				Annual Forb				Perennial Forb			
Year		NM	DPM	$P \geq F$	Undisturbed	NM	DPM	$P \geq F$	Undisturbed	NM	DPM	$P \geq F$	Undisturbed
1988[1]	Mean	40.1	47.7	0.1495	12.6	7.9	14.5	0.1754	0.0	32.2	32.5	0.7662	12.6
	SD	21.7	32.4		5.3	14.4	18.5		0.0	15.2	21.1		5.3
1989		34.0	41.9	0.1041	12.9	3.1	6.5	0.2435	0.0	30.9	35.5	0.4190	12.9
		13.0	32.1		3.2	4.8	11.8		0.0	9.1	27.3		3.2
1990		29.7	34.7	0.4127	19.2	2.2	1.7	0.8646	0.1	27.6	33.0	0.3072	19.0
		20.1	25.1		5.6	7.2	3.7		0.2	14.1	23.2		17.5
1991		19.2	29.4	0.2096	7.4	6.5 b	13.5 a	0.0531	0.4	12.7	15.9	0.5811	6.8
		12.9	18.1		2.9	10.8	17.8		0.6	8.4	10.3		2.9
1998		12.8	11.5	0.8699	8.6	0.2	0.3	0.9020	0.0	12.1	11.0	0.9022	8.6
		13.0	8.9		8.1	0.3	0.9		0.0	12.8	9.0		8.1

[1] Shading of a variable indicates there was significant interaction between the main effects of seed mix and grazing or ROW ($P < 0.10$); significant differences between main effects should be ignored.

[2] Means within a row (within total, annual or perennial) with different letters are significantly different at $P < 0.10$.

Table D.4. Percent cover of native and non-native forbs in each native seed mix (NM) and dryland pasture seed mix (DPM) treatments at Milo from 1988 to 1998.

		Native Forb				Non-native Forb			
Year		NM	DPM	$P \geq F$	Undisturbed	NM	DPM	$P \geq F$	Undisturbed
1988	Mean	36.4	39.1	0.3330	8.5	3.7	7.9	0.2557	0.1
	SD	17.4	24.4		8.1	5.6	10.1		0.1
1989[1]		31.0	35.9	0.1772	12.9	2.8	4.5	0.3170	0.0
		9.2	28.2		3.2	4.8	9.3		0.0
1990		28.2	33.8	0.1639	9.9	1.2	1.3	0.1958	0.1
		14.9	25.3		5.6	3.7	2.3		0.2
1991[1]		11.6	17.7	0.5441	7.0	7.4	12.0	0.1116	0.4
		7.2	11.4		2.9	13.6	15.2		0.6
1998		9.4	10.7	0.8264	8.5	2.9	0.5	0.5230	0.1
		8.4	9.1		8.1	7.7	0.8		0.1

[1] Shading of a variable indicates there was significant interaction between the main effects of seed mix and grazing or ROW ($P < 0.10$); significant differences between main effects should be ignored.

Table D.5. Percent cover of bare ground, litter and little club moss in each native seed mix (NM) and dryland pasture seed mix (DPM) treatments at Milo from 1988 to 1998.

		Bare Ground				Litter				Little Club Moss			
Year		NM	DPM	P ≥ F	Undisturbed	NM	DPM	P ≥ F	Undisturbed	NM	DPM	P ≥ F	Undisturbed
1988	Mean	65.1	66.0	0.7462	12.3	32.6	28.9	0.2774	41.8	2.4	5.1	0.8484	45.9
	SD	18.0	23.1		3.7	15.5	14.2		5.9	6.5	11.2		8.3
1989		71.9	69.9	0.9503	25.5	27.7	30.2	0.5393	30.1	0.4	0.0	0.4999	44.4
		11.4	9.5		7.1	11.7	9.5		10.1	0.8	0.0		13.4
1990[1]		51.5	54.6	0.3719	26.8	45.2	37.4	0.1070	38.9	3.3	8.0	0.4539	34.3
		19.9	24.8		15.4	18.9	14.8		19.8	4.7	16.4		30.9
1991		51.9	53.2	0.8349	21.6	47.1	44.9	0.7372	25.0	1.0	1.8	0.2313	53.4
		16.9	13.6		8.3	17.0	14.2		11.3	1.7	3.7		12.6
1998		10.5	16.0	0.1673	4.6	81.3	82.7	0.7759	27.0	2.4	1.3	0.3151	68.4
		7.9	15.6		4.5	18.0	15.4		23.6	4.7	2.2		20.2

[1] Shading of a variable indicates there was significant interaction between the main effects of seed mix and grazing or ROW ($P < 0.10$); significant differences between main effects should be ignored.