University of Alberta

REVEGETATION AND SPATIAL PATTERN OF PIPELINE RECLAMATION IN SANDHILLS OF ALBERTA ASPEN PARKLAND

by

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Your file Votre référence
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As for you, my flock...Is it not enough for you to feed on good pasture? Must you also trample the rest of your pasture with your feet? Is it not enough for you to drink clear water? Must you also muddy the rest with your feet? (Job 12:7-10)

...Ask the animals, and they will teach you; or birds of the air and they will tell you; or speak to the earth and it will teach you; or let the fish of the sea inform you. Which of all these does not know that the hand of the Lord has done this. In his hand is the life of every creature and the breath of all mankind. (Ezekiel 34:17-18)

For Mom & Dad
you have made all this possible

and

Denise
you make everything possible

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER I
INTRODUCTION

1. OBJECTIVES

Earlier research has focused on various aspects of pipeline installation impacts on the environment, agriculture productivity and the effectiveness of some reclamation techniques, however none have focused specifically on topsoil handling techniques and effects of shallow topsoil stripping. The effects of shallow topsoil stripping on soils, vegetation establishment and whether or not the technique can be accurately applied are questions that need to be answered. Because of the sensitivity of sand hills grasslands, gaining a better understanding of vegetation establishment and community development on extremely sandy textured soils following pipeline installation was also an objective of this research. Various erosion control techniques commonly used in pipeline reclamation on sandy soils, have not been scientifically tested nor compared to vegetation establishment without use of erosion control techniques. Natural recovery has been disregarded as a viable revegetation technique on soils susceptible to erosion, but never scientifically tested on sandy soils. This research compared the use of native grass seed mixes with natural recovery in vegetation establishment.

Plants may have unique spatial responses to disturbances. No research to date has investigated spatial patterns of native grasses colonizing a large linear disturbance. This research attempted to detect spatial pattern of native grasses in natural colonization of a pipeline RoW through wavelet analysis. Identifying spatial patterns in early secondary successional community development may be valuable knowledge to continue advances in revegetation.

2. BACKGROUND

The Canadian Prairie Ecozone is approximately 34 million ha in size and is considered to be one of the most highly disturbed ecosystems in the world. The majority of Canada's Prairie Ecozone lies within Saskatchewan and Alberta. Saskatchewan contains approximately 70% of the Canadian Prairie Ecozone based on 1994 satellite data, with 21% of its native prairie grassland remaining (Hammermeister et al. 2001).

Due to difficulties associated with satellite imagery interpretation, the amount of remaining native prairie is speculated to be closer to 18%. Alberta contains about 27% of the Canadian Prairie Ecozone of which 44% remains as native grassland (Alberta Prairie Conservation Forum 2000). Most of this disturbance has resulted from a mass conversion of the landscape to agricultural land uses, specifically cultivation. In the last five decades fossil fuel extraction and transportation have contributed to the degradation and loss of native prairie ecosystems throughout the Prairie Ecozone, particularly in Alberta.

Approximately 276,000 km of oil and gas pipeline runs throughout the province of Alberta (Alberta Ministry of Resource Development 2000). Disturbance from pipeline activity in the Grassland Natural Region in Alberta, coupled with access roads (45,000 km) and wellsites (75,000) have contributed to further fragmentation of native prairie (Sinton and Pitchford 2002). In most situations the construction and installation of pipeline requires development of a right-of-way (RoW). Right-of-ways (RoWs) vary in width from 5 m to as much as 100 m where adjacent parallel lines are laid. Pipeline reclamation research is lagging behind practice, with techniques derived from small field plots becoming practice before thoroughly researched on a field scale.

Plant species composition in native prairie ecosystems is well understood and this knowledge has become fundamental in the revegetation of pipeline RoWs and advances made in design and use of native seed mixes. Studies demonstrating the relationships between species composition and ecosystem community structure and function have been the foundations for advances in reclamation practises. Seed mixes composed of native grass species have been relatively successful where pipelines traverse native prairie, however limitations due to species availability and seed costs have constrained the potential of revegetation success. Despite increased understanding of the role and importance of native vegetation coupled with advances in reclamation practises, few scientifically rigorous studies have been completed in native prairie. Research on sandy soils assessing vegetation responses to topsoil handling techniques, erosion control techniques and seeding with native seed mixes versus allowing natural recovery is particularly sparse. Native plant community dynamics following a disturbance are complex, with lack of knowledge in what species occupy early seral stages, plant species' response to spatial characteristics of disturbance patches and existence of spatial associations or disassociations. Pattern analysis of species presence and absence could provide valuable insights into pipeline revegetation with information on whether individual species colonize and establish specific areas of the RoW and if particular species are associated or disassociated spatially with other species.

3. ECOLOGICAL SUCCESSION

Ecological succession, or more specifically ecosystem development, is a dynamic process involving changes in structure, composition and function of organisms and the physical environment. Obvious patterns in these changes through time, in the absence of significant natural or human disturbances, are predictable (Odum 1993). The process includes temporary communities, referred to as seral stages, of which species composition is determined by a series of immigration and extinction events. Succession continues toward more stable communities, which eventually enter equilibrium with the regional climate and disturbance regime forming a climax community. Clements (1916) developed the theory that succession of individual communities, although each at a different stage within a particular region, all progress to a single climactic stage. His theory is referred to as the monoclimax theory. Clements attributed the driving force of the monoclimax strictly to climate. Tansley (1929) would not accept the theory that succession was solely climate controlled and hence introduced the polyclimax theory. Tansley suggested that numerous factors (edaphic, topographic and regional and topoedaphic climates) control community development and there are many possible terminal stages. Gleason (1926) challenged Clements' organizational theory of strategy at the community level and suggested what is known as the individualistic theory, that succession was solely the result of individual responses to specific conditions. Both Clements and Gleason accredit successional changes entirely to plants (Odum 1993).

Successional theories such as initial floristics (Egler 1954) and the resource ratio hypothesis (Tilman 1988) were developed from the original theories of Clements and Gleason. Connell and Slatyer (1977) developed three models for succession: facilitation, tolerance and inhibition. Facilitation assumes only early successional species colonize a patch following disturbance and modify the habitat to promote establishment of late successional species. Tolerance suggests both early and late successional species establish immediately following a disturbance. In this theory, late successional species tolerate competition for resources and persist until resources are modified to the extent that early successional species can no longer survive and late successional species assume dominance. Inhibition evokes that early successional species establish and modify the environment to favour their own growth requirements and late sucessional species cannot establish until early successional species perish. Grime (1977) classified all external plant growth limiting factors into two categories, stress and disturbance. He grouped species into three groups based on level of stress and disturbance in the species' habitat: competitors (low stress and low disturbance), stress tolerant (high stress and low disturbance) and ruderals (low stress and high disturbance).

The resource-ratio hypothesis (Tilman 1988) is a model displaying species' response to changes in resource ratios over time. He suggests light at the soil surface in primary succession is maximum and nitrogen is minimum. As vegetation establishes, soil surface light decreases and nitrogen increases. Species adapted to high light and low nitrogen conditions dominate early seral stages. As the canopy closes, and with addition of organic matter increasing soil nutrients, these species are removed from the community and other more shade tolerant species establish and persist. Therefore the resource-ratio present in that space in time denotes the compositional characteristics of that seral stage. The climax community in theory is self perpetuating, however, due to disturbances, succession regresses to a seral stage and whether a climax community is ever reached is questioned.

Odum (1993) suggests ecosystems and communities do not function as superorganisms but are nonequilibrium systems that maintain the ability for self organization with both holistic and individualistic processes of community development. Current theory holds that the holistic component of biotic modification of the physical environment by the community acting as a whole, the individualistic component of competition and coexistence between populations, and the community metabolism component of shifts in available energy from production to respiration supporting increasing organic structure, are all inherent in ecosystem development. Ecological succession is generally accepted as a two phase process with early serals dominated by opportunistic species tending to be random and later stages becoming more self-organized.

There are two specific types of succession, primary and secondary. Primary succession begins on sterile sites where conditions for life are not at first favourable (Odum 1993) such as lava flows, bedrock and large scale dune complexes. Secondary succession occurs where vegetation is removed through disturbance from sites with previously supported, well developed plant communities, but soil nutrients and other conditions are still favourable for plant growth. Time scales and their predictability are quite different for both types. Primary succession occurs over centuries and millennia while secondary succession occurs over decades and centuries. These time scales greatly depend on the physical and environmental conditions of the site (Holochek et al. 1989). For these reasons the focus is on secondary succession when managing native grasslands.

3.1 Grassland Succession

Grassland ecosystem successional processes proceed as described above. However, limiting resources, a unique disturbance regime and a semiarid climate produce communities with unique plant species composition, structure and function.

Coupland (1961) estimated that in three quarters of a century since the first settlement, approximately 60% of Canada's natural grassland has been cultivated and the remaining 16 million ha has been subjected to various degrees of overgrazing. Recent estimates for Alberta show there are approximately 4 million ha of native prairie on crown and private lands remaining, which is 44% of what was historically native prairie grassland (Alberta Prairie Conservation Forum 2000). Of this, 630,000 ha are of the northern fescue subregion.

Secondary succession in native grasslands, unless invasion by perennial weeds or exotics has occurred, proceeds through native and introduced annual forbs to native perennial forbs and short lived weedy grasses (Coupland 1961), followed by long lived native grasses. Coupland (1961) suggested rate of succession on abandoned cultivated fields varies due to many factors, including size of the tilled area and therefore isolation from a supply of disseminules of native grass species, degree of aridity of the years following abandonment and duration of tillage prior to abandonment. Size of disturbance, isolation of the disturbance patch, severity and intensity of disturbance, return time of the disturbance and climatic conditions following disturbance all affect rate of succession following any disturbance. A plant community approaching late succession in its composition, under the most favourable conditions, can develop within 20 years.

Conditions in early stages of secondary succession favour species with high reproductive potentials (large offspring investments). These are species with low competitive abilities that produce extremely large numbers of seed. These characteristics are inherent to early successional annual forbs. Species favoured in more competitive later successional stages have lower growth potentials but greater capabilities for obtaining and utilizing scarce resources (large investments in maintenance and survival of adult plants). These characteristics are inherent to many native grass species. These two modes are known as r-selection and k-selection and species exhibiting them as r- and k-strategists (Odum 1993). The letters r and k are derived from important constants in growth equations. The constant (k) represents the upper carrying capacity level, and (r) the inherent or intrinsic rate of growth of the population when in an unlimited environment.

3.2 Succession on Sandy Soils in Aspen Parkland

Plant diversity is relatively high in sandy soil native prairie compared to other grasslands. In regions where moisture is sufficient, tree species such as *Populus tremuloides* Michx. (trembling aspen) advance into the grassland. In xeric positions on dunes, successional communities of herbaceous plants occur. The pioneer grasses are *Sporobolus cryptandrus* (Torr.) Gray (sand dropseed), *Achnatherum hymenoides* (R.& S.) Barkw. (indian rice grass), *Elymus canadensis* L. (canada wild rye) and *Calamovilfa longifolia* (Hook.) Scribn. (sand reed grass) (Coupland 1961). They are accompanied in early stages of establishment by several annual and perennial forbs characteristic of sand dune plant communities, *Psoralidium lanceolatum* (Pursh) Rydb. (lance-leaved psoralea), *Chenopodium pratericola* Rydb. (narrow-leaved goosefoot) and *Helianthus* species.

With additions of organic matter to the soil and with profile development, the rate of water infiltration declines. The shift in soil conditions favour mid grass species such as *Hesperostipa comata* (Trin. & Rupr.) Barkw. (needle and thread grass), which invades and others follow. Throughout this gradual transition towards a mixed prairie community dominated by *Hesperostipa comata, Calamovilfa longifolia* persists (Coupland 1961) while other early successional sand grasses are restricted to active sand in disturbance patches. On some sites *Sporobolus cryptandrus* or *Calamagrostis montanensis* (Scribn. ex Vasey) (plains reed grass) indicate early successional stages on sand. More mature plant communities on sandy soils can be found where *Calamovilfa* and *Sporobolus* are less important components in the sward (Coupland 1961).

The aspen parkland ecoregion of Alberta presently makes up 7.9% of the province (Kerr et al. 1993) of which less than 5% is natural habitat (Wallis 1987, Kerr et al. 1993). In a biophysical inventory of the Wainwright study area, Fehr (1984) divided the aeolian dune complex into five physiographic categories: active blowouts, stabilized blowouts, dune ridge, interdune depressions and sand flats, each with characteristic plant composition and succession. Active blowouts are initially colonized by sedge and grass species, followed by lichens and an increasingly dense herb-dwarf shrub layer. Dominants include *Carex siccata* Dewey (dry-spike sedge) (5.3% cover), *Calamovilfa longifolia* (3%), *Elymus canadensis* (2%), *Acnatherum hymenoides* (2%), *Festuca saximontana* Rydb. (sheep fescue) (1%) and *Heterotheca villosa* (Pursh) Shin. (hairy golden-aster) (0.6%). Dominants of the stabilized blowouts include *Calamovilfa longifolia* (8% cover), *Carex siccata* (6%) and *Festuca saximontana* (5.2%). Other important species include *Selaginella densa* Rydb. (prairie clubmoss) (4.3% cover), *Carex obtusata* Lilj. (blunt sedge) (1.8%) and *Koeleria macrantha* (Ledeb.) Schultes june grass (1.8%). *Juniperus horizontalis* Moench (creeping juniper) is an important colonizer and stabilizer of active and stabilized blowouts with covers of 4 and 16%, respectively. This decumbent evergreen shrub creeps in from outside the blowout and then roots inside stabilizing active sand.

A well developed low shrub layer is characteristic of interdune depressions. Aspen is the dominant species (21.3% cover). The herb-dwarf shrub layer is composed of *Juniperus horizontalis* (20% cover), *Selaginella densa* (8.3%), *Arctostaphylos uva-ursi* (L.) Spreng. (common bearberry) (3%) and *Juniperus communis* (L.) (common juniper) (2.5%). Graminoid species present include *Calamovilfa longifolia* (7.5% cover), *Festuca* *saximontana* (2.1%), *Juncus balticus* Willd. (Baltic rush) (1.6%) and *Carex siccata* (1.5%) (Fehr 1984).

Aspen stands with a thick shrub layer are the dominant vegetation type on north aspect slopes. A variety of xeric vegetation types are found on southern aspects of dune ridges. Blowout vegetation is typical of blowout hollows on dune ridges. On lower and middle slope positions vegetation types characteristic to interdune depressions are present.

Sand flats are composed of aspen stands and grassland vegetation. Composition of grassland communities varies considerably. On xeric sand flats dominant species include *Calamovilfa longifolia* (15% cover), *Artemisia frigida* Willd. (pasture sage) (11.3%), *Koeleria macrantha* (8.8%), *Festuca saximontana* (8%) and *Festuca altaica* Trin. ssp. *hallii* (Vasey) V. Harms (plains rough fescue) (6.3%). Forbs such as *Pulsatilla patens* (L.) P. Mill. ssp. *multifida* (Pritz.) Zamels (prairie crocus), *Antennaria microphylla* Rydb. (small-leaf everlasting), *Chamaerodes erecta* (L.) Bunge ssp. *nuttallii* (Pick. ex Rydb.) Hult. (American chamaerodes), *Heterotheca villosa, Gaillardia aristata* Pursh (giant blanket flower), and shrub species *Juniperus horizontalis* and *Rosa arkansana* Porter (prairie rose) occur in these stands. *Selaginella densa* is an important ground cover in poorly vegetated stands and has an average canopy cover of 27.5%. Aspen stands in sand flats have an average canopy cover of 57.5%. Understory species include *Mianthemum stellatum* (L.) Link (false Solomon's seal), *Vicia Americana* (Muhl. ex Willd.) ssp. *americana* (American vetch), *Thermopsis rhombifolia* (Nutt. ex Pursh) Nutt. ex Richards (golden bean) and *Carex siccata* (Fehr 1984).

4. DISTURBANCE

Ecosystems are a direct product of the regional disturbance regime and communities are a direct product of the local disturbance regime. A disturbance is any discrete event in time and space, which disrupts ecosystem, community or population structure and changes resources, substrate availability or the physical environment (Picket and White 1985). Natural disturbances include fire and grazing, which influence the rate of succession and the successional pathway for community development. The collective term for these disturbances is the natural disturbance regime. Anthropogenic disturbances are created by activities such as cultivation or resource extraction. Ecosystems and communities develop and reach a dynamic steady state in composition, structure and function under these combined natural and anthropogenic disturbances. Individual species reach this state through morphological and physiological adaptation.

Over time individuals of most generations experience disturbances, and only resistant individuals survive, reproduce and pass their genes to the next generation (Forman 1997). However, anthropogenic activities on the landscape alter the natural disturbance regime of grassland ecosystems, which in turn affects plant community composition. Hobbs and Hueneke (1992) developed a model suggesting how species composition is affected by changes in the natural disturbance regime. This model suggests decreases in frequency and intensity of natural disturbances decrease native species diversity. However, increase in disturbance frequency and intensity also can promote elimination of native species and enhancement of invasion. This is the case when disturbances such as fire are infrequent as a result of suppression and grazing is both frequent and intense.

4.1 Fire and Grazing

Prior to settlement, wild fires and herds of bison moved across the prairies of North America. These disturbances interact with one another over a variety of spatial and temporal scales occurring as a functional characteristic of this region (Glenn et al. 1992).

Historically fire has been a vital event in the prairie region (Nelson and England 1971, Higgins 1984, 1986). It occurred naturally from lightning strikes, and was accidentally and deliberately set by aboriginal peoples for attracting game, removing pests and signalling. Occurrence of fires varied in season and space but predominantly occurred in July and August (Higgins 1986). Many opinions among current land users reflect policies of active fire suppression from the days of early European settlement on the prairie region (Nelson and England 1971). Fire is often seen as a large destructive force that destroys crops, wildlife and their habitats, leaving behind a blackened, desolate area (McKay and Campbell 1994). However, grassland ecosystems developed under and rely on disturbance to perpetuate its unique characteristics through time (Daubenmire 1968, Vogl 1974).

Grazing is a disturbance that is an original component of the natural disturbance regime. However, this disturbance has been altered from its historic form. Historically, fescue grassland was grazed periodically by large ungulates such as bison (Coupland and Brayshaw 1953). Presently livestock grazing is the most common land use of native prairie grasslands (Kerr et al. 1993). Although grazing still occurs, the patterns produced are different because of differences in grazing habits between bison and domestic cattle (Plumb and Dodd 1993). Campbell et al. (1994) concluded that the expansion of woody plants is also attributed to extirpation of plains bison, which suppress aspen through browsing, trampling and wallowing on saplings and toppling small trees. Bailey (1978), Anderson and Bailey (1979), Wright and Bailey (1982) and Campbell et al. (1994) found increased cover of woody plants in fescue prairie, which helps support the theory that bison grazing, coupled with fire, suppressed tree and shrub expansion.

Current grazing regimes tend to be more continuous, more intensive and allow native plants little time for recovery (Kerr et al. 1993) compared to historic regimes. With advances in grazing research the development of systems such as rotational and deferred grazing have greatly improved rangeland management.

Grazing influences the individual plant, the plant community, litter, soil and soil microorganisms. Individual plant response to grazing is related to regional climatic conditions, site conditions, palatability, morphology, phenology, competition from other plants, intensity of grazing and grazing history (Saskatchewan Agriculture Development Fund n.d. cited in Kerr et al. 1993). A plant's ability to recover from grazing depends on the ability to replace photosynthetic tissue, retain a competitive position in the plant community (Caldwell 1984; Kerr et al. 1993), and the ability to maintain carbohydrate reserves to survive periods of dormancy. Wheatgrasses, *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths (blue grama) and *Hesperostipa comata* may shift from a tall, upright growth form to a prostrate growth form as a response to long term grazing (Romo and Lawrence 1990). Plant species are classified as decreasers, increasers or invaders based on their response to grazing pressure. Decreasers have either high palatability and are favoured by grazing ungulates or are species less adapted to compete under grazing pressures. Increasers are less palatable or are highly adapted to compete under grazing pressures. Invaders encroach and out compete decreasers and increasers with increased grazing pressure. Grasses are well adapted to grazing because their apical meristem is at, or below, the soil surface and is not removed by grazing animals. The effect of grazing on individual grasses depends on the species, season, intensity, frequency and duration of the defoliation event (Vallentine 1990).

The initial effect on heavily grazed plants is a decrease in density, vigour, productivity and canopy cover of palatable forage plants. Overgrazing depletes carbohydrate reserves, which plants need for winter survival, early spring growth and growth after defoliation (Saskatchewan Agriculture Development Fund n.d. cited in Kerr et al. 1993). Root biomasses of heavily grazed plants tend to be lower and more concentrated in the upper regions of the soil profile (Vallentine 1990). Severe grazing intensities can deplete photosynthetic activity to where insufficient carbohydrates are produced to promote root growth. Decreased root production reduces plant competitive ability allowing it to be more susceptible to environmental stress such as temperature extremes and lack of moisture (Romo and Lawrence 1990). Willms et al. (1986), from studies in Alberta, suggested dormant season grazing in fescue prairie does not have unfavourable effects on forage yield but enhances grass plant vigour by stimulating tillering.

Grazing benefits individual plants by removing older tissues less efficient in photosynthesis, increasing light availability and increasing stomatal resistance. This promotes water conservation, increases forge production due to compensatory growth, releases nutrients and recycles nutrients in animal wastes, speeding senescent forage breakdown by trampling. Creation of favourable microsites in hoofprints for seedling establishment occurs, especially on hard packed, well drained soil (Saskatchewan Agriculture Development Fund n.d. cited in Kerr et al. 1993).

Increased grazing pressures affect the plant community as a whole. Generally less palatable subdominant species in the community increase as grazing increases, and species composition shifts from taller to morphologically shorter grasses as soil conditions change (Kerr et al. 1993) or invasive exotics are allowed to establish. Therefore shifts in composition also produce shifts in community structure and functon. Moss and Campbell (1947), Looman (1969), and Willms et al. (1985, 1988) all noted shifts in fescue grassland from rough fescue and oat grass to less palatable forbs, sedges and invader species.

Grazing allows formation of patches within the community which contribute to spatial and temporal habitat heterogeneity and therefore produce greater species diversity. High variability in composition, structure and function is characteristic of natural systems.

Litter is the accumulation of undecomposed organic matter at the soil surface (Kerr et al. 1993). Litter conserves moisture by insulating the soil against solar radiation, reducing temperature, light and evaporation at the soil surface (Hopkins 1954, Weaver and Rowland 1952, Willms et al. 1986). Although litter has an important ecological function in grasslands, removal by grazing can have beneficial affects. Light to moderate grazing reduces organic matter build up. Subsequent trampling breaks down dead plant material and exposes mineral soil (Trottier 1992, Kerr et al. 1993) and creates microsites for seedling establishment. Grass tillering increases when light penetration increases following defoliation (Langer 1963). Litter loss can produce moisture deficits in arid conditions because soil temperature is higher and roots are near the surface (Willms et al. 1986). This moisture deficit is also contributed to by reduced snow trap due to the loss of standing litter; erosion potential by wind and water can increase on erodible substrates and slopes.

When infiltration capacity is reduced under compacted soil conditions and more bare ground is exposed due to plant cover removal, runoff and erosion can increase (Antevs 1952, Branson 1975, Kerr et al. 1993). Naeth et al. (1990) concluded surface bulk density and penetration resistance increase in heavily grazed areas. Under increased surface bulk density and penetration resistance soil water at the root zone in mixed grass prairie is reduced (Naeth et al. 1991). Naeth and Chanasyk (1995) found grazing reduces soil water by impacting infiltration via treading and on evapotranspiration through defoliation. They also concluded maintaining plant cover to allow snowmelt infiltration is critical to recharge soil water in fescue grassland.

In fescue grassland, Willms et al. (1988) noted soil organic matter, carbohydrates and depth of topsoil (Ah horizon) were significantly greater on ungrazed patches but nitrates, ammonia and available phosphorus were greater on overgrazed patches. Studies by Dormaar and Willms (1998) in fescue grasslands showed heavy grazing of fescue grassland can lighten topsoil colour, decrease soil moisture, raise pH, lower total P, increase $NaHCO_3$ and soluble P and increase soil temperature. Total N remains the same, but C:N ratios decrease because total carbon decreases. When carbon is abundant in relation to nitrogen, microbial N demands and N immobilization potentials are high (Shariff et al. 1994) but when C:N ratios are low N immobilization potentials are low and net N mineralization may increase (Holland and Detling 1990, Shariff et al. 1994). This imbalance in N mineralization can lead to luxury uptake by plants. Therefore the phrase from Holochek et al. (1989) "take half leave half" may be crucial to maintaining balances in N cycles (Shariff et al. 1994).

4.2 Pipelines

Pipeline installation is a major, anthropogenic disturbance to native prairie ecosystems. The removal of existing vegetation occurs in lifting the topsoil from the RoW. Pipeline construction commonly increases surface soil bulk density, reduces topsoil depths and decreases soil organic matter (Naeth 1985). Naeth (1985) found changes in soil and hydrology most significantly impacts on revegetation. Soil hydrologic properties may be altered when a native grassland ecosystem is disturbed by pipeline installation (Cannon and Landsburg 1990, Naeth et al. 1987, Zellmer et al. 1987, Kerr et al. 1993). Backfilling the trench creates berms, which disrupt natural surface drainage patterns (Kerr et al. 1993). In severe cases of soil compaction, groundwater flow regimes may be altered. Soils may take 50 years to physically and chemically return to conditions similar to those prior to disturbance (Whitman et al. 1943, Dormaar and Smoliak 1985).

Depending on local climate and post site management, revegetation rate and pathway can differ greatly with site. The time it takes to reach predisturbance vegetation structure and function can vary greatly and in some cases never be achieved due to influences such as site management and invasion by perennial invasive exotics.

5. PIPELINE RECLAMATION

In most cases, pipeline RoWs can be successfully revegetated (Kerr et al. 1993). Until recently, the objective of revegetation has been to control erosion rather than to reestablish natural vegetation composition (Kerr et al. 1993). Although erosion must be controlled on steep slopes or sites with high erosion potential, the use of rapidly establishing, dense and highly productive grass species may severely inhibit native grassland community development through succession.

Revegetating disturbances with native plant species has become a common practice to improve revegetation success and provide more structurally and functionally natural plant communities in native prairie grasslands. Typically, native seed mixes are provided by commercial seed companies, and often are comprised of species that are not local ecotypes or are cultivars. The use of non local ecotypes may result in poor adaptability or more highly competitive plants and potentially a loss of genetic diversity (Kerr et al. 1993). Before seeding was used in revegetation, most pipelines were left to revegetate naturally.

Natural recovery is essentially the process of revegetation of disturbed areas by allowing natural plant succession. Natural recovery largely depends on climatic conditions and therefore, varies among Alberta ecoregions (Kerr et al. 1993). The effects of disturbance on species composition are variable depending on vegetation history of the area and life history of the dominant vegetation and presence of introduced or invasive species (Armesto and Pickett 1985). The community composition following pipeline installation, under natural recovery, depends mainly on seed bank composition and its requirements for germination and establishment. Gibson and Brown (1991) attributed differences in species' establishment rates to composition of the seed bank formed after the field was abandoned from cultivation. Perez et al. (1998), from studies in the Nebraska sandhills prairie, found seed quantity, species diversity and seed germination were highest in the upper 0 to 5 cm of topsoil.

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CHAPTER II

EVALUATION OF PIPELINE RECLAMATION TECHNIQUES IN ALBERTA ASPEN PARKLAND SANDHILLS

1. INTRODUCTION

Pipeline installation usually includes stripping the soil A horizon (topsoil) from either a portion of or the entire right-of-way (RoW). Topsoil conservation is important because it is high in organic matter, making it a superior substrate for plant growth compared to subsoil (Landsburg and Cannon 1995), and preventing soil quality reduction from horizon mixing. Soil chemical and physical characteristics are estimated to require 50 years for restoration to predisturbance conditions (Whitman et al. 1943, Dormaar and Smoliak 1985). Naeth et al. (1987) suggest that a period of 100 years would be required to restore lost soil organic matter. Pipeline trenches are dug with soil removed in one, two or three lifts separating B (subsoil) and C (parent material) horizons, depending on profile depth. The length of time soil is stockpiled is believed to impact viability of plant propagules, forms and levels of soil nutrients and amount of organic matter. Shallow topsoil stripping reduces burial of viable native plant propagules such as seeds from the seed bank, stolons and rhizomes, all of which are generally concentrated in the upper A horizon in sandhills prairie. Perez et al. (1998) found the highest concentration of seed and species diversity in the 0 to 5 cm depth, making shallow topsoil stripping an attractive method to best utilize the native seed bank.

Soil erosion, via wind or water, is of concern where soils have high erosion potential due to texture, exposure and slope degree. Many reclamation techniques have been introduced to reduce soil erosion, including use of cover crops and straw, but often have secondary effects. Straw can affect moisture content, nutrient availability and seedling establishment (Jacoby 1969, Wilson and Gerry 1995, Morgan and Seastedt 1999, Török et al. 2000, Baer et al. 2003, Wilson et al. 2004). Control of early successional annual plants with lower competitiveness generally has no effect on establishment and survival (Wilson et al. 2004) as they decrease and disappear from the stand in two to three years (Naeth 1985, Baer et al. 2003). Thus annual ruderal species that colonize and establish quickly following disturbance may be a valuable and cost effective means of erosion control.

Revegetation in the past was achieved through natural recovery or seeding of a single tame agronomic forage or tame agronomic forage mix. These agronomic species, even as a small proportion of a seed mix, can dominate the plant community (Depuit and Coenenberg 1979). Use of native species for revegetating disturbances has become common practice and natural recovery has recently been revived as a viable revegetation method in appropriate situations. These methods are considered the best to influence successional pathways and plant community structure and function towards predisturbance conditions.

Sandy soils are highly erodible and rapidly drained (Loucks et al. 1985, Steuter et al. 1990, Lesica and Cooper 1999), especially following a disturbance that removes existing vegetation. Disturbances such as pipeline construction shift the successional status back to early seral stages of secondary succession. During this period of succession water holding capacity can be reduced due to loss of organic matter and erosion potential is heightened. Seeding late successional native grass species may be valuable to rapidly reach characteristically later stages of succession, if the species can establish and survive. However a late successional plant species may not be physiologically or morphologically adapted to the harsh growing conditions resulting from the disturbance. Using soil stabilization and soil handling techniques that mimic later stages of succession may facilitate late successional species establishment and survival in early seral stages.

If characteristically late successional native species are able to establish when seeded, the question arises as to whether species composition parallels natural communities and those that establish from natural recovery. When natural stages in succession are skipped, are natural functioning biologically diverse communities the product? Early successional plant species are important components in biological diversity (Pickett and Thompson 1978, Bunnell 1995, Lesica and Cooper 1999). If establishment is successful do differences between a seeded community and a naturally established community persist?

The objectives of this research were to compare effects of shallow topsoil stripping with conventional techniques, cover crop use and straw crimping with no erosion control, and seeding a native grass mix with natural recovery. These comparisons were addressed through measurement of specific vegetation and soil chemical and physical characteristics affecting revegetation.

2. MATERIALS AND METHODS

2.1 Site Description

The Alliance pipeline is a high volume, natural gas pipeline that runs from west of Fort St. John, British Columbia, Canada to the Aux Sable liquid processing facility near Chicago, Illinois, United States of America (Figure 2.1). The total distance of the pipeline is 2,988 km (1,559 km in Canada and 1,429 in the United States). The research site is located within the NE ¼ and SE ¼ of 22 43 5 W4 and the SW ¼ and SE ¼ of 23 43 5 W4, approximately 25 km southeast of Wainwright, Alberta on Alberta Public Lands. The site has short, warm summers and long, cold, dry winters. Mean annual precipitation is 450 mm (Fehr 1984) with 300 mm occurring in the May through September growing season (Strong and Leggat 1981). During the research period, annual and growing season precipitation were above long term normals for 1999 and 2000 and below for 2001 (Tables 2.1 and 2.2).

The research site is located in the Central Aspen Parkland Subregion of the Aspen Parkland Ecoregion and classified as sandhills native prairie. The topography is gently undulating (slope 2 to 9%) and soils are dark brown chernozems, rego dark brown chernozems and dark brown regosols on glaciofluvial aeolian deposits of sand and sandy loam texture. Soils are well drained and highly erodible following disturbance to vegetation and have an agriculture capability classification of 6. Dominant graminoid herbaceous species are *Hesperostipa comata* ((Trin. & Rupr.) Barkw) (needle and thread grass), *Koeleria macrantha* (Ledeb.) Schultes (june grass), *Festuca saximontana* Rydb. (sheep fescue), *Calamovilfa longifolia* (Hook) Scribn. (sand reed grass) and *Carex* sp. (sedges). Dominant forbs are *Selaginella densa* Rydb. (prairie clubmoss), *Solidago missouriensis* Nutt. (low goldenrod) and *Cerastium arvense* L. ssp. *strictum* (L.) Ugbor. (field chickweed). Dominant shrubs are *Symphoricarpos occidentalis* Hook. (western snowberry), *Amelanchier alnifolia* Nutt. (saskatoon berry) and *Rosa woodsii* Lindl.

(wood's rose) (Coupland and van Dyne 1979). The dominant tree species is *Populus tremuloides* Michx. (trembling aspen).

The pipeline was installed in spring and summer 1999 running east to west. Located in native prairie on Alberta Public Lands, the pipeline falls under the legislation of the Alberta Public Lands Act and therefore requires use of native species in revegetation. The land is under a grazing lease and is grazed mid-summer each year. Pipeline reclamation and application of research treatments occurred in fall 1999.

2.2 Experimental Design

The experimental design is a split block, split-split plot replicated four times (Figure 2.2). Each of the four blocks is split into a conventional and a shallow topsoil stripping treatment. Each main plot is the full width of the RoW (32 m) and is 75 m long. The length of each plot is divided into three erosion control treatments (subplots); 25 m of straw crimping, 25 m of cover cropping and 25 m of no erosion control. Each 25 m erosion control treatment is then split into two 12.5 m revegetation treatment subplots that were either seeded with a commercial native seed mix or not seeded to represent natural recovery. Thus, there are 3 erosion control and 2 revegetation treatments within each of the 8 soil stripping treatment plots for a total of 48 plots.

The research site was fenced in summer 2000 to exclude cattle grazing throughout the duration of the research. Grazing was excluded because some measurements required permanent markers that could be damaged by cattle. Although not commonly practiced, deferred grazing by livestock has been recommended for at least one year following revegetation of pipeline RoW. This research presents results for a two year grazing deferral.

2.3 Treatments Application

Half of the 8 main plots were conventional stripped with the upper 10 to 15 cm of topsoil (entire A horizon) removed. The other half were shallow stripped with the top 5 cm stripped and piled separately from the second lift of the remaining topsoil. Subsoil from the trench was removed in a single lift and this soil was used to infill the trench. There was no mixing of topsoil and trench soil in any of the treatments. With shallow topsoil stripping the first lift is replaced as the uppermost soil layer. Topsoil stripping was done between August 18 and 19, 1999 with D6R-XL and D6M-LPG caterpillars equipped with blades. Shallow topsoil stripped plots had the first lift stockpiled on the southeast corner of the 5 m temporary extra work space and the second lift on the southwest corner to prevent admixing.

In fall 1999, *Secale cereale* L (fall rye) was drill seeded at 17 kg ha^{-1} with 15 cm row spacing. This cover crop was used to stabilize the highly erodible soils and to increase native seedling establishment by protecting seedlings from sun and wind, increasing snow trap and soil moisture. Plots were to be seeded in north and south passes across the RoW, but at the reclamation foreman's discretion the plots were seeded east and west down the RoW length, dropping the seed drill on plots requiring cover crop. When the seed drill was lifted to cross natural recovery plots, seed dropped from the drill boots. Therefore, plots that were not to have cover crop had some seeded areas. The plots were stratified to avoid sampling these areas.

Triticum aestivum L. (wheat) straw assessed for noxious and high-density weed problems was baled, then spread at approximately 5400 kg ha^{-1} and crimped into the soil with coulters (disks on the implement) at 15 cm spacing. The crimped straw theoretically provides protection for seedlings to wind, reduces soil erosion, increases snow trap and soil moisture and adds organic matter to the soil, which may improve water holding capacity.

The site was erroneously fertilized (35 N - 11 P - 0 K – 3S) by the pipeline reclamation company at a rate of 200 kg ha^{-1} in fall 1999. Preliminary site reconnaissance indicated no evidence of residual fertilizer in spring 2000. The readily available form of nitrogen in the fertilizer likely rapidly leached following snowmelt.

A native grass mix was seeded at 9 kg ha^{-1} to half of each erosion control treatment within each of the soil stripping treatments. The seed mix was Alliance Pipeline Number Seven (Table 2.3) for use primarily on sandy, droughty soils. The seed was drilled at 12.5 cm row spacing to a depth of 1 to 3 cm. Plots were seeded in fall 1999. Natural recovery plots did not receive any seed other than those treatments that also included cover cropping.

Festuca rubra L. (creeping red fescue) was erroneously included in the seed mix instead of *Festuca altaica* ssp. *hallii*. The species seeded as sheep fescue was also questioned as the taxonomy of this species is complex. Sheep fescue, native to Alberta prairie is also called Rocky Mountain fescue, *Festuca saximontana* Rydb. and has taxonomically been referred to as *Festuca ovina* L. var. *saximontana* (Rydb.) Gl. The common name, sheep fescue, refers to *Festuca ovina*, which is not native and is widely sold as a cultivar. Because the seed mix used only common names the actual species seeded is uncertain. *Festuca saximontana* did establish from the seed bank in natural recovery treatments and was found on adjacent undisturbed grassland. Another sheep fescue was identified only on seeded plots indicating the seeded sheep fescue was either morphologically different than the native *Festuca saximontana* or the tame species *Festuca ovina* was included in the native seed mix.

2.4 Soil Properties

In the second field season, 3 composite soil samples were collected from each experimental unit (Figure 2), at depth increments 0 to 5, 5 to 10, 10 to 15 and 15 to 20 cm. Samples were collected along a north-south transect at intervals 7, 14 and 21 m, air dried, sieved to 2 mm and stored in sealed plastic bags.

Two of the three samples were randomly selected for chemical analyses at depth increments 0 to 5 and 5 to 10 cm. The depths selected for analysis were strategically selected to identify any effects the topsoil stripping treatment had on soil properties. Total organic carbon and total organic matter were determined by wet oxidation-redox titration (Tiessen and Moir 1993). Available nitrogen (NO_3) was determined using 0.001M $CaCl_2$ extraction (Carter 1993).

One of the three samples from the two natural recovery treatments within each block was randomly selected and analyzed at depth increments 0 to 5 and 5 to 10 cm for particle size analysis. Two of the three samples from the two seeded treatments within each block were randomly selected and analyzed at depth increments 0 to 5, 5 to 10 and 15 to 20 cm for soil moisture retention. Depths for both particle size and moisture retention were strategically chosen to clearly identify treatment effects. Only one sample was selected from each experimental unit for particle size because of homogeneity of the soils determined by preliminary site reconnaissance (Appendix A1). Particle size was determined by hydrometer (Carter 1993). Samples were not treated for organic matter or calcium carbonates because organic matter was below 5% and calcium carbonates were low. Soil moisture retention was measured by pressure plate extraction (Carter 1993) at matric potentials of -10, -33 and -1500 kPa.

2.5 Vegetation Properties

Cover measurements were made in July 2000 and 2001. Within each experimental unit, 6 stratified, random, 0.1 m^2 quadrats were sampled. Within each quadrat, percent bare ground, live vegetation canopy cover by species and straw cover in the straw crimp were assessed in the first field season with lichen, *Selaginella densa*, dung and litter added to the cover assessment for the second field season. Species density (number of individual plants/unit area) was measured in July 2001 in 6 randomly located quadrats in each experimental unit. Plant species diversity was determined from cover and density data.

The seed bank was assumed to be consistent throughout the site since disturbance history and edaphic conditions were relatively consistent throughout. Canopy cover and plant density were observed at species level and grouped for statistical analyses where functional roles and management considerations were considered. The groups included total vegetation, native grass, native forbs, perennial exotics and annual exotics. Native species were classified as those species which occurred on undisturbed areas of the site that were not present as a result of human introduction and species found in the undisturbed grasslands of Alberta. Exotic species included alien or introduced species including those considered to be naturalized, benign or invasive.

2.6 Statistical Analyses

Soil chemical, soil moisture retention, plant cover and density data were all statistically analyzed using the mixed procedure in SAS. The mixed procedure was chosen to eliminate the compounding effect that split plot designs have on error term. Sattherwaite approximation was used to adjust degrees of freedom for unequal variances.

Blocks were treated as random factors. Mean comparisons were performed using contrast statements (SAS Institute 2000).

Paired t-tests in SAS were used to compare soil moisture retention for the three matric potentials and comparisons between year 1 and year 2 data for native grass and annual forb canopy cover. Correlation analysis in SAS was used to determine correlation coefficients between soil moisture retention data at each matric potential and organic carbon; available nitrogen and organic carbon; and organic carbon and soil particle size. Soil particle size data were analyzed using the mixed procedure in SAS. Plant diversity (number of species/experimental unit) measurements were compared between years using a paired t-test in Microsoft Excel. Significance for all analyses was set at a 95% confidence level with p-values for significant effects below 0.05.

Extreme outliers were observed in available nitrogen data and when excluded from analysis the difference in means between straw crimping and the other two erosion control treatments, although still significant, was reduced. These outliers were not removed from the data before analysis because they were consistent across depths for a particular subsample which rules out laboratory error. The values for these data ranged between 7 and 30.0 mg N/ kg soil. A possible explanation for these outliers is due to high wildlife activity on the RoW. Sampled locations may have been locations with animal excrement (feces or urine) even though care was taken not to sample locations with visible evidence of feces. This could possibly explain the higher occurrence of these outliers in straw crimped treatments (14 of 16 outliers) which were frequented by deer and moose for bedding and grouse feeding on wheat seed remaining in the straw.

3. RESULTS AND DISCUSSION

3.1 General Results

Soils were sand textured (90 to 94% sand), deficient in total organic carbon (1.08 to 1.65%) and low in available nitrogen (NO_3 1.58 to 6.48 mg kg^{-1}) (Table 2.4). The extremely coarse texture coupled with very low organic carbon resulted in low soil moisture retention.

Live vegetation cover averaged 13.8% in 2000 and 12.6% in 2001. Native grass cover increased from 1.9% in 2000 to 7.4% in 2001. Native forbs decreased over the two growing seasons from 6.6% to 1.5%. Perennial exotics were similar in the two years at 0.05 and 0.08% cover; annual exotics cover decreased from 4.9% to 1.4%. Straw cover decreased from 16% to 12.1%. Cover crop cover also decreased from 0.8 to 0.02% over two years. Bare ground uncharacteristically increased from 70.6% in 2000 to 76.2% in 2001.

In the second growing season, plant density was 117 plants m^{-2}, comprised mainly of native grasses and annual exotics with a few native forbs and perennial exotics (Table 2.5). Although plant community species composition ratios changed considerably over the two growing seasons, overall plant diversity in the experimental unit remained relatively constant at 17.3 species 400 m^{-2} in 2000 and 17.6 in 2001 (Figure 2.3). Species present in year one were present in year two but proportions of annual species decreased and perennials such as native grasses increased.

3.2 Topsoil Stripping

3.2.1 Effect on Plant Establishment and Colonization Dynamics

Conserving the soil seed bank through shallow topsoil stripping did not increase native plant cover over conventional topsoil stripping (Table 2.6) and density (Table 2.7, Figure 2.4). More viable propagules were expected to concentrate in the upper 5 cm of the A horizon as described by Perez et al. (1998) with the theoretical potential to improve vegetation establishment.

Topsoil stripping was significant when the three-way interaction of topsoil stripping, erosion control and seeding was tested ($p = 0.0181$). This was considered the result of cascading influences of seeding and erosion treatments, but the interaction of these two treatments alone was not significant ($p = 0.8497$). Three-way interactions are extremely difficult to interpret and easy to make erroneous conclusions, thus no conclusions were made on which treatment combinations performed better. However, we can be confident the topsoil stripping treatment influences this result.

The unexpected result of topsoil treatments, as a main effect, not significantly affecting vegetation properties was not due to topsoil treatment misapplication. There was no significant interaction of topsoil stripping treatment and depth for organic carbon ($p = 0.4588$) (Table 2.8). Organic carbon at 0 to 5 cm for shallow topsoil stripping was numerically lower than conventional stripping (Table 2.8). The upper 5 cm had significantly more than the 5 to 10 cm increment, but only when analyzed as a main effect (depth) (Table 2.8). The interaction between topsoil stripping and depth for sand composition was significantly higher in the conventional topsoil stripping treatment at 0 to 5 cm than the shallow stripping treatment ($p = 0.0169$) (Table 2.9). This indicates treatments were applied correctly otherwise mixing would have resulted in higher sand at 0 to 5 cm in the shallow topsoil treatment. The lack of topsoil stripping treatment effect on native plant cover and density cannot be attributed to soil available nitrogen as stripping had no effect on available nitrogen. These results support those of Dejong and Button (1973), who found nitrate and phosphorus concentrations in the upper 15 cm did not change with soil mixing at pipeline installation.

3.2.1.1 Effect of *Hesperostipa comata* Abundance

Hesperostipa comata ssp. *comata* (needle and thread grass) was the most abundant native grass in natural recovery plots comprising 48% of native grass canopy cover, 28% of total vegetation cover and averaging 25.5 plants m^{-2} (Figure 2.4). The species is not usually considered early successional. However, Lesica and Cooper (1999) who found *Hesperostipa comata* dominant in early seral vegetation of the Centennial Sandhills of southwest Montana, and this study, show it is a significant colonizer and may be abundant in seed banks in sandhills prairie ecosystems. Its 2001 canopy cover was significantly higher ($p < 0.0001$) in unseeded (4.7%) than seeded (2.3%) treatments indicating niche replacement of native grass species established from planted seed. Lack of significant effect on *Hesperostipa comata* canopy cover between shallow topsoil stripping (3%) and conventional topsoil stripping (4%) treatments indicates abundance of *Hesperostipa comata* seed in the seed bank confounded results for native grass canopy cover. Even if soil mixing had occurred there would have been no difference in native grass canopy cover. Perez et al. (1998) found *Hesperostipa comata* was one of the most abundant cool season grasses in the seed bank in the Nebraska sandhills. This may not be the case in all situations because seed bank composition is dependent on past disturbance events, edaphic conditions and granivory (Schott and Hamburg 1997). Archibold (1980), found species present, number of individuals and number of non-germinating seeds differed greatly under different land uses. Perez et al. (1998) also found correlation consistently low between number of seeds in the seed bank and germination.

The abundance of *Hesperostipa comata* was not a product of seed dipersed from adjacent undisturbed areas. Rabinowitz and Rapp (1981) found the majority of seed from *Schizachyrium scoparium* (Michx. Nash) (little bluestem), *Andropogon gerardii* Vitman (big bluestem) and *Sorghastrum nutans* (L.) Nash (indian grass) dispersed less than 2 m from the parent plants with only 2.3%, 0.8% and 8.9% of total recovered seed dispersing to a distance of 2 m. These findings paired with lack of wind dispersal capability would support the argument that establishment of needle and thread grass came from the seed bank.

The native and exotic annual forbs that established from the seed bank were also abundant. The lack of statistical differences in annual exotic and native forb cover for the two topsoil stripping treatments indicates these annual species were abundant in the seed bank. Even if mixing of the topsoil and subsoil had of occurred, because of the large quantities of seed in the seed bank it would be difficult to determine statistically if shallow topsoil stripping improves plant establishment. Thus the lack of difference in cover and density of native plants with topsoil stripping treatments over the short-term is most likely due to the large amounts of needle and thread grass and annual forb seed present in the soil seed bank.

3.2.1.2 Long Term Influences of Shallow Topsoil Stripping on Vegetation

Although effects of shallow topsoil stripping on native vegetation cover and density were not evident in the two years of this research, it would be valuable to investigate if differences in plant community composition, structure and function occur after 2 years. Species less common in the seed bank may be reduced further through soil mixing with conventional topsoil stripping which could alter succession and future community composition affecting overall site biodiversity. The seedbank was not examined in this study but cover in years 1 and 2 and density in year 2 showed an abundance of annual forbs establishing from the seedbank. The uncharacteristically high establishment of native grasses, primarily *Hesperostipa comata*, is not supported by traditional successional theory (Perez et al. 1998). Perez et al. (1998) found a low abundance of annuals established from sandhills prairie soil relative to perennial grasses even though *Chenopodium album* L. (lamb's quarters) was the most abundant species in the seed bank. Perennial grasses with commonly high germination and emergence in sandhills prairie following disturbance, such as *Sporobolus cyptandrus* (Torr.) Gray (sand dropseed) with up to 20,000 seeds m^{-2} on the seed bank (Lippert and Hopkins 1950), had low establishment in this study and made up only 2% of the total vegetation cover in 2001. Potvin (1988) found sand dropseed contributed <1% of ground cover when it comprised as much as 50% of the seed rain indicating some perennial grasses display temporal variation in viable seed dispersal and colonization of disturbed sites.

3.2.2 Effect on Soil Properties

Topsoil stripping alone did not affect sand or clay content (Table 2.9). The interactions between topsoil stripping treatment and depth were significant with sand content at 0 to 5 cm higher under conventional than shallow topsoil stripping. Sand increased significantly ($p = 0.0236$) with depth. Clay was significantly higher ($p < 0.0001$) at 5 to 10 cm than at 0 to 5 cm, declining with depth. Clays tend to leach from surface horizons to the B horizon where they accumulate. The clay at 5 to 10 cm was visible during sampling as a lens in block 4. This clay lens may have skewed the clay data for this depth increment throughout the site. Because blocks are treated as a random factor they cannot be tested using the mixed procedure. Therefore, the general linear model was used to test clay content by block. Block 4 had significantly higher clay content (6.25%) than block 3 (5.75%), 2 (5.5%) and 1 (3.25%).

Topsoil stripping treatments did not significantly affect organic carbon but there was a significant difference in organic carbon between depth increments (Table 2.8). Total organic carbon was significantly higher at 0 to 5 cm than 5 to 10 but was not significantly correlated with clay ($r = 0.17$, $n = 16$) or sand ($r = - 0.04$, $n = 16$). These results contradict those of Lesica and Cooper (1999), where high correlation was found between sand and organic matter ($r = - 0.86$, $n = 10$). This may mean the variation between stripping treatments was too small to be identified by the sample size. Total organic carbon treatment means ranged from 1.08 to 1.65%. Soils with such low organic carbon and extremely high sand would be rapidly drained and the smallest increases in organic carbon may be biologically significant in retaining moisture essential for plant growth and survival, especially during drought periods.

Soil moisture retention within treatment was significantly different at each matric potential ($p < 0.0001$). This was unexpected considering the relatively homogeneous and extremely coarse soil textures. The sharp decrease between -10 and -33 kPa compared to the degree of change between -33 and -1500 kPa (Figure 2.5) is due to the extremely sandy texture. Once the matric potential reaches a particular threshold the degree of moisture retention decrease is less dramatic. Erosion control and topsoil stripping treatments had no significant effects on soil moisture retention although straw crimped treatments had slightly lower numerical moisture retention than the other erosion control treatments (Table 2.10). There is no certain explanation for these results, but it may be interesting to investigate the effect of root biomass on soil moisture retention since straw crimped treatments had less cover and lower densities.

Topsoil stripping had no significant effect on soil moisture retention, but moisture retention decreased with depth (Figure 2.6). Larger particle sizes were expected to correlate with lower moisture retention, but this was not the case. There was no significant correlation between sand and moisture retention at -10 kPa ($r = -0.05$; $p = 0.78$), -33 kPa ($r = -0.18$; $p = 0.32$) and -1500 kPa ($r = -0.09$; $p = 0.62$). Although depth significantly affected particle size, the difference in sand or clay content for any depth increment was negligible (Figure 2.7). There was, however, a significant correlation between total organic carbon and soil moisture retention at each matric potential (-10 kPa ($r = 0.64$; $p < 0.0001$), -33 kPa ($r = 0.75$; $p < 0.0001$) and -1500 kPa ($r = 0.76$; $p < 0.0001$)). Organic carbon, which was also significantly affected by depth, explains the greater soil moisture retention in the upper depth increments. Potvin (1993), in researching native grass seedling establishment along topographic/moisture gradients in the Nebraska sandhills, found seedling establishment and survival greatest in valley slope positions attributing this to higher available moisture at this topographic slope position and concluding soil moisture was the major environmental limiting factor for seedling establishment rather than nutrients or light. Potvin's findings are supported by those of this research indicating the importance of soil organic carbon for soil moisture retention.

3.3 Erosion Control

3.3.1 Effect on Vegetation Establishment

Erosion was not a problem in year one (2000) across all treatments because of timely precipitation kept soil moist and stabilized during the establishment of annuals and native grass seedlings. Some erosion was evident in year two in the most exposed areas of the RoW and where vegetation was sparse.

Vegetation cover and plant densities were generally lower in straw crimping treatments (Tables 2.6 and 2.7). Applying straw at 5400 kg ha^{-1}, without consistent spreading, caused a bedding effect reducing canopy cover and inhibiting vegetation growth. Numerically lower densities for total vegetation, native grass, native forbs, and annual exotics were not statistically significant. Morghan and Seastedt (1999) found plant densities were unaffected but plant foliage decreased under a sugar and sawdust mulch. Mean densities for interactions between straw crimping and revegetation treatment for total vegetation and native grass were not significantly different with straw crimp seeded treatments higher than straw crimped natural recovery treatments showing straw did not reduce vegetation establishment (Table 2.7). The obvious reduction in plant growth in straw crimped treatments may have resulted from light reduction at the soil surface or by insulation of the soil reducing soil temperature. Intense heat, which is often observed at the surface on pipeline RoW, can negatively impact vegetation growth (Naeth et al. 1993), therefore the straw crimping treatment should have had a positive effect on vegetation. Adding a carbon source reduced available nitrogen in other studies (Wilson and Gerry 1995, Morghan and Seastedt 1999, Török et al. 2000, Baer et al. 2003, Wilson et al. 2004) but not in this one. Erosion control treatments had a highly significant effect on bare ground in both years (Table 2.6).

Although cover crop and no erosion treatments had significantly higher canopy cover than straw crimped treatments, the straw crimped treatment had significantly less bare ground as expected because straw covered 36% of the soil surface. Perennial exotics cover was not significantly different among erosion control treatments. Canopy cover (0.14%) and density (0.7 plants m^{-2}) were numerically highest under straw crimping and thus biologically significant since any increase in perennial exotics can compromise revegetation success. Species such as *Crepis tectorum* L. (narrow-leaved hawk's beard) would be expected in straw. Species such as *Poa pratensis* L. (kentucky bluegrass) would have come from the seed mix as it was present in seeded treatments. Overall seeding did not significantly increase perennial exotics cover (Table 2.6) except with *Festuca rubra* L. (creeping red fescue). Therefore increased perennial exotics can be attributed to straw crimping.

The fall rye cover crop and no erosion control treatments were equally effective in native vegetation establishment (Tables 2.6 and 2.7). The timely rains in early spring in year one facilitated the early establishment and rapid growth of fall rye in cover cropped treatments and annual weeds on plots without erosion control. During an extremely dry spring cover crops may be sparse and small, providing less protection from erosion which could ultimately impact the success of revegetation. In these conditions, plots without erosion control may actually have better native vegetation establishment due to erosion protection provided by more drought tolerant annuals. Canopy cover for native grass in no erosion control treatments were numerically higher than canopy cover in cover cropped treatments for both years (Table 2.6) This may indicate that the annual forbs had a slightly less competitive effect on native grasses than fall rye. The use of a cover crop did not lower bare ground compared to those treatments with no erosion control (Table 2.6).

3.3.2 Function of Early Successional Ruderals

Native and non-native annual forbs in treatments without erosion control provided the same function as the cover crop in establishing early, reducing erosion and providing protection for emerging native grass seedlings. Annual native and non-native plants, classified as early-successional ruderals, reduced in cover from year one (2000) to year two (2001) (Figure 2.8). The decrease in annual exotics and native grasses was significantly different ($p < 0.0001$ and $p < 0.0001$) (Figure 2.9). Many annual native species such as *Chenopodium pratericola* Rydb. (narrow-leaved goosefoot) and *Lepidium densiflorum* Schrad. (common peppergrass) and annual exotics like *Descurainia sophia* (L.) Webb (flixweed) and *Lappula squarrosa* (Retz.) Dumort. (bluebur), remained among the highest plant densities in year two (Figure 2.5). These plants were stunted with most *Lepidium densiflorum* , *Descurainia sophia* and *Lappula squarrosa* less than 10 cm tall with canopy covers of 0.24%, 0.14% and 0.96%, respectively compared to year one 0.27%, 0.43% and 2.16%. *Chenopodium pratericola* dominated the site in year one with 6.3% canopy cover compared to 0.02 % in year two. Annual species did not inhibit establishment of native grasses. Even where densities were highest on natural recovery treatments, these treatments actually had slightly higher native grass canopy cover than those that were cover cropped (Table 2.6). Wilson et al. (2004) found controlling annuals in restoration plots did not affect native grass establishment or survival. The annuals provide the same function as the cover crop in reducing soil erosion. These species established early in spring providing early ground cover and throughout the growing season provide shelter from harsh winds and intense heat that may have been detrimental to native grass seedling establishment. The large reduction in annual cover in just one growing season indicates the low competitive abilities of these species and their potential in providing cover and erosion control in pipeline revegetation. Similarly, Naeth (1985) found a large reduction in *Descurainia sophia* on revegetated pipelines in southern Alberta in just a couple of years and Baer et al. (2003) found early successional annuals disappeared after three years in a tall grass prairie restoration.

3.3.3 Effect on Soil Properties

Straw crimped treatments had significantly higher available nitrogen than cover crop and no erosion control treatments, which were not significantly different from each other (Table 2.11) supporting work by Stephenson and Schuster (1944) and Wilson et al. (2004). Straw should increase C:N ratios resulting in nitrogen immobilization and available nitrogen deficiency (Lindemann et al. 1989), but crimped straw did not contribute to soil organic carbon in year two (Table 2.8) and C:N ratios promoted immobilization (Figure 2.10). There was no positive correlation between available nitrogen and total organic carbon ($r = 0.03$; $p = 0.8019$). Soil moisture retention indicated no significant differences between erosion control techniques.

The high levels of available nitrogen may result from less vegetation in straw crimp treatments resulting in less available nitrogen uptake. Total plant density in the straw crimp treatment had approximately 50 plants m^{-2} less than cover crop or no erosion control treatments (Table 2.7). Seeded treatments had significantly less available nitrogen than natural recovery treatments (Table 2.11), which had significantly lower total vegetation densities than seeded treatments (Table 7).

In sandy soils, available nitrogen is readily leached, but straw may have reduced leaching in straw crimp treatments. The straw mulch may have also reduced soil temperature which in turn would reduce available nitrogen use by microorganisms. Soil moisture may have been higher due reduced evaporation and microbial mineralization of organic nitrogen may have been increased, producing higher levels of available nitrogen in straw crimp treatments. Stephenson and Schuster (1944) found straw mulching conserved soil moisture between 5 and 7.5 cm of equivalent rainfall. Wilson et al. (2003) attributed higher levels of available nitrogen in straw mulch treatments to a significant increase in soil moisture leading to increased mineralization by microorganisms. This effect is supported by the growth, survival and activity of microorganisms reduced under stressed soil conditions due to low water potential (Ψ) (Harris, 1981). Microorganisms use of energy to maintain water potential equilibrium with their environment [$(\Psi_t)_{cellular} = (\Psi_t)_{substrate}$] increases through osmotic regulation which further stresses these organisms. This increased stress combined with biochemical inhibition due to high intercellular concentration of solutes caused by low water potential leads to reduced microorganism growth, activity and death (Brown 1976, 1978; Watson 1970 Cited in Harris 1981). Nitrogen mineralization is optimized at 30 (- 0.3 bar) to 300 kPa (-3 bar) and decreases rapidly at 500 kPa (-5 bar) (Sindhu and Cornfield 1967 Cited in Sommers et al. 1980). If straw crimped treatments had field matric potentials < 500 kPa (- 5 bar) and cover crop and no erosion control treatments had matric potentials > 500 kPa (-5 bar) then straw crimp treatments would have increased microbial nitrogen mineralization. Soil matric potentials were not measured in the field, in this study, therefore this effect would have to be studied further. Whether or not this phenomenon would produce significant differences in nitrogen mineralization also would have to be tested experimentally.

3.4 REVEGETATION TREATMENTS

3.4.1 EFFECT ON SOIL AND VEGETATION PROPERTIES

Seeded treatments had less available nitrogen than natural recovery treatments (Table 2.11). Although not statistically significant, this difference is attributed to significantly higher density and canopy cover of native grasses using up more available nitrogen. These results contradict those of Wilson et al. (2004) where seeded treatments had higher levels of available nitrogen. In Wilson's research, seeded plots were tilled and control treatments were not. This would result in a large release of nitrogen in seeded treatments compared to the control, especially considering Wilson's research was conducted on a 20 year old oldfield. In this study both seeded and natural recovery treatments were disturbed by pipeline installation. Annual forbs appear to use less nitrogen than establishing native grasses, in contrast Wilson et al. (2004) found where herbicide was used to decrease annual species, available nitrogen was significantly higher. In this study vegetation density in year two was higher, canopy cover lower and native grass density and cover significantly lower in natural recovery than seeded treatments (Tables 2.6 and 2.7). Higher total vegetation density and higher nitrogen was due to the large number of small annual forbs (native and non-native) in the natural recovery treatment with observationally less extensive root masses compared to native grasses. If *Festuca rubra*, which was erroneously included in the seed mix, had been included in the data analysis as a native species grass density and cover would have been even higher in seeded treatments. *Festuca rubra* had high establishment with 6 plants m^{-2} in year two, second only to seeded green needle grass at 7 plants m^{-2} and natural establishing needle and thread grass at 25 plants m^{-2} (Figure 2.8). Plant species differ in above and below ground tissue concentrations of nitrogen and uptake rates, thus affecting nitrogen mineralization and influencing available soil nitrogen (Wedin and Tilman 1990). Wedin and Tilman found early successional grasses had lower uptakes and greater tissue concentrations, which contributed to nitrogen feedback and greater mineralization. The lower available nitrogen in seeded treatments may have resulted from a community occupied by a greater number of species with high uptake and low inputs compared to natural recovery treatments.

Native and non-native seeded grasses increased competition and therefore reduced canopy cover for native forbs and annual exotics significantly in year two (Table 2.6). Plants with higher nitrogen uptake and lower inputs, leading to slower mineralization are considered superior competitiors (Pastor et al. 1984, Tilman 1988). There were no significant differences in canopy cover for native forbs between seeded and natural recovery treatments in year one (Table 2.6). The native grass seedlings were not as robust in year one (native plant cover 2.1% in year 1 and 8.1% in year 2), possibly applying less competitive stress on native forbs. These results may be confounded by the annual native forbs in the data. Nevertheless, the competitive effect of the seeded grass is further expressed in canopy covers and annual exotics density, where year 2 annual exotic canopy cover and density were significantly lower in seeded compared to natural recovery treatments (Tables 2.6 and 2.7). The interaction between seeding and topsoil stripping treatments on annual exotics was also statistically significant ($p = 0.0048$), but was the result of the cascading influence of the seeding treatment. The same effect is evident in native forb density being significantly lower in seeded treatments compared to natural recovery (Table 2.7).

Seeded treatments had numerically higher perennial exotics canopy cover and density compared to natural recovery treatments (Tables 2.6 and 2.7) due to perennial tame forages that were probably in the seed mix. If creeping red fescue was included as a perennial exotic, canopy cover and density for perennial exotics in seeded treatments was statistically significantly higher (Table 2.12). Seeding did not reduce bare ground and there was no significant difference in bare ground between seeded and natural recovery treatments (Table 2.7). In natural recovery treatments, annual exotics reduced bare ground, shown by total vegetation density being significantly lower in the seeded treatment than in the natural recovery treatment (Table 2.7).

3.4.2 Community Development and Succession

The undisturbed area adjacent the RoW was sampled for cover and density along a single transect comparing treatments to the native plant community. Only 14 species were present in the undisturbed area (Figure 2.11) compared to 34 in seeded treatments (Figure 2.12) and 29 in natural recovery treatments (Figure 2.13). Species composition reflected heavy grazing with high densities of increaser graminoids and unpalatable forbs (Figure 2.11). Seeded and natural recovery treatments differed in plant species composition. Natural recovery treatments had four more native forb species than seeded treatments, likely a result of competition from seeded native grasses. Natural recovery treatments had three fewer perennial exotic grasses and of the two species in natural recovery treatments only *Bromus inermis* Leyss. ssp. *Inermis* (smooth brome) was not seeded. The adjacent RoW to the south was seeded to *Bromus inermis*, which currently dominates the old RoW. Some exotic grass seed (*Agropyron cristatum* (L.) Gaertn. ssp. *pectinatum* (Bieb.) Tzv. (crested wheatgrass), *Poa pratensis* (L.) ssp. *pratensis* (kentucky bluegrass) other than those erroneously included, may have been present in the seed mix because these species were only found on seeded treatments.

Natural recovery treatments had slightly higher *Koeleria macrantha* density which is surprising considering it was a component of the native seed mix. Some other seeded species that were not present, or only present at low densities in the natural recovery treatments, may have inhibited *Koeleria macrantha* establishment. Seeded treatments had 14 times more *Achnatherum hymenoides* (R.& S.) Barkw. (indian rice grass) plants and 32 times more *Nassella viridula* (Trin.) Barkw. (green needle grass) plants compared to natural recovery treatments. Often native seed mixes are designed with the same species that occur naturally, but due to seed availability and cost, composition percentages do not parallel natural community composition. This study indicates that in the short term species composition is influenced by seeding through inhibition of establishment of seed bank species, introducing exotic species that otherwise would not be present, and producing a community that is not representative of a natural community. Zink et al. (1995) discussed the potential of pipelines functioning as invasion pathways into undisturbed communities. Whether these influences persist through time and how seed mixes alter successional pathways require longer term research.

3.5 TIMESCALES

Shallow topsoil stripping had no effect on vegetation establishment. Over time community composition may be quite different on shallow topsoil stripping treatments because of plant propogule conservation and shallow topsoil stripping may prove to have a significant effect on community dynamics following future disturbances. Straw crimp treatments are applied to control erosion and provide a source of organic matter. This research found that over a two year period following treatment application straw crimping did not contribute to soil organic carbon. Over a longer period of time straw crimp treatments may increase soil organic carbon, which would result in increased moisture retention and may ultimately affect composition. How plant communities that are the product of a native seed mix respond over time is very important. Do these communities that have uncharacteristically high densities of some species maintain these densities, or over time do the densities decrease and more closely resemble that natural community? These are important questions that must be answered to completely evaluate the performance of native seed mixes. These questions require long term studies on sites where substantial short term data exist so changes evident over time can be confirmed. The importance of the various stages of natural succession in the development of native plant communities is still not fully understood because of the complexity of interactions and variations in plant community types.

4. PRACTICAL APPLICATIONS

The extra lift required in shallow topsoil stripping increases costs through increased time and labour, but does provide biological benefits. Shallow topsoil stripping, despite the requirements for preciseness, can be applied accurately and seems to be essential in conserving organic carbon in environments like sandhills grasslands that have low soil organic carbon. There are also potential long term benefits in preserving the seed bank and other viable propogules.

Cover cropping, although easy to apply, only reduced annuals and did not facilitate vegetation establishment. Cover cropping with fall rye would be beneficial if it established in the fall to provide early spring erosion control; this was not the case as the cover crop emerged the same time as annuals on no cover crop treatments. Erosion protection provided by the cover crop can be achieved with naturally establishing annual weedy species which may compete less with desirable vegetation. These annual species may be essential steps in the successional pathway and community development. Straw crimping had few beneficial effects. The even application of straw is very difficult to achieve, especially with high application rates such as 5400 kg ha^{-1} where straw was too heavy to be crimped into the soil. The straw was also the source of some exotic species. The increased nitrogen availability and soil moisture, as a result of straw crimping, serve no benefit when there is less vegetation. If application rates are decreased and care taken to ensure even straw distribution then this erosion control technique may be more effective.

Seeding, produced greater canopy cover of native grasses and resulted in a substantial introduction of a non-native species compared to natural recovery. Seeding errors such as the fescue mix up are rare and could be avoided with more rigorous quality control. Seeding also reduced native forb density and canopy cover. Natural recovery is a viable method of revegetation, even on large RoW (>30 m) on highly erodible soils. The key to revegetating sandy soil disturbances is adequate early spring precipitation. As long as plants establish, erosion is reduced and a natural plant community can establish through natural recovery. However, precipitation cannot be predicted nor is it guaranteed. In some regions we can, with high probability, rely on moisture from snowmelt. Sandy soils in semiarid environments are not usually subject to water erosion as the biggest concern is wind erosion. Spring snowmelt provides moisture to aid establishment of fall seeded mixes and annual weedy species with both providing erosion protection. Allowing annual weeds to grow and persist provides extensive cover and effective erosion control throughout the growing season without applying competitive stress on desirable native species. In using early establishing annual weeds for erosion control, monitoring becomes essential to ensure aggressive perennials do not establish and dominate. In severe drought conditions where annuals are inhibited from establishing or where topsoil is nonexistent, mitigative measures such as straw crimping can ensure erosion protection.

Seeding a native grass mix alters community composition with a high proportion of the community comprised of grasses. This can be problematic on revegetated pipeline RoW in grazing systems. Livestock, such as cattle, are attracted to the large amount of palatable forage, which can lead to destruction of RoW vegetation and increased erosion. Visual observations indicate that livestock grazing deferred for two years improved revegetation success. These management practices are essential for sandy soil grasslands and other areas prone to erosion. Less palatable plants such as annual weeds and native forbs, more common in natural recovery plant communities, may be less attractive to livestock and minimize livestock impacts where grazing deferral or exclosures are not feasible (Plate 2.1).

5. CONCLUSIONS

General Conclusions

1. Shallow topsoil stripping, erosion control and seeding affected vegetation and soil parameters measured on the pipeline RoW.
2. The importance of natural succession, and more specifically the role and value of annual plant species, in the establishment of vegetation in early-seral stages following a disturbance is evident.
3. The short term benefits or shortfalls of the various reclamation techniques studied may be quite different than those noticed over the long-term.

Topsoil Stripping Treatments

1. Topsoil stripping had no significant effect on vegetation.
2. The lack of shallow topsoil stripping effects on native vegetation resulted from establishment of large amounts of *Hesperostipa comata* from the seed bank.
3. Shallow topsoil stripping preserved organic carbon in the 0 to 5 cm depth of the A horizon.
4. Total organic carbon is the primary soil characteristic affecting soil moisture retention on soils >90% sand.

Erosion Control Treatments

1. Erosion control treatments did not improve native vegetation establishment.
2. Fall rye has a greater competitive effect than annual forbs on native grass canopy cover and density.
3. Straw crimp reduced bare ground, but significantly reduced native vegetation canopy cover.
4. Soils under straw crimp had higher available nitrogen as nitrate.

Revegetation Treatments

1. Seeding a native grass mix significantly increased canopy cover and density of native grasses.
2. Treatments seeded with a native grass mix had lower native forb canopy cover and density.
3. Seeding a native grass mix introduced undesirable tame forage species, which included *Festuca rubra*, *Festuca ovina* and *Poa pratensis*.
4. Seeding a native grass mix reduced annual exotic plant density including: *Descurania sopheia*, *Lepidium densiflorum* and *Lappula squarrosa*.
5. Seeding a native grass mix resulted in lower available soil nitrogen as nitrate.

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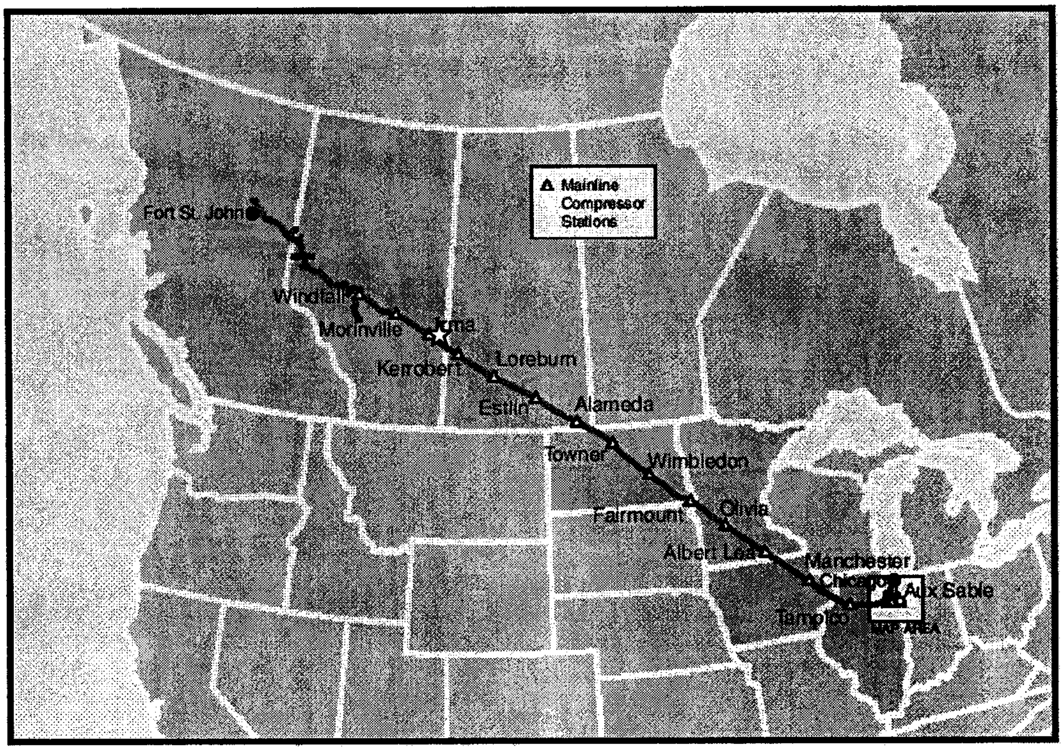

Figure 2.1. Route of the Alliance Pipeline natural gas mainline. The star denotes the approximate study area (Alliance Pipeline 2000).

Table 2.1. Long term climate means from the Hughenden Meteorology Station (Fehr 1984).

Hughenden 52°31' N; 110°58' W	694 m ASL
Mean annual temperature	2.0 °C
Extreme maximum temperature	34.4 °C
Extreme minimum temperature	-44.0 °C
Annual precipitation	411.7 mm
Annual snowfall	98.9 mm
Annual rainfall	282.2 mm
Frost free period	97 days
Mean prevailing wind direction	NNW
Mean prevailing wind speed	15.9 km/h
Annual potential evapotranspiration	508 to 559 mm

Table 2.2. Monthly precipitation data for the Fabyan Meterological Station for 1999, 2000 and 2001 (Environment Canada 2004).

Fabyan 52° 58' N; 111° 0' W	698 m ASL		
	1999	2000	2001
January	45.2	15.8	3
February	6	6.6	5
March	8.4	25.3	2
April	29.1	17	25.6
May	54.5	50.5	46.4
June	32.9	56.6	81.1
July	143	115	36.1
Aug	84.6	51	2.7
September	7.4	75.4	16.8
October	13.8	4.3	8.3
November	8.8	3	11.2
December	12.4	13.8	11.8
Total	446.1	434.3	250
May to September Total	322.4	348.5	183.1

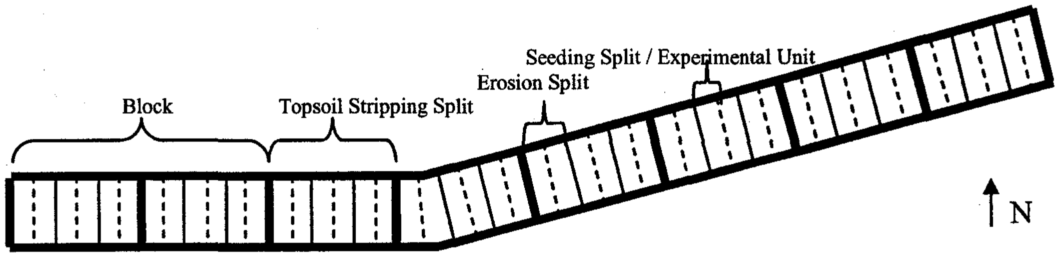

Figure 2.2. Split block, split-split plot experimental design and treatment layout. Plots are the entire width (32 m) of the pipeline right-of-way running east-west.

Table 2.3. Reclamation seed mix (Alliance Pipeline Seed Mix #7).

Species	Common Name	Seed Mix by Composition (%)	Seed Mix by Weight (%)
Festuca ovina L.	Sheep Fescue	25	9.4
Festuca altaica Trin ssp. *hallii* (Vasey) V. Harms	Plains Rough Fescue	25	25.5
Nasella viridula (Trin.) Barkw.	Green Needle Grass	15	21
Koeleria macranthra (Ledeb.) Schultes	June Grass	10	1.1
Acnatherum hymenoides (R.& S.) Barkw.	Indian Rice Grass	15	27.1
Elymus lanceolatus (Scribn.& Sm.) Gould	Northern Wheatgrass	10	15.9

Table 2.4. Soil parameter treatment means for the pipeline right-of-way collected in year 2 of the study (2001).

Treatment	Depth	Total Organic Carbon (%)	Available Nitrate (mg N/kg soil)	Moisture Retention 10 kPa	Moisture Retention 33 kPa	Moisture Retention 1500 kPa
		SE 0.229	SE 1.091	SE 0.389	SE 0.430	SE 0.305
Conventional Topsoil Stripping						
Cover Crop	0-5 cm	1.21	2.77	4.62	3.16	2.59
Natural	5-10 cm	1.08	2.83	4.92	2.97	2.41
Recovery	15-20 cm			2.74	1.78	1.30
Cover Crop	0-5 cm	1.65	3.38			
Seeded	5-10 cm	1.38	3.37			
No Erosion Control	0-5 cm	1.46	2.22	4.31	3.15	2.30
Natural	5-10 cm	1.29	3.08	3.76	2.89	2.12
Recovery	15-20 cm			2.82	1.70	1.33
No Erosion Control	0-5 cm	1.43	3.75			
Seeded	5-10 cm	1.23	2.97			
Straw Crimp	0-5 cm	1.39	6.38	4.21	2.99	2.26
Natural	5-10 cm	1.27	6.48	4.40	3.17	2.14
Recovery	15-20 cm			2.73	1.59	1.22
Straw Crimp	0-5 cm	1.28	2.67			
Seeded	5-10 cm	1.13	2.80			
Shallow Topsoil Stripping						
Cover Crop	0-5 cm	1.48	2.65	4.43	3.11	2.45
Natural	5-10 cm	1.09	2.70	3.69	2.63	1.96
Recovery	15-20 cm			2.28	1.48	1.29
Cover Crop	0-5 cm	1.43	1.92			
Seeded	5-10 cm	1.28	2.17			
No Erosion Control	0-5 cm	1.56	2.34	4.67	3.20	2.61
Natural	5-10 cm	1.28	2.10	4.13	2.90	2.13
Recovery	15-20 cm			2.55	1.76	1.31
No Erosion Control	0-5 cm	1.50	1.82			
Seeded	5-10 cm	1.21	1.58			
Straw Crimp	0-5 cm	1.38	5.30	3.72	2.72	2.09
Natural	5-10 cm	1.18	3.90	3.67	2.43	1.91
Recovery	15-20 cm			2.31	1.54	1.34
Straw Crimp	0-5 cm	1.58	3.52			
Seeded	5-10 cm	1.35	3.95			

Treatment	Depth	Particle Size Sand (%)	Particle Size Silt (%)	Particle Size Clay (%)
		SE 1.035	SE 0.800	SE 0.803
Conventional Topsoil Stripping				
	0-5 cm	91.4	4.4	4.3
	5-10 cm	91.9	3.4	4.8
	10-15 cm	91.9	4.6	3.5
	15-20 cm	92.8	3.9	3.4
Shallow Topsoil Stripping				
	0-5 cm	90.1	4.4	5.5
	5-10 cm	90.6	3.8	5.6
	10-15 cm	94.1	3.0	2.9
	15-20 cm	94.3	3.3	2.5

SE = standard error.

Table 2.5. Vegetation parameter treatment means for the pipeline right-of-way collected in year 1 (2000) and 2 (2001).

	Canopy Cover (%) 2000								Cover Canopy (%) 2001								Density (plants/0.1 m²) 2001				
Treatment	Total Vegetation (3.637)	Perennial Exotics (0.084)	Annual Exotics (3.052)	Native Grass (0.569)	Native Forb (2.206)	Straw (4.981)	Cover Crop (0.858)	Bare Ground (8.187)	Total Vegetaion (1.640)	Perennial Exotics (0.123)	Annual Exotics (0.820)	Native Grass (1.060)	Native Forb (0.689)	Straw (5.004)	Cover Crop (0.037)	Bare Ground (5.730)	Total Veg (3.439)	Perennial Exotics (0.238)	Annual Exotics (3.182)	Native Grass (0.815)	Native Forb (0.348)
Conventional Topsoil Stripping																					
Cover Crop																					
Natural Recovery	11.85	0.00	2.54	1.52	7.40	0.00	1.46	91.17	12.77	0.00	3.40	6.92	1.96	0.21	0.04	87.25	17.88	0.00	12.42	4.38	0.83
Seeded	16.42	0.00	4.88	3.17	7.29	0.00	3.50	86.63	16.98	0.08	0.58	11.13	0.85	0.00	0.00	82.83	11.83	0.04	2.58	6.96	0.63
No Erosion Control																					
Natural Recovery	19.02	0.00	6.83	2.44	9.40	0.00	0.00	84.33	14.00	0.00	2.58	8.73	2.52	0.00	0.00	86.25	14.04	0.00	7.63	5.00	0.96
Seeded	14.27	0.00	5.81	3.73	4.17	0.00	0.00	89.92	14.98	0.21	0.19	10.06	0.83	0.00	0.00	84.58	9.75	0.21	1.08	6.50	0.50
Straw Crimp																					
Natural Recovery	17.81	0.21	9.56	0.75	7.23	45.88	0.00	40.46	11.23	0.17	2.44	5.73	2.77	41.96	0.04	52.79	7.58	0.04	2.04	4.13	0.96
Seeded	9.83	0.00	5.46	0.94	3.00	53.67	0.00	40.42	12.17	0.00	0.15	6.67	1.31	35.75	0.00	55.75	8.42	0.00	0.38	5.63	0.42
Shallow Topsoil Stripping																					
Cover Crop																					
Natural Recovery	8.71	0.02	1.54	1.63	5.50	0.00	2.58	84.63	10.81	0.00	1.71	6.52	1.98	0.00	0.08	88.83	12.71	0.00	6.96	3.17	1.29
Seeded	17.17	0.00	1.92	2.19	12.58	0.00	2.29	79.50	11.29	0.00	0.67	7.79	1.13	0.00	0.08	87.38	11.50	0.00	4.38	5.63	0.50
No Erosion Control																					
Natural Recovery	12.65	0.13	4.08	1.63	6.79	0.00	0.00	83.63	11.83	0.00	1.94	7.92	1.81	0.00	0.00	85.17	16.92	0.00	10.75	4.58	1.04
Seeded	16.79	0.13	6.17	2.19	7.21	0.00	0.00	85.67	15.90	0.08	0.44	8.06	0.94	0.00	0.00	86.79	11.46	0.04	1.33	6.00	0.71
Straw Crimp																					
Natural Recovery	10.21	0.02	4.29	1.00	4.77	40.00	0.00	44.38	7.04	0.13	1.71	4.35	0.83	28.26	0.04	67.63	9.38	0.71	5.50	3.08	0.50
Seeded	10.92	0.10	5.00	1.35	3.31	51.79	0.00	35.83	12.46	0.25	0.94	5.13	0.94	39.13	0.00	49.00	9.08	0.08	1.04	5.46	0.38
Overall Treatment Mean	13.80	0.05	4.84	1.88	6.55	15.94	0.82	70.55	12.62	0.08	1.39	7.42	1.49	12.11	0.02	76.19	11.71	0.05	4.67	5.04	0.73

Standard errors are in brackets under each cover and density grouping.

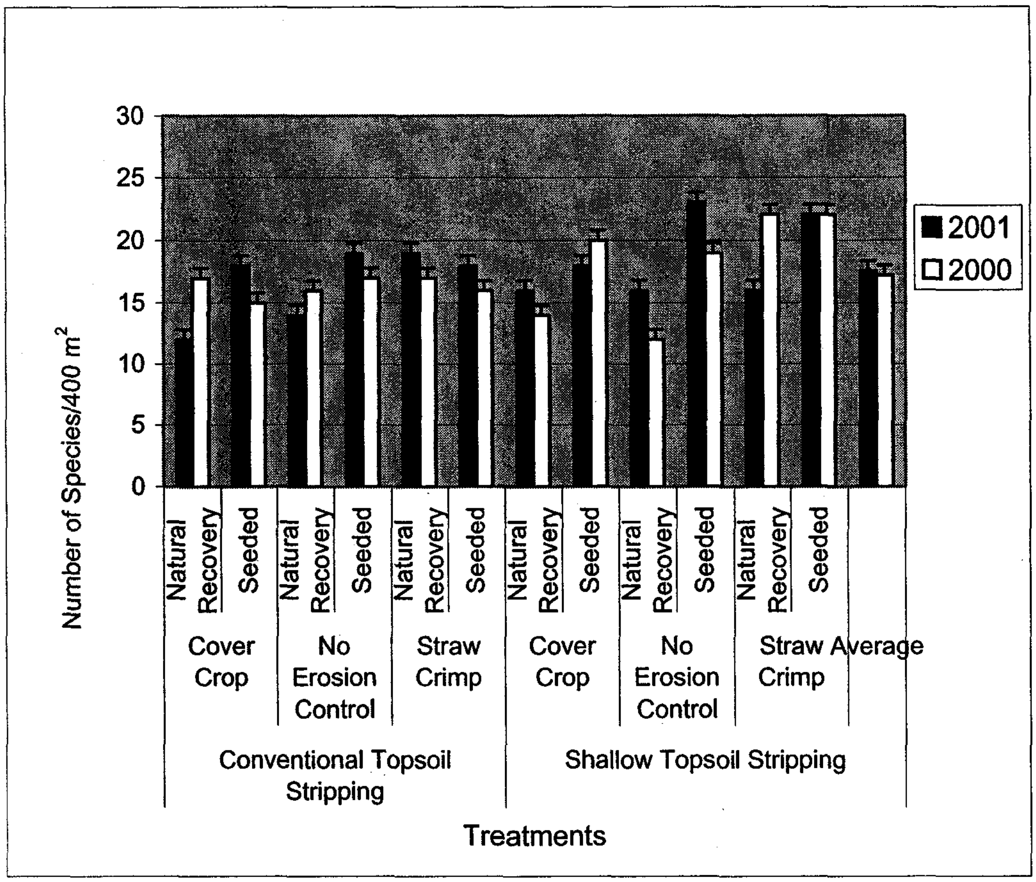

Figure 2.3. Plot mean plant species diversity on the pipeline right-of-way for year 1 (2000) and 2 (2001). Standard Deviation = 3.0 (indicated by error bars).

Table 2.6. Vegetation percent canopy cover means and comparisons on the pipeline right-of-way in year 1 (2000) and 2 (2001).

Treatment	Total Vegetation	Native Grass	Native Forbs	Perennial Exotic	Annual Exotic	Bare Ground
2000 (year 1)						
Topsoil Stripping						
Shallow	12.74 a	1.64 a	6.65 a	0.07 a	3.83 a	68.94 a
	(2.4)	(0.29)	(1.04)	(0.04)	(2.24)	(6.52)
Conventional	14.87 a	2.09 a	6.41 a	0.03 a	5.85 a	72.15 a
	(2.4)	(0.29)	(1.04)	(0.04)	(2.24)	(6.52)
p	0.2706	0.3115	0.8029	0.5316	0.2376	0.5974
Erosion Control						
Cover Crop	13.54 a	2.09 a	8.20 a	0.00 a	2.72 a	85.48 a
	(2.59)	(0.28)	(1.55)	(0.05)	(2.39)	(6.49)
No Treatment	15.68 a	2.49 a	6.89 a	0.06 a	5.72 a	85.88 a
	(2.59)	(0.28)	(1.55)	(0.05)	(2.39)	(6.49)
Straw crimp	12.19 a	0.99 b	4.52 a	0.08 a	6.08 a	40.27 b
	(2.59)	(0.28)	(1.55)	(0.05)	(2.39)	(6.49)
p	0.3306	0.0015	0.2846	0.4847	0.2170	< 0.0001
Revegetation						
Seeded	14.23 a	2.23 a	6.26 a	0.04 a	0.04 a	69.66 a
	(2.38)	(0.24)	(1.04)	(0.04)	(2.15)	(6.07)
Natural Recovery	13.38 a	1.49 b	6.81 a	0.06 a	0.06 a	71.43 a
	(2.38)	(0.24)	(1.04)	(0.04)	(2.15)	(6.07)
p	0.5955	0.0014	0.5990	0.6113	0.9518	0.5021
2001 (year 2)						
Topsoil Stripping						
Shallow	11.56 a	6.63 a	1.27 a	0.07 a	1.23 a	77.47 a
	(1.29)	(0.67)	(0.41)	(0.06)	(0.72)	(3.81)
Conventional	13.69 a	8.20 a	1.71 a	0.07 a	1.56 a	74.91 a
	(1.29)	(0.67)	(0.41)	(0.06)	(0.72)	(3.81)
p	0.1298	0.1670	0.2683	1.0000	0.6617	0.4726
Erosion Control						
Cover Crop	12.96 a	8.09 a	1.48 a	0.02 a	1.59 a	86.57 a
	(1.27)	(0.64)	(0.49)	(0.07)	(0.66)	(4.31)
No Treatment	14.18 a	8.69 a	1.52 a	0.07 a	1.29 a	85.70 a
	(1.27)	(0.64)	(0.49)	(0.07)	(0.66)	(4.31)
Straw Crimp	10.72 b	5.47 b	1.46 a	0.13 a	1.31 a	56.29 b
	(1.27)	(0.64)	(0.49)	(0.07)	(0.66)	(4.31)
p	0.0028	0.0057	0.9931	0.5096	0.5340	0.0007
Revegetation						
Seeded	13.96 a	8.14 a	1.00 a	0.10 a	0.49 a	74.39 a
	(1.23)	(0.57)	(0.40)	(0.05)	(0.65)	(3.67)
Natural Recovery	11.28 b	6.69 b	1.98 b	0.05 a	2.30 a	77.99 a
	(1.23)	(0.57)	(0.40)	(0.05)	(0.65)	(3.67)
p	< 0.001	0.0055	0.0012	0.3729	< 0.0001	0.1277

Standard errors are in brackets. Comparisons with the same letters are not significantly different. Significant difference $p < 0.05$.

Table 2.7. Total vegetation, native grass, native forbs perennial exotic and annual exotic mean plant density (plants/0.1 m^2) comparisons for year 2 (2001) for reclamation treatments.

Treatment	Total Vegetation	Native Grass	Native Forbs	Perennial Exotic*	Annual Exotic
2001					
Topsoil Stripping					
Shallow	11.84 a	4.65 a	0.74 a	0.049 a	4.99 a
	(2.92)	(0.59)	(0.21)	(0.04)	(2.66)
Conventional	11.58 a	5.43 a	0.71 a	0.049 a	4.35 a
	(2.92)	(0.59)	(0.21)	(0.04)	(2.66)
p	0.7645	0.3774	0.9175	1.0000	0.4258
Erosion Control					
Cover Crop	13.48 a	5.03 a	0.81 a	0.01 a	6.58 a
	(3.19)	(0.55)	(0.26)	(0.05)	(2.95)
No Treatment	13.04 a	5.52 a	0.80 a	0.06 a	5.20 a
	(3.19)	(0.55)	(0.26)	(0.05)	(2.95)
Straw Crimp	8.61 a	4.57 a	0.56 a	0.07 a	2.23 a
	(3.19)	(0.55)	(0.26)	(0.05)	(2.95)
p	0.1497	0.3252	0.6770	0.6555	0.2393
Revegetation					
Seeded	10.34 a	6.03 a	0.52 a	0.06 a	1.80 a
	(2.93)	(0.47)	(0.19)	(0.04)	(2.66)
Natural	13.08 b	4.06 b	0.93 b	0.03 a	7.55 b
Recovery	(2.93)	(0.47)	(0.19)	(0.04)	(2.66)
p	0.0015	< 0.0001	0.0021	0.5500	< 0.001
Interaction					
Straw Crimping	not seeded	not seeded			
and Seeding	8.48 a	3.60 a			
	(3.28)	(0.62)			
	seeded	seeded			
	8.75 a	5.54 a			
	(3.28)	(0.62)			

Standard errors in brackets. Treatment comparisons with the same letters are not significantly different. Significant difference $p < 0.05$. Creeping red fescue not included in perennial exotic data analysis (*).

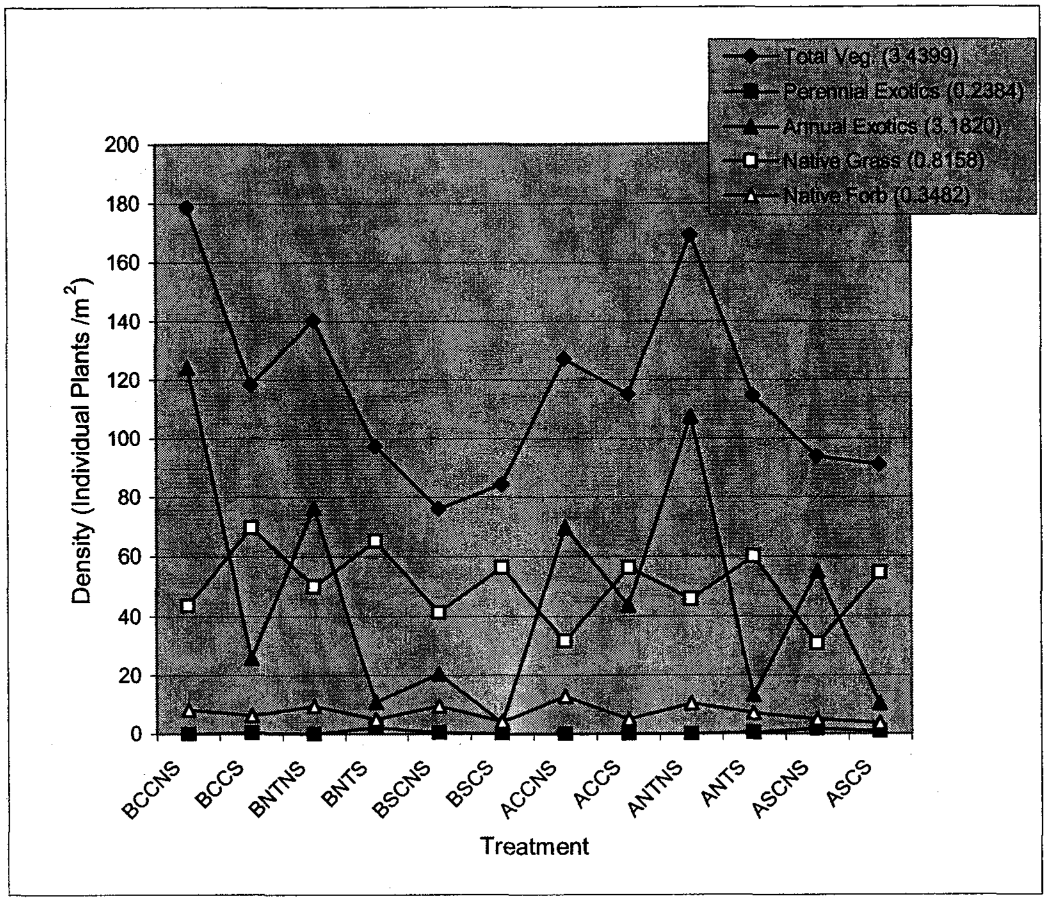

Figure 2.4. Mean total vegetation, perennial exotics, annual exotics, native grass and native forb densities for reclamation treatment combinations on the pipeline right-of-way for year 2 (2001). A = shallow topsoil stripping, B = conventional topsoil stripping, CC = cover crop, NT = no erosion control, SC = straw crimp, S = seeded, NS = natural recovery. Standard errors are included in the legend in brackets.

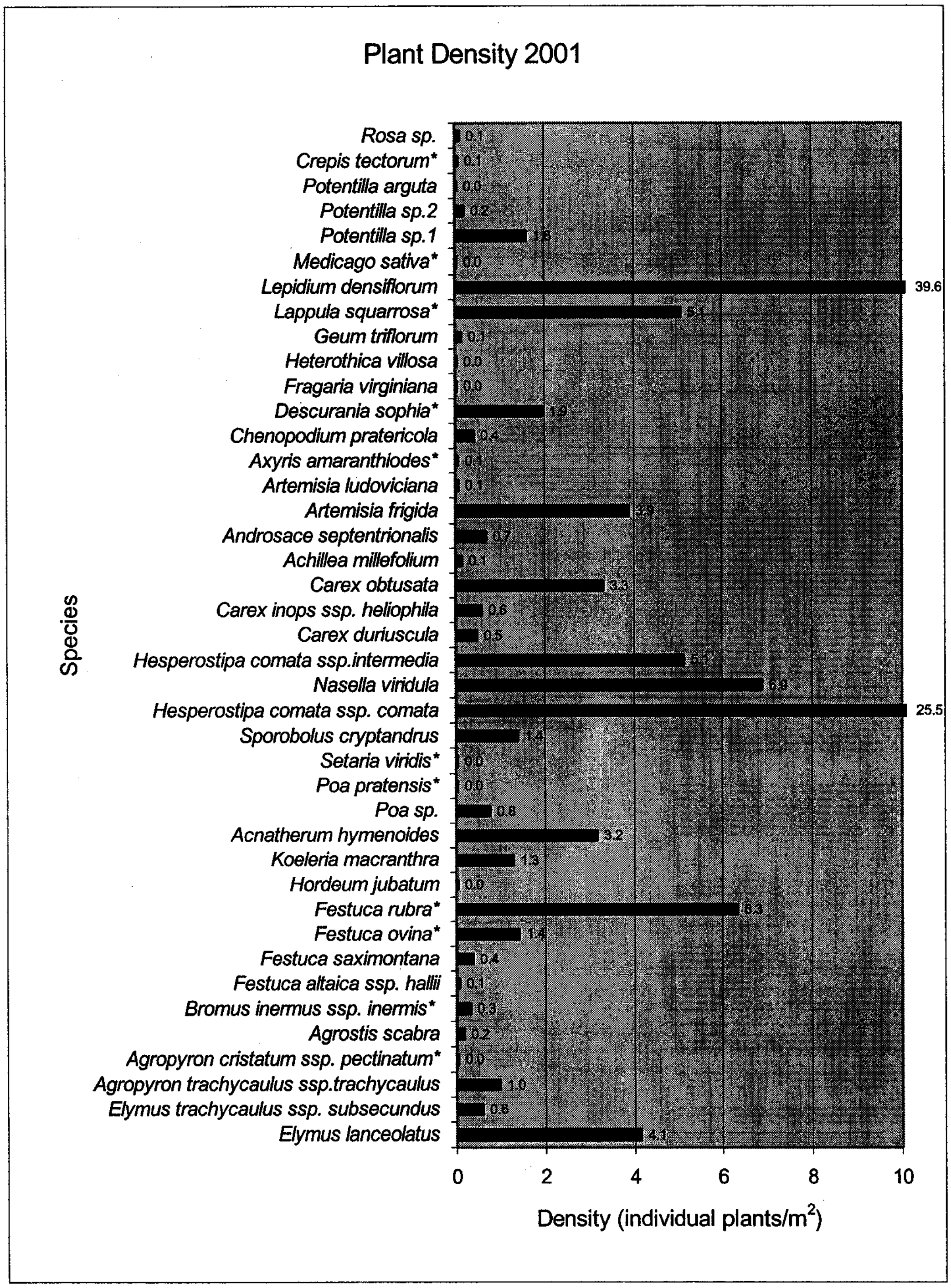

Figure 2.5. Mean plant species densities on the pipeline right-of-way in year 2 (2001). Introduced species (*).

Table 2.8. Mean total organic carbon and mean comparisons for soil samples collected on the pipeline right-of-way in year 2 (2001).

Effect	Strip	Erosion	Revegetation	Depth (cm)	Mean (%)	Standard Error	Mean Comparison	p
Strip	Shallow				1.36	0.173	a	0.7444
	Conventional				1.32	0.174	a	
Erosion		Cover Crop			1.33	0.179	a	0.9182
		No Erosion Control			1.37	0.179	a	
		Straw Crimp			1.32	0.179	a	
Revegetation			Natural Recovery		1.31	0.166	a	0.4066
			Seeded		1.37	0.166	a	
Depth				0-5	1.46	0.165	a	0.0005
				5-10	1.23	0.165	b	
Strip*Depth	Shallow			0-5	1.49	0.178	a	0.4588
	Shallow			5-10	1.23	0.178	a	
	Conventional			0-5	1.40	0.178	a	
	Conventional			5-10	1.23	0.178	a	

Comparisons with the same letters are not significantly different. Significant difference $p < 0.05$.

Table 2.9. Soil particle size mean comparisons on the pipeline right-of-way in year 2 (2001).

Effect	Strip	Depth	Mean (%)	Std. Error	Mean Comparison	p
Clay						
Strip	Shallow		4.13	0.6735	a	0.7648
	Conventional		3.97	0.6735	a	
Depth		0-5	4.88	0.7020	a	< 0.0001
		5-10	5.19	0.7020	b	
		10-15	3.19	0.7020	c	
		15-20	2.94	0.7020	d	
Strip*Depth	Shallow	0-5	5.50	0.8037	a	0.0994
	Conventional	0-5	4.25	0.8037	a	
	Shallow	5-10	5.63	0.8037	a	
	Conventional	5-10	4.75	0.8037	a	
	Shallow	10-15	2.88	0.8037	b	
	Conventional	10-15	3.50	0.8037	b	
	Shallow	15-20	2.50	0.8037	b	
	Conventional	15-20	3.38	0.8037	b	
Sand						
Strip	Shallow		92.28	0.8067	a	0.7904
	Conventional		91.97	0.8067	a	
Depth		0-5	90.75	0.7856	a	0.0236
		5-10	91.25	0.7856	b	
		10-15	93.00	0.7856	c	
		15-20	93.50	0.7856	d	
Strip*Depth	Shallow	0-5	90.13	1.0351	a	0.0169
	Conventional	0-5	91.38	1.0351	b	
	Shallow	5-10	90.63	1.0351	a	
	Conventional	5-10	91.88	1.0351	b	
	Shallow	10-15	94.13	1.0351	c	
	Conventional	10-15	91.88	1.0351	b	
	Shallow	15-20	94.25	1.0351	c	
	Conventional	15-20	92.75	1.0351	b	

Comparisons with the same letters are not significantly different. Significant difference $p < 0.05$.

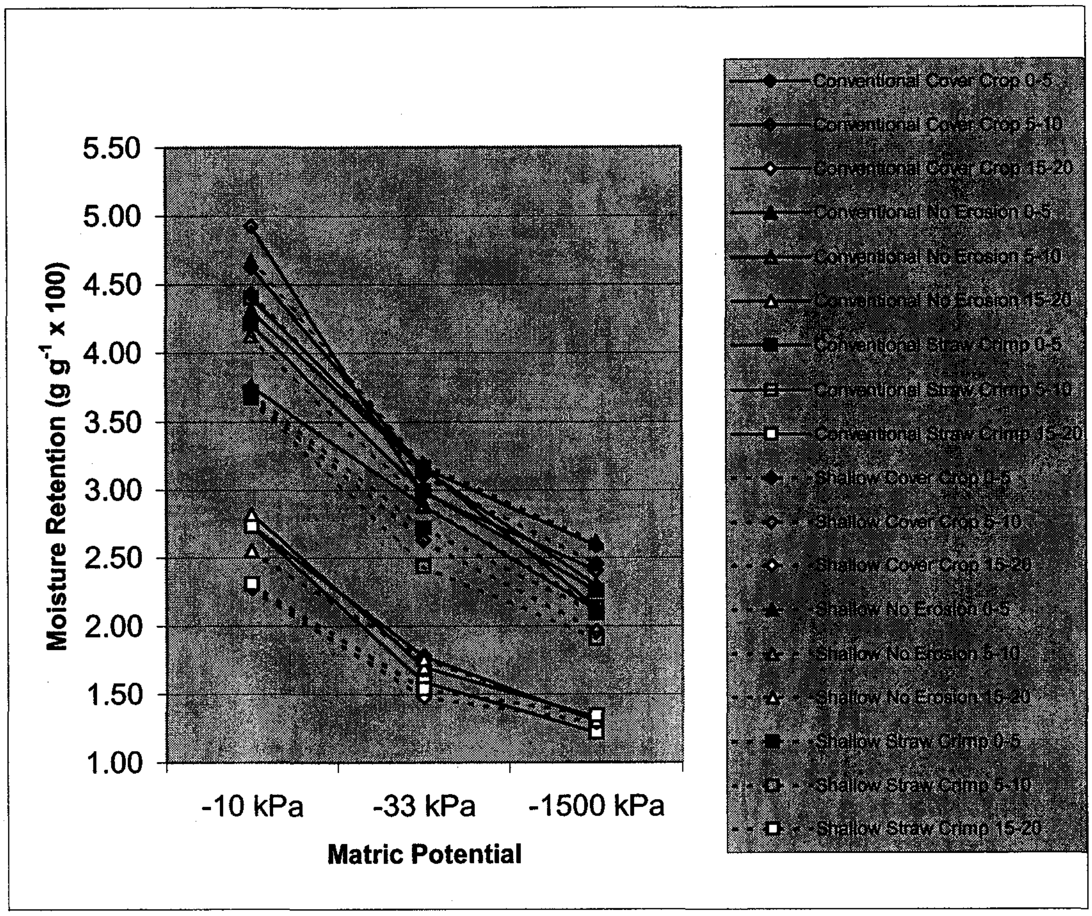

Figure 2.6. Soil moisture retention percentages from the pipeline right-of-way at three depth increments.

Table 2.10. Mean comparisons of soil moisture retention for depth in year 2 (2001).

Matric Potential kPa	Depth Increment (cm)	Estimate (%)	Standard Error	Mean Comparison	p
-10	0 - 5	4.32	0.253	a	0.0005
	5 -10	4.09	0.253	b	
	15 - 20	2.56	0.253	c	
-33	0 - 5	3.05	0.382	d	0.0009
	5 - 10	2.83	0.3812	e	
	15 - 20	1.64	0.3812	f	
-1500	0 - 5	2.38	0.232	g	0.0005
	5 - 10	2.11	0.232	h	
	15 - 20	1.3	0.232	i	

Comparisons with the same letter are not significantly different. Significant difference $p < 0.05$.

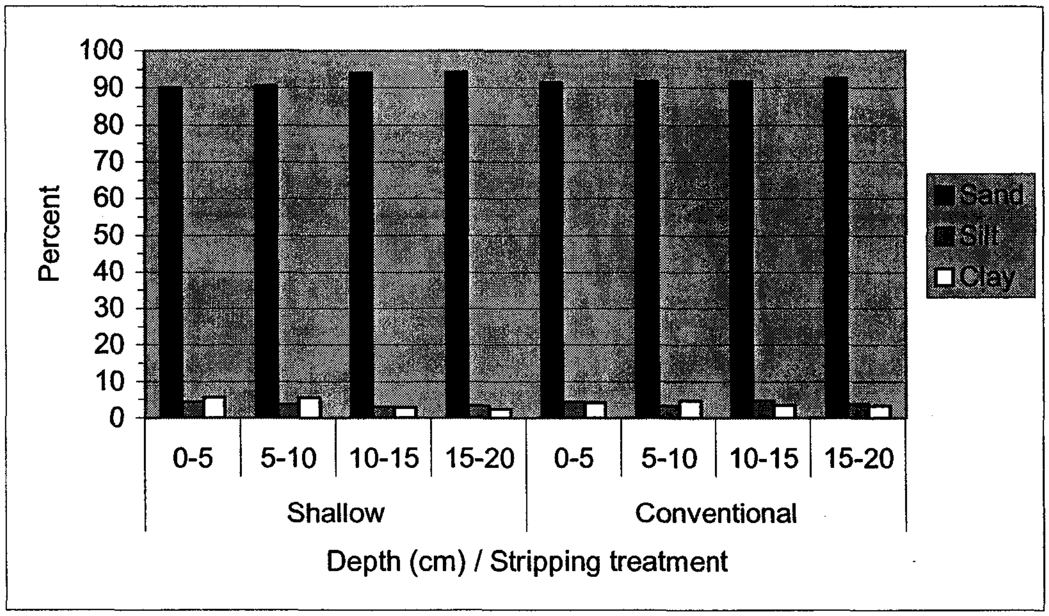

Figure 2.7. Soil particle size as a function of depth and topsoil stripping treatment on the pipeline right-of-way.

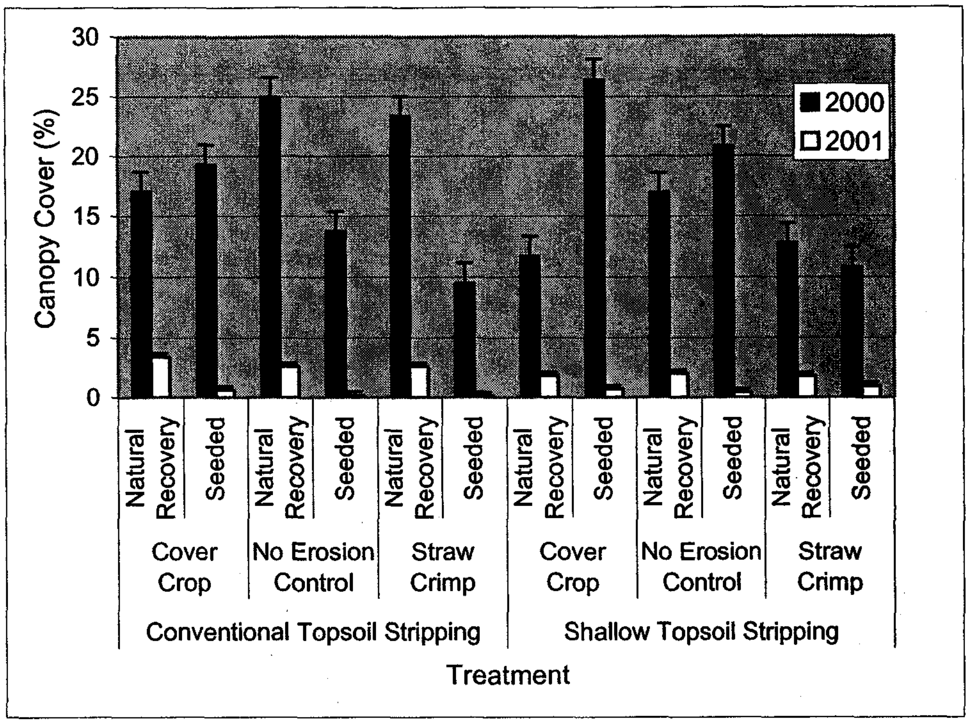

Figure 2.8. Comparisons of Year 1 (2000) and 2 (2001) mean canopy cover for annuals forbs on the pipeline right-of-way. Standard error are indicated by error bars.

Table 2.11. Soil available nitrogen (NO_3) mean comparisons on the pipeline right-of-way in year 2 (2001).

Effect	Strip	Erosion	Revegetation	Depth	Mean (mg N/kg soil)	Standard Error	Mean Comparison	p
Strip	Shallow				2.82	0.402	a	0.1602
	Conventional				3.56	0.402	a	
Erosion		Cover Crop			2.72	0.473	a	0.0143
		No Erosion Control			2.47	0.473	a	
		Straw Crimp			4.38	0.473	b	
Revegetation			Natural Recovery		3.55	0.377	a	0.0805
			Seeded		2.88	0.377	a	
Depth				0 – 5	3.21	0.377	a	0.8978
				5 - 10	3.16	0.377	a	

Comparisons with the same letter are not significantly different. Significant difference $p < 0.05$.

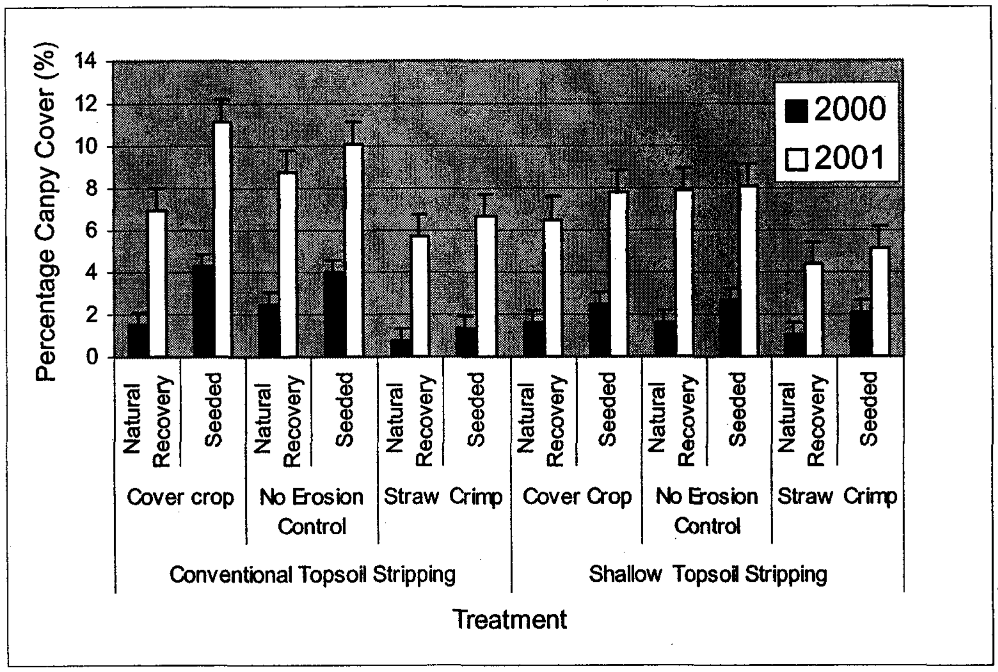

Figure 2.9. Change in native grass canopy cover between two growing seasons (2000 to 2001). Standard erorr bars for 2000 = 0.5699 and 1.0606 for 2001.

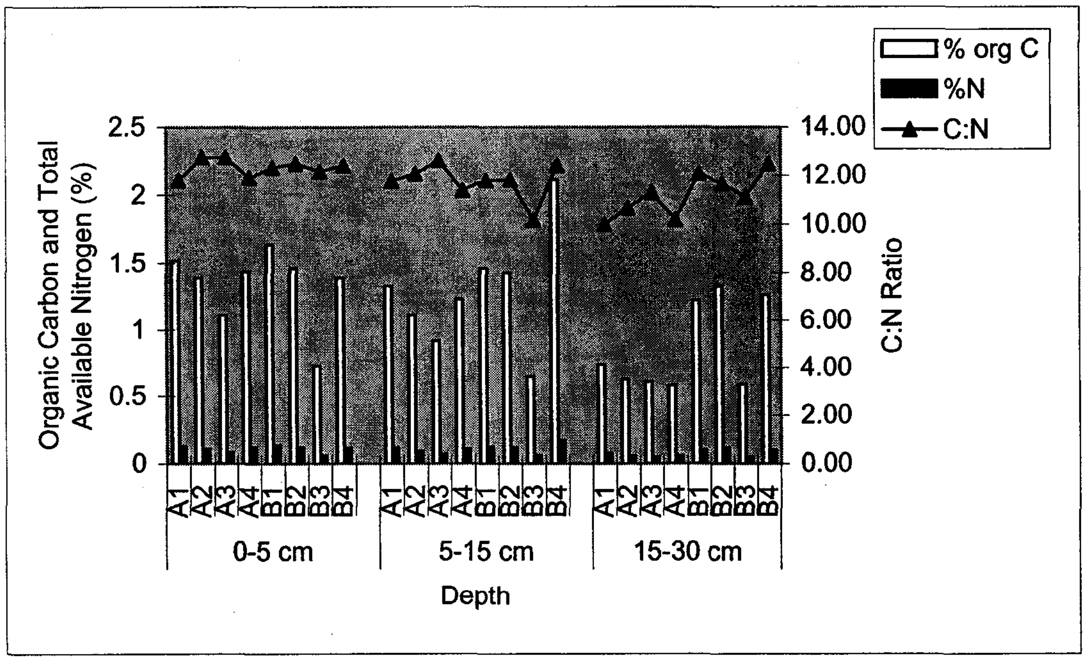

Figure 2.10. Soil carbon and nitrogen levels and C:N ratios observed on the pipeline right-of-way in year 1 (2000) as a function of depth and topsoil stripping treatment. A = shallow topsoil stripping, B = conventional topsoil stripping and numbers indicate blocks.

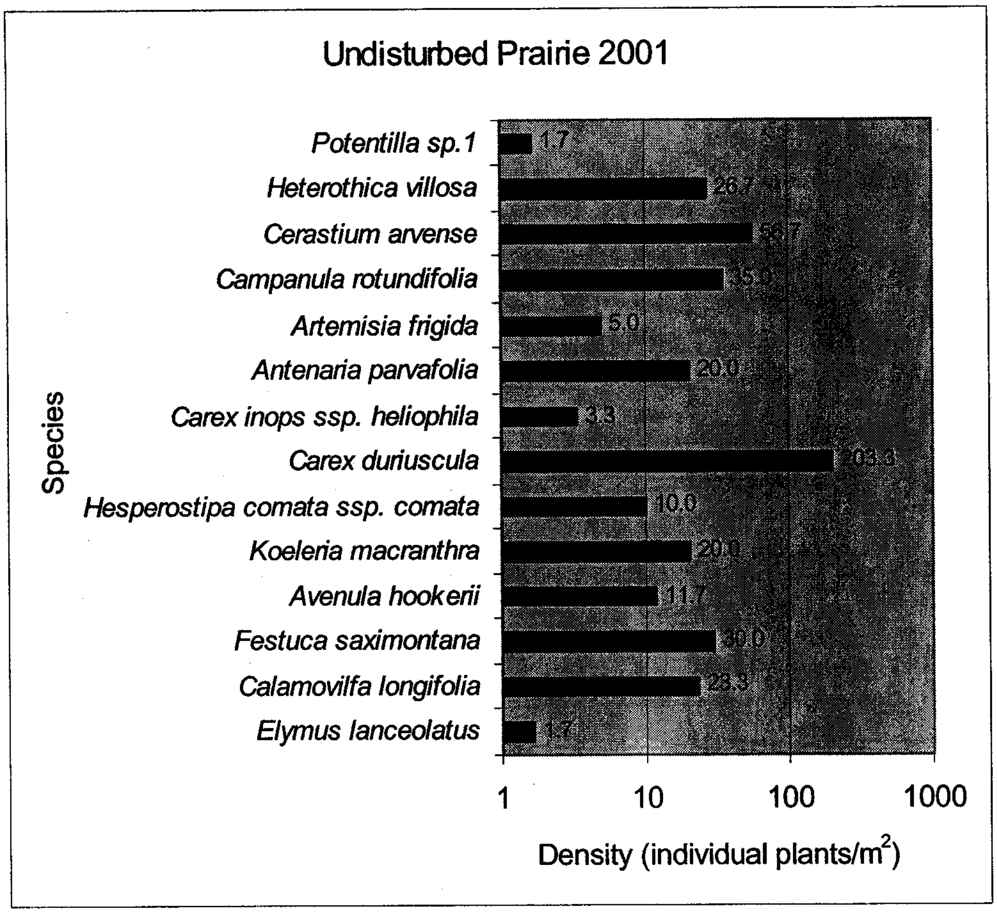

Figure 2.11. Mean plant species density on undisturbed grazed native prairie adjacent to the pipeline right-of-way in July 2001.

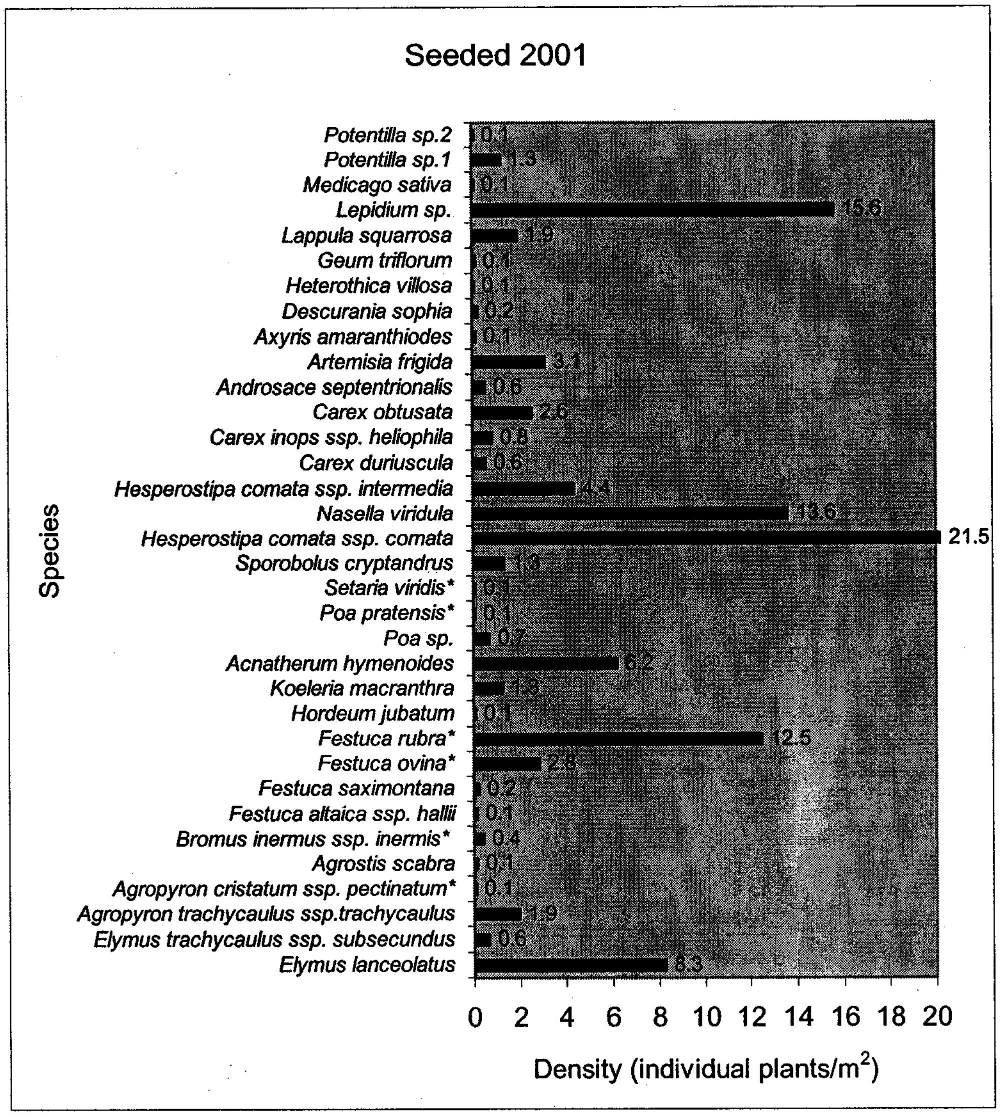

Figure 2.12. Mean plant species density for seeded treatments on the pipeline right-of way in July 2001.

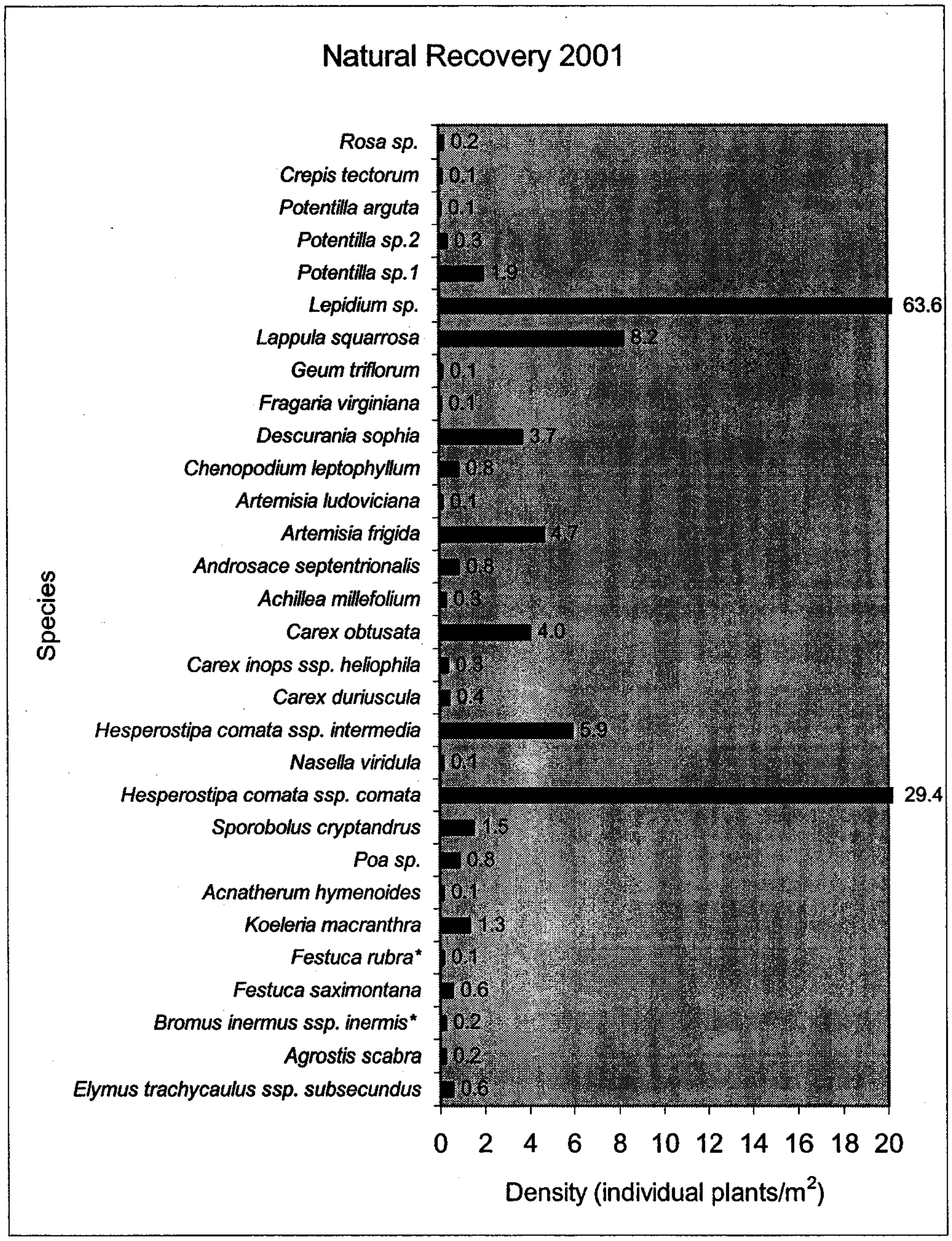

Figure 2.13. Mean plant species density for natural recovery treatments on the pipeline right-of-way in July 2001.

Table 2.12. Comparison of mean canopy cover and mean densities for revegetation treatments for perennial exotics with or without creeping red fescue included on the pipeline right-of-way in year 2 (2001).

	2001 Perennial Exotics	
Treatment	Mean Canopy Cover (std. error)	Mean Density (std. error)
Seeded (crf* included)	4.17 (0.31)	1.60 (0.12)
Natural Recovery (crf included)	0.12 (0.31)	0.05 (0.12)
Seeded (crf not included)	0.10 (0.05)	0.06 (0.04)
Natural Recovery (crf not included)	0.05 (0.05)	0.03 (0.04)

* crf = creeping red fescue

Plate 2.1. Photographs comparing a) sites exclosed from grazing for two seasons and b) areas of the right-of-way that were grazed the same season as they were seeded. Note the persistence of the cover crop (fall rye) and the lack of native grass cover and higher amounts of bareground on the grazed right-of-way.

a)

b)

CHAPTER III

SPATIAL PATTERNS OF FIVE NATIVE GRASS SPECIES IN COLONIZATION OF A PIPELINE RIGHT-OF-WAY IN ALBERTA ASPEN PARKLAND SANDHILLS

1. INTRODUCTION

The predictability of the physical arrangement of plants in space, at a particular scale, is referred to as their spatial pattern (Dale 1999). Patchy spatial distribution of plants can be evident at several different scales (Dale 1999). Spatial patterns can be the result of interactions between a number of factors including climate, topography, soil conditions, past disturbance, predation, competition and other interactions with neighbouring plants (adapted from Dale 1999). Due to the complexity of interactions among organisms, their positions are not expected to be truly independent of each other, but it is possible that their distribution can appear to be indistinguishable from random dispersion (Skellam 1952, Greig-Smith 1979). The perception of plant distribution also depends on scale (Dale 1999).

In nature, pattern may be generally homogeneous over short distances, but displays variation over greater distances (Matérn 1986). Spatial pattern in its simplest form is the alternation of gaps and patches resulting in an interrupted pattern, which essentially has two scales or phases (Dale 1999). The scale of pattern in a two phase mosaic can be defined as the average distance (d) between the centers of adjacent dissimilar phases and an equivalent definition is to refer to half the average distance between the centers of similar phases that are separated by a single domain of the alternate phase (Dale 1999) (Figure 3.1a). For a mosaic of more than two phases, the second definition of scale needs to be modified slightly to refer to half the average distance between the centers of domains of the same phase between which no other domains of the same phase occur (Dale 1999) (Figure 3.1b). Based on this definition, it is possible for different phases in the same mosaic to have different scales (Dale 1999). Intensity of pattern at a particular scale is the average difference in density between patches and gaps (Dale and MacIsaac 1989).

Association is a term used to describe the tendency of plants of different species to be found in close proximity more often than expected (positive association) or less often than expected (negative association) (Dale 1999). Associations, positive or negative, can also be classified according to their cause; ecological coincidence occurs when plants of different species grow close together or far apart because of similar or divergent ecological requirements or capabilities (Dale 1999). Ecological coincidence, whether positive or negative, is expected to bring about a like association between two species. If species A is associated with B, B is expected to be associated in the same way with species A (Dale 1999). Where the plants of one species modify the environment to the extent that they have a direct effect on the occurrence of the other species, the association is referred to as influence (Dale 1999), which is similar to the facilitation or inhibition models of succession (Connell and Slatyer 1977). The importance of species association to spatial pattern is that the spatial pattern of one species can affect the spatial pattern of the species associated with it (whether positive or negative) and therefore affect the whole community (Dale 1999). Knowing that a specific species is associated with another species or a specific scale may be useful in predicting the presence of that species within a community.

Research has generally covered the responses of animals to landscape features (Kikkawa 1964, Mech 1970, Gaines and McClenaghan 1980, Thomas et al. 1982, Swingland and Greenwood 1983, Forman and Godron 1986, Saunders et al. 1987, Saunders and Hobbs 1991, Noss 1993). Very little has been published on the responses of plants to spatial characteristics of the landscape (van der Pijl 1969, Harper 1977, Myster and Pickett 1992, Bradshaw and Spies 1992, Dale and Mah 1998, Dale 1999) and no other study has researched spatial patterns in the colonization response of native grasses to large linear disturbances such as pipeline installations.

Pipeline rights-of-way (RoW) and other disturbances occurring in natural ecosystems are often reclaimed and revegetated with native plant species. Where these disturbances occur in native prairie, revegetation often consists of seeding a native grass mix. On pipeline RoW, native grass mixes are most commonly drill seeded. The expensive seed mixes are usually seeded either parallel or perpendicular to the RoW. The goals of this research were to apply a spatial pattern analysis method to a reclamation field situation to evaluate the following.

1. The performance of the wavelet analysis method in detecting spatial patterns in the colonization of a large linear disturbance by native grasses.
2. Spatial patterns exhibited by native grasses colonizing a large linear disturbance.
3. Positive or negative associations between the native grasses assessed.
4. Determine whether a recommendation to seed native seed in patterns that resemble natural colonization patterns occurring on linear disturbances is warranted in that greater success may be achieved in native plant establishment and ideally reproduce plant communities that are more similar to those that exist naturally.

2. MATERIALS AND METHODS

2.1 SITE DESCRIPTION

The research site was located within the NE ¼ and SE ¼ 22 43 5 W4 and SW ¼ SE ¼ 23 43 5 W4 approximately 25 km southeast of Wainwright, Alberta on Alberta Public Lands. The site is located in the Central Aspen Parkland Subregion on native prairie. Topography is gently undulating (slope 2 to 9%) and the sand and sandy loam textured soils are dark brown chernozems, rego dark brown chernozems and dark brown regosols on glaciofluvial aeolian deposits. Soils have an agriculture capability classification of 6, are well drained and highly erodible following disturbance to the vegetation cover. Dominant graminoid herbaceous species are *Hesperostipa comata* (Trin. & Rupr.) Barkw. (needle and thread grass), *Koeleria macrantha* (Ledeb.) Schultes (june grass), *Festuca saximontana* Rydb. (sheep fescue), *Calamovilfa longifolia* (Hook) Scribn. (sand reed grass) and *Carex* sp. (sedge). Dominant forbs are *Selaginella densa* Rydb. (prairie club moss), *Solidago missouriensis* Nutt. (low goldenrod) and *Cerastium arvense* L. ssp. *strictum* (L.) Ugbor. (field chickweed). Dominant shrubs are *Symphoricarpos occidentalis* Hook. (western snowberry), *Amelanchier alnifolia* Nutt. (saskatoon berry) and *Rosa woodsii* Lindl. (wood's rose). The dominant tree is *Populus tremuloides* Michx. (trembling aspen).

The pipeline was installed in spring and summer 1999 running east to west. Located in native prairie on Alberta Public Lands, the pipeline falls under the legislation of the Alberta Public Lands Act and therefore requires revegetation with native species.

The land is under a grazing lease and grazed annually each year mid summer. Pipeline reclamation and application of the treatments occurred in fall 1999.

2.2. Reclamation Treatment Applications

Half of the 8 main plots have conventional stripping with the upper 10 to 15 cm of topsoil (entire A horizon) removed. The other half have shallow stripping where the top 5 cm is stripped first and piled separately from the second lift of the remaining topsoil. Subsoil from the trench was removed in a single lift and piled in a spoil pile. The spoil was used to infill the trench. There was no mixing of topsoil and spoil in any of the treatments. With shallow topsoil stripping the first lift is replaced as the uppermost soil layer. Topsoil stripping was done between August 18 and 19, 1999 with D6R-XL and D6M-LPG caterpillars equipped with blades. Shallow topsoil stripped plots had the first lift stockpiled on the southeast corner of the 5 m temporary extra work space and the second lift on the southwest corner.

In fall 1999 *Secale cereale* L. (fall rye) was drill seeded at 17 kg ha^{-1} with 15 cm row spacing. A cover crop was used to stabilize the highly erodible soils and to increase native seedling establishment by protecting seedlings from sun and wind, increasing snow trap and soil moisture. Plots were to be seeded in north and south passes across the RoW, but at the reclamation foreman's discretion the plots were seeded east and west down the length of the RoW dropping the seed drill on plots where cover crop was required. When the seed drill was lifted to cross natural recovery plots seed dropped from the drill boots. Therefore, plots that were not to have cover crop ended up having some seeded areas. Where fall rye encountered the spatial pattern sampling transect, in natural recovery treatments, plants were hand pulled to eliminate competitive influence.

Triticum aestivum L. (wheat) straw that was assessed for noxious and/or high density weed problems was baled and then spread at approximately 5400 kg ha^{-1} and crimped into the soil with coulters (disks on the implement) at 15 cm spacing. The crimped straw theoretically provides protection for seedlings to wind, reduces soil erosion, increases snow trap and soil moisture and adds organic matter to the soil, which may improve water holding capacity.

The site was erroneously fertilized (35 N - 11 P - 0 K -3 S) by the pipeline reclamation company at a rate of 200 kg ha^{-1} in the fall of 1999. Preliminary site reconnaissance indicated no evidence of residual fertilizer in the spring of 2000. This was probably the result of the readily available form of nitrogen in the fertilizer being rapidly leached following snowmelt.

A native grass seed mix was seeded at 9 kg ha^{-1} to half of each erosion control treatment within each of the soil stripping treatments. The seed mix was Alliance Pipeline number seven mix for use primarily on sandy droughty soils. The seed was drilled at 12.5 cm row spacing to a depth of 1 to 3 cm. Plots were seeded in fall 1999. Natural recovery plots did not receive any seed. Seeded plots were not sampled in this study because the goal was to observe spatial patterns in natural colonization.

2.3 Experimental Design

The experimental design is a split block, split-split plot replicated four times (Figure 3.2). Each of the four blocks is split into a conventional and a shallow topsoil stripping treatment. Each main plot is the full width of the RoW (32 m) and is 75 m long. The length of each plot is divided into three erosion control treatments (subplots); 25 m of straw crimping, 25 m of cover cropping and 25 m of no erosion control treatment. Each 25 m erosion control treatment is then split into two 12.5 m subsubplots that were either seeded with a commercial native seed mix or not seeded to represent natural recovery. Thus, there are 6 treatments within each of the 8 soil stripping treatment plots for a total of 48 plots.

Twenty-four transects each containing 360 contiguous permanent 0.01 m^2 quadrats bisect the width of the pipeline RoW in each natural recovery treatment and its associated erosion control and topsoil stripping treatment. Each transect of contiguous quadrats was 36 m long covering 2 m of undisturbed native prairie on the north and south sides of the RoW and 32 m of RoW. Presence and absence was determined for two C4 species *Calamovilfa longifolia* and *Sporobolus crypytandrus* (Torr.) Gray (sand dropseed) and three C3 species *Acnatherum hymenoides* (R. & S.) Barkw. (indian rice grass), *Koeleria macranthra* and *Hesperostipa comata* within the permanent quadrats. The species were chosen based on their reclamation and forage value and their ecological importance in sandhills prairie ecosystems. C3 and C4 species were chosen so both photosynthetic pathways would be represented because each pathway has a significant ecological strategy. The study also compared pipeline reclamation techniques to determine if topsoil stripping or erosion control influenced colonization spatial pattern.

The entire research site is located within a grazing lease and is grazed mid-summer each year. The research site was fenced in summer 2000 to exclose grazing by cattle throughout the duration of the research. This fence was installed because the transects required permanent markers, cattle needed to be removed to eliminate the likelihood that these permanent markers would be damaged. Although not commonly practiced, deferred grazing by livestock is recommended for at least one year following revegetation of pipeline RoW. Thus this research presents results for a two year grazing deferral.

2.4 Analyses

Spatial pattern was analyzed with wavelet analysis (Daubechies 1988). The first step is wavelet transformation, where a pattern template (the wavelet) is compared to a data sequence. The data sequence in this study was the presences and absences in each quadrat along each transect for a particular species. The Mexican Hat formation wavelet was used in the transformations (Figure 3.3). The patchy nature of native plant communities when analyzed for spatial pattern can produce numerous resonance peaks (patterns with lower strength of expression or likewise lower variance) in the variogram. Dale and Mah (1998) found this formation produced fewer resonance peaks in the variogram which facilitated interpretation. The Mexican Hat formation, because of its shape, is well suited for detecting pattern in presence and absence data. The wavelet moves along the data sequence in a hypothetical window, set at the smallest possible scale (10 cm in this study), producing positive peaks (white bands) where the data sequence closely matches the wavelet formation and negative troughs (dark bands) where the data differs greatest from the wavelet formation. The window changes to the next successive scale, with the same wavelet formation within it, again moving along the data sequence producing peaks and troughs, and continuing to do so up to the largest manually selected scale (12 m in this study), which is usually one third of the transect length.

Graphically the wavelet transform is expressed in a two dimensional, grey-scale diagram (Figure 3.4).

The results of the wavelet transformation can contain complex patterns that may be difficult to interpret. Therefore a second step consisting of the calculation of the wavelet variance is used to simplify the interpretation. Wavelet variance is the average of the squares of the wavelet coefficients, at each point along a transect at a particular scale. Because variance is a function of scale, number and comparative magnitude of the two dimensional transform data, a greater number of peaks or a stronger signal from the transformation will produce a higher variance (Bradshaw and Spies 1992). Wavelet variance is expressed graphically in a scalogram (Figure 3.5). Peaks in variance indicate the likelihood that patches of the observed species or gaps are repeating at a particular scale. Peaks are subjectively determined by a high point in the variance curve of the scalogram and compared for relative strength. The occurrence of the patch or gap at a particular scale can only be confirmed through statistical testing of the variance curve.

The variance curves in the study were not tested statistically because of the large number of species and transects sampled over the two field seasons and the resultant number of variance curves (240) to analyze. This large number is further increased by variance curves with the occurrence of multiple peaks to analyze for significance. Instead of statistical testing, a large number of transects (24) was used to compare scalograms and compared for repeating patterns for each species. Essentially both the wavelet transformation and the scalogram are required for analysis. The scalogram identifies at what scale patches and gaps are occurring, but the scalogram cannot indicate whether the pattern is a patch or a gap. The wavelet transformation grey-scale diagram indicates whether the pattern is a patch or gap, but present difficulties in identifying the exact scale of pattern.

3. RESULTS AND DISCUSSION

3.1 Effectiveness of Wavelet Analysis in Determining Spatial Pattern in Plants

3.1.1 Difficulties in Interpretation

As expected from the work of Bradshaw and Spies (1992), wavelet analysis results were difficult to interpret with multiple scales of pattern, small amplitudes and numerous resonance peaks in many of the scalograms (Figure 3.6). The results of this study are typical of spatial pattern analyses using wavelets when observing presence and absence vegetation data. Due to the patchy nature of vegetation, patterns can be complex with multiple scales of pattern occurring. Research into the application of wavelet analysis has described the advantage for resolution capabilities when sampling along transects of greater length in relation to sampling density (Bradshaw and Spies 1992). The length of the transects in this study was constrained by the width of the pipeline RoW and the length therefore predetermined. However, the sampling density in relation to transect length in this study was high with 360 samples per transect. Other vegetation studies using wavelets have used sampling densities of 200 samples per transect (Bradshaw and Spies 1992).

The expression of the scalograms is greatly influenced by the scale of the variance axis and comparison and interpretation of transects for repetition of pattern is difficult. For example, the *Hesperostipa comata* variance curves for shallow topsoil stripped transects in block 2 with no erosion control, straw crimp and cover crop, present different degrees of expression as a result of the change in scale of the variance axis (Figure 3.7). The scale at which the variance is graphed in the scalogram will impact its interpretation. This attribute makes interpretation and conclusions on comparisons of numerous data sets arduous and impractical. To visually analyze 120 graphs for one season of data in this research and observe each of those graphs at two or three scales for the variance axis would mean trying to manage comparisons of 72 scalograms for one species and 144 graphs for that same species over two growing seasons. Therefore all scalograms for each species, in one season, were compared at a single, mutually functional scale of variance to observe repetition of patterns.

3.1.2 Spatial Pattern Detection

The wavelet analysis technique was successful in detecting spatial patterns in native grasses naturally colonizing a recently disturbed pipeline RoW along a single transect. Figure 3.8 displays the wavelet transform (a) and wavelet variance scalogram (b) of one transect for *Hesperostipa comata* in 2001. The grey-scale diagram and scalogram portray a strong signal at a scale of 5 m with a weaker resonance peak at 0.9 m. This indicates an alternating pattern of patches and gaps with their centers at 5 m. For the same transect in 2000 (Figure 3.9) the same pattern indicated the method is consistent and there was no change in spatial arrangement or colonization over two growing seasons. Plants that established in year one persisted and were present in year two. A scalogram of a different transect, of the same species, from year two showed a pronounced pattern occurring at 2.5 m (Figure 3.10). Not only is the dominant pattern occurring at a different scale than in figures 3.8 and 3.9, but when the same transect from 2000 was observed the pattern was not consistent (Figure 3.11).

There are four possible explanations for these results. There may have been error in the placement of the quadrats along some transects, due to breakage and removal of plot markers, meaning that the exact location was not sampled in each year. Another explanation is that some seedlings that established in year one may have perished or new seedlings emerged in year two. Species may have been misidentified. *Hesperostipa comata* may have been mistakenly identified as *Acnatherum hymenoides* in year 1, or a combination of the three occurrences. What is most interesting is that the two different transects from 2000 had similar expression in their scalograms (Figures 3.8b and 3.9). Ultimately, these results indicate that wavelet analysis can effectively identify reoccurring patterns and some patterns that are revealed are specific to the individual transect. The occurrence of specific patterns suggests there are site specific control factors affecting spatial dynamic in these early successional plant communities. Such factors may be spatial variability in resources.

One of the reasons for selecting the wavelet analysis method was its ability to detect existing pattern with a particularly large amount of random error in the data. Wavelet analysis can accurately detect the scale of pattern in data with a certain amount of error. Dale and Mah (1998) found detection of scale in data with 20% error (intentionally generated) to be accurate, but displayed a 50% decrease in the amplitude of the expression and small resonance peak from the erroneous data. This means if 72 of the 360 contiguous quadrats had incorrect data (species present instead of absent or vice versa) the correct pattern of scale would still be evident. Dale and Mah (1998) found that in data with 40% error existing spatial pattern was no longer distinguishable. In this research, 144 quadrats would need to contain erroneous data for patterns to be unrecognizable through the wavelet analysis method. If the combination of sampling error and changes in species presence along the transect produced a level of error greater than 40% then this would restrict observation of existing spatial pattern. If the level of error was not greater than 40% then spatial pattern is not being repeated for some species. When transects from the same erosion treatments were compared no consistent pattern was evident. *Hesperostipa comata* was the only species found on every transect sampled, *Koeleria macrantha* was found on all but two transects over years 1 and 2. The occurrance of the other three species was more sporadic.

Visual observations, made during sampling, indicated that individual native grass seedlings were often located under the canopy of a taller individual annual forb. Annual forbs were not sampled for presence and absence, but presence and absence data for these species when analysed for spatial patterns may show positive associations with certain native grasses. Future studies are needed to investigate potential spatial relationships between native grasses and annual forbs. Such research may provide insight to the role of annual plants during revegetation of disturbances.

3.2 Individual Species Response and Patterns

Numerous patterns of scale for patches and gaps on the pipeline RoW were found for *Hesperostipa comata*. The scalograms for each transect are grouped by year and topsoil stripping treatment to facilitate interpretation (Figure 3.12). A pattern at a scale of 12 m was found for 29% of transects. On the grey-scale diagrams of two transects displaying pattern at this scale, patches were near the centre of the RoW and gaps were located near the edges or as 12 m patches throughout the RoW (Figure 3.13). Even though they both express scales of pattern at 12 m, they differ greatly in number of presences and absences occurring along the transect. A pattern at a scale of 0.1 m was found for 83% of *Hesperostipa comata* transects. The occurrence of pattern at this scale may be a result of the smallest sampling scale being 0.1 m (10 cm). Juvenile plants were close to 10 cm in diameter and a single individual often occupied a single quadrat. This may indicate biologically, that *Hesperostipa comata* may have a negative association with itself at a scale of 10 cm. A summary of patterns observed for *Hesperostipa comata*, through wavelet analysis, are listed in (Figure 3.14). Some patterns are repeated but many are represented only once. Although numerous transects may be indicating a pattern at a particular scale the strength of expression must also be considered. Although 83% of the transects indicate a pattern at 0.1 m, the expression of variance in the scalograms was not as strong as it was for other scalograms indicating pattern at 12 m (Figure 3.12).

Koeleria macrantha had a similar response as needle and thread grass displaying a pattern at a scale of 0.1 m (Figure 3.15). *Koeleria macrantha* also appears to closely match with the size of the smallest scale of sampling (10 x 10 cm), which may indicate a positive association between needle and thread grass and June grass. For *Koeleria macrantha* transects, 42% expressed a pattern at 0.1 m, 29% had a repeating pattern at 0.5 m and 19% at 1 m. Other patterns were present, but were not repeating. A summary of patterns for *Koeleria macrantha*, through wavelet analysis, are listed in (Figure 3.16). Both needle and thread and June grass were found throughout the RoW and therefore were not responding as specialists within the linear disturbance.

Calamovilfa longifolia transects were analyzed from 2001 and a consistent pattern was evident, repeating in nearly every transect (Figure 3.17). Assuming that the similarities observed between year 1 (2000) and 2 (2001) presence and absence raw data would produce equivalent results, when analyzed for spatial pattern, only year 2 (2001) data were analyzed. Most transects indicated peaks at 1.5 m and 12 m. Peaks at 1.5 m displayed some drift. The pattern matched observations in the field. Sand reed grass recolonized only from the edges of the RoW via vegetative spread through rhizomes. It colonized from both edges of the RoW, but was most commonly present on the less disturbed north edge. Virtually no plants established from seed anywhere else on the RoW (1 of 16 transects) (Figure 3.18). Although the seed bank was not sampled, the likelihood that sand reed grass seed was absent from the seed bank is improbable. This indicates that sand reed grass did not readily establish from seed in the RoW disturbed area and appears to function strictly as an edge species. Sand reed grass may be responding to competition of other species in the RoW rather than to size and shape of the disturbance and may have a negative association with other grass species. Since other species indicated patterns at the same scale as sand reed grass this is not likely. Sand reed grass is considered an important early successional colonizer but these results suggest it may require an undisturbed edge to colonize from and therefore establishment would be extremely slow on wide disturbances. Umbanhowar (1992) found that *Pascopyron smithii* (Rydb.) A. Love (western wheat grass), also a rhizomatous species, had greater abundances on artificial earthen mounds than off mound when compared to *Calamovilfa longifolia* at mid-slope positions. This indicates that although *Calamovilfa longifolia* had higher abundances off the mound it recolonized the mound less rapidly.

Sporobolus cryptandrus was only present in three transects in both 2000 and 2001. When these transects were analyzed for 2001 two repeating patterns were evident, two transects indicated patterns at 5 m and two at 2 m (Figure 3.19). Field observations of *Sporobolus cryptandrus* sand dropseed indicated few species established and it was found only in the most exposed areas. Areas that had dense annual plant growth had virtually no establishment of *Sporobolus cryptandrus*. This provides some insight into establishment of *Sporobolus cryptandrus*. *Sporobolus cryptandrus* establishment seemed concentrated in the centre of the RoW and tended to be scarce or non-existent near the edges (Figure 3.20) potentially indicating it responds to linear disturbances of this size as an interior species.

Achnatherum hymenoides was only found once in one of 24 transects for 2001 and therefore could not be analyzed for spatial pattern. Observations were made of *Achnatherum hymenoides* in 2000. These occurrences may have been the result of sampling error. Plots seeded with *Achnatherum hymenoides* that contained this species in 2000 also had it in 2001. Therefore, the individuals did not perish. *Achnatherum hymenoides*, as a seedling, closely resembles seedlings of needle and thread grass both having caespitose growth habits, acute ligules and rolled leaves. Therefore, results for needle and thread grass in 2000 may have data missing because presences were mistaken as *Achnatherum hymenoides*. This species only established from seed that had been drilled in seeded plots and although present naturally did not establish from the seed bank on the RoW. *Achnatherum hymenoides* was found established in natural blowouts near the RoW but did not establish in natural recovery plots from the seed bank. It appears to be responding to the same control factors for establishment as *Sporobolus cryptandrus*. It too seemed to be absent from plots that had rapid vegetation establishment by annuals, which was found at significantly lower densities and canopy covers in seeded plots. In seeded plots *Achnatherum hymenoides* established quickly from the seed mix.

4. SUMMARY AND CONCLUSIONS

Wavelet analysis can be used to determine spatial patterns in plant communities, in spite of difficulties in the interpretation of results. This research has shown that native grasses respond to spatial characteristics of disturbances such as a pipeline RoW. Some species indicated consistent repeating patterns while others varied in the patterns observed. The patchy nature of vegetation resulted in multiple scales of pattern for an individual species. Some species respond as generalists others as specialists.

It may be feasible to adjust seeding patterns of a RoW according to species spatial responses and patterns of scale. For example, *Sporobolus cryptandrus* was an interior species and occurred in patches of 2 and 5 m. When seeding this species on a linear disturbance best establishment and efficient seed use may be achieved by seeding it only in the interior and in 2 m wide strips. *Calamovilfa longifolia*, which responded as an edge species, may perform best when seeded along the edges in a 1.5 m strip or should not be seeded at all as it was shown to colonize vegetatively. Species such as *Hesperostipa comata* and *Koeleria macrantha*, although generalists in the areas of the RoW that they occupy, may be seeded together because of a positive association but also indicated particular sizes of patches that they occurred in. Further research is required to confirm if seeding native seed mixes in particular patterns increase revegetation success and maximizes seed quantity used.

Specific Conclusions

1. Needle and thread grass was a generalist occupying all areas of the right-of-way, but produced a spatial pattern of patches and gaps at numerous scales but the most common with the strongest expression was at 12 m.
2. June grass was also a generalist, and produced a spatial pattern of patches and gaps at numerous scales, but produced the strongest expression with repetition at 0.5 m.
3. Needle and thread grass and june grass may have a positive association at 0.1 m.
4. Sand reed grass was an edge specialist colonizing primarily the edges of the right-of-way. It produced repeating patterns at scales of 1.5 m and 12 m.
5. Sand dropseed was an interior specialist colonizing primarily the interior of the right-of-way. It produced patterns at scales of 2 m and 5 m, however only three transects had this species present therefore we must consider the few number of transects analyzed.
6. Annual forbs may have positive associations in spatial pattern with some native grass species.

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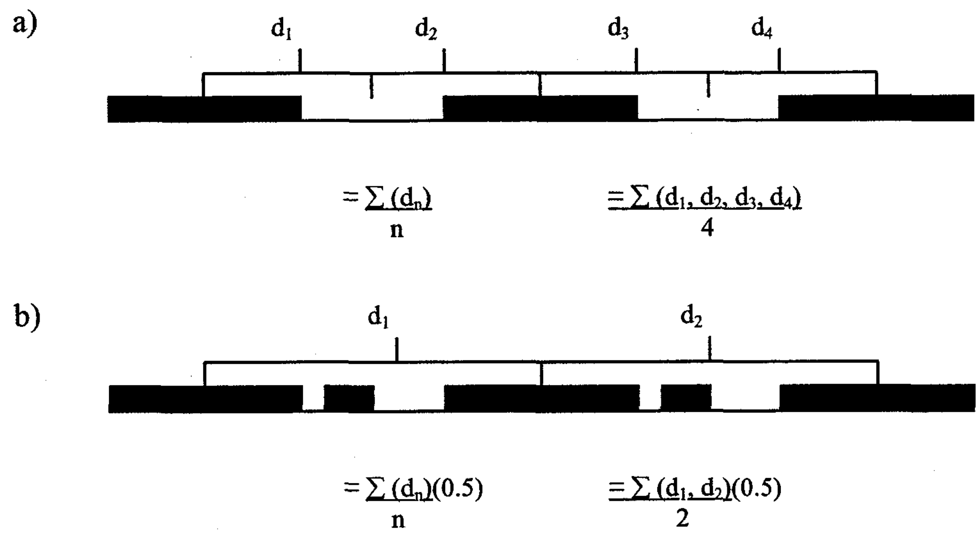


Figure 3.1. Diagramatical and mathematical definitions of scale of pattern in a) a two-phase and b) multi-phase mosaic.

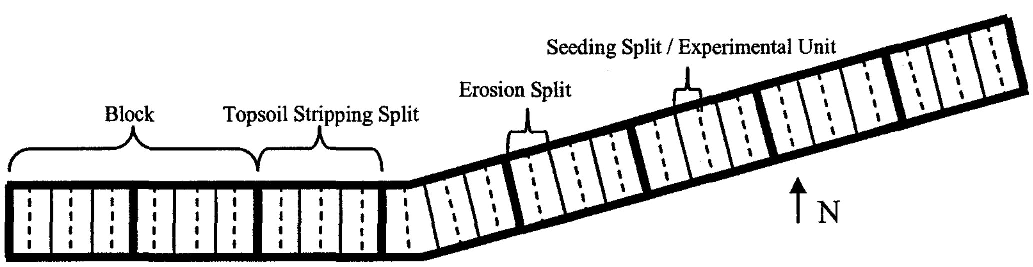


Figure 3.2. Split block, split-split plot experimental design and treatment layout. Plots are the entire width (32 m) of the right-of-way of the east-west pipeline.

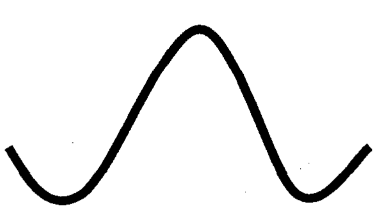


Figure 3.3. Mexican Hat wavelet formation.

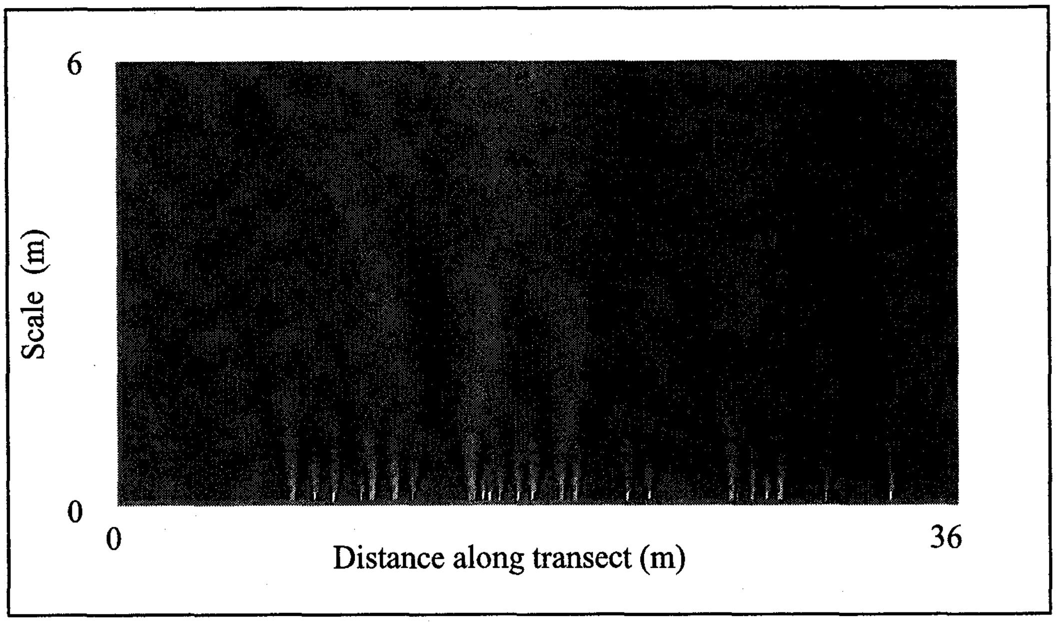


Figure 3.4. Example of grey-scale diagram produced by the by the wavelet transformation of a 36 m long transect of 10 x 10 cm contiguous quadrats of presence and absence data for one species of native grass.

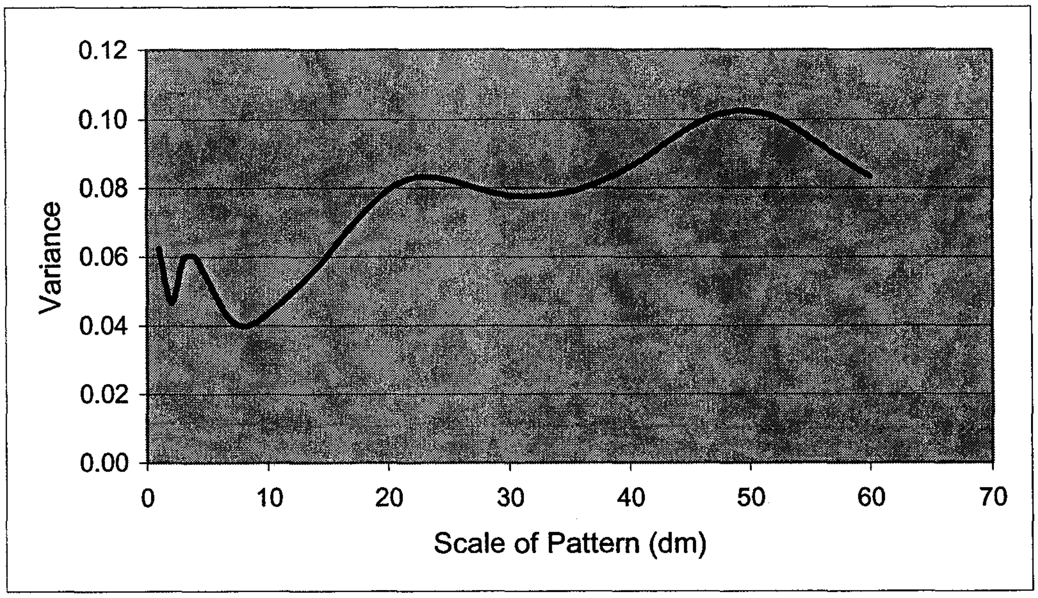


Figure 3.5. Example of a scalogram of the wavelet transformation in Figure 3.4 of a 36 m long transect of 10 x 10 cm contiguous quadrats of presence and absence data for one species of native grass.

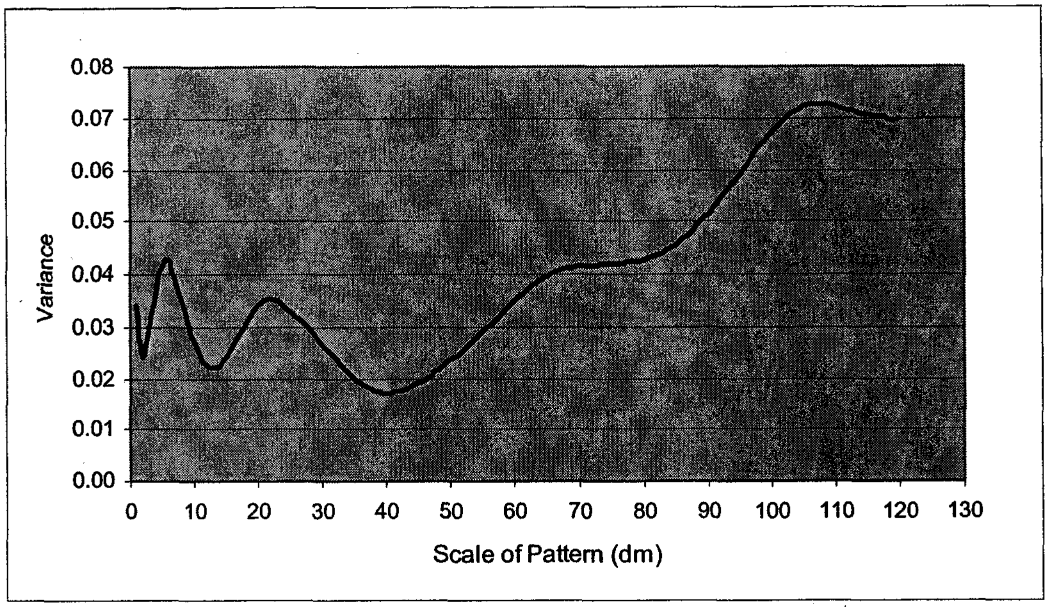
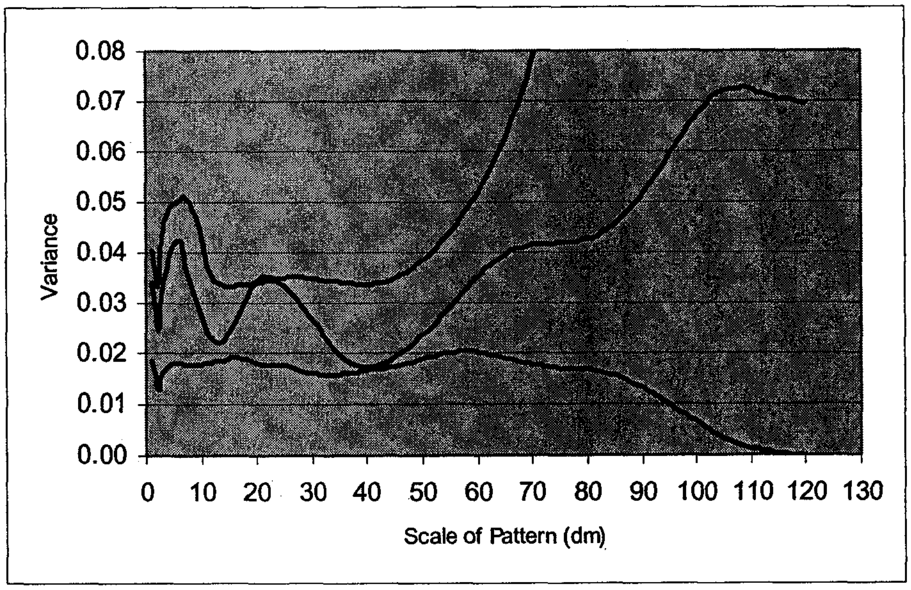


Figure 3.6. Scalogram displaying the difficulty of interpretation due to multiple scales of pattern, variations in amplitudes and resonance peaks.



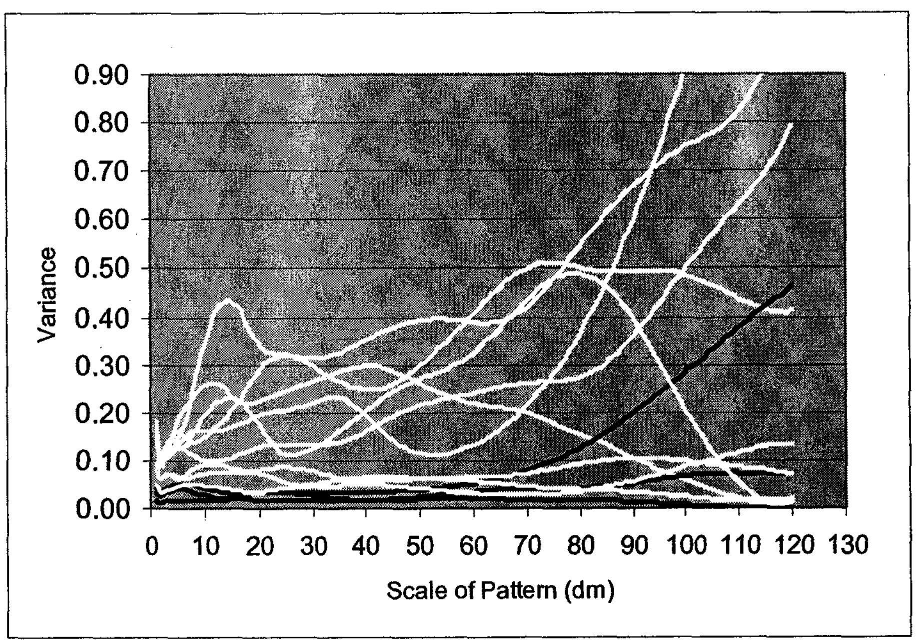


Figure 3.7. The complications in interpreting scalogram results with changing the scale of the variance axis. Three transects in black in the top scalogram are also in black in the bottom scalogram. The two scalograms have different scales on the variance axises. Scalograms are of *Hesperostipa comata* transformations.

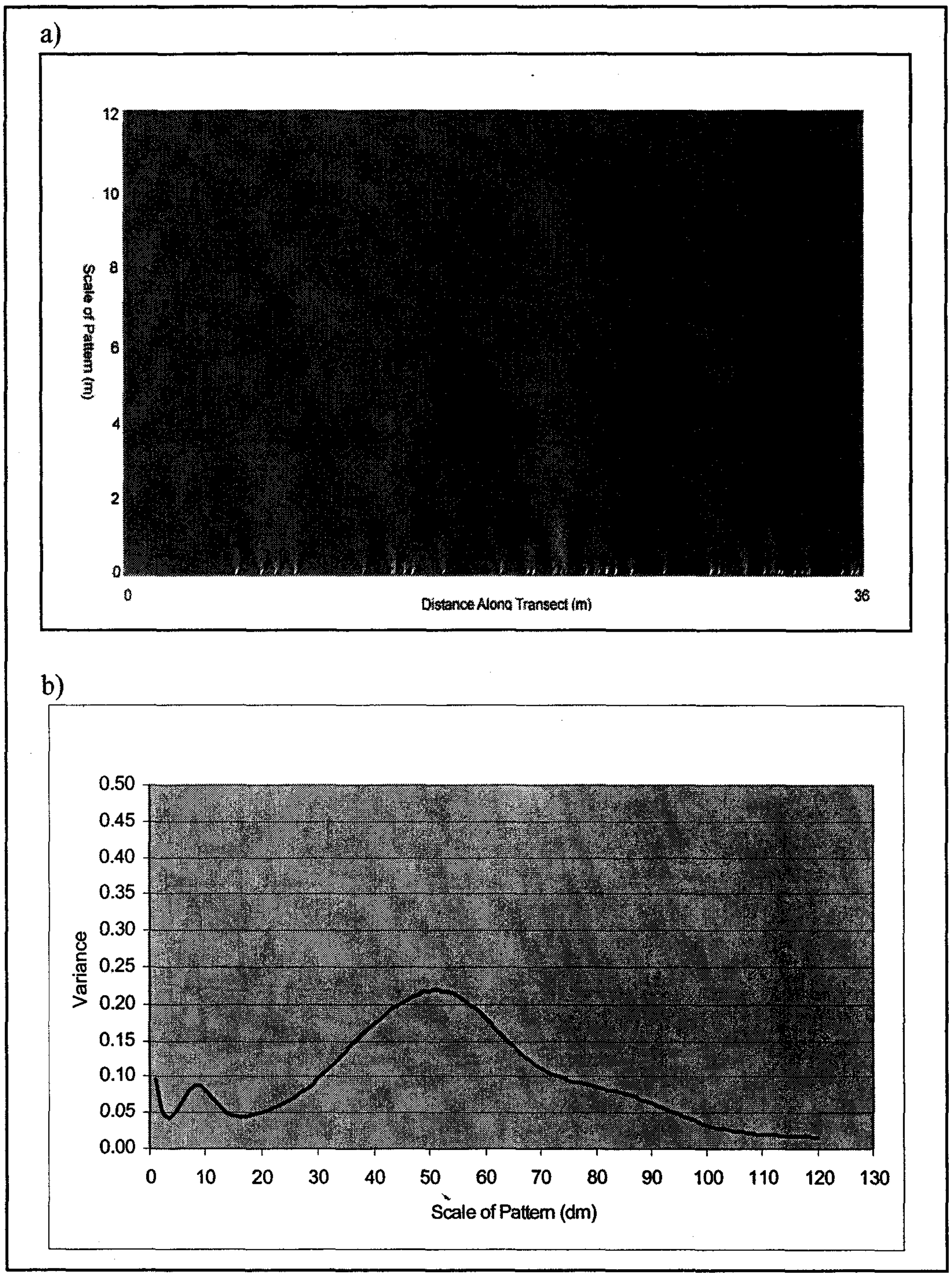


Figure 3.8. Wavelet transformation a) grey-scale diagram and b)scalogram for a *Hesperostipa comata* transect from year two (2001).

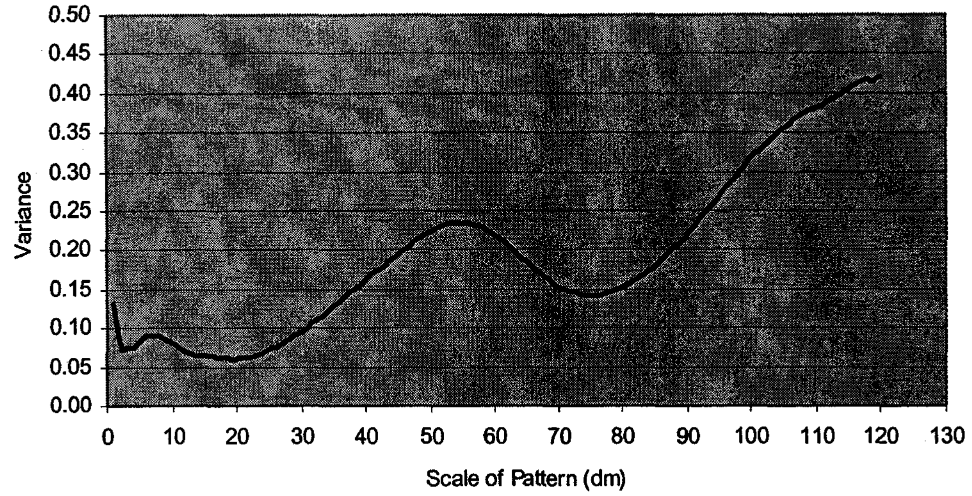


Figure 3.9. Scalogram of the same *Hesperostipa comata* transect as in Figure 3.8 but from year 1 (2000).

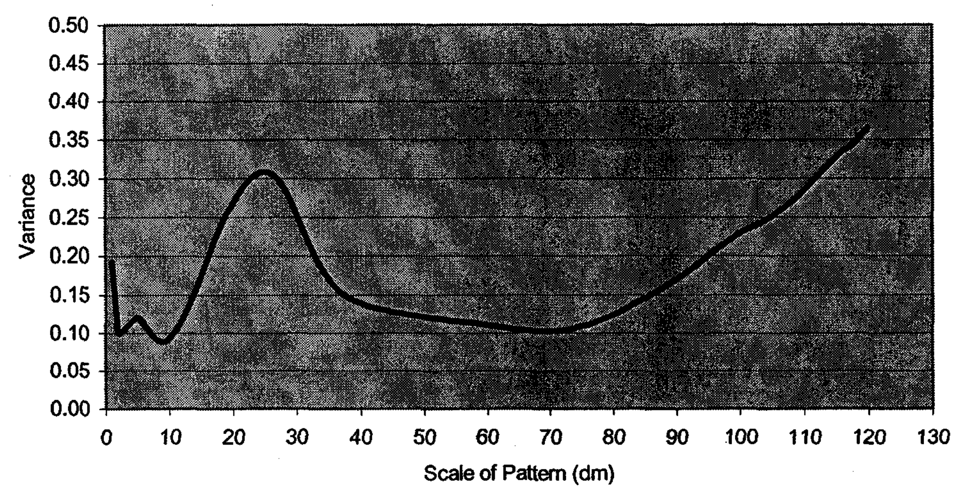


Figure 3.10. Scalogram of a different *Hesperostipa comata* transect from year 2 (2001) than in Figure 3.8 indicating a different scale of pattern at 25 dm.

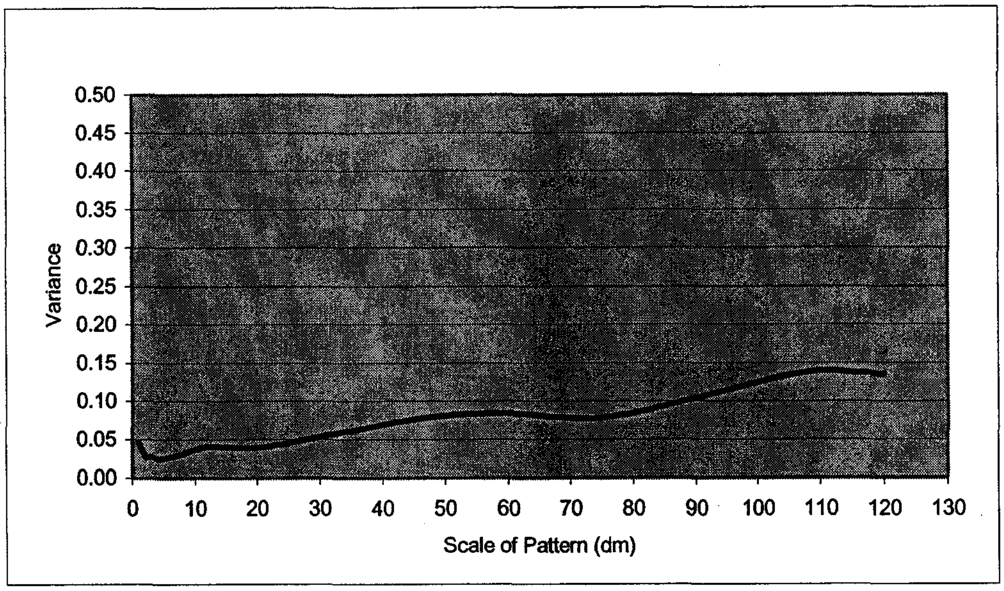


Figure 3.11. Scalogram of the same *Hesperostipa comata* transect in Figure 3.10 but from year 1 (2000) indicating lack of repetition in pattern over two growing seasons.

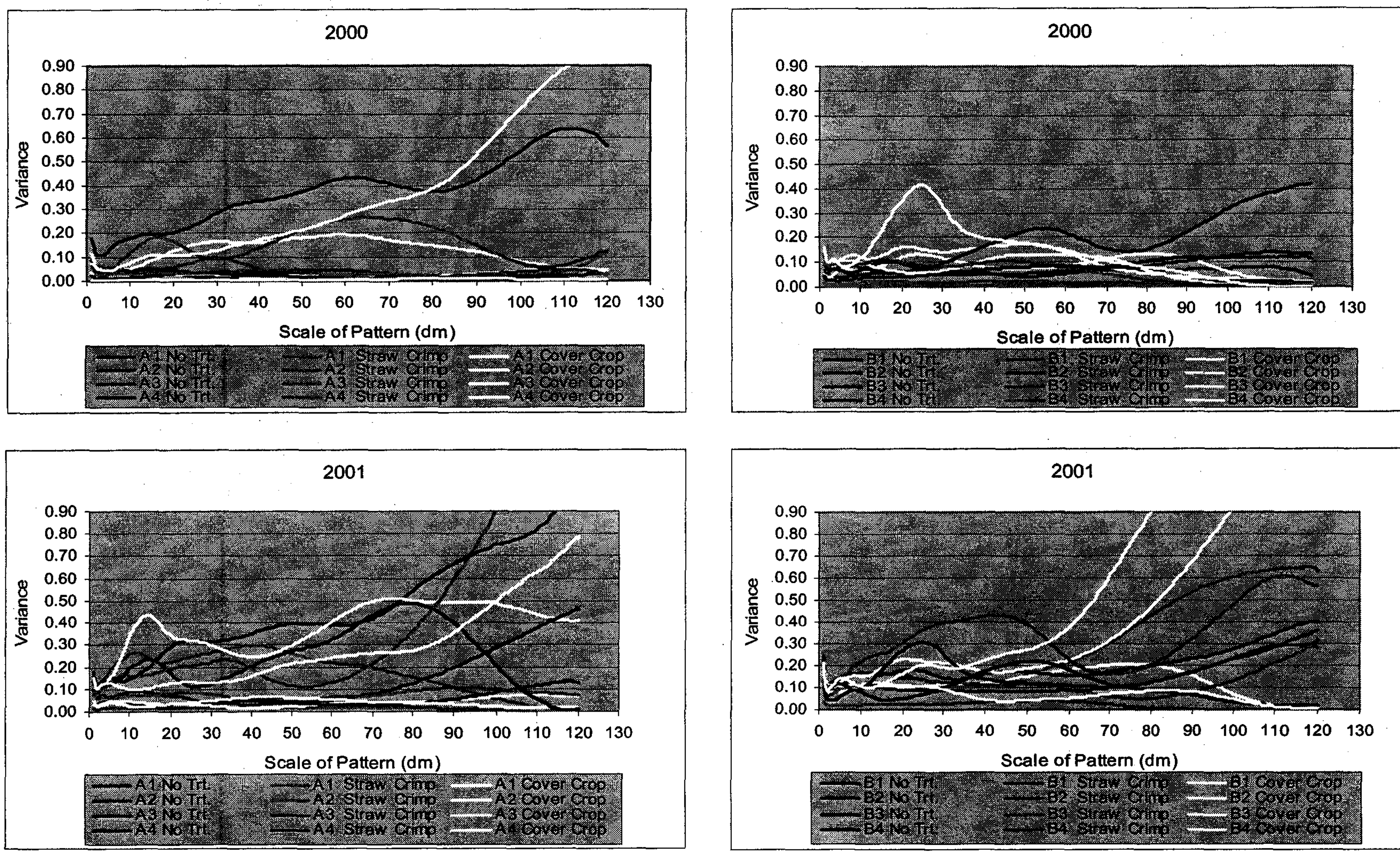


Figure 3.12. All scalograms for each needle and thread grass transect over both years (2000 and 2001). Transects are separate by shallow (A) and conventional (B) topsoil stripping treatments and erosion treatments within years to facilitate visual comparison.

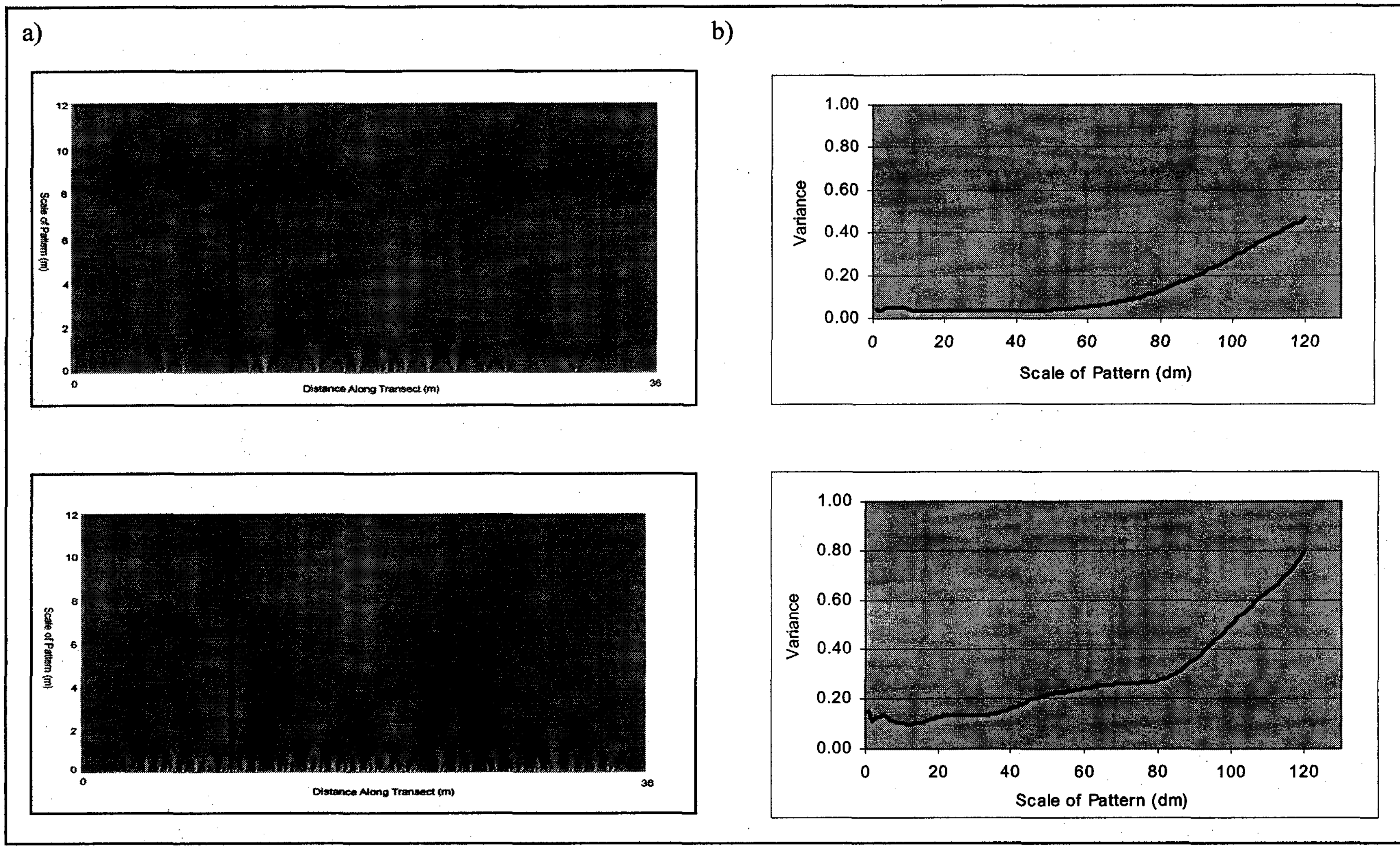


Figure 3.13. a) Wavelet transformation grey-scale diagrams and b) scalograms for two separate transects both indicating patterns a 12 m, but having different raw data as observed in the grey-scale diagrams.

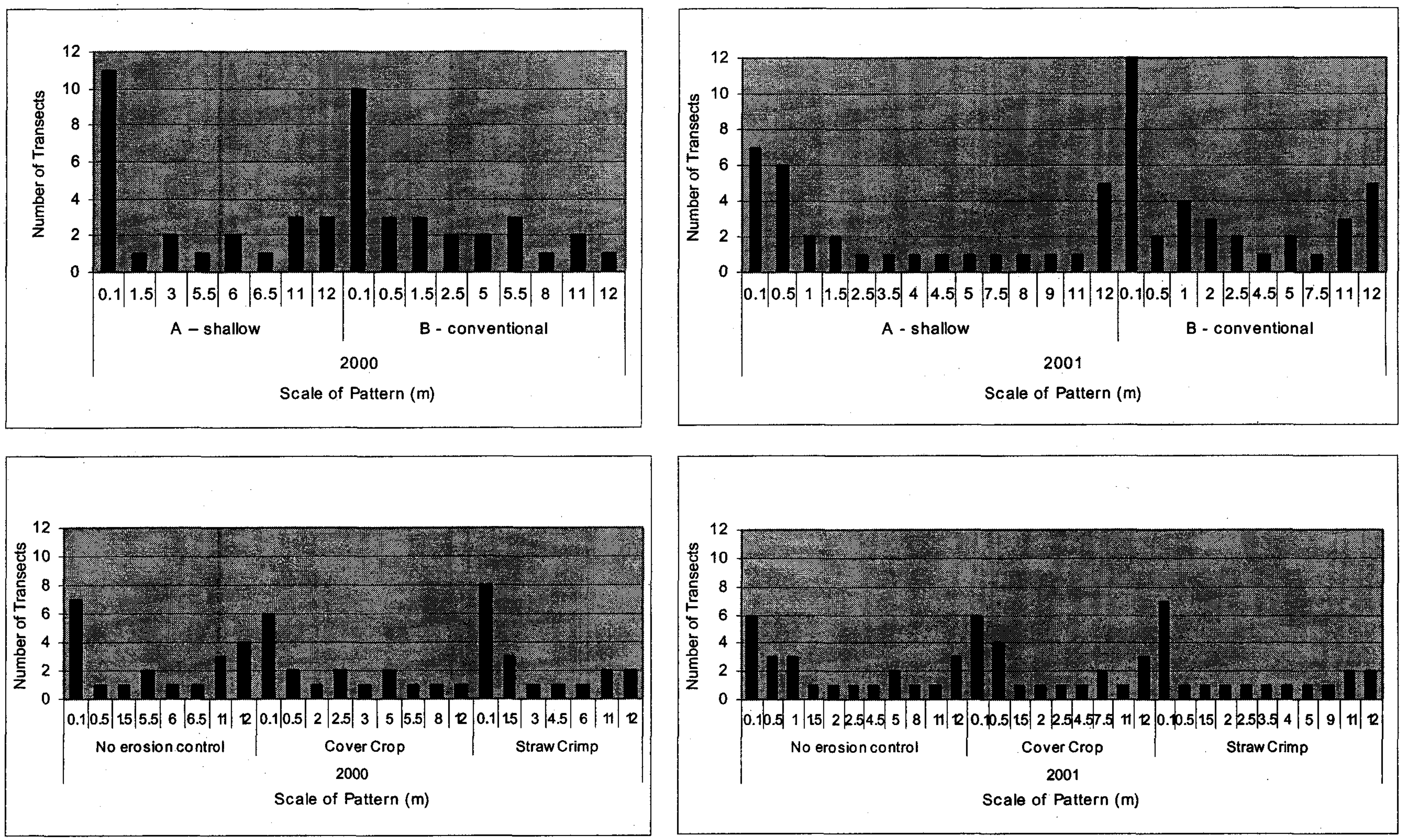


Figure 3.14. Summary of the number of *Hesperostipa comata* transects expressing pattern at a specific scale. Transects are summarized by a) topsoil stripping treatment and b) erosion control treatment for years 1 (2000) and 2 (2001).

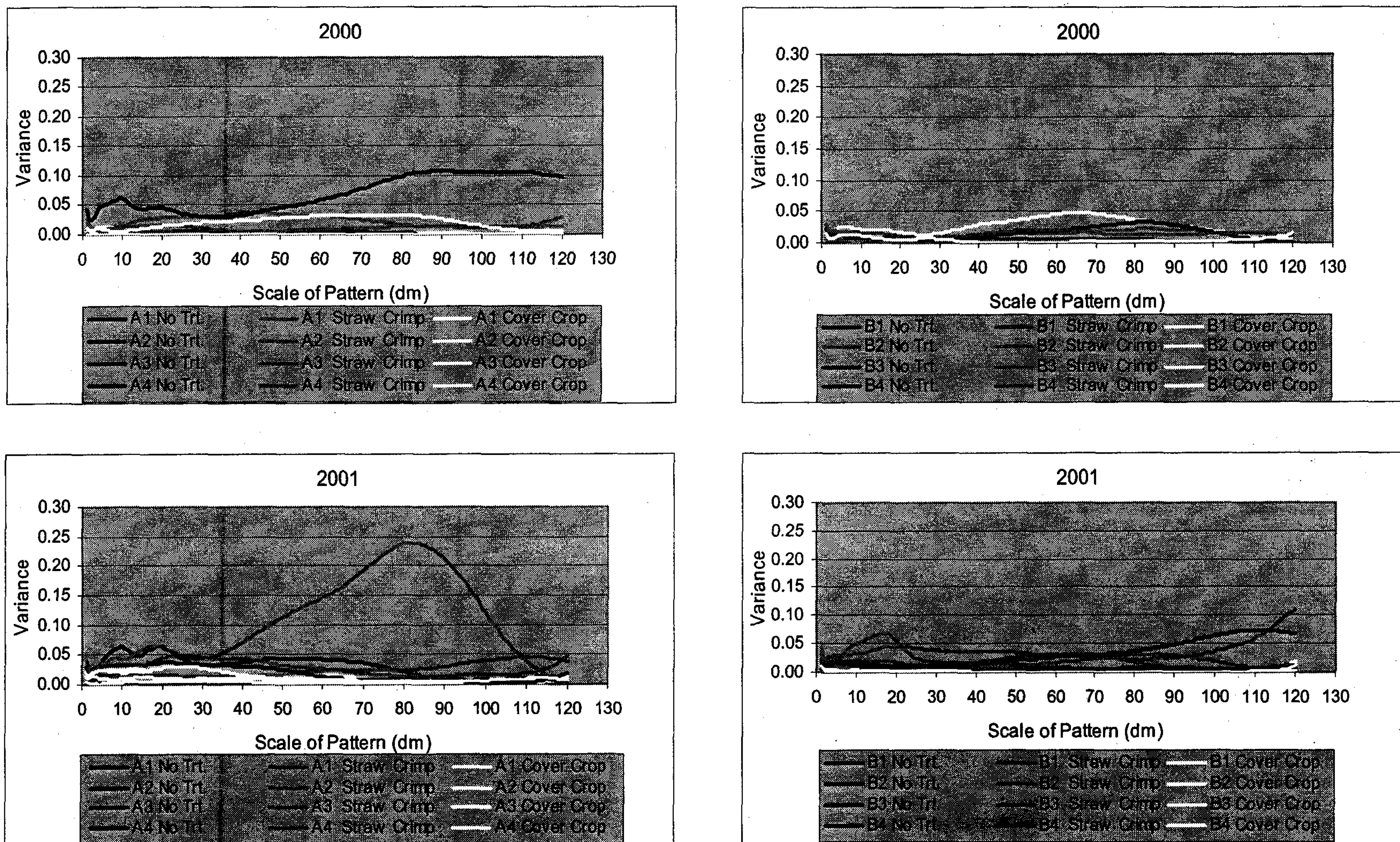


Figure 3.15. All scalograms for each *Koeleria macrantha* transect over both years (2000 and 2001). Transects are separated by shallow (A) and conventional (B) and erosion control treatments within years to facilitate visual comparison.

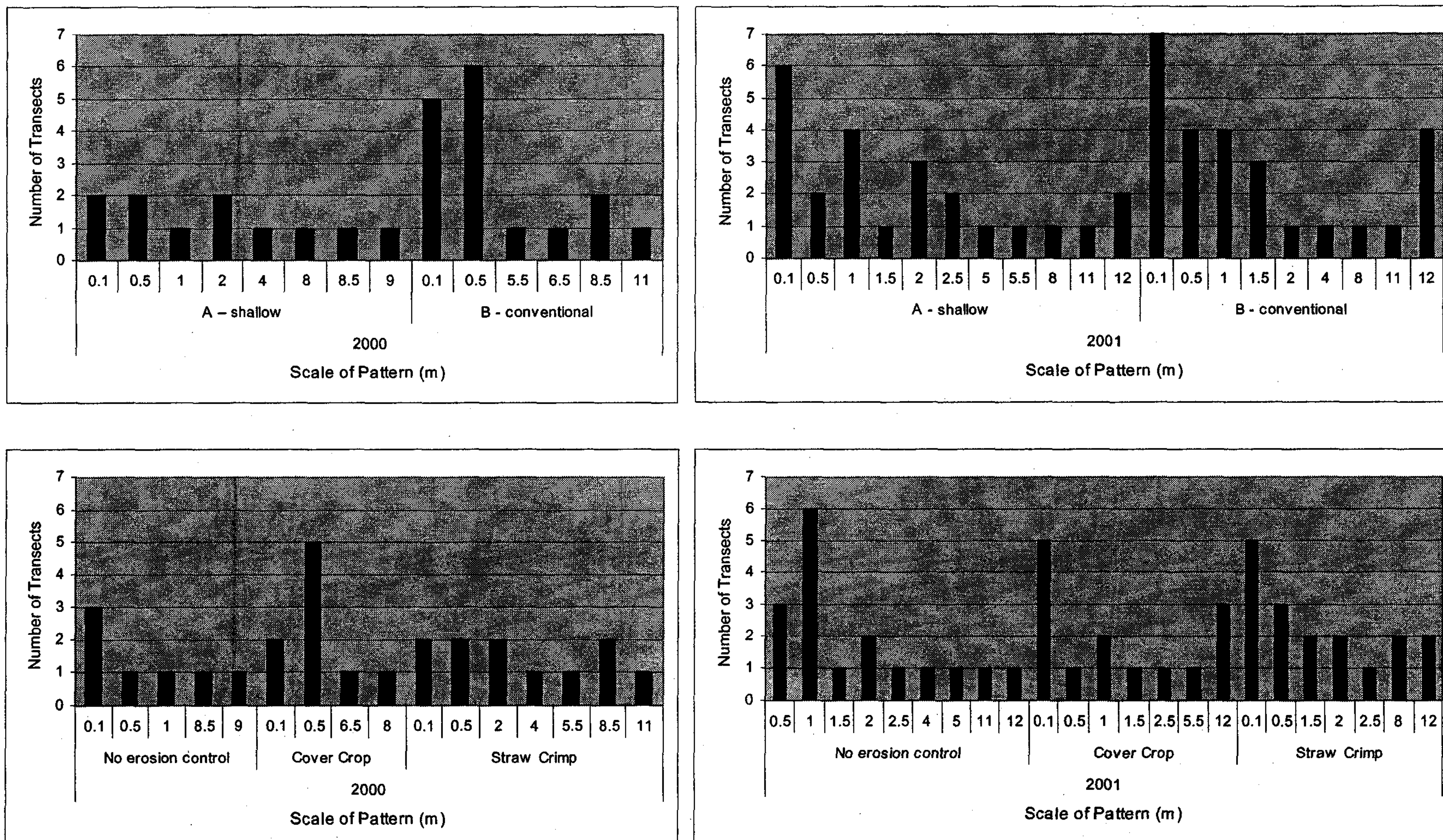
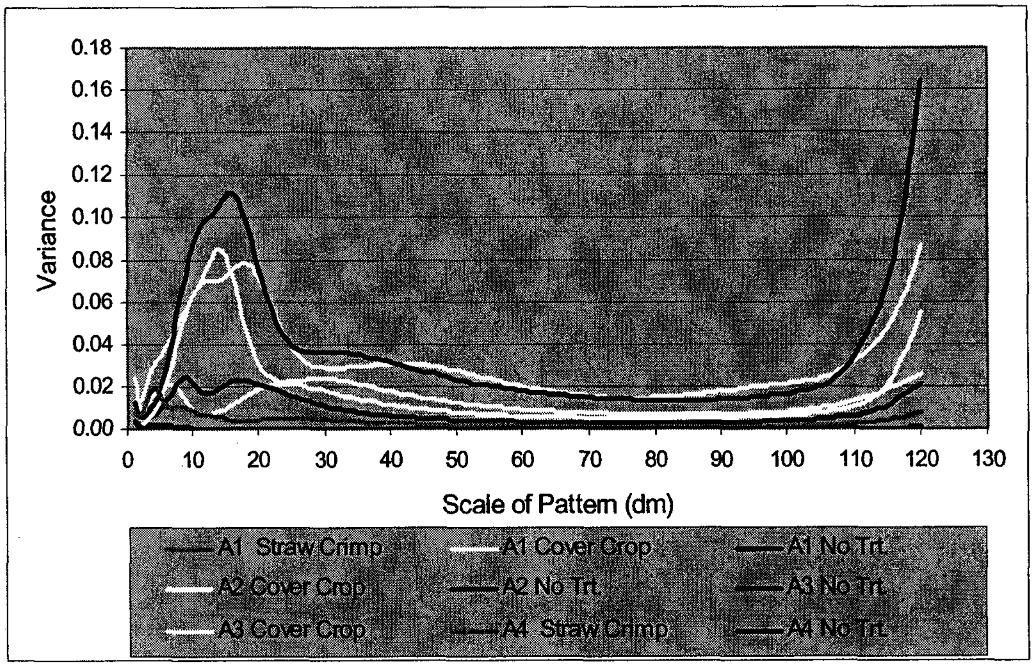


Figure 3.16. Summary of the number of *Koeleria macrantha* transects expressing pattern at a specific scale. Transects are summarized by a) separated by topsoil stripping treatment and b) separated by erosion control treatments for years 1 (2000) and 2 (2001).



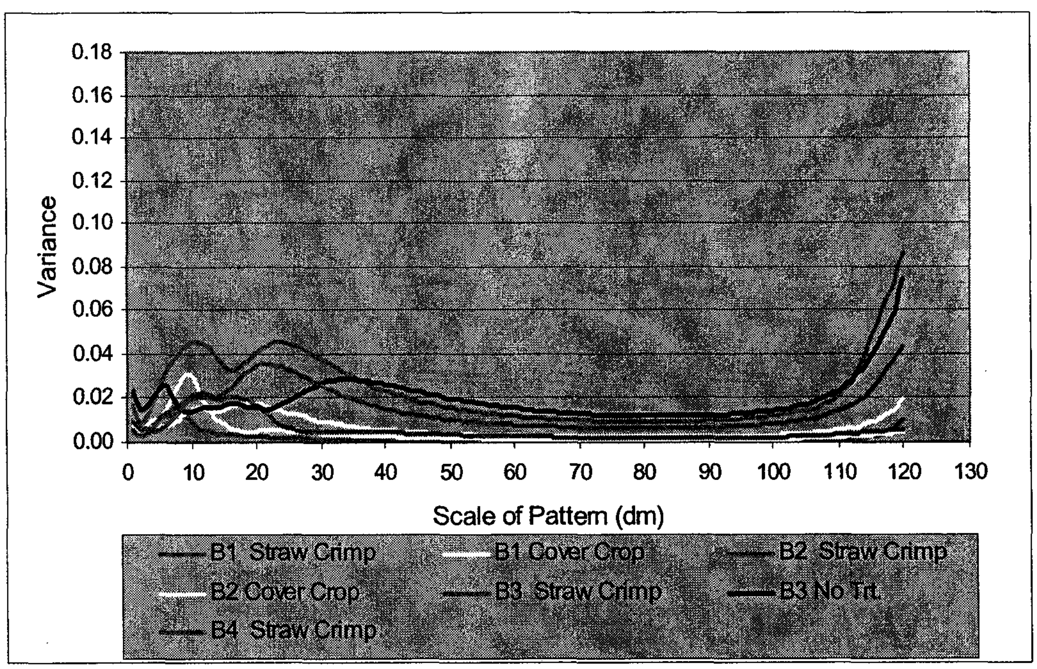


Figure 3.17. All scalograms for sand reed grass transects for year 2 (2001). Transects are separated by shallow (A) and conventional and erosion control treatments.

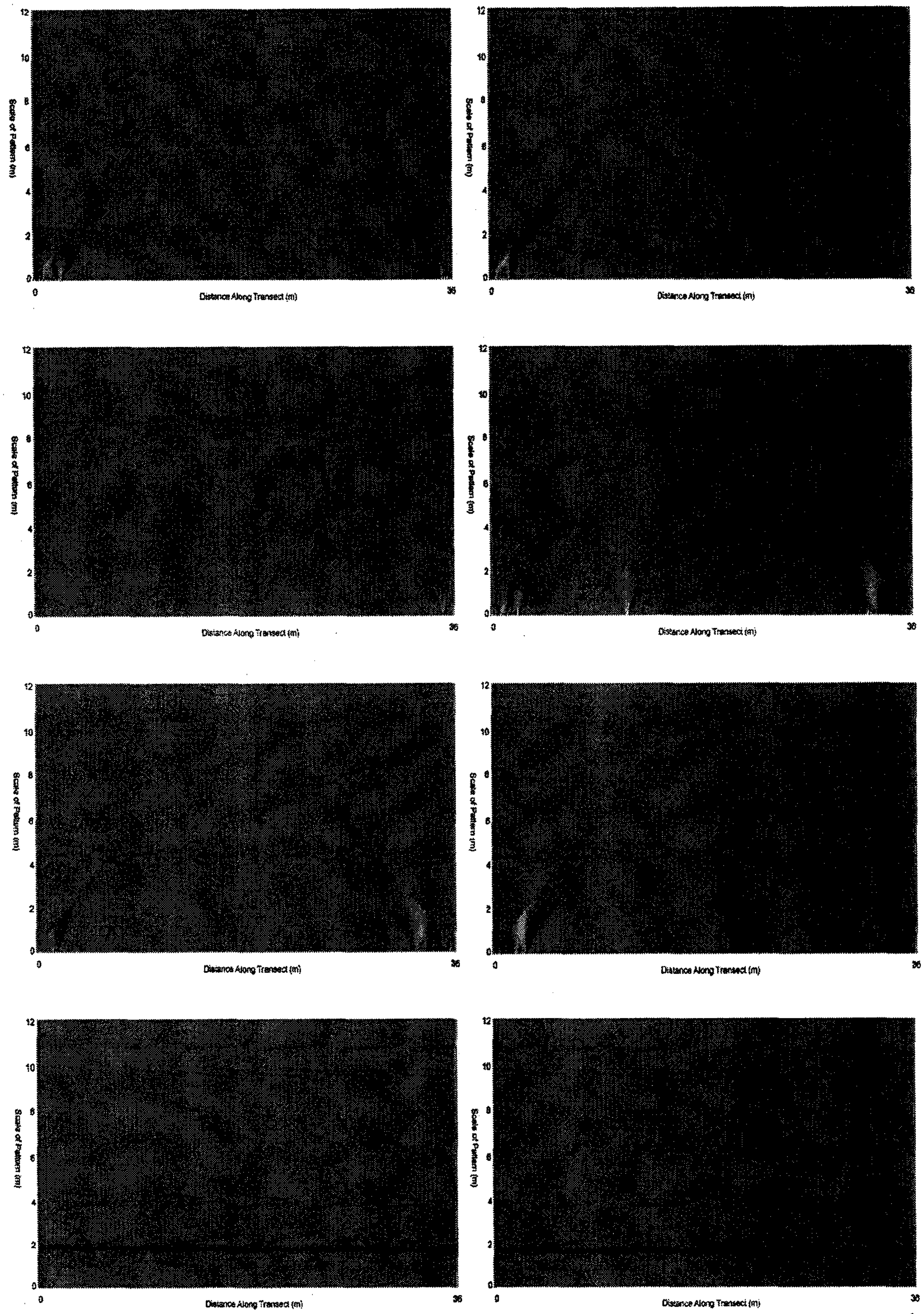


Figure 3.18. Grey-scale diagrams of all transects for *Calamovilfa longifolia* in year 2 (2001). x axis is the distance (m) along the transect and y is scale of pattern (m).

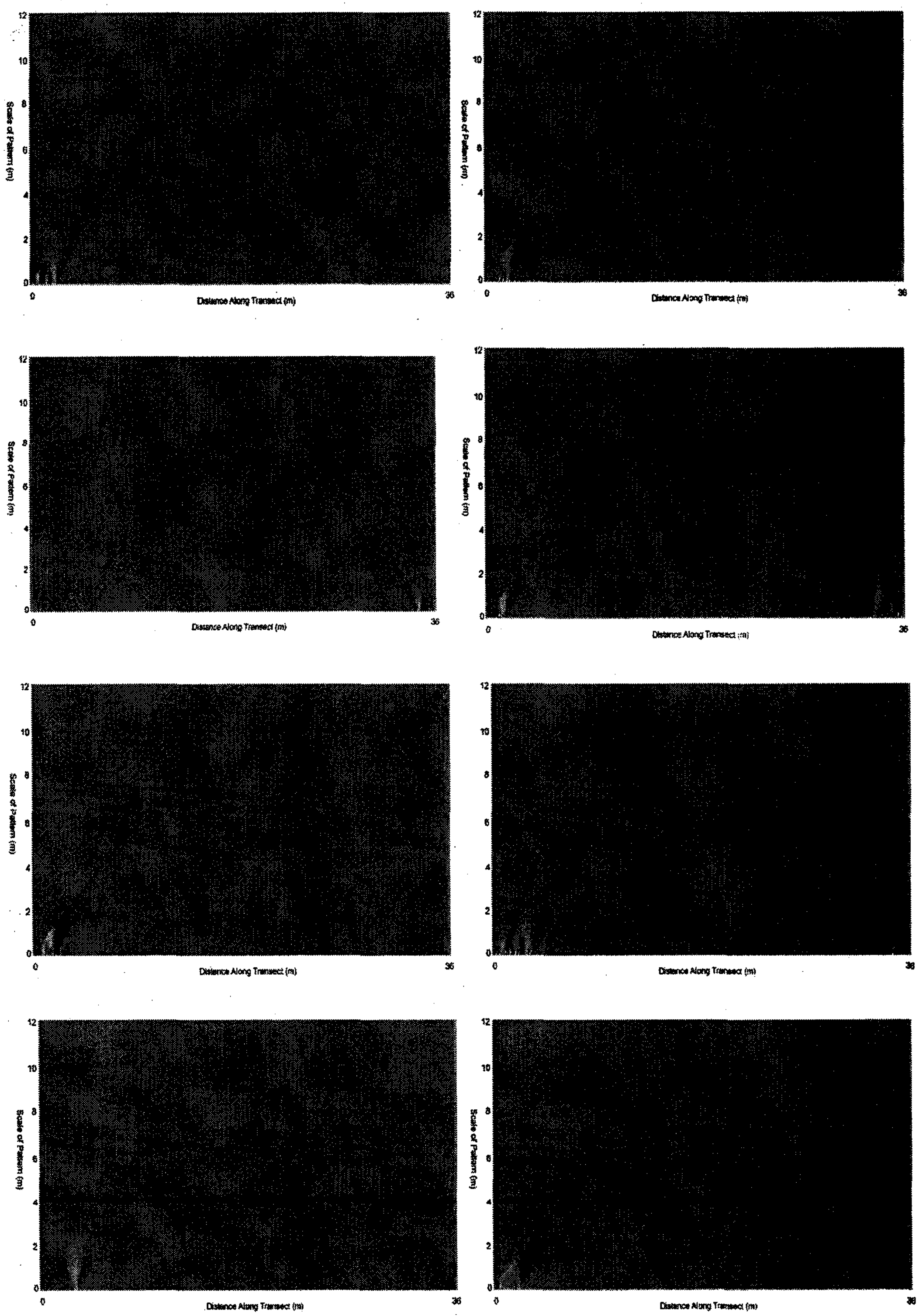


Figure 3.18 continued. Grey-scale diagrams of all transects for *Calamovilfa longifolia* in year 2 (2001). *x* axis is the distance (m) along the transect and *y* is scale of pattern (m).

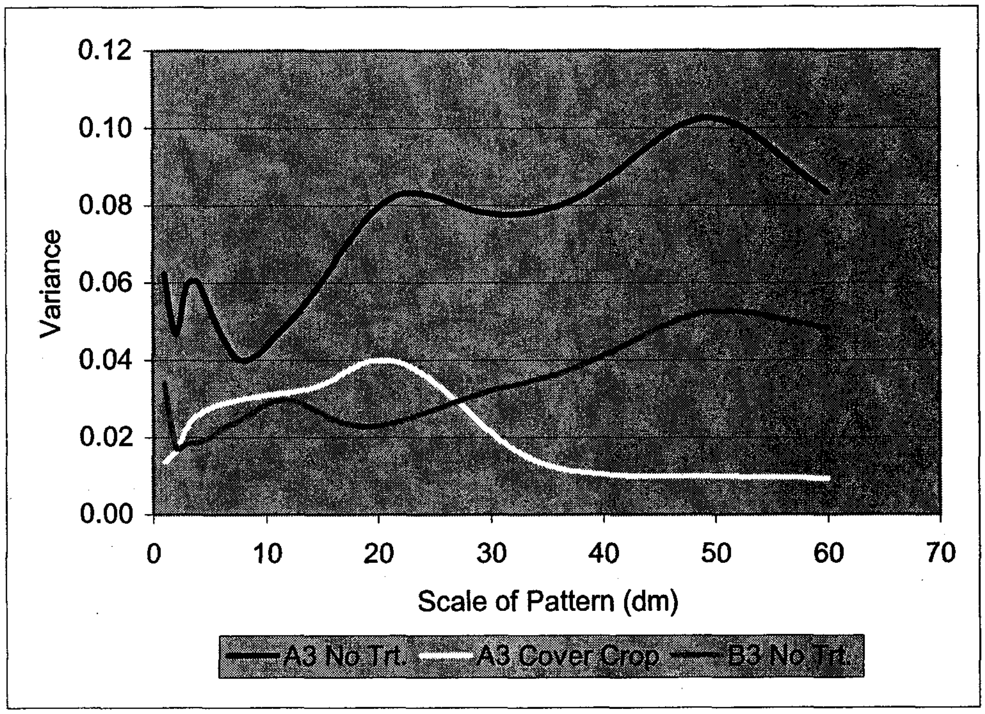


Figure 3.19. Three scalograms for *Sporobolus cryptandrus*. Separated by shallow (A) and conventional (B) topsoil stripping and erosion control treatments for year 2 (2001).

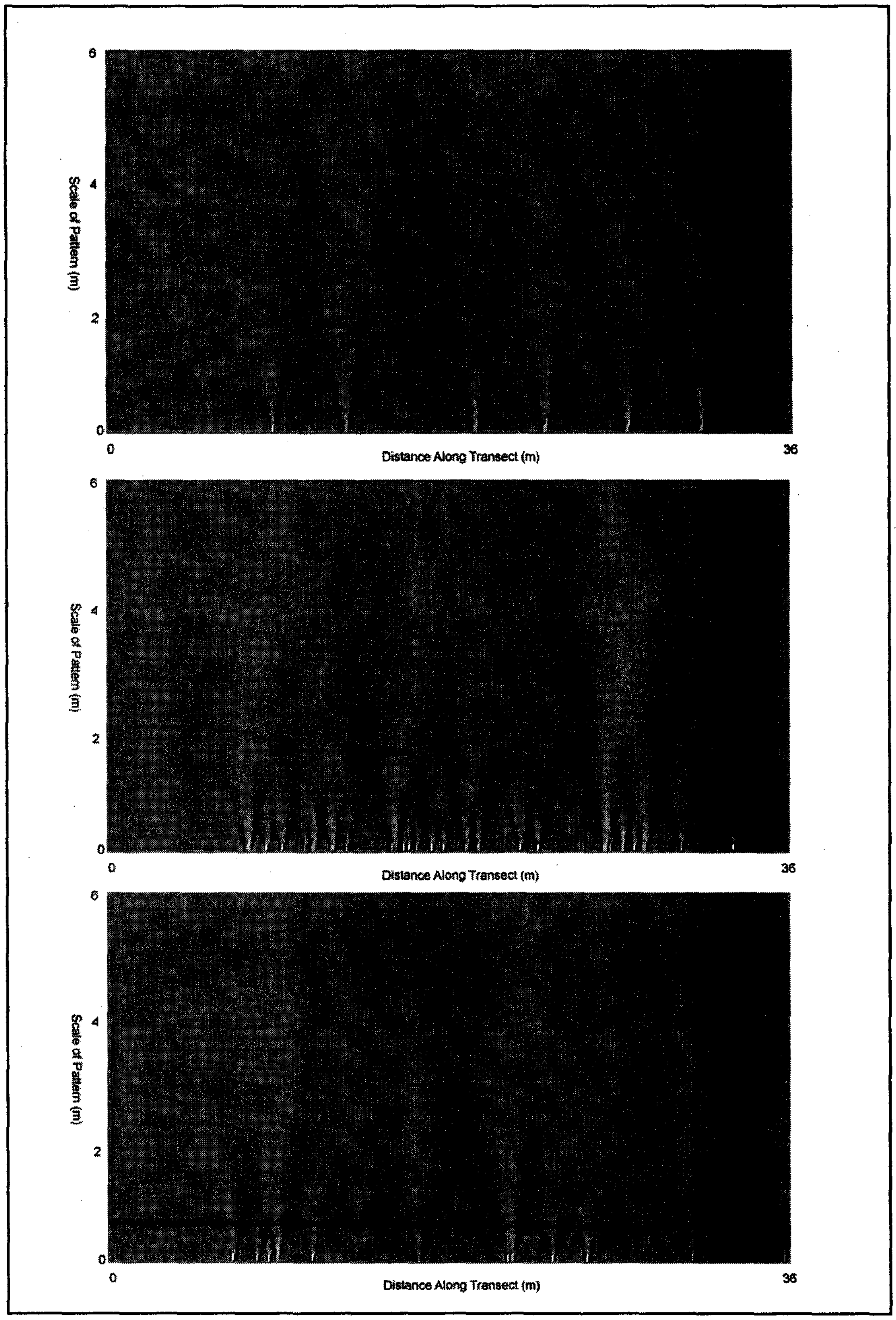


Figure 3.20. Grey-scale diagram of the three *Sporobolus cryptandrus* transects from year 2 (2001).

CHAPTER IV
SYNTHESIS

1. INTRODUCTION

Earlier research has focused on various aspects of pipeline installation impacts on the environment, agricultural productivity and the effectiveness of some reclamation techniques. None focused specifically on topsoil handling techniques and effects of shallow topsoil stripping. Due to the sensitivity of sandhills grassland, gaining a better understanding of vegetation establishment and community development on extremely sandy soils following pipeline installation, was an objective of this research. The effects of shallow topsoil stripping on soils, vegetation establishment and whether or not the technique can be accurately applied are issues that need to be addressed. Various erosion control techniques commonly used in pipeline reclamation on sandy soils, have not been scientifically tested nor compared to vegetation establishment without use of erosion control. Natural recovery has been disregarded as a viable revegetation technique on soils susceptible to erosion, but never scientifically tested on sandy soils. This research compared the use of native grass seed mixes with natural recovery in vegetation establishment.

No research to date had investigated spatial colonization response of plants within linear disturbances. This research investigated presence or absence of spatial pattern of native grasses in colonization of a pipeline right-of-way (RoW). This research well help provide a better understanding of how pipeline RoW recolonize and revegetate as a community, the responses of individual species and how reclamation techniques influence these responses.

2. EDAPHIC CONDITIONS

As expected, edaphic conditions were important in RoW reclamation. Most intriguing was the topsoil stripping treatment's ability to preserve the small amounts of soil organic carbon present in these coarse textured soil surface horizons. This proved essential in increasing soil moisture retention, which for these rapidly drained soils is beneficial for plant growth and community establishment. Straw crimping and similar mulching techniques which are primarily used to reduce soil erosion are often secondarily applied to increase C:N ratios resulting in nitrogen immobilization (Lindemann et al. 1989). This research identified that these treatments actually lead to increases in available nitrogen in the form of nitrate. This result is opposite to changes in soil available nitrogen during secondary succession following a disturbance, where mineral cycles become more closed as succession proceeds (Odum 1993). Therefore, straw crimping and mulching treatments might actually inhibit community succession by perpetuating conditions favoured by *r*-strategists (early successional ruderals) such as annual weedy species.

3. SUCCESSION

Community development differed greatly between seeded and natural recovery treatments. Communities produced as a result of seeding, although not significantly less diverse in total number of species present, were less diverse in the types of plants present. Seeded plots were dominated by grasses and contained no native perennial forb species that were found in natural recovery treatments. The long term influences that these results have on community composition and function are areas for potential future research.

Annual native and non-native forb species that established from the seed bank are essential to early stages of succession. These species provide erosion protection without altering natural successional pathways. If annuals are correlated in spatial pattern to native grass, as this research suggests, it would indicate their importance in community development and succession and support the facilitation model of succession suggested by Connell and Slatyer (1977). However, more research is required to investigate potential positive spatial associations between annuals forbs and native grasses. This research along with others (Naeth 1985, Baer et al. 2003, Wilson et al. 2004) has shown that annual weedy species decline over time and may not need to be controlled. They may actually be the best alternative for providing erosion control leading to compositionally more natural communities in pipeline RoW reclamation.

4. COLONIZATION DYNAMICS AND SPATIAL PATTERN

The spatial responses of native grasses in colonization of a disturbance had not been studied prior to this research. Species such as *Calamovilfa longifolia* (Hook) Scribn. (sand reed grass) and *Sporobolus crypytandrus* (Torr.) Gray (sand drop seed), thought to be significant to colonization and stabilization of sandy soils (Lippert and Hopkins 1950), were small components of the early seral stage communitiy and through their spatial patterns proved to be specialists in their responses to a large linear disturbance. Other species more common in mid to late stages of succession, *Hesperostipa comata* (Trin. & Rupr.) Barkw. (needle and thread grass), *Koeleria macrantha* (Ledeb.) Schultes (june grass), were found in abundance establishing from the seedbank and were the dominant colonizers, which supports findings by Lesica and Cooper (1999). In fact, *Hesperostipa comata* establishment from the seed bank was so abundant that its abundance is credited to eliminating significant effects in vegetation as a result of shallow topsoil stripping. These species responded spatially as generalists to the linear disturbance.

Spatial patterns were observed for individual native grass species through wavelet analysis. These patterns provided insight into areas of the RoW occupied by certain species and scale of pattern (sizes of patches and gaps) they occurred in. These spatial patterns may be mimicked when seeding with a native seed drill through spacing and using compositionally different seed mixes in adjacent passes of the drill. This would require seeding down the length of the RoW rather than across the RoW which is currently the most common technique. However, more research is required to evaluate community dynamics and revegetation success under various seeding trials considering their spatial patterns. This also would require further research and verification of what potential patterns of scale for each species and whether they are consistent with changes in scale of the disturbance (width of the RoW).

5. CONCLUSION

Over the short term, using a shallow topsoil stripping treatment does not improve vegetation establishment, but it is important in maintaining soil organic carbon which is essential for increasing soil moisture retention. Soil moisture retention is important for these rapidly drained soils. Despite speculation, this research showed that shallow topsoil stripping can be applied accurately. Erosion control techniques did not provide erosion control that significantly improved vegetation establishment and in the case of straw crimping actually inhibited plant growth. Plots without an erosion control treatment were protected from erosion by temporary annual species cover. Seeding a native seed mix, although producing greater canopy cover and densities of native grass, also reduced plant diversity. Seeding was also the most significant contributor to introducing undesirable plants. Natural recovery was a viable revegetation technique for sandy soils even on a large RoW and promoted a compositionally more natural plant community.

Wavelet analysis was effective in detecting spatial patterns for individual grass species. Spatial pattern analysis indicated that plants indeed respond spatially in their colonization strategies to disturbances. Spatial patterns of plants commonly used in reclamation seed mixes, once identified, could increase seeding effectiveness and maximize the quantity of seed used.

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APPENDIX

A1. Soil characteristics from August 1999 site reconnaissance of topsoil stripping treatment plots.

Block 1 Shallow Topsoil Stripping

Predominant Soil Classification: Orthic Dark Brown Chernozem
Parent Material: Loamy sand to sand textured glaciofluvial-eolian.
Drainage: Rapidly
Topography: Undulating (2 to 5%)

Horizon	Depth (cm)	Texture	Structure	Consistency
Ah	10-15	loamy sand	stuctureless (single grain)	loose
Bm	15-25	loamy sand	stuctureless (single grain)	loose
C	25-120	Sand	stuctureless (single grain)	loose

Block 1 Conventional Topsoil Stripping

Predominant Soil Classification: Orthic Dark Brown Chernozem
Parent Material: Loamy sand to sand textured glaciofluvial or eolian
Drainage: Rapidly
Topography: Undulating (2 to 5%)

Horizon	Depth (cm)	Texture	Structure	Consistency
Ah	10-15	loamy sand	stuctureless (single grain)	loose
Bm	15-25	loamy sand	stuctureless (single grain)	loose
C	25-120	Sand	stuctureless (single grain)	loose

Block 2 Shallow Topsoil Stripping

Predominant Soil Classification: Orthic Dark Brown Chernozem
Parent Material: Loamy sand to sand textured glaciofluvial – eolian.
Drainage: Rapidly
Topography: Undulating (2 to 5%)

Horizon	Depth (cm)	Texture	Structure	Consistency
Ah	10-15	loamy sand	stuctureless (single grain)	loose
Bm	15-25	loamy sand	stuctureless (single grain)	loose
C	25-120	Sand	stuctureless (single grain)	loose

Block 2 Conventional Topsoil Stripping

Predominant Soil Classification: Orthic Dark Brown Chernozem
Parent Material: Loamy sand to sand textured glaciofluvial-eolian.
Drainage: Rapidly
Topography: Undulating (2 to 5%)

Horizon	Depth (cm)	Texture	Structure	Consistency
Ah	10-15	loamy sand	stuctureless (single grain)	loose
Bm	15-25	loamy sand	stuctureless (single grain)	loose
C	25-120	sand	stuctureless (single grain)	loose

Block 3 Shallow Topsoil Stripping

Predominant Soil Classification: Rego Dark Brown Chernozem
Parent Material: Loamy sand to sand textured glaciofluvial or eolian
Drainage: Rapidly
Topography: Hummocky (2 to 5%)

Horizon	Depth (cm)	Texture	Structure	Consistency
Ah	10-15	loamy sand	stuctureless (single grain)	loose
C	15-120	sand	stuctureless (single grain)	loose

Block 3 Conventional Topsoil Stripping

Predominant Soil Classification: Orthic Dark Brown Chernozem
Parent Material: Loamy sand to sand textured glaciofluvial or eolian
Drainage: Rapidly Topography: Undulating (2 to 5%)

Horizon	Depth (cm)	Texture	Structure	Consistency
Ah	10-15	loamy sand	stuctureless (single grain)	loose
Bm	15-25	loamy sand	stuctureless (single grain)	loose
C	25-120	sand	stuctureless (single grain)	loose

Block 4 Shallow Topsoil Stripping
Predominant Soil Classification: Orthic Dark Brown Chernozem
Parent Material: Loamy sand to sand textured glaciofluvial or eolian
Drainage: Rapidly
Topography: Undulating (2 to 5%)

Horizon	Depth (cm)	Texture	Structure	Consistency
Ah	10-15	loamy sand	stuctureless (single grain)	loose
Bm	15-25	loamy sand	stuctureless (single grain)	loose
C	25-120	sand	stuctureless (single grain)	loose

Block 4 Conventional Topsoil Stripping
Predominant Soil Classification: Orthic Dark Brown Chernozem
Parent Material: Loamy sand to sand textured glaciofluvial or eolian
Drainage: Rapidly
Topography: Undulating (2 to 5%)

Horizon	Depth (cm)	Texture	Structure	Consistency
Ah	10-15	loamy sand	stuctureless (single grain)	loose
Bm	15-25	loamy sand	stuctureless (single grain)	loose
C	25-120	sand	stuctureless (single grain)	loose