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ISBN 0-315-21206-3

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THESIS – THÈSE

Title of Thesis – Titre de la thèse

Ecosystem Reconstruction and Stabilization Following Pipeline Construction Through Solonetzic Native Rangeland In Southern Alberta

Degree for which thesis was presented Grade pour lequel cette thèse fut présentée M.Sc.	Year this degree conferred Année d'obtention de ce grade 1985
University – Université University of Alberta	Name of Supervisor – Nom du directeur de thèse Dr. W.B. McGill Dr. A.W. Bailey

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ECOSYSTEM RECONSTRUCTION AND STABILIZATION FOLLOWING PIPELINE CONSTRUCTION THROUGH SOLONETZIC NATIVE RANGELAND IN SOUTHERN ALBERTA

by

MARY ANNE NAETH

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

IN

RECLAMATION

DEPARTMENT OF SOIL SCIENCE

DEPARTMENT OF PLANT SCIENCE

EDMONTON, ALBERTA

SPRING, 1985

THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR MARY ANNE NAETH

TITLE OF THESIS ECOSYSTEM RECONSTRUCTION AND STABILIZATION FOLLOWING PIPELINE CONSTRUCTION THROUGH SOLONETZIC NATIVE RANGELAND IN SOUTHERN ALBERTA

DEGREE FOR WHICH THESIS WAS PRESENTED MASTER OF SCIENCE

YEAR THIS DEGREE GRANTED SPRING, 1985

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I this infer,
that many things, having full reference
to one consent, may work contrariously:
as many arrows, loosed several ways,
come to one mark; as many ways meet in one town;
as many fresh streams meet in one salt sea;
as many lines close in the dial's centre;
so may a thousand actions, once set afoot,
end in one purpose, and be all well borne
without defeat.

William Shakespeare

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ECOSYSTEM RECONSTRUCTION AND STABILIZATION FOLLOWING PIPELINE CONSTRUCTION THROUGH SOLONETZIC NATIVE RANGELAND IN SOUTHERN ALBERTA submitted by MARY ANNE NAETH in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in RECLAMATION.

Co-Supervisors

Date April 18, 1985

This thesis is dedicated
to the memory of
my beloved father

Raymond Carl Naeth

October 7, 1930 - October 1, 1984

ABSTRACT

A study was conducted in solonetzic mixed prairie of southern Alberta to evaluate selected ecosystem responses to pipeline installation and to estimate the longevity of these responses. The study area was located 50 km northeast of Brooks. Four sites were selected in a corridor containing pipelines that had been installed in 1957, 1963, 1968, 1972 and 1981. Two sites were in an early season grazed section of the range and two were in a late season grazed section.

Each study site was 100 m by 135 m, encompassing 17 transects on different aged pipelines and areas of construction activity. Moisture and temperature regimes were monitored year round. Soils were analyzed to determine organic matter content, particle size distribution, soil moisture retention, pH, electrical conductivity, ion composition and bulk density. Plant species composition, frequency, basal area and ground cover characteristics were determined in 1982 and 1983.

Trenching caused the most extensive disruption of the ecosystem whereas grading and compaction by heavy equipment were less disruptive. In the trench, clay content, total water, surface temperature in the summer, winter temperature with depth, surface bulk density and total soluble salts particularly near the soil surface increased. Water retention became more uniform with depth and bulk density with depth; winter surface temperature and surface organic carbon decreased with trenching. Bulk density increased in the pipelay, work and stockpile transects. Changes in bulk density were altered relatively little by time following disturbance; there was a distinct trend towards predisturbed conditions for soil moisture and chemical changes, especially in the trench.

Botanical composition of the right-of-way (r-o-w) was severely altered by pipeline construction. Following disturbance, pioneer and introduced species dominated the r-o-w, particularly over the trench. After 26 years there was evidence of succession towards the undisturbed prairie vegetation.

Changes in vegetative factors due to pipeline construction were compounded by the grazing regime imposed on the system. Late season grazing appeared to result in a slower return to predisturbed conditions by favouring the establishment and dominance of introduced species such as *Agropyron pectiniforme* and pioneer species such as *Descurainia sophia.* Early season grazing reduced the dominance of pioneer and introduced species but resulted in more bare ground over the r-o-w for a longer period of time. *Selaginella densa*, which occupied over 50% of the ground area in the undisturbed prairie, was eliminated by the disturbance and had not reinvaded even the oldest r-o-w.

Although the ecosystem was severely altered by pipeline disturbance the changes brought about were not often detrimental to plant growth. From this study it is evident that successful revegetation after pipeline construction in solonetzic mixed prairie requires an effective range management program to expedite a stable, erosion-reducing ground cover compatible with the functioning of a native mixed prairie ecosystem.

ACKNOWLEDGEMENTS

I thank my advisors Dr. A.W. Bailey and Dr. W.B. McGill for their guidance throughout the course of this research. I am especially grateful to Dr. Bailey for his concern and support during the final months of the thesis writing. I thank Dr. D.J. Pluth for serving as a co-supervisor during Dr. McGill's absence.

I am grateful for the advice and valuable suggestions offered by my committee members: Dr. B. Bolwyn, Dr. A.W. Fedkenheuer, Professor R.H. Knowles and Dr. G.R. Webster. Dr. J. Campbell, R. Hermesh and R. Johnson are acknowledged for their review of the thesis and R. Johnson for his participation in the defence.

Financial support in the form of a Research Development Grant from the Alberta Environmental Centre in Vegreville is gratefully acknowledged.

NOVA, An Alberta Corporation and the Eastern Irrigation District are acknowledged for allowing access to their pipeline rights-of-way and their community pasture, respectively. I also thank Nova, An Alberta Corporation, for constructing the shelters for the microloggers.

I thank the staff of the Alberta Environmental Centre. My association with them is highly valued. The administrative support of Dr. Bolwyn, head of Plant Sciences, is especially appreciated. His encouragement and support during the project will always be remembered. I am grateful to G. Wheeler for taxonomic assistance in identification and verification of plant species. Numerous summer field crew members including L. Dietz, F. Figuerchuk, R. Kostyniuk, D. Lynds, L. Lukenchuk, G. McCormick, L. Robinson, P. Romaniuk, D. Schuler and I. Whitson assisted with everything from chasing cows out of plots to taking neutron probe readings. A special thank you is extended to my technician, B. Lardner. Bertha was an unending source of help whenever needed. Her capable field assistance and taxonomic skills were especially appreciated. I thank her for this as well as the hours of companionship, the friendship and the moral support.

Staff of the Irrigation Branch in Brooks were most helpful. D. McKenzie checked dataloggers in all kinds of inclement weather. His assistance and interest in the project are most gratefully acknowledged. R. Jones is acknowledged for his support of the project as well as assistance in getting four wheel drives and soil coring units whenever needed.

Staff of the Conservation and Development Branch are also acknowledged. Dr. C. McKenzie was never too busy to dig out a soil survey report, obtain coring trucks and equipment or just sit down and discuss the project. His assistance and that of Neil Clark are gratefully acknowledged.

B. Paterson, Head of the Drainage Branch, is thanked for providing a heavy duty coring unit and a technician, P. Gogolinski, for the initial access tube installation.

I am grateful to the Princess Compressor Station personnel of NOVA, An Alberta Corporation. They were always available to provide tools and electrical outlets and to get me "unstuck" when wet weather took its toll.

J. Hermans, a Section Head in the Conservation and Development Branch, is acknowledged for his interest in and support of the project. He was a constant source of information. I would also like to thank John for sharing his observations of crested wheatgrass growth over the right-of-way for this led to the inception of the project.

The assistance of J. Mitchell of Foothills Pipelines Ltd. was invaluable during the initial stages of the project. I am particularly grateful for the helicopter tour of the pipeline corridor and assistance with preliminary site selection.

On a cold Grey Cup day in 1981, B. Bolwyn, C. Labine, B. Gogolinski, W. McGill, D. Mckenzie, and A. Melenka gave of their time in the pursuit of science to install microloggers and access tubes. I am grateful.

C. Labine of Campbell Scientific Canada Corporation helped with instrumentation from the beginning of the project. He was always available to answer questions about the microloggers and to assist with any of the problems encountered.

Dr. J.F. Dormaar is gratefully acknowledged for his interest and assistance throughout the project. He was always available for discussion and many times assisted in getting an obscure reference.

The technical staff of the Department of Soil Science are gratefully acknowledged for their time and assistance in getting the endless number of laboratory analyses completed. I am most grateful to J. Konwicki for his patience in teaching me to analyze soil samples. He was always ready with a cheery word when the mornings came too early and the nights were too long. His constant source of helpful hints were invaluable. I thank K. Nguyen, J. Khatkar, T. Mish, M. Klutz, P. Geib and W. Power for their assistance.

C. Woytowich is acknowledged for the use of his computer program for the soil moisture data analysis. His willingness to listen and to offer suggestions made the computer programming for this study so much easier.

I thank B. Irving for assistance with the SPSS:X analysis of variance programs.

M. Goh's assistance in textforming the first draft of this manuscript was invaluable. Her time and skills are gratefully acknowledged.

W. Power and P. Geib are acknowledged for the drafting in this thesis. I am especially grateful to Wendy for the many late nights she worked in order to complete the first draft on time and for her patience in doing the final revisions.

A. Melenka is gratefully acknowledged for his support and assistance during the initial parts of this study. I am especially thankful for his continuing interest and special friendship.

I thank B. and M. Melenka for a place to call home during the academic terms. I am grateful for their encouragement, interest and friendship throughout the duration of this project.

My special thanks go to Dr. D.S. Chanasyk. His constant support, both professionally and personally, helped me through many rough spots and made this a most rewarding time in my life.

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I. INTRODUCTION

Activities associated with transport of Alberta's petroleum resources necessitate pipeline construction. Installation of a pipeline disrupts the soil and the hydrology of an area as well as the associated flora and fauna. Each ecosystem reacts differently, thereby varying environmental impacts of pipeline installation and complicating quantification of cause and effect links between pipeline disturbances and such impacts.

Suitable pipeline installation techniques and reclamation procedures for a given ecosystem can be determined only if both the short and long term effects of pipeline construction are understood. Data demonstrating the mechanisms causing these effects have not been adequately documented. Most investigations of pipeline disturbances in agricultural areas have concentrated on effects on arable crop production. They provide inadequate information on ecosystem reconstruction and stabilization in natural uncultivated grasslands.

For the 1972 to 1981 period, cattle provided 36% of the farm income in Alberta (Alberta Agriculture 1983). The importance of the livestock industry in Alberta necessitates optimum production on rangeland. A decline in productivity due to anthropogenic disturbances such as pipeline construction should therefore be minimized.

Optimum rangeland productivity can be attained if pipeline installation and revegetation procedures for mixed prairie range on Solonetzic soil (solonetzic mixed prairie) range are based on firm knowledge of and are compatible with that ecosystem's functioning. The need to document and assess the impact of pipeline disturbances on solonetzic mixed prairie ecosystems formed the basis for this study. It had two overall objectives:

1. To document and assess selected ecosystem responses to pipeline installation in solonetzic mixed prairie rangeland in southern Alberta.
2. To study the longevity of these selected ecosystem responses.

Specific objectives were:

1. To examine the effects of pipeline installation on selected soil physical and chemical properties.
2. To examine the effects of pipeline installation on vegetation.
3. To examine the effects of early and late season grazing on revegetation of pipeline disturbances.
4. To examine the foregoing within different zones of construction activity and on different aged pipeline rights-of-way.
5. To compare these disturbed areas to the undisturbed native prairie.

II. LITERATURE REVIEW

A. GRASSLAND ECOSYSTEMS

In grassland ecosystems the dominating vegetative component is herbaceous; trees are usually lacking due to moisture deficiency (Coupland 1979). Grasslands cover 30% of the world's land area (Stoddart *et al.* 1975) and occur under a variety of climatic regimes at mid-latitudes on every continent and many larger islands throughout the world (Collinson 1977). Such grasslands include the North American temperate grassland, the African veld and the South American pampas.

Temperate zone grasslands are classed as natural or semi-natural (Coupland 1979). Natural grasslands are those in which climate is the main controlling factor under light to moderate grazing pressure by ungulates. They occur in areas too arid for the development of forest but with sufficient moisture for the development of a permanent herbaceous layer. Semi-natural grasslands are deforested areas in regions of forest climate, held relatively stable by various natural and anthropogenic means.

Grasslands of North America extend from southern Canada to central Mexico. In Canada grasslands include the mixed prairie association, the fescue grasslands, the true prairie association, the aspen parkland and the Palouse prairie (Coupland 1961).

The climate of North American grasslands is characterized by warm to hot, dry summers and cold winters with little snowfall. Annual precipitation ranges from 250 to 750 mm, with marked periodicity within and between seasons. Annual droughts of several weeks to months are common. Precipitation determines the nature and extent of natural grasslands by affecting the supply of soil moisture. Soils with higher moisture contents support taller grasses with deeply penetrating and highly ramified roots. With decreasing soil moisture, vegetation gradually changes from sub-arid regions of tall grasses to mixed prairie of tall and short grasses and finally to the short grass formation.

Canadian grassland soils developed from glacial drift deposited during the last ice age 10,000 to 15,000 years B.P. (Legget 1961). Grassland soils tend to be high in organic matter. Natural grassland soils may contain over 12 Mg/ha of roots compared with 2 to 5 Mg/ha of above ground material (Russell 1973). With growth, these roots release exudates which contribute to the buildup of organic matter in the soil. Soil pH is somewhat acidic if there is sufficient precipitation to cause leaching but it is usually basic under more arid conditions where precipitation is insufficient and there is an accumulation of salts. Grassland soils and landscapes reflect the ecosystems through which they evolved and are generally at a steady state in their development.

Despite the limitation of vegetative structure to a single major stratum, plant species diversity is high. Grasslands are made up of plant communities with a vegetative mixture of herbaceous spermatophytes dominated by the family *Gramineae* (grass). This family comprises 20% of the species present and 90% of the canopy biomass. Other prominent plant groups include: *Carex* species (sedges), forbs (non-grass-like herbs) and occasionally dwarf shrubs (Coupland 1979).

Dix (1964) stated that the universal characteristic of grassland vegetation was changeability attributable to inherent factors such as susceptibility to fire or to external forces such as climatic fluctuations. There have been extensive studies of the responses of mixed prairie vegetation to fluctuations in weather. Weaver and Albertson (1956) reported significant decreases in basal cover corresponding to water stress associated with drought conditions. Ungrazed *Bouteloua-Buchloe* communities declined from 89% basal cover to 85, 66, 58, 25, 31 and 22% between 1934 and 1939. Species composition changes generally included a reduction in shallow rooted species, the disappearance of many native forbs, an increase in deeply rooted species and a substantial increase in ruderals. These changes occurred as a result of below normal precipitation during each of the seven successive years. Weaver and Albertson (1956) studied the effect of drought on 88 representative mixed prairie ranges in Kansas and Nebraska during 1939. Vegetation had been reduced to a short grass community of sparse cover from overgrazing, grasshoppers, dessication and dust deposits. In some areas where grazing had not been a factor, the midgrass layer had also completely disappeared and only remnants of the most persistent forbs remained. Annual species had occupied some bare soil from the destruction of grass cover, but by 1939 most areas were dominated by cacti. After the drought, succession proceeded through weedy and short-lived grass stages towards the short grass community. Similar disturbances of vegetation development were reported for the droughts of 1952 to 1954.

Mixed prairie species that increased during drought periods included *Bouteloua gracilis* and *Agropyron smithii* (Weaver 1954). Sarvis (1941) studied drought effects on mixed prairie and found *Stipa comata* decreased and *Agropyron smithii* increased. Whitman *et al.* (1943) reported decreases in *Bouteloua gracilis, Stipa comata, Agropyron smithii, Koeleria macrantha, Andropogon scoparius* and *Calamovilfa longifolia* and increases in *Carex* and *Poa* species in North Dakota mixed prairie due to the combined effects of drought and grazing. With the cessation of drought and reduced grazing pressures rapid improvement in ground cover occurred.

Ellison and Woolfolk (1937) studied the effect of drought on moderately grazed mixed prairie. Decreases in cover ranging from 62 to 79% were reported for *Bouteloua gracilis, Agropyron smithii, Buchloe dactyloides* and *Stipa comata* from 1933 to 1935. *Poa sandbergii* increased by 179%. Hurtt (1951) reported reductions of 88 to 98% for these species and increases of 75% for *Poa sandbergii* in grazed mixed prairie. Sharp declines were also measured for ungrazed areas.

Southern Alberta mixed prairie was studied by Clarke *et al.* (1943) during 1928 to 1939. In ungrazed *Bouteloua-Stipa* communities basal cover for grasses decreased from 26 to 14%. *Bouteloua gracilis* and *Stipa comata* decreased continuously and *Koeleria macrantha, Poa sandbergii* and *Agropyron smithii* decreased more sporadically. Species responded similarly in both grazed and ungrazed areas leading the authors to conclude that climate as opposed to moderate grazing was the principal factor affecting the vegetative cover.

The effects of sustained periods of favourable weather on mixed prairie communities has not been documented. Coupland (1950) studied mixed prairie in the Brown soil zone of Saskatchewan and Alberta and concluded that since 1944 the weather had not interfered with continued increases of species formerly occupying only more sheltered locations. Grass cover of ungrazed to moderately grazed ranges responded favourably to enhanced environmental conditions with grass cover doubling since 1944. *Stipa comata* and *Bouteloua gracilis* declined from 62 to 44% and *Stipa curtiseta* and *Agropyron dasystachyum* increased from 15 to 31% in percentage composition. Coupland (1959) concluded that fluctuations in species composition within vegetation in equilibrium with the climate are much greater in grassland than in forest.

Smoliak (1956) found that May and June precipitation was closely associated with forage yield in Alberta mixed prairie. Seasonal mean temperature, hours of bright sunshine and wind mileage had significantly negative correlations with forage yield.

Succession on mixed prairie abandoned from cultivation had been documented by Coupland (1950, 1961). During the first two years after abandonment, the lands were dominated by annual weeds; notably *Salsola kali, Sysimbrium altissimum, Lepidium densiflorum* and *Thlaspi arvense*. In the third to eighth years, perennial forbs dominated, with the half shrub *Artemisia frigida* as the final dominant. Early grasses included *Hordeum jubatum* and *Agrostis hiemalis*. These were both short lived species and were readily replaced by rhizomatous species such as *Agropyron smithii*. The length of time for the community to approach that of the climax was 15 to 50 years. Piemeisel (1938, 1940 and 1951) reported on similar studies following land abandonment in sagebrush grassland in Idaho. During the first two years the area was dominated by *Salsola kali*, followed by *Descurainia sophia* in the next two years and *Bromus tectorum* in the following five years. Piemeisel (1940) commented on the early stages of secondary succession where annuals were dominant and had an exceedingly rapid turnover of one generation per year. If excessive removal of vegetation (such as overgrazing) was prevented, the development of the early stages of secondary succession proceeded from initial weed stages to an annual grass stage. By inducing excessive vegetation removal, the process was reversed from this annual grass stage to the initial weed stage which would be maintained as long as the disturbance persisted.

Coupland (1961) documented the invasion of the grassland climax where ground cover had been disturbed. The principal ruderals in order of abundance were: *Sysimbrium altissimum, Salsola pestifer, Solanum triflorum, Grindelia perennis, Bilderdykia convolvulus, Lappula squarrosa, Chenopodium album, Amaranthus graecizans, Cheirinia inconspicua, Monolepis nuttalliana, Allionia hirsuta* and *Chamaerhodes nuttallii.*

Vegetation communities are also closely associated with soil and topographic characteristics. Coupland (1950, 1961) classified the mixed prairie of Alberta and Saskatchewan and found distinct associations between these factors and the dominating vegetation communities. Thus the distribution of individual species is a function of climate and substrate with variations as marked as the heterogeneity of these factors.

The large area of grassland occurring east of the Rocky Mountains in Canada consists of four grassland associations, documented by Coupland (1950, 1952, 1961) (Figure 2.1). The mixed prairie association extends for approximately 1000 km from the base of the foothills, along the Canada-USA border to near the Saskatchewan-Manitoba border. This line forms the base of a large (378,000 square km) triangle whose apex is located along the Saskatchewan-Alberta border for approximately 500 km north of the Canada-USA border. The true prairie association lies to the east of this triangle with the fescue grassland association along its west and north sides in association with the aspen parkland.

Coupland (1961) classified the vegetation of the mixed prairie into five different faciations. The *Stipa-Agropyron* faciation occurs on well developed soils of medium texture throughout the Dark Brown soil zone and adjacent parts of the Brown soil zone. A more xeric community, the *Stipa-Bouteloua-Agropyron* faciation, is found on soils of loam texture in the drier part of the Brown soil zone, while the *Stipa-Bouteloua* faciation is limited to sandy loams in this area. The *Bouteloua-Agropyron* faciation dominates Solonetzic soils, except in Alberta, where the coarser textured Solonetzic soils support vegetation of the *Stipa-Bouteloua* faciation.

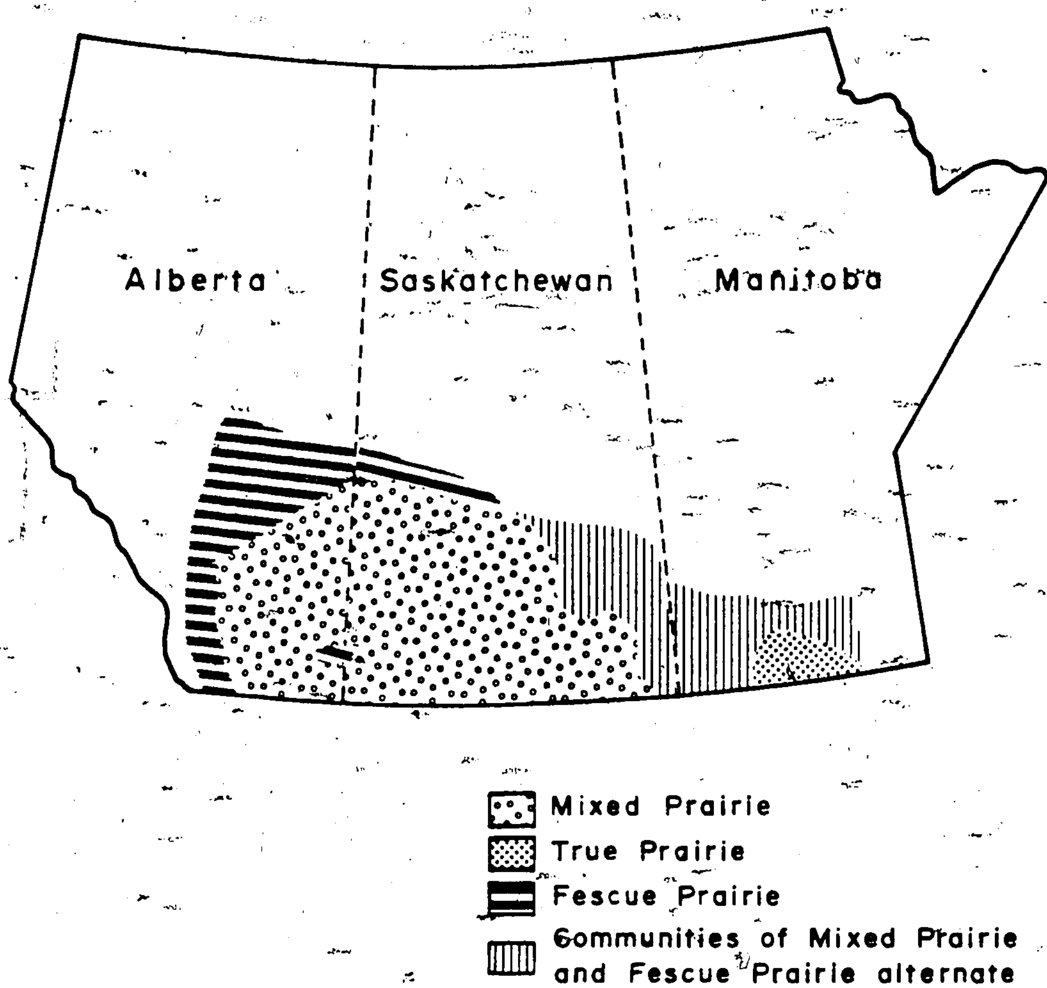

Figure 2.1. Natural grassland associations of the Prairie Provinces. (Adapted from Coupland 1961).

The *Agropyron-Koeleria* faciation occupies areas of lacustrine clays which are presently mostly under cultivation.

B. GRAZING

The first cattle and sheep were brought into western Canada around 1700 through fur trading posts on the Hudson Bay (Johnston *et al.* 1981). Ranching began in Alberta around 1877 when cattle brought in from Montana were overwintered near Fort Macleod. By 1880 large herds were becoming more common. In 1979 there were 7.6 million hectares of rangeland in Alberta comprising 12% of the total land area (Smoliak *et al.* 1979).

Range has been defined by Stoddart *et al.* (1975) as those areas of the world which by reason of physical limitations (low and erratic precipitation, rough topography, poor drainage, or cold temperatures) are unsuited to cultivation. It provides a source of forage for free-ranging native and domestic animals, as well as a source of wood products, water and wildlife. Rangeland has been described as a "dynamic entity" because of its potential for change and the interdependence of its component parts (Donald 1946).

Grazing is one of the main factors affecting rangeland ecosystems. The effect of the grazing animal through defoliation, selective grazing, trampling, deposition of dung and urine, and the dispersion of seeds may be both beneficial and harmful. Grazing significantly affects both herbage yield and litter accumulation. Data from Smoliak *et al.* (1979) reveal that moderate continuous grazing of Alberta mixed prairie and fescue rangelands resulted in a 60% decrease in herbage production. Stelfox and McGillis (1976) reported that ungrazed mixed prairie range produced 63% more forage than grazed areas. In southern Saskatchewan, Coupland (1973) found that the total standing crop on grazed range varied from 39 to 44% of that on ungrazed. Marked decreases in yield of mixed prairie grasses with grazing were also reported by Lodge (1954) and of fescue grassland by Peake and Johnston (1965). In western North Dakota, standing vegetation of grazed mixed prairie was 44% of the ungrazed, while on grazed range it was 37% of the ungrazed (Whitman 1974). Preliminary studies on rangeland ecosystems in Saskatchewan indicated that maximum standing crops were reduced with grazing by 38, 70 and 32% for green shoots, dead shoots and underground parts respectively (Coupland *et al.* 1974). Observations from the same study indicated that individual shoots produced more leaves under grazing.

Litter accumulation on grazed grasslands was generally lower than that of ungrazed range in most natural grassland ecosystems (Coupland 1979). An exception was in the true prairie, where litter was up to 2 times higher in grazed areas due to trampling by cattle. Peake and Johnston (1965) reported that the annual yield of litter decreased markedly with grazing intensity from 12.4 Mg/ha in ungrazed to 9.2 Mg/ha in lightly grazed and 4.9 Mg/ha in heavily grazed fescue prairie. On mixed prairie Smoliak (1965) found litter also decreased with grazing from 0.7 Mg/ha in ungrazed areas to 0.4 Mg/ha under moderate continuous grazing. These decreases in litter accumulations have been attributed to the reduced amount of plant material as a result of consumption by cattle.

Defoliation has been considered the most important influence of grazing animals on grasslands (Watkin and Clements 1978). The effects of defoliation on individual grass plants are dependent on whether the leaf area and/or the stem apex has been removed. When part of a young, immature leaf is removed and the basal meristems are left intact, only the final size of the leaf and its ability to produce photosynthates are reduced (Booysen *et al.* 1963; Tainton 1981). However, meristem removal terminates growth of the leaf. Removal of mature, non-photosynthetic leaves may permit more light to penetrate to the basal parts of the plants encouraging tillering, and thereby stimulating growth. Removal of all or part of a mature photosynthetic leaf will reduce the photosynthetic system of the plant with concommitant reductions in carbohydrate and nitrogen reserves (Hyder 1972). Reduction in nutrient reserves slows the growth of the entire plant, decreasing rooting volume and depth and reducing forage production.

Partial or complete defoliation results in a mass reduction of the underground plant material, the reduction being proportional to the severity of the treatment (Crider 1955;

Troughton 1957). At least a portion of the roots stopped growing when 50% or more of the top growth of grass was removed; and stopped completely when 80 to 90% of the top growth was removed. After severe defoliation roots remained inactive for up to 17 days (Crider 1955). In mixed prairie grasses Smoliak (1965) reported reductions of underground plant parts with grazing, due to partial or complete defoliation. In the uppermost 54 cm of soil, the total underground plant material in an area protected from grazing for 33 years was 40.0 Mg/ha and in a grazed area 33.4 Mg/ha. Johnston (1961a), working in fescue grasslands of southwestern Alberta, found total underground plant parts were higher beneath grazed rangeland than beneath ungrazed range. This increase was attributed to the more humid conditions and the taller, more productive grasses than those of the *Stipa-Bouteloua* community. It is likely, however, that the changes reflect the increase in shallow rooted species and the decrease in the more deeply rooted midgrasses which are less resistant to grazing.

When the apex of a grass plant is removed, stem growth is terminated and flowering and seed production are prevented (Booysen *et al.* 1963). A secondary effect of stem apex removal is an increase in tiller density. This has been attributed to the removal of growth regulators secreted by the apex that inhibit the development of lateral tillers (Tainton 1981). Even though reduced stem development reduces yields, the improved quality of the new leafy material may compensate for the yield reduction. Stem apex removal also reduces the number of leaves on the plant, thereby reducing the photosynthetic capacity of that plant.

The number of tillers may also be reduced by defoliation. When photosynthetically active tissue is removed, carbon assimilation is reduced and available carbohydrate supplies are used for renewal of leaf growth before that of tiller initiation (Youngner 1972). The leaf replacement potential of grass is dependent on time, rate of defoliation, environmental conditions, location of apical meristems and species (Hyder 1972).

Grazing, through defoliation, creates greater extremes in micro-environment than were present prior to severe defoliation (Smoliak *et al.* 1979). The reduction in canopy coverage alters light intensity, increasing soil temperature and evaporation. It also affects interception and redistribution of precipitation by plant material and influences infiltration. Litter is decreased and soil erosion potential is increased (Lorenz 1974). These changes subject the areas with reduced plant cover to more extreme freezing and thawing cycles, and subsequent damage to roots and stems through breakage.

On mixed prairie sites in North Dakota, Whitman (1974) found summer air temperatures above grazed vegetation averaged 1.5°C higher than above the ungrazed. Soil temperature to 120 cm was higher under grazed vegetation, averaging 21.4°C for the season, compared to 17.9°C for the ungrazed. Wind movement at a height of 15 cm was 2.1 km/h over grazed areas and 0.6 km/h for ungrazed. Soil moisture content was higher in ungrazed areas until midsummer. Relative humidity and water vapour pressure near the ground were more extreme on grazed areas, affecting evaporation rates. Similar results were reported by Peake and Johnston (1965) for fescue grasslands.

Grazing animals tend to be selective in their diets. Sheep and cattle tend to select leaves in preference to stems, and young leaves in preference to older leaves (Davies 1952; Milton 1953; Arnold 1960; Dudzinski and Arnold 1973; and Stobbs 1973a, 1973b, 1975). The selected species tend to be higher in crude protein, P, soluble carbohydrates, digestibility and gross energy and lower in lignin and structural carbohydrates. Selection of a particular plant depends on relative palatability and accessibility (Arnold 1964; Greenhalgh 1966). Cattle, because of their larger jaws and mode of grazing action, are less selective than sheep (Dudzinski and Arnold 1973).

The effects of treading on range have been reported extensively by Edmond (1958, 1962, 1963, 1964, 1966, 1970); with earlier studies by Bates (1935). The static load exerted by cattle is 112 to 165 kN/m² with the dynamic load twice as high (Lull 1959). Cattle tend to make 8000 to 10000 foot impacts/day of 90 cm² each, yielding a total trodden area of 0.01 ha/day/animal (Farris 1954).

Treading can cause significant and progressive reductions in herbage yield as stocking rates increase (Edmond 1958, 1964, 1966, 1970; Brown 1968; Bryant *et al.* 1972; Harris 1973).

Plant-numbers may decline immediately after treading due to reduced tiller density (Edmond 1958; Campbell 1966). Recovery of these damaged and buried tillers may be rapid (Edmond 1958), but new tillers may have lower growth rates than the old tillers (Campbell 1966).

Treading and defoliation due to grazing affect botanical composition (Bates 1935; Davies 1938; Edmond 1958, 1962, 1966), and are important factors in plant competition (Edmond 1958, 1962, 1966; Brown 1968; Harris 1973). Grazing influences the presence and dominance of plant species. Selective grazing initially favours unpalatable species. Treading associated with grazing may cause severe leaf damage, particularly in soft-leaved species, thereby favoring strong-leaved species. Creeping species with less exposed meristematic regions are favored over the more upright species (Tainton 1981).

In Alberta mixed prairie, light grazing produced a *Bouteloua-Stipa* vegetative cover while no grazing produced a *Stipa-Bouteloua* cover (Peake and Johnston 1965; Smoliak 1965). When a range is overgrazed, shallow-rooted species tend to replace the deeper rooted ones, tall and midgrasses disappear and *Bouteloua gracilis* increases. As overuse continues, unpalatable species, especially *Artemisia frigida, Phlox hoodii*, and *Gutierrezia sarothrae* increase. Later *Selaginella densa* and *Opuntia polyacantha* increase and the area is further invaded by *Grindelia squarrosa, Chenopodium* species, *Tragopogon dubius, Hordeum jubatum*, and *Salsola kali* (Smoliak *et al.* 1972). Peake and Johnston (1965) noted a decrease in grasses and an increase in forbs and shrubs with grazing. Smoliak (1965) and Smoliak *et al.* (1972) found that basal areas of *Bouteloua gracilis, Koeleria macrantha* and *Selaginella densa* increased under grazing, while those of *Stipa comata* and *Agropyron* species decreased.

Time of grazing has a profound effect on associated range reactions to grazing (Edmond 1964). Some grasses and most forbs are highly susceptible to defoliation at any time while others show little effect (Heady 1975). Sensitivity to defoliation appears to increase rapidly at the time of floral initiation and seed formation and decreases rapidly as plants mature (Cook *et al.* 1958).

Bailey *et al.* (1980) studying *Festuca scabrella-Stipa curtiseta* rangelands of central Alberta indicated that light spring (June) grazing stimulated additional grass and forb production. Grass production decreased under heavy spring and fall grazing while forb production increased under spring grazing. Brougham (1959) indicated frequent hard grazings during spring reduced dry matter yield. Results of his study indicated less intensive grazing of pastures in late spring would further increase dry matter production. Prevention of overgrazing in summer and autumn ensures persistence of pasture species so high annual yields are maintained. Differences between seasonal growth patterns are apparently determined by species tolerance to different intensities of grazing and modified action of environmental factors on growth following changes in herbage cover and botanical composition (Brougham 1960). Clarke (1930) found that grasses not grazed until they had grown considerably in the spring produced more forage annually than those grazed in the early spring. Plants allowed to develop considerable leafage accumulated more energy in their roots for overwinter use than plants closely grazed throughout the summer and fall.

The growth rate of pasture peaks when full canopy is developed (Tainton 1981). Theoretically, maximum yield can be achieved by maintaining full canopy for as much of the season as possible. Litter accumulation from this type of grazing regime, particularly in higher moisture grasslands and the impracticality of having a pasture devoid of grazing for such a long period indicates that although such a practice may maximize productivity, it does not optimize use. Range management practices involving sufficient non-grazing periods to permit plants to recover from one grazing before being subjected to another is necessary.

Animals affect seed dissemination and establishment helping to maintain the heterogeneity of the grazing environment (Harper 1969). Seeds are disseminated either through attachment to the animal or intestinally. Treading may be advantageous where it aids in covering seeds that would otherwise not find favorable conditions for germination. Hoof action may break crusted soil surfaces, creating more favorable germinating conditions. Dung pats are also ideal sites for colonization by seeds.

Treading affects the hydrologic regime of grasslands. Compaction and puddling are indirect effects of treading. Compaction is the increase in density due to applied pressure. Puddling refers to the reduction in apparent specific volume or void ratio of the soil caused by mechanical work (Bodman and Rubin 1948). Several researchers have reviewed the effects of compaction and puddling on soil physical characteristics and plant growth (Tanner and Mamaril 1959; Rosenberg 1964; Barley and Greacen 1967; Gradwell 1968; McCarty and Mazurak 1976). Such effects include mechanical resistance to root penetration, reduced aeration, altered thermal regime and moisture availability. Infiltration and percolation rates decrease and runoff and erosion potential increase (Duley and Kelly 1939; Duley and Domingo 1949; Robinson and Alderfer 1952; Lull 1959; Johnston 1962; Rauzi 1963; Sharp *et al.* 1964; Gifford and Hawkins 1976; Blackburn 1983). Alderfer and Robinson (1947) found that runoff increased from 0 to 2% on ungrazed range to 33 to 80% on heavily grazed range.

Natural mulch is considered a primary factor in determining total annual infiltration of water into rangelands (Dyksterhuis and Schmutz 1947; Tomanek 1948; Hopkins 1954; Rauzi 1960). Mulch also reduces the impact of treading on plants (Lull 1959; Brown 1968; Beard 1972).

At present, evaluating the hydrologic impact of grazing is difficult. Most of the literature relates grazing impacts to infiltration rates, but only a few studies provide reasonable estimates of constant infiltration rates for a given site. Data are not sufficient to evaluate the effect of range condition on hydrologic impacts of grazing. Gifford and Hawkins (1978) have indicated that the greatest need in this area of research is for a detailed definition of the long-term effects of grazing on infiltration as a function of site, range condition and grazing intensity. Infiltration rates must be coupled with appropriate methods for determining runoff volumes, storm hydrographs and long term water yields.

Treading has been associated with decreased stability of soil structure (Chappell *et al.* 1971) and slowing of soil forming processes (Liacos 1962). Changes in soil chemical and biological properties have also been associated with treading.

Johnston *et al.* (1971) reported that very heavy grazing compared to light grazing of fescue grassland at Stavely, Alberta changed the Ah horizon from black to dark brown, increased pH from 5.7 to 6.2 and reduced percent organic matter and soil temperature. Thus a heavily grazed range developed a drier microclimate over a seventeen year period. After continuous heavy summer grazing of a *Stipa-Bouteloua* prairie soil in southern Alberta, spring moisture was reduced and pH was lowered (Smoliak *et al.* 1972). There was little effect on bulk density or texture. Smoliak *et al.* (1972) attributed these effects to changes in amounts and kinds of roots due to species changes caused by overgrazing. Johnston *et al.* (1971) attributed changes to increased use of vegetation and loss of organic matter due to increased grazing pressure and subsequent increased erosion.

In grazed ecosystems nutrients are cycled from the soil, through the plants and then returned to the soil either directly or through animals. Domestic animals, through excretion, introduce two recycling pathways for redistribution and mineralization of nutrients within the ecosystem: contribution of inorganic available nutrients, and contribution of residual organic nutrients in soil (Rychnovska 1979; Till 1979). As stocking rates increase, turnover rates of nutrients have been reported to increase, resulting in a greater retention of nutrients in the system if that system is fertilized (Mott 1974). Although there was a greater removal of nutrients per hectare in animal product, it was compensated for by additional nutrients remaining in an available form and in the recycling pool. As the rate of transport increased, the efficiency of nutrient utilization also increased and the quantity of fertilizer required for a given production level decreased. Thus the increase in the cycling pool represents the mobilization of nitrogen formerly unavailable in organic reserves in the soil. Other researchers have reported data to the contrary, indicating that grazing may reduce the turnover rates of nutrients (Floate 1981).

Excreta tend to affect small areas of the range system. Hilder (1964) found that 33% of the faeces from cattle were found in 5% of the grazed area, concentrating around night bedding places. Each defecation has been reported to affect 0.09 m^2 and each urination 0.28 m^2 but grass growth may be affected over an area of 1 m^2 for each urination (Wilkinson and Lowrey 1973). Significant responses to excreta were found 60 days later from an area more than 100 cm in diameter surrounding cattle dung patches 30 cm in diameter (MacDiarmid and Watkin 1971). Work in New Zealand has demonstrated that faeces and urine in the soil system can contribute to herbage yield increases of up to 40% even though most elements in faeces are bound in relatively resistant organic fractions and unless removed by dung-feeding insects, the bulk of these bound elements remain at the soil surface for many years (Angel and Wicklow 1975; Gillard 1967).

Excretion can lead to strikingly detrimental effects due to high salt concentrations. Urine can stimulate areas of grass growth, which in turn depress legume growth (Drysdale 1965). Faeces are often responsible for the death of covered plants and for uneven grazing (Weeda 1967). Marten and Donker (1964) reported that 93% of the ungrazed areas contained dung pats.

Several researchers have studied nitrogen cycling in range ecosystems. The total N available for ingestion by grazers varies directly with herbage productivity and phenological stage of plant development and ranges from 100 to 600 kg/m^2/yr of biomass (Lauenroth 1979; Woodmansee *et al.* 1981). With moderate grazing of perennial native grassland 65 to 85% of the herbage produced is returned to the soil system by wastage and trampling (Coleman *et al.* 1977; Woodmansee 1978). Cattle ingest 0.2 to 2 kg/m^2/yr of N from range plant biomass but retain only 15 to 20% of it (Woodmansee *et al.* 1981). Similar values of 0.25 kg/m^2 were reported by Coupland and Van Dyne (1979). The remainder is returned to the soil plant system mostly as urine and faeces, with 50 to 80% of the excreted N contained in urine (Woodmansee *et al.* 1981). Through NH_3 volatilization, 50 to 80% of the excreted N contained in urine may be lost to the system (Watson and Lapins 1969; Floate and Torrance 1970; Stewart 1970; Woodmansee 1978).

Floate (1981) concluded that increased tillering under moderate grazing may be associated with greater N uptake from soil and its retention in the rapid cycling pool, while severe grazing may impair this uptake system. If plant growth is impaired through trampling, N uptake may be reduced. Species composition changes and increased bare ground associated with trampling may affect nutrient uptake and hence N cycling. Floate (1981) also commented on compaction and puddling caused by treading, possibly inducing anaerobic conditions in wet soils, which, combined with the incorporation of fresh plant material into the ground, may affect microbial decomposition.

Increased herbage intake and utilization by grazing animals leads to a larger proportion of plant N being returned to the soil via the animal excreta than by the plant litter pathway (Floate 1981). The grazing animal pathway is also considered to be important for the transfer of N fixed by legume-rhizobia symbiosis to adjacent plants (Floate 1981). Smoliak *et al.* (1972) reported no changes in total or available N as affected by grazing of mixed prairie.

Grazing animals have been considered responsible for the removal of N from the ecosystem. If animals are removed from the system, 0.1 to 0.4 $g/m^2/yr$ of N may also be removed from low to high productivity grasslands respectively (Woodmansee *et al.* 1981). Henzell and Ross (1973) found that 4 to 28% of the dietary N in the system was removed by grazing animals, with the largest losses from dairy cattle. Under semi-arid range conditions, less than 1 kg/ha of N is removed as animal products, whereas under intense pasture production in more favourable climates up to 56 kg/ha may be lost annually.

Grazing has been associated with narrowing of the C:N and C:P ratios in soil organic matter (Floate 1981). Smoliak *et al.* (1972) found that under continuous heavy summer grazing of mixed prairie total C, alcohol/benzene-extractable C, alkaline soluble C and polysaccharides were increased. These increases were attributed to increased amounts of manure deposited by sheep under heavy grazing. Johnston *et al.* (1971) reported that heavy grazing compared to light grazing of fescue grasslands reduced percent organic matter and percent total P but increased $NaHCO_3$-soluble P. Clark *et al.* (1978) in a similar study concluded any long term effects of grazing on P cycling are mainly through the effects on decomposition of plant and microbial residues. Daubenmire and Colwell (1942) in studies of the *Agropyron-Poa* prairie of eastern Washington found decreased amounts of total P in the soil below ten centimetres as a result of grazing. Lower total P levels under grazing were also reported by Daniel and Harper (1934). Cook and Harris (1950) indicated that available soil moisture was likely more important than available P in influencing the P contents of plants. This was supported by Lodge (1954), who also found other changes in the chemical composition of forage in the late leaf stage. Ether extract, crude fibre and ash were lower in grazed plants and protein, N-free extract, Ca and P were higher. Preferential grazing on young green shoots high in K content hastened the return of K to the soil because urine is high in potassium (Barrow and Lambourne 1962; Clark *et al.* 1978).

Although nutrient cycling is affected by grazing, O'Connor (1981) cautioned against extrapolations from one situation to another without considering the spatial distributions and dimensions of grazing influences.

C. SOLONETZIC SOILS

Distribution And Characterization

In Canada, the Solonetzic Soil Order is composed of three great groups, representing stages in soil development: Solonetz, Solodized Solonetz, and Solod (Canada Soil Survey Committee 1978).

There are approximately 4.93 million hectares of Solonetzic soils in Alberta, comprising 30% of the arable land in the province (Peters 1973). The low-relief plain running north to south through central Alberta from Vegreville to Brooks is the most concentrated area of Solonetzic soils in Canada (Alberta Agriculture 1981). There are 1.5 million hectares of Solonetzic soil in the Brown soil zone of Alberta.

Solonetzic soils are characterized by a Bnt horizon of low permeability. This horizon, which is hard when dry and a sticky mass when wet, severely restricts root and water penetration below the A horizon. The Solonetzic order is defined on the basis of the exchangeable Ca:Na ratio being less than ten in the B horizon (Canada Soil Survey Committee 1978).

Solonetzic soils occur on level to undulating topography where surficial materials are shallow and saline or alkaline bedrock is relatively close to the surface. The water table can be high and internal drainage is always restricted. Solonetzic soils are characterized by blowout patches where areas of topsoil have eroded, exposing the Bnt horizon. In uncultivated areas these blowout pits are between 10 and 25 cm deep and can cover up to 50% of the area (Alberta Agriculture 1981).

The low productivity associated with Solonetzic soils is due to the inhospitable nature of the Bnt horizon, high salt content, and restricted subprofile drainage, as well as the acidic A horizon of some soils.

Genesis

Pawluk and Dumanski (1969) and Pawluk (1982) summarized the classical theories of the genesis of Solonetzic soils as advanced by Gedroits (1912, as cited by Pawluk 1982) and de Sigmund (1926). The main points in this process are described here.

Solonetzic soils have developed on saline parent materials mainly under grass cover in semiarid to subhumid climates. They can develop only if there is an accumulation of soluble salts (salinization) in the soil profile. In Alberta, these salts are most often translocated by groundwater and are predominantly sodium or magnesium sulphates.

As long as soluble salts are brought to the surface by groundwater, pedogenic development will not likely proceed beyond the stage of saline Regosols. If groundwater flow is decreased or intercepted, the upward movement of salts in the discharge area may also be decreased or halted. Ions in the pore water, such as sodium and magnesium, can then be leached and concentrated as precipitates at depth or adsorbed to colloidal clay surfaces. Domination of the exchangeable cations by sodium can result in dispersion of soil colloids which fill soil voids, thereby reducing permeability. Dispersed organic matter stains the B horizon dark brown to black and together with the dispersed clays forms a sticky mass when wet and a hard columnar structure when dry, called a Bnt horizon. Water movement through the profile is then restricted and hydrolysis of sodium clays results in high pH values (solonization). The resulting soil is an Alkaline Solonetz.

Leaching, if continued, can reduce the amount of colloids in the A horizon creating a highly siliceous, platy, Ae horizon. This horizon will become acidic if the sodium is removed (solodization), and a Solodized Solonetz is formed. The Ae horizon thickens as the leaching process continues and a deeper rooting zone is formed. The Bnt starts to disintegrate, bases are mobilized and organic matter can accumulate. The Bnt begins to break into blocky aggregates and the soil is classified as a Solod. Plant roots can more readily penetrate the B horizon. Sodium salts are still present in the C horizon and the Ae may be acidic. The cycling of calcium ions through root penetration and plant decomposition can reduce the A horizon acidity. Further organic matter addition and decomposition can alter the leached Ae to an Ah horizon leading to Solonetzic subgroups of Brown, Dark Brown and Black Chernozems.

Deep Plowing

Deep plowing physically breaks the Bnt horizon, reducing bulk density and facilitating root and water penetration. Improved soil structure is expected to result from bringing calcium up from the C horizon to replace the sodium in the Bnt, thereby preventing its reformation. Surface pH is raised by bringing calcium carbonate to the surface.

Deep plowing was first introduced in the U.S.S.R. in the 1950's in an attempt to improve the productivity of Solonetzic soils (Botov 1959). North American studies of deep plowing began in the 1960's with Cairns (1962) being the first researcher to investigate the technique in Alberta.

Variability in crop response to deep plowing is reported in the literature. Increased productivity of Solonetzic soils after deep plowing has been attributed to calcium enrichment of the surface and B horizons, reduction of exchangeable sodium percentage, reduction of sodium adsorption ratio and alkalinity potential and increase in soil pH through the introduction of calcium carbonate into the A and B horizons (Cairns 1970, 1971, 1972a, 1972b; Peters 1973; Harker *et al.* 1977; Lavado and Cairns 1980; Alzubaidi and Webster 1982).

Crop yield improvements have also been attributed to changes in physical properties of deep-plowed soils. The decrease in sodium and increase in calcium in the upper horizon results in more water stable aggregates, and lower soil breaking strength (Mech *et al.* 1967; Rasmussen *et al.* 1972). Reduced bulk density improves water transmission properties. This leads to improved infiltration and percolation rates, reduced waterlogging and greater depth of water storage (Eck and Taylor 1969; Rasmussen *et al.* 1972), providing a more suitable medium for root development.

Decreases in crop productivity after deep plowing Solonetzic soils have been attributed to poor tilth (Bowser and Cairns 1967; Lavado and Cairns 1980), reduced infiltration (Mech *et al.* 1967; Lavado and Cairns 1980), increased soil hardness (Lavado and Cairns 1980) and increased crust strength (Sandoval *et al.* 1972). These detrimental effects of deep plowing appear to be linked to changes in the Ap horizon, such as increased clay content, increased exchangeable sodium and loss of organic matter.

Longevity of the effects of deep plowing is uncertain due to the relatively short time such soils have been under observation. Preliminary results do not indicate a reversion to the pre-plowed condition. A 33% increase in both wheat and barley productivity was reported six years after deep plowing (Cairns and Bowser 1969). Another study by Toogood and Cairns (1978) indicated that increased productivity persisted nine to sixteen years after deep plowing. Rasmussen *et al.* (1972) reported reduced bulk densities to a depth of 90 cm remained eight years after deep plowing.

Pipeline installation in Solonetzic soils is in many respects similar to deep plowing. It causes the complete breakup of the Bnt and the mixing of the A, B and C horizons. The data on deep plowing, however, provide only a preliminary indication of what might be expected from pipeline installation because the area affected is so much smaller than that under deep plowing (de Jong and Button 1973).

Studies are presently underway to evaluate a three lift procedure for Solonetzic soils whereby the A, B and C horizons are replaced separately and in their natural sequence. Preliminary results from using this approach in surface mining operations have been reported as favourable with best results occurring after incorporating bottom ash into the soil horizons (Ziemkiewicz, P., personal communication, 1984). There are no data for this three lift procedure in pipeline construction, but studies are underway.

D. PIPELINES

There were 180,208 km of pipelines in the province of Alberta in 1981 (Webb 1982). These pipelines range in size from large oil (6.8%) and gas lines (11.9%) to small distribution (38.7%) and flow lines (9.2%). Secondary gas (21.3%) and oil lines (4.7%), water and other substance secondary lines (6.3%) and the Alaska Highway line (1.1%) make up the total.

E. PIPELINE INSTALLATION

The phases of installation for the pipelines studied as documented by NOVA, An Alberta Corporation (Stupart 1981) and Hardy Associates (1978) Ltd. (1983) are presented below.

Prior to installation the pipeline company establishes the most feasible design and route, then seeks regulatory approval for pipelines 150 mm or larger in diameter and 16 km or longer in length (Government of the Province of Alberta 1980). This often involves balancing engineering constraints, cost considerations, safety requirements and service and market conditions.

The land through which the pipeline will pass is termed a right-of-way (r-o-w) (Figure 2.2). Each r-o-w is generally 18 to 30 metres wide (depending on pipeline size) and is comprised of four areas: the stockpile, trench, pipelay and work areas. The stockpile area is on one side of the trench where topsoil and subsoil from the trenching operation are placed in two

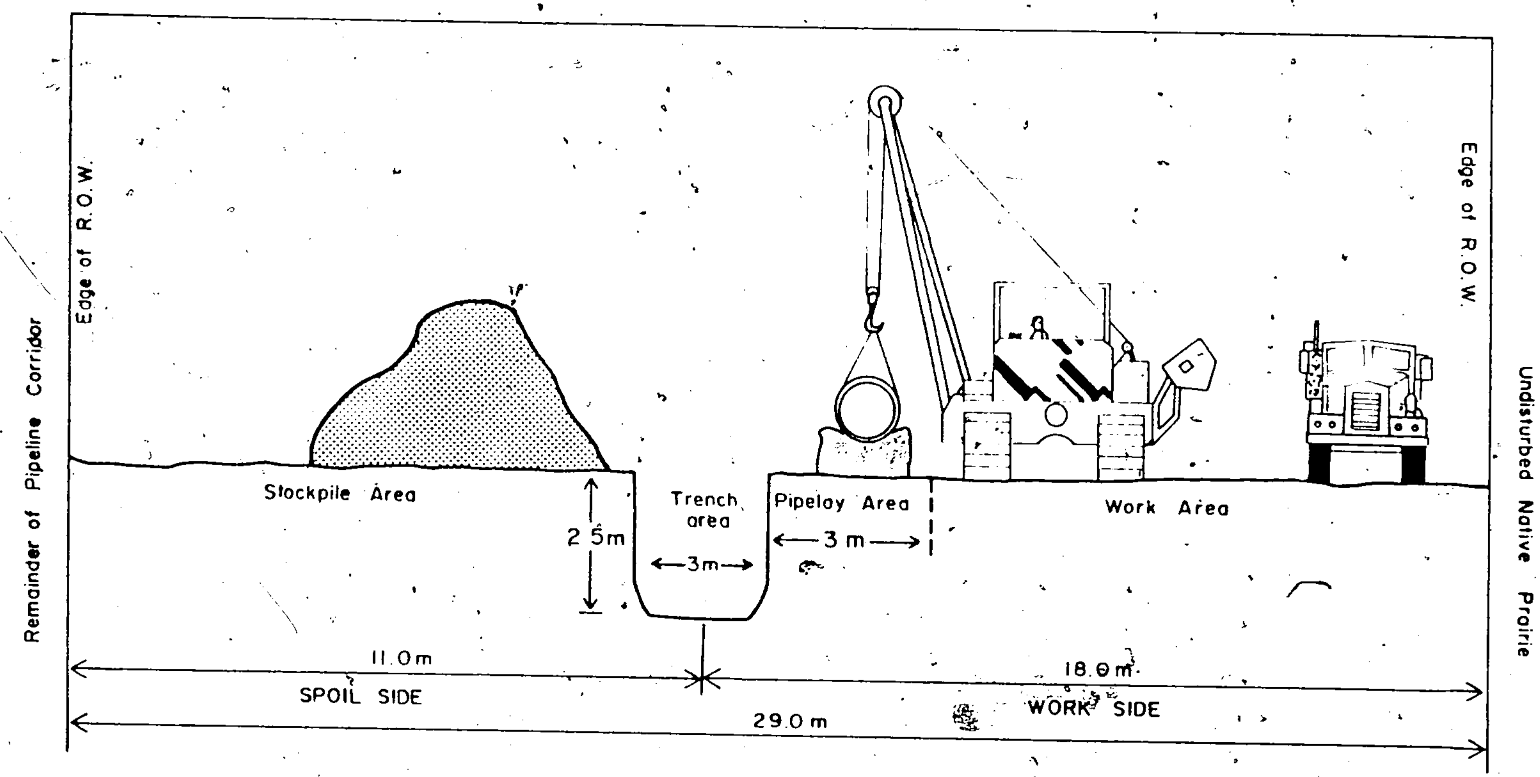

Figure 2.2. A cross section of the 1981 right-of-way.

piles until they are later used to backfill the trench. The area directly adjacent to the trench on the other side is the pipelay area and is the portion of the r-o-w where the pipe is strung until installation. Adjacent to this is the work area over which most vehicular movement occurs. Pipeline spreads are sections of the total pipeline project and are often awarded as separate contracts to pipeline construction companies.

The first steps in the construction of any spread involve clearing, topsoil conservation and grading. Hardy Associates (1978) Ltd. (1983) claimed reduced success of seedling establishment and vegetation persistence with topsoil salvage on Solonetzic soils where 20 to 50% of the area has eroded surface horizons (blowouts). They suggest that the most viable alternative is to replace trench material as a mixture of A, B and C horizon material. Thus on Solonetzic soils this initial phase involves only grading the entire r-o-w with a bulldozer to fill in blowout areas to provide a smooth working surface.

Trenching is done by ditchers, backhoes, clams and/or rippers. Trench depth ranges from 1 to 1.5 metres for the smaller diameter pipelines and up to 3 metres for the larger lines. Trench depth must allow for approximately 0.8 m of soil over the pipe. Trench width is generally 30 to 60 cm larger than the pipe diameter. In this operation spoil material is conveyed to the stockpile area.

When trenching is completed, or prior to this, the pipe is strung along the ground near the trench on the pipelay area and bent to fit the trench contours. Each section of the pipe is then lined up; pipe ends are cleaned, buffed and clamped into position. Next the sections are welded together and the welds checked radiographically.

The line is coated either on site or at the factory to protect against corrosion. Coating involves cleaning, priming and wrapping with polyethylene tape and outwrap. Coating is checked for small holes with an electrical detector.

The next step is to lower in the pipeline segments. This is done by a tractor with sidebooms. Tie-in crews follow and weld the pipeline segments together at places such as road and river crossings and other tie-in points. The trench is then backfilled and soil material is tamped with a bulldozer. Before the pipeline is ready to be put into operation, it is cleaned and hydrostatically tested. The final stages of construction involve grading the r-o-w, installing markers to show pipeline location and revegetation..

F. PIPELINE RECLAMATION AND REVEGETATION

Odum (1969) explicitly defined the states and functions of a mature ecosystem. If such a system were to be disturbed, these states and functions would have to be re-established for restoration to occur. Thus early revegetation and reclamation following a disturbance become extremely important.

Revegetation is the re-establishment of a vegetative cover over disturbed lands. Restoration refers to the return of a disturbed area to its predisturbed condition. Reclamation involves rebuilding an ecosystem to a self-sustaining state, which may or may not resemble predisturbed conditions, depending on predetermined final land use.

Sims *et al.* (1984) set three objectives for the reclamation of disturbed lands which are:-

1. to restore or improve the aesthetic value of the landscape,
2. to restore the utility of the land for use by man to a level at least equal to the level of usefulness before the disturbance and
3. to restore in a manner which imparts permanency to the the reclaimed condition.

Reclamation procedures are site specific and are conducted to satisfy company design requirements, to reduce short term and residual impacts of the disturbance and to meet regulatory demands. Investigations of the flora, fauna, hydrology, soil and land use of the study site are designed to document areas in which conflicts may exist between the project and some environmental feature at the time of construction. These data form, in part, the basis for pipeline design, routing and construction.

The main objective in revegetation is to establish a permanent, self-sustaining ground cover as quickly as possible. In any pipeline installation bare ground enhances the potential for wind and water erosion. Ground cover is the most important factor in controlling soil erosion, It decreases the impact of raindrops, increases infiltration and slows runoff. Water quality is improved through reduced erosion and soil moisture is increased by decreasing runoff. Ground cover also reduces wind erosion by decreasing the area of exposed bare ground and improving soil structure.

Loss of land use options is minimized by attempting to return the site to near predisturbed conditions as quickly as possible. Reclamation efforts are aimed towards compatability with ecosystem functioning in order to minimize disturbance. This is also in keeping with federal and provincial regulations governing natural resource developments, which indicate a disturbed area must be returned to a capability equal to or better than that of predisturbed conditions.

Reclamation practices of NOVA, An Alberta Corporation, vary with predisturbed land use and desired end land use. The general approach and rationale to these practices have been discussed with NOVA personnel and are summarized here.

Consideration of special reclamation needs is necessary when selecting species for revegetation. Native rangeland is generally seeded with a broad mixture of native and/or introduced species. With linear disturbances, such as pipeline r-o-w, custom seeding of each range is difficult. The mixture generally includes some species capable of growing under each set of environmental conditions encountered in a given area. Species that are capable of providing quick ground cover with a large root holding capacity are selected. They must be capable of providing a self-sustaining ground cover on non-arable land that will provide adequate resources for a predetermined end land use. Seedling forage plants are preferentially grazed by large herbivores. To ensure that not all species will be eliminated by overgrazing, species of differing palatability are included. Competitive ability and life expectancy are taken into consideration to facilitate the re-invasion of indigenous species and the creation of the most stable ground cover possible. The time frame for this type of reclamation is five to twenty years (Walker and Associates Ltd. 1981a).

One of the most controversial subjects in revegetation is the use of native versus introduced species. Introduced species do not occur in unmanaged communities of vegetation in a specified area. Native species are part of the natural assemblage of vegetation within a region. Most researchers are biased towards using either native or introduced species. Few studies have objectively compared native and introduced species and statistically tested quantitative evaluations are sparse (Sims *et al.* 1984).

Introduced cultivars have been studied for many years. There is substantial data on the autecology of each cultivar. Knowledge of response to fertilization, time of floral initiation, winter survival and seed production is available. Thus one may determine suitable management goals for each cultivar and more accurately predict the success of revegetation. These cultivars are, however, considered to be adapted to optimum nutrient conditions. Chapin (1980) indicated that these rapidly growing species are likely to suffer physiological stress in a nutrient poor system, reducing dry matter yield. Continued success in nutrient poor sites is believed to require fertilization which can increase susceptibility to winter kill and to snow mould (Mitchell 1970). Van Cleve (1977) found that introduced species performed poorly without fertilization and after five years even the most successful species showed a marked decline. However, Fyles (1984) working in high elevation mine sites concluded that the capacity of reclaimed systems to mineralize N increased with age of the disturbance and that after six to nine years sufficient N was mineralized from the soil organic N pool to maintain plant productivity without further inputs of fertilizer N.

Native species are often not available from commercial seed suppliers, are relatively expensive and may be poor seed producers. Chapin (1980) considered native species to be more physiologically adapted to unfertilized habitats because they were slower growing and therefore less likely to exhaust soil nutrients and survive longer on accumulated reserves.

Depuit and Coenenberg (1979) reported that in most reclaimed sites native species establish and yield better than cultivars in the first two years. Farmer *et al.* (1974), Richardson (1975) and Brown *et al.* (1976) indicated introduced species often outyield native species in the first two years but by the third year native species yield higher. Coupland *et al.* (1974) reported similar data for seeded cropland in southern Saskatchewan. These initial flushes of growth of introduced species are often associated with the first years after revegetation when sites had been fertilized. Mitchell (1973, 1976) speculated that native species required strict matching to site but if adapted to the site and climate, needed no further management to persist and grow. Stands of introduced species presented no permanent barrier to the invasion of native species in arctic sites. Monsen (1975) similarly commented that species used in revegetation should be ecologically adapted to the area and cautioned that although introduced species afford better protection for the soil initially they can develop into monocultures which decline in vigour with time.

A few studies compared introduced and native species in the same revegetation trials. Lesko *et al.* (1975) concluded that native species did not appear to have an advantage over introduced species in the first two growing seasons in mine reclamation. Macyk and Stewart (1977) reported limited success with native species compared to introduced species in mining reclamation near Grand Cache, Alberta. Russell and Takyi (1979) and Takyi and Russell (1980) found that introduced species provided better ground cover than the native species in revegetation of oil sands.

Brown *et al.* (1976) suggested that mixtures of native and introduced species were best for revegetation, whereas Klock *et al.* (1975) considered these mixtures to be a disadvantage because they affected yields of individual species. Brown and Johnston (1976) tested native and introduced species in alpine mine sites in Montana and found that the density of native plant species was higher. In a similar study, using transplants, survival of native species was reported as 75% and that of introduced species as 38% after the first year (Brown and Johnston 1978).

With grazing, it has been suggested that seed mixtures of native grassland species such as *Agropyron smithii*, *Agropyron trachycaulum*, *Agropyron inerme* and *Oryzopsis hymenoides* were best suited for revegetation efforts (Berg 1975). The USDA (1979) reported that revegetated sites should be protected from livestock to allow seedling establishment. Hofman *et* *al.* (1977), studying the effects of grazing on reclaimed coal mine sites, reported that grazing reduced productivity and that grazing management was necessary for successful revegetation. Similarly Depuit *et al.* (1977) and Depuit and Coenenberg (1979) recommended that newly seeded areas must be given time for sufficient development to withstand impacts of grazing. Spring and summer grazing were considered less detrimental than continuous grazing.

When considering species for revegetation of rangeland, the benefit of soil stabilizing properties, as well as forage value must be considered. Annual herbage yield for short grass prairie, mixed prairie and fescue prairie regions are approximately 0.3 to 0.4, 0.5 to 0.6, and 0.7 to 1.2 Mg/ha respectively (Lodge 1969). Lyles and Allison (1980) indicate that small amounts of native grasses compared to introduced grasses are needed in order to effectively prevent erosion. They calculated that a total dry weight of 0.3 Mg/ha would be equivalent to 1.3 Mg/ha of flat grain stubble. McCalla and Army (1961) estimated that 0.8 Mg/ha of wheat residue was needed for effective wind erosion control on clay loam soils. For the Manyberries area Luciuk *et al.* (1984) calculated that native range with a 40% carryover would provide the equivalent protection of 0.7 Mg/ha while *Agropyron pectiniforme* grazed to 30% carryover would be equivalent to 1.1 Mg/ha. Thus increased vegetative protection from introduced species provided an added advantage not only to erosion control but also for meat production. Ideally the combined use of introduced and native species allows for maximum animal gains, while minimizing erosion pressures on native range sites (Lodge 1970).

The use of *Agropyron pectiniforme* in native ranges illustrates the benefits and problems of introduced species in a native species community. *A. pectiniforme* has a long history of use on North American ranges and the literature on this species is extensive (Currie 1970). *A. pectiniforme* is in full production a month before native grasses (Smoliak 1982). It is a strong competitor with native species (Heinrichs and Bolton 1950) and weeds (Westover and Rogler 1934; Allred 1940; Hubbard 1949), but never establishes successfully into climax stands of *Bouteloua* or *Stipa* species (Allred 1940). Pavlychenko (1942) studied competition between *A. pectiniforme* and perennial native species after *A. pectiniforme* was seeded into established stands of weeds. Even the most persistent weeds were suppressed after a five year period.

Smoliak (1982) suggested *A. pectiniforme* is ideal for early season grazed pastures in the mixed prairie. It produces two to three times as much forage per unit area as native range and can be grazed more heavily than native range without reducing productivity. *A. pectiniforme* must be grazed to a five cm stubble to prevent the formation of seed heads resulting in uneven utilization in subsequent years. Invasion of *A. pectiniforme* stands by native species was greater under spring or spring-fall grazing than under only fall grazing (Currie 1970). Other studies (Heinrichs and Bolton 1950; McWilliams and Van Cleave 1960) indicated *A. pectiniforme* seeded on depleted range could increase herbage production over unseeded range. Houston (1957) reported similar observations with protection from grazing. Hubbard (1949) found establishment of *A. pectiniforme* was not successful when it was seeded into sod unless the sod was seriously depleted by overgrazing. When continuously grazed, *A. pectiniforme* maintained an almost pure stand with no native species encroachment, was associated with low herbage yield, poor ground cover and increased susceptibility to soil erosion. From these and other studies (Reitz *et al.* 1936; Hull and Stewart 1948) the basic conclusion was that native species must be more or less subdued before successful stands of *A. pectiniforme* could be established and that these stands are best maintained if heavy spring or continuous grazing is prevented.

Hubbard (1949) concluded that for long term production and erosion control, native species were better than *A. pectiniforme* for range reseeding. Dormaar *et al.* (1980) indicated some of the potential problems associated with *A. pectiniforme* on Alberta native range. The soil under *A. pectiniforme* as compared to that under native species had higher bulk densities, reduced energy flow, less stable and more extractable organic matter, decreased aggregation of soil particles and greater susceptibility to soil erosion. After 40 to 49 years *A. pectiniforme* remained a monoculture with relatively little native species invasion. They concluded, however, that *A. pectiniforme* was a suitable alternative to native range on abandoned or marginal crop land in southern Alberta. Similar conclusions had previously been drawn by Clarke and Heinrichs (1941) and Peake and Chester (1943). Kilcher (1969) had termed *A. pectiniforme* the king of tolerance to adversities of establishment and nature.

It is evident from the literature that much more research comparing native and introduced species is needed before these preliminary conclusions can be more readily accepted. Moore *et al.* (1977) concluded that perhaps researchers involved in revegetation efforts should concern themselves more with successional status of a species rather than whether or not it is introduced or native. Competitive weeds may be expected on nearly all reclamation sites and it may be more useful to plant introduced perennial grasses which establish easily and show some competitive parity with weeds rather than attempting to replant higher seral stage native species. Conversion programs may then be applied at a later date to encourage the re-establishment of native species when the sere has advanced to a point which favors their success.

G. IMPACTS OF PIPELINE INSTALLATION

The impact of pipeline installation in Solonetzic rangelands has not been well documented. Data for other ecosystems are also rare. Problems associated with pipeline installation appear to be linked to soil compaction, loss or mixture of topsoil with subsoil, decreased organic matter levels, disturbed internal drainage, increased surface stoniness and weediness. Hardy Associates (1978) Ltd. (1983) indicated that although topsoil was salvaged at many sites in Alberta, there was evidence of horizon mixing. Mixing occurred mainly over the trench and stockpile areas but was also evident over some work and pipelay areas. Mixing was attributed to stockpiling method, backfilling equipment, incomplete backfilling, disposal of excess spoil material and depth of topsoil salvaged.

Soil compaction has been identified as a problem in most pipeline impact studies. Cannell (1977) and Trouse *et al.* (1971) reviewed soil conditions such as increased compaction that can often depress crop yields. Culley *et al.* (1981, 1982) found consistently higher bulk densities over the r-o-w on medium to fine textured soils, but not on coarse textured soils. Bulk densities were higher at all depths but differences decreased with depth. Highest bulk densities always occurred over the trench. Ramsay and Mackenzie (1978), Stewart and Mackenzie (1979) and Shields (1979) found similar trends on clay loams and sands. Shields (1979) reported soil compaction was 10% greater along the r-o-w than on the undisturbed areas. Button (1971) and de Jong and Button (1973) reported decreased bulk densities from 1.55 Mg/m^3 to 1.44 Mg/m^3 on all zones of the r-o-w in Solonetzic soils. On Chernozemic loams bulk densities increased from 1.2 Mg/m^3 to 1.4 Mg/m^3. Season of construction appeared to have little effect on compaction levels (Stewart and Mackenzie 1979). Halvorson *et al.* (1980) indicated that machine compaction of trenches of sandy loam soils resulted in an increased bulk density of 1.57 Mg/m^3 compared to 1.24 Mg/m^3 in the adjacent undisturbed area. Bulk densities of finer textured clay loams and silty clay loams did not seem to be altered by construction. Rowell and Crepin (1981), studying cultivated Chernozems, found compaction to be a major problem with conditions more serious over the trench than on other parts of the r-o-w.

Associated soil physical responses to pipeline installation included reduced porosity and hydraulic conductivity and increased soil strength (Button 1971; de Jong and Button 1973; Stewart and Mackenzie 1979; Culley *et al.* 1981). Button (1971) and de Jong and Button (1973) indicated trenching increased the air-filled pore space and the oxygen diffusion rate of Solonetzic soils but had little effect on the aeration of Chernozemic soils.

Changes in soil hydrologic properties have been associated with pipeline installation. Culley *et al.* (1981) reported lower saturated hydraulic conductivity on all zones of the r-o-w, particularly over the trench. Water holding capacity was reduced at all depths over the r-o-w but especially over the trench. These trends were also reported by Button (1971), de Jong and Button (1973), Mackenzie (1977, 1978a, 1978b) and Stewart and Mackenzie (1979). On Chernozemic soils, Button (1971) and de Jong and Button (1973) found no consistent effect on -33 kPa moisture content but a reduced -1500 kPa moisture content with depth. In Solonetzic soils trenching lowered the -33 kPa moisture content at depth, usually decreasing the available water.

The effect of pipeline installation on chemical properties depends on degree of horizon mixing, subsequent tillage and changes in physical properties. Button (1971) and de Jong and Button (1973) found that horizon mixing lowered NO_3-N, P and K and increased EC and pH in the top 15 cm of the trench and stockpile areas. They also reported significant increases in exchangeable Na, Ca and Mg for this depth interval. Electrical conductivity decreased between depths of 30 to 60 cm, and with time due to tillage and leaching of salts. Incorporation of topsoil resulted in increased NO_3-N, P and K below 15 cm in the trench area. In Solonetzic soils Button (1971) and de Jong and Button (1973) found pH increases of two units over the trench and stockpile, compared to increases of approximately 0.5 unit in Chernozemic soils. Culley *et al.* (1981, 1982) noted similar responses in their study with lower P and K values on some r-o-w. Culley *et al.* (1981) reported decreases in CEC over all r-o-w zones. Sodium adsorption ratio often increased over the r-o-w. Button (1971) reported SAR's for the 0 to 15 cm depth of Solonetzic soils of 4.9 over the trench, 4.1 on the work area and 0.8 in the undisturbed area. At depths of 30 to 60 cm, SAR for both Chernozemic and Solonetzic soils tended to increase. All SAR's decreased after 4 years. In Chernozemic soils, SAR often increased in the 0 to 30 cm depth increment. Soil organic matter loss was greatest over the trench and stockpile areas at depths of 0 to 15 cm. Levels of organic matter were also lower on the work area than on the undisturbed area. Trends were similar for the 15 to 30 cm depth increment. Rowell and Crepin (1981) reported organic matter losses of 40 to 50% over the pipeline r-o-w in the 0 to 30 cm depth increment of Chernozemic soils, with major losses over the trench. Winter construction was associated with reduced loss of soil organic matter (Stewart and Mackenzie 1979). Reduced soil organic matter levels on the r-o-w adversely affected both N status and soil tilth (Stewart and Mackenzie 1979; Culley *et al.* 1981).

Reduced crop yields are often associated with pipeline disturbances. Culley *et al.* (1981) reported a 50% reduction in corn yield for the first two years after pipeline installation. This reduction was associated with reduced plant height, density and root density as well as reduced maturity and slightly reduced nutrient content. Smaller but observable yield reductions were reported for some sites four years after pipeline installation. Stewart and Mackenzie (1979) indicated pipeline installation affected crop yield the first year with these reductions persisting but diminished after five years. Yields on all sites were lowest on the trench and were associated with reduced maturation, lower corn moisture content and lower plant density. Similar trends were observed by Shields (1979), who found corn, soybean and small grain yields were reduced by 40% the first year and 20 to 30% after 4 years. Ramsay and Mackenzie (1978) measured yield reductions of up to 34% for corn and soybeans. They indicated these reductions increased with increases in clay content. Rowell and Crepin (1981) found that plant height and crop density over the r-o-w was lower than in adjacent undisturbed Chernozemic soils.

Hardy Associates (1978) Ltd. (1983) evaluated 154 pipeline construction sites throughout Alberta. Pipeline size ranged from 76 to 1219 mm and age ranged from 1 to 69 years. They found reduced crop yields over the r-o-w for over 50% of the sites. Thirteen percent of the sites had improved crop yields and 30% were unchanged. Forty-one percent of the annually cultivated sites had crops with 10% or less cover, shorter plants and/or increased weediness. All irrigated sites had poorer yields and 54% of improved forage sites had reduced yields. In Solonetzic soils, the crop yield was improved or unchanged over the trench in two thirds of the sites but decreased over the stockpile areas in 62% of the sites. The poorer crop yields over the r-o-w were attributed to topsoil mixed with or buried under saline parent material. On non-Solonetzic soils, 50% of the sites had reduced crop yields. Differences over the trench and stockpile areas were not evident. Reduced crop yields were lowest in the Gray and Black soil zones. Crop yield response to pipeline construction did not appear to be correlated with size of pipeline. Most sites showed some reductions in the first year following construction but this trend did not always persist.

Other studies in western Canada have indicated little or no yield differences with pipeline disturbances. Toogood (1974) found significant yield losses on only one out of ten sites for a silty clay loam. Button (1971) and de Jong and Button (1973) indicated no significant decrease in wheat yields on Chernozemic or Solonetzic soils.

In some cases a significant yield increase was found and attributed to improved tilth and mineral nutrients brought up from the subsurface (Toogood 1974). Toogood (1974) found that improved oats and barley yields over the trench on Black Chernozems were associated with taller plants and fewer plants per unit area. Button (1971), de Jong and Button (1973) and Hardy Associates (1978) Ltd. (1983) found no significant yield changes on Solonetzic soils over recently installed lines. Older lines had significant yield increases, possibly due to leaching of salts and improved soil physical properties. NO_3-N accounted for up to 30% of the increases in yield. Fertilizer and manure amendments increased crop yields equally over and off the r-o-w (Stewart and Mackenzie 1979). Winter construction techniques resulted in higher yields in spoil banks and working areas compared to fall construction (Stewart and Mackenzie 1979).

Reid (1977) studied the effects of pipeline installation on sandy soil grasslands in southern Alberta and found no significant differences in yield on older lines. Recently installed lines had a variable cover of *Agropyron pectiniforme* if seeded or weedy species if not seeded. Disturbed sites with only natural revegetation resembled the adjacent undisturbed sites after several years. Hardy Associates (1978) Ltd. (1983) found decreases in productivity on native rangeland due to lack of topsoil replacement, topsoil and subsoil mixing, competition with weeds, gopher holes, finer soil texture over the r-o-w and subsoil left on stockpile and work areas. Eighty-one percent of all native rangeland sites had more than 10% reductions in live cover, height and/or increased weediness over the trench. Similar trends were found over the stockpile and work areas. All native forage sites on Brown Solonetzic soils were over gas pipelines from 7 to 20 years old. Vegetative cover decreased at most sites while height increased. Weedy species were more abundant over the entire r-o-w at all sites than on the adjacent control areas. These trends were attributed to the calcareous saline parent material covering the surface of the r-o-w.

There are limited data on the impact of pipeline installation on microbial populations. Parkinson *et al.* (1980) found that stockpiling had little effect on microbial biomass in the short term. After a four month period they found no change in respiration or biomass.

Soil temperature has a profound effect on plant growth and nutrition. Increased soil temperatures due to operation of the pipeline could increase crop yields as well as increase competitive ability and root length (Power *et al.* 1970; Valentine and Barley 1976; Morrow and Power 1979).

Winter root activity of *Poa pratensis* has been studied by Hanson and Juska (1961). This European species has a growth pattern similar to cool season native grasses common in the study area. Maximum vegetative development occurs in the spring and autumn. Temperatures too low for top growth can stimulate root and rhizome development. Underground organ weight in grasses can increase from November to May in mild climates with root tips dividing at temperatures as low as 0°C and optimum root growth at soil temperatures of 4 to 16°C.

Nielsen and Humphries (1966) reported that temperatures for optimum root production are lower than those for optimum shoot production and that roots tolerate a narrower range of temperatures than do plant tops. Morrow and Power (1979) found temperatures of 18°C to be optimum for root dry matter production by most cool season grasses. Optimum temperature for above ground dry matter production was 18° to 23°C. Dry matter production of warm season grasses such as *Bouteloua gracilis* increased as temperature was increased. Temperatures of 35°C inhibited bud initiation of *Poa pratensis* and dormancy was induced in *Phalaris* species at 40°C (Darrow 1939).

Temperature also affects the mineral nutrition of plants by altering the concentration of soluble nutrients in the soil or affecting the ability of the plant to absorb and use nutrients (Neilsen *et al.* 1960; Power *et al.* 1964; Nielsen and Humphries 1966; Morrow and Power 1979). Increased root temperature increased transpiration rates (Kleinendorst and Brouwer 1965), and increased temperatures decreased the proportion of non-structural carbohydrates and the nitrogen content of the shoots.

Most species germinate and seedlings emerge at soil temperatures of 13 to 18°C (Johnston *et al.* 1969). The optimum temperature range for germination of cool season grasses is 10 to 30°C, but germination is possible at temperatures lower than 0°C (Troughton 1977).

As temperature increases, water use efficiency decreases. Temperatures of 13 to 23°C were optimum for efficient water usage for production from cool season grasses (Morrow and Power 1979).

Morrow and Power (1979) found that cool season grasses have a wide range of adaptability to soil temperature. Existing and antecedent environmental parameters are involved in gas exchange rates in the plant (Sosebee 1977). These acclimation effects apparently involve photosynthetic enzyme systems and help minimize CO_2 loss during the warm season and maximize net CO_2 gain during the cool season. Mooney and West (1964), studying California shrubs, found that acclimation to a warmer environment brought about an increased photosynthetic water use efficiency at higher temperatures and a reduction at lower temperatures. Native species also exhibited noticeable displacement of their optimal temperature following acclimation. Temperature acclimation effects were observed after temperature treatments as short as 24 hours, suggesting a biochemical basis for the acclimation. Acclimation responses varied with species from almost total compensation for environmental changes to lack of compensation. There were strong correlations of acclimation capacity with environmental variability and with ecotypic variation.

Increased soil temperatures were observed over pipelines filled with warm water which heated the soil and increased crop yields (Rykbost *et al.* 1975a, 1975b). Similar observations were made by Stewart and Mackenzie (1979) over an oil pipeline in clay loam and sand. They found soil temperatures over the trench to be higher than those of the undisturbed prairie or other transects of the r-o-w. These higher temperatures were attributed to changes in the thermal diffusivity of the soil, changes in surface properties and/or plant cover and temperature of the gas in the line.

Gas flow will likely create a localized increase in soil temperature if temperature of the fluid in the pipe is higher than that of the surrounding soil (Deaton and Frost 1964). Soil moisture often migrates away from a hot pipe, creating a dry core around the pipe, which has a lower thermal conductivity and reduces the heat disposal efficiency of the pipe (Boersma 1970).

Erosion problems associated with pipeline installation appear to be common (Wyldman and Poliquin 1973; Robinson *et al.* 1974; Chen *et al.* 1975; Crabtree 1979; Regnier and Handyside 1979; Hardy Associates (1978) Ltd. 1979, 1980; Martz and Campbell 1980). Pulverization of the soil during stripping and replacing operations may leave the soil more prone to wind and water erosion. Berms left over the trench may disrupt natural surface drainage patterns. Water flow may become concentrated along the line resulting in erosion. Chen *et al.* (1975) suggested that erosion could be reduced if construction during time of highest rainfall was avoided.

III. SITE CHARACTERIZATION

A. SITE SELECTION

Four study sites were established within a natural gas pipeline corridor approximately ten km east of Princess, Alberta (Figure 3.1). Sites 1 and 4 were located in NW and NE 16-20-11-4, respectively and sites 2 and 3 in NW and NE 15-20-11-4, respectively. All four study sites were located within a four km distance. Studies were confined to the r-o-w leased by NOVA, An Alberta Corporation and to control areas immediately adjacent to the r-o-w.

The study sites had slopes of less than two percent. Soils were Brown Solodized Solonetz and Brown Solod with prominent blowout patches. Vegetation was of the *Bouteloua-Stipa-Agropyron* faciation. The 1968, 1972 and 1981 r-o-w were seeded to similar mixtures of introduced species; the 1957 and 1963 r-o-w were not seeded. Sites 2 and 3 were in an early season grazed section of the range and sites 1 and 4 were in a late season grazed section.

B. CLIMATE

The area has a continental prairie climate characterized by warm summers, cold winters, and low precipitation (Bowser 1967; Strong and Leggat 1981; Kjearsgaard *et al.* 1982). The soil moisture regime is semiarid.

Major storms track south of the area in winter and north of the area during summer, resulting in among the lowest summer and winter precipitation totals in the province (Table 3.1). Moisture is considered to be a moderate to severe limiting factor to crop growth. High potential evapotranspiration and a large moisture deficit result from high summer temperatures, low precipitation and strong winds. The prevailing winds are from the west to northwest with strongest winds from the south. Low winter temperature and shallow snow cover subject vegetation to harsh winter conditions.

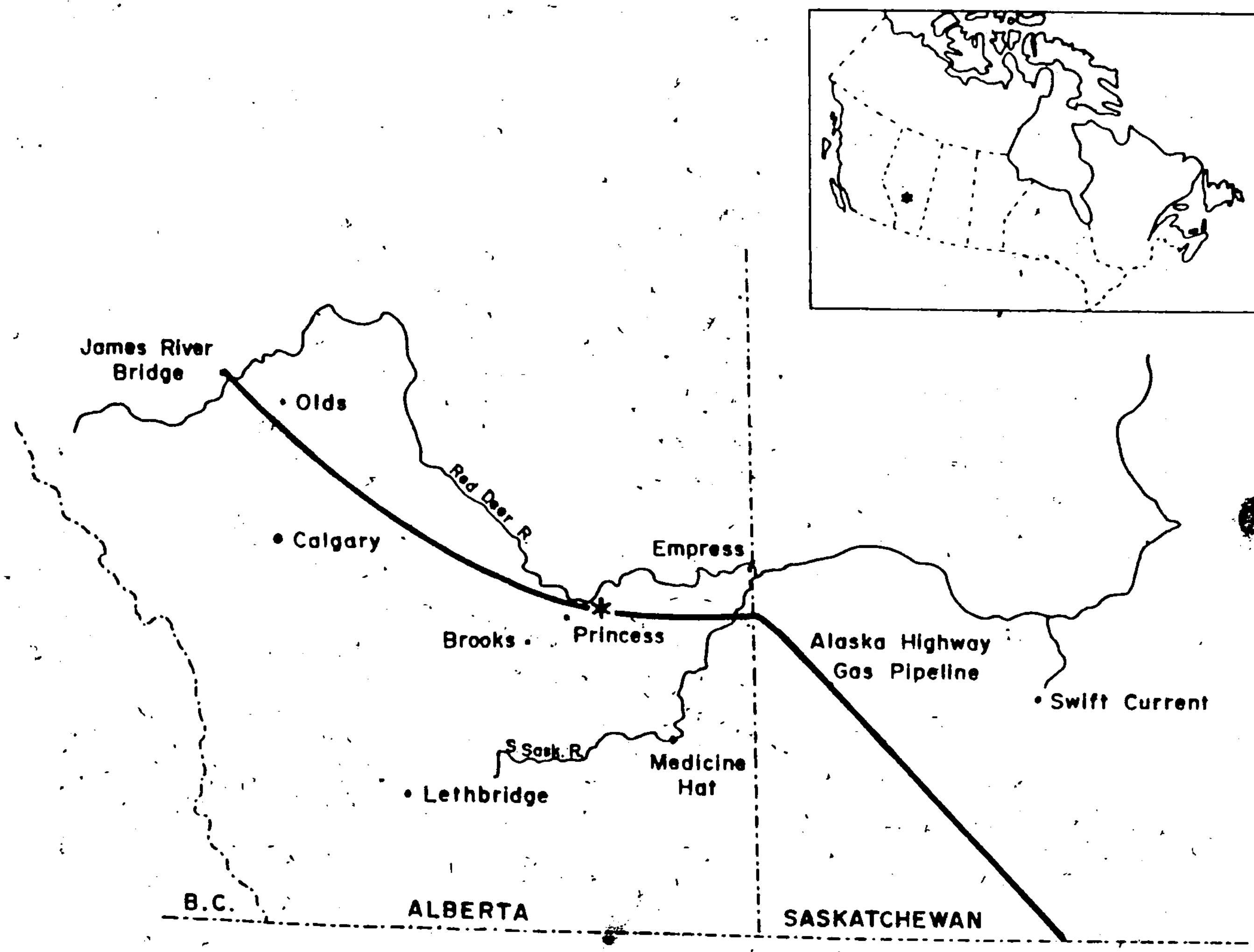

Figure 3.1. Location of the study area.

Table 3.1. **Climatic data (1951 to 1980 average) at the Brooks AHRC meteorological station.**

Parameter	Mean
Precipitation	
mean annual	355 mm
May to September	224 mm
average snowfall	106 cm
average annual soil moisture deficit	227 mm
Temperature	
annual mean	3.9°C
July mean	18.9°C
January mean	-12.8°C
average growing season (days with mean temp. above 5.6°C)	183 days
average frost free period (0°C)	116 days
Average wind velocity	12 km/h
Average number of Chinook days	20

From Atmospheric Environment Service

C. PHYSIOGRAPHY, RELIEF AND DRAINAGE

The study area is situated in the Alberta Plains Physiographic Region, within the Rainy Hills sheet. The study sites were located in the eastern portion of the Kininvie Plain which is mainly undulating moraine with common occurrences of flats and meadows. The western portion is characterized by areas of higher relief and localized soft rock outcrops. Surface elevations range from 760 to 790 m. The eastern portion of the Kininvie Plain is characterized by lower elevations of 730 to 760 m. The plain is capped with a thin to absent veneer of till through which the underlying saline soft rock materials outcrop. The area is situated between the Red Deer and Bow Rivers and drained by Matzhiwin, Onetree, and Little Sandhill Creeks (Wyatt *et al.* 1937; Kjearsgaard *et al.* 1982).

D. SURFICIAL AND BEDROCK GEOLOGY

In the study area, four bedrock formations, all of Upper Cretaceous age, form the uppermost geologic deposits (Wyatt *et al.* 1937; Kjearsgaard *et al.* 1982). These are the Horseshoe Canyon, Bearpaw, Oldman and Foremost formations. The study sites are all underlain by the Oldman formation and the surrounding area is underlain by the Bearpaw formation.

The Oldman is a nonmarine formation composed of pale gray, thick bedded, medium to coarse grained feldspathic sandstone; green and gray mudstone; dark gray and brown carbonaceous shale; and ironstone concretionary beds. The Bearpaw formation is of marine origin and is composed of dark gray blocky shale and silty shale, greenish glauconitic and clayey sandstone and thin concretionary ironstone and bentonite beds.

The most common surficial materials are till and fluvial-lacustrine followed by fluvial, fluvial-eolian and lacustrine with minor amounts of outwash gravels and soft rock. Some glacial drift was likely brought in from the Hudson Bay Region, whereas some originated from the underlying sandstone and shales in the vicinity.

E. SOILS

In a soil survey of the County of Newell, Kjearsgaard *et al.* (1982) classified the soils into the Steveville, Hemaruka and Halliday series. From a map (scale 1:63,360) in this survey report, soils at sites 1, 2 and 4 were identified as 60% Steveville, 30% Hemaruka and 10% Halliday while site 3 was composed of 60% Hemaruka, 20% Steveville and 20% Halliday. Norwest Soil Research Ltd. (1981) surveyed the pipeline r-o-w for NOVA, An Alberta Corporation. They identified several areas of Solonetzic soils in the Princess-Millicent area. These soils were comprised of 25% Solods and 75% Solodized Solonetz with descriptions corresponding to those given by Kjearsgaard *et al.* (1982).

Steveville Series

This series is a Brown Solodized Solonetz with a common horizon sequence of Ah, Ae, Bnt, Csk. Surface horizons are brown and weakly structured, especially the Ae. The Bnt has a hard columnar structure. Subsoil texture is loam to clay loam with an alkaline pH. Lime occurs near the 40 cm depth.

These soils, formed on fine loamy soft rock, are very stony and have numerous eroded pits. Steveville soils are found on undulating to rolling topography with slopes of two to fifteen percent. They are moderately well drained and associated with soils of the Hemaruka, Halliday and Ronalajne series. There is little or no potential for cultivated agriculture. Grazing capacity is 19 to 24 ha/AUY (animal unit year).

Halliday Series

The common horizon sequence of this Brown Solod is Ah, Ae, AB, Bnt, BC, Cca, Csk. The A horizon is brown to gray-brown and slightly acidic. The Ae and AB horizons are very distinct. The series is characterized by a transitional AB horizon often retaining the round-topped form but losing any strong secondary structure and is easily broken into subangular blocky peds. The transition to the columnar structured Bnt horizon is gradual in both colour and texture. This Bnt horizon is generally of clay loam texture and dark brown in colour. The structural characteristics gradually become less obvious through the BC horizon and disappear entirely in the Cca horizon at 45 to 55 cm. The mildly alkaline pH of the B horizon increases to moderately alkaline in the lime horizon.

These soils developed on fine loamy till, occurring in the lower slope position undulating and hummocky areas. Slopes range from two to fifteen percent. Soils of the Halliday series are usually associated with soils of the Hemaruka, Ronalaine and Cecil series where soft rock materials are closer to the surface. The soils are moderately well drained and rated poor for irrigation due to their solonetzic B structure, and subsurface salts. Agricultural capability is rated as marginal and grazing capacity is 14 to 19 ha/AUY. Under continued dryland farming, medium to strongly acidic conditions can develop in the A horizon to the point where crop growth is affected.

Hemaruka Series

This Brown Solodized Solonetz has a common horizon sequence of Ah, Ae, Bn or Bnt, Csk. The A horizon has a distinct Ah of approximately eight cm and an Ae of approximately three cm. The brown to grayish-brown A horizon has a loam texture with a neutral to slightly acidic pH. The Bnt horizon is characterized by a hard, columnar round-topped structure, highly resistant to breakdown. It is generally clay loam to clay in texture, dark grayish-brown in colour and of a neutral to mildly alkaline pH. The lower B tends to be more weakly structured and gradually decreases in alkalinity at depths of 35 cm below the surface. The C horizon is characterized by lighter colours, a moderately alkaline pH and a clay loam texture. Sandy loam lenses are common in till materials.

Soils of the Hemaruka series developed on fine loamy till. They occur on undulating and hummocky topography, most often occupying the lower slope position. Slopes range from two to twenty-five percent. Eroded pits and slight stoniness are common features. These soils are often associated with soils of the Halliday, Steveville, Cecil and Ronalaine series. They are moderately well drained, marginal for dryland agricultural capability, and poor for irrigated agriculture. The grazing capacity has been assessed at 16 to 24 ha/AUY.

F. VEGETATION

The study area supports vegetation of the *Bouteloua-Stipa-Agropyron* faciation (Coupland 1961). This faciation is characterized by the dominant grasses *Bouteloua gracilis, Stipa comata* and *Agropyron smithii*. *Bouteloua gracilis* contributes 16 to 28% of the forage yield. *Stipa* species, predominantly *Stipa comata* in dry areas and *Stipa curtiseta* in moister areas, contributes 30 to 46% of the forage yield. *Agropyron dasystachyum* and *Agropyron smithii* comprise 10 to 29% of the total forage yield, the upper percentage range occurring after moister periods. *Koeleria macrantha* and *Poa sandbergii* are common grasses. Forbs are abundant and shrubs are limited. The dominant shrub is *Artemisia cana*; the dominant half shrub is *Artemisia frigida* and the most abundant forbs are *Phlox hoodii* and *Selaginella densa*. *Carex stenophylla* and *C. filifolia* are the principle sedges.

Overgrazing for extended periods of time results in a short grass disclimax, often a *Bouteloua-Stipa* faciation dominated by *Bouteloua gracilis* (Coupland 1961). The *Bouteloua-Stipa* community that develops is recognized as a successional type or facies. During moist years a *Stipa-Bouteloua* or *Bouteloua-Stipa* character is retained in some sites while others swing towards *Stipa-Agropyron*. Areas of *Bouteloua-Agropyron* are common on Solonetzic soils with large blowout areas and are considered as serules representing a stage in succession (Hanson and Whitman 1937). Here *Agropyron* species occupy the blowout areas and *Bouteloua* occupies the areas with topsoil.

Strong and Leggat (1981) classified vegetation of the area as short grass prairie dominated by *Bouteloua gracilis* with secondary occurrences of *Stipa comata*. Kjearsgaard *et al.* (1982) classified the vegetation as short grass prairie of the *Bouteloua-Stipa* complex. *Bouteloua gracilis* and *Stipa comata* were identified as the dominant grasses with significant occurrences of *Agropyron smithii*. Walker and Associates Ltd. (1981a) indicated that the study area was of the *Stipa-Bouteloua-Agropyron* faciation. The mixed prairie of southern Saskatchewan and Alberta is further described in reports by Hubbard (1950), Moss (1955), Wroe *et al.* (1979) and Walker and Associates Ltd. (1981b).

The classification by Strong and Leggat (1981) and by Kjearsgaard *et al.* (1982) were likely based on overgrazed conditions which tend to favour the increase of the low grasses such as *Bouteloua* and the decrease of both *Stipa* and *Agropyron* species. Thus the association resembles the short grass prairie more so than the mixed prairie. The nomenclature used by Clarke (1930), Clarke and Tisdale (1936) and Clarke *et al.* (1942, 1943) may a have been used in the above mentioned reports.

G. UTILIZATION

The native range of the study area was utilized for extensively managed cattle production. The eastern part of the range (sites 2 and 3) was grazed from the first of May until the end of July and the western part (sites 1 and 4) was grazed from the first of August until November. The area was stocked at a rate of 11 ha/AUY (Shanks, B., Eastern Irrigation District, personal communication, 1983). The area has never been cultivated. In 1964, the Eastern Irrigation District (EID) Grazing Association assumed management, at which time the area was fenced and the present grazing règime established.

H. PIPELINE CORRIDOR

The corridor contains five adjacent natural gas pipelines, on a r-o-w approximately 100 m wide (Table 3.2). All lines were installed using what are believed to be similar procedures. Information regarding installation of these older lines has not been well documented and has been obtained through discussions with NOVA, An Alberta Corporation and Foothills Pipelines Ltd. employees. The installation procedures for the lines in this corridor were described under Pipeline Installation (Chapter 3). The 1981 r-o-w was 29 m wide with the trench, pipelay and work areas 18 m wide and the stockpile area 11 m in width. This r-o-w paralleled the 1957 r-o-w with the 1957 work and pipelay areas becoming the 1981 stockpile area. A ditcher was used to trench the area to a depth of 3 m; the width of the trench was 2.1 m.

The 1981 r-o-w was seeded with a mixture of introduced species in the autumn of 1981 (Table 3.3). Seed was planted with a drill at a rate of 13 to 14 kg/ha. Depth of seeding was 5 to 15 mm and row spacing was 20 cm (Walker and Associates Ltd. 1981a). Ammonium phosphate (11-55-0 or 11-48-0) and ammonium nitrate (34-0-0) fertilizers were broadcast by airplane four weeks after spring growth had begun. These fertilizers were applied at 35 kg/ha N and 15 kg/ha P to maintain active green growth (Walker and Associates 1981b). Passive control methods such as location of salt licks away from the r-o-w were employed to reduce heavy grazing and trampling.

The natural gas in the lines was heated. Discharge temperature out of the Princess compressor station was 10 to 13°C without compression. With compression (20 to 30% of the time), gas temperature in the older lines was near 32°C and in the 1981 line was near 40°C. The line was first pressurized in August 1981, and gas flow began on September 1, 1981 (Johnson, C., NOVA, An Alberta Corporation, personal communication, 1983).

I. EXPERIMENTAL DESIGN

Each of the four study sites was 100 m by 135 m, spanning five r-o-w with an undisturbed (control) area on either side. These sites were divided into 17 east-west transects representing different areas of pipeline construction activity and different ages of pipeline r-o-w (Figure 3.2).

The term 'native prairie' refers to areas not on the r-o-w but too close to the disturbance to be considered truly undisturbed. Undisturbed native prairie refers to areas far enough from the r-o-w not to have been subjected to vehicular movement or fertilization during construction and revegetation operations.

Statistical analyses for specific data are described in the pertinent chapters. Analyses were performed at the 5% level of significance.

Table 3.2. Age and size of natural gas pipelines in the study sites.

Year of Installation	Diameter (cm)
1957	86.4
1963	86.4
1968	91.4
1972	106.7
1981	106.7

Table 3.3. Seed mixture used on the 1981 right-of-way.

Species	Variety	Kg/ha
Agropyron pectiniforme	Fairway	2
Elymus junceus	Mayak	2
Agropyron dasystachyum	Sodar	2
Agropyron trachycaulum	Revenue	1
Agropyron elongatum	Orbit	1
Agropyron trichophorum	Greenleaf	1
Elymus angustus	Prairieland	1
Medicago species	Drylander	1
Onobrychis viciifolia	Melrose	1
Astragalus cicer	Oxley	1
Total		13

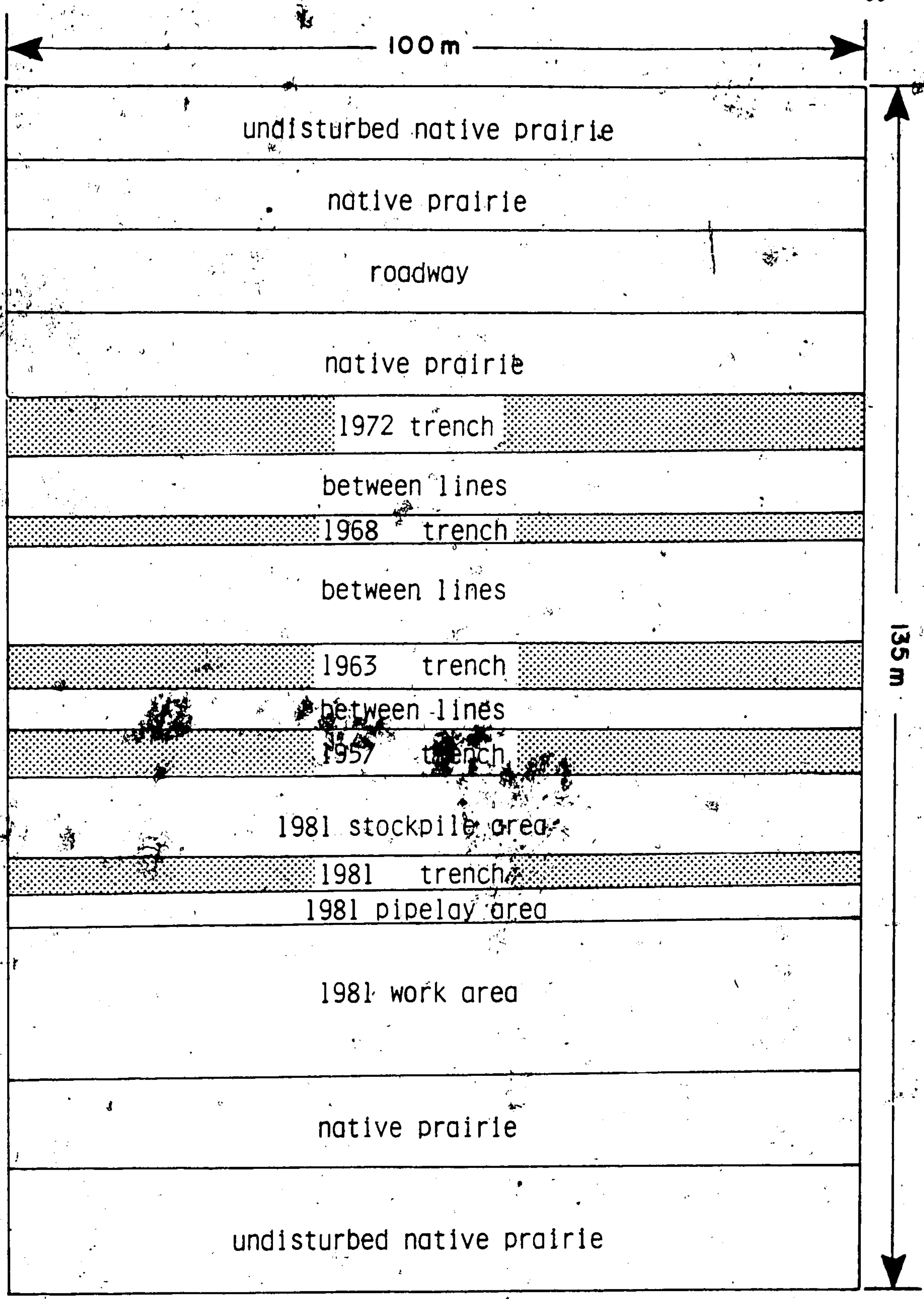

Figure 3.2. Site design.

IV. SOILS

A. MATERIALS AND METHODS

Soil Sampling

In May 1983, soil samples were obtained from all transects in sites 1, 2 and 3 with a hydraulic coring unit. Sampling was done along a straight line in each site. In site 2, five soil samples approximately 16 m apart were taken from each transect. In sites 1 and 3, three samples were taken per transect and samples were approximately 25 metres apart.

Samples were separated into depth increments of 0 to 5, 5 to 15, 15 to 30, 30 to 45, 45 to 60 and 60+ cm. Soil samples were air dried and ground to pass a 2 mm sieve with a Nasco-Asplin soil grinder. The samples were stored in plastic bags and used for chemical analyses, pressure plate extractions and particle size analyses.

In July 1983, soil samples to a depth of 76 mm were taken from all sites and transects with a Uhland core sampler to obtain cylindrical samples 76 mm in diameter and 76 mm long. Sampling was the same as that described above. Samples were used to determine bulk density, particle size distribution and organic carbon content of the near-surface zone.

Soil Classification

The soils of the study sites were classified as Brown Solodized Solonetz and Brown Solod (Site Characterization, Chapter 3). Depth to the B horizon was approximately 24 to 36, 12 to 20 and 27 to 39 cm in sites 1, 2 and 3 respectively, as determined from shallow pits. Variability in depths of all horizons was evident within and among sites.

Meteorological Data

Monthly precipitation and temperature data for the study years, as well as the 30-year average for the area were obtained from Atmospheric Environment Service for the Alberta

Horticultural Research Center (AHRC) in Brooks. AHRC is approximately 50 km southwest of the study area.

Statistical Analysis

Data were tested for homogeneity of variance using Cochran's test for homogeneity. All parameters were analyzed with an SPSS.X (University of Alberta Computing Services User Proc.) analysis of variance program. Parameters with significant F values were further analyzed using Student-Newman-Keul's (SNK) and Duncan's multiple range tests. Data are reported as analyzed by SNK unless otherwise stated. All tests were run at the 5% level of significance following Steel and Torrie (1980) and Eason *et al.* (1980). All soil properties evaluated were analyzed for among transect differences in the same site and for among site differences.

SOIL PHYSICAL PROPERTIES

Field Measurements

Soil Moisture

In November 1981, neutron probe access tubes were installed in sites 1, 2 nd 3 (Appendix I, Tables 1 and 2). Tubes were installed to depths attainable by a hydraulic coring unit, except over the trenches, where a hand auger was used. Depth of tube installation was approximately 40 cm in the trenches and approximately 100 cm in the other transects. In June 1983, additional tubes were installed to a depth of approximately 75 cm (Appendix I, Tables 1 and 2) and tubes over the 1981 trench were extended to directly above the pipe (110 cm). All tubes were spaced approximately 10 m apart.

Soil moisture was measured with a Campbell Pacific Nuclear 503 Hydroprobe, starting at a depth of 15 cm and proceeding in 10 cm increments. One 30 second reading was taken at each depth. Surface moisture measurements were taken with this probe using a shield attachment. Soil moisture readings were taken approximately every two weeks from springmelt through late October and occasionally throughout the first two winters. The neutron scattering technique as a means of assessing soil moisture is discussed by Gardner and Kirkham (1952), McHenry (1962), Bell and McColloch (1966), and Luebs *et al.* (1968).

Soil Temperature

Soil temperature was monitored throughout the year using thermistors and a Campbell Scientific Inc. CR5 digital recorder in site 2 and Campbell Scientific Inc. CR21 microloggers in sites 1 and 3. The microloggers and thermistors were installed in November 1981. Microloggers were located in a shelter constructed from a section of pipe which was installed to a depth of one metre. Depths of thermistors and their locations are listed in Tables 3 and 4 of Appendix I. Measurements were recorded every three hours. Daily mean, minimum and maximum temperatures and standard deviations were also recorded.

Bulk Density With Depth

Bulk density was measured with a Campbell Pacific Nuclear 501 Depthprobe, using the neutron probe access tubes. Measurements were taken in 10 cm depth increments starting at a depth of 15 cm, in June and September 1982 and in August 1983.

Analytical Methods

Near Surface Bulk Density

Bulk density of Uhland core samples was determined by the core method, correcting for coarse fragments (McKeague 1978).

Soil Moisture Retention

Water content was determined at -33 kPa and -1500 kPa using the pressure plate extraction method (McKeague 1978). A pressure plate extractor (#1600) and a ceramic plate extractor (#1500) (both from Soil Moisture Equipment Co., Santa Barbara, California) were used for -33 kPa and -1500 kPa, respectively. The retainer ring diameter was 5 cm; soil sample size was 10 g. Control soil samples were run with every 18 samples. Coefficients of variation of these controls were 7.0 and 7.6% for -33 kPa and -1500 kPa, respectively. Available water capacity was calculated by subtracting water content at -1500 kPa from that at -33 kPa.

Particle Size Analysis

Percent sand, silt and clay were determined for soil samples at all depths on the undisturbed transect and for surface samples only on the 1981 r-o-w and the 1957 trench transects using the hydrometer method (McKeague 1978). An ASTM Soil Hydrometer 152H (temperature 20°C) was used. Sample size was 40 g; from each site, three replicates for each transect were analyzed. Soil textural classes were assigned according to the Canada Soil Survey Committee (1978) textural triangle.

SOIL CHEMICAL PROPERTIES

Hydrogen Ion Activity

An Accumet pH metre, model 630, was used to determine pH of a 1:1, soil:water suspension, using the method outlined by Day (1965). Internal standards, run with every 20 samples, had a coefficient of variation of 0.4%.

Saturation Extracts

Soluble cations, anions and electrical conductivity were determined by the saturation paste method (McKeague 1978).

Soil samples from a Duagh (Black Solonetzic loam) Ap horizon (0 to 8 cm) were used to determine the effect of standing time on saturation paste chemical contents. Five replicates for each standing time of 4, 8, 12, 16, 20 and 24 hours were analyzed. Results were used to determine the optimum standing time of the saturation pastes from the study site soil samples.

Soluble calcium and magnesium were determined by atomic absorption on a Perkin-Elmer Atomic Absorption Spectrophotometer, Model 503 following the manufacturer's instructions. Soluble sodium and potassium were determined by flame emission on the same instrument. Calcium and magnesium dilutions were prepared with La_2O_3 as the diluent and potassium and sodium dilutions with Li_2CO_3 as the diluent. The spectrophotometer was calibrated using the above diluents. Internal standards were run with every 20 samples and had coefficients of variation of 10, 8, 4 and 8% for calcium, magnesium, sodium and potassium, respectively.

Bicarbonate and carbonate contents were determined by titration with a Radiometer Titrator Type TTT 11b according to the methods outlined by Page *et al.* (1982). Internal standards had a coefficient of variation of 8% and were run with every 20 samples.

Electrical conductivity was determined on a YSI Model 31 Conductivity Bridge following the manufacturer's instructions. For both electrical conductivity and soluble ions, a Hamilton Digital Diluter, model 100004, was used to prepare dilutions. Internal standards had a coefficient of variation of 3% and were run with every 20 samples.

Sulfate and nitrate were determined on a Technicon Autoanalyser II (industrial method numbers 226-72W and 487-77A for sulfate and nitrate, respectively. Internal standards run with every 20 samples had a coefficient of variation of 8%. Nitrate concentrations were determined according to Armstrong *et al.* (1967) and sulfate determinations according to Lazarus *et al.* (1965).

Organic Carbon

Total carbon was determined by oxidation with a Leco Carbon Determinator CR12, Model 780-000 according to the manufacturer's instructions. Internal standard soil samples were run with approximately every 20 samples and had a coefficient of variation of 1.0%. Soil samples for organic carbon determination were ground on a Siebtechnik laboratory disc mill, Model TS100A, to pass through a 0.15 mm sieve. Carbonates were determined by acid neutralization to pH 8.2 using a Radiometer Titrator Type TTT 11b (Black 1965). Internal standards were run with every 20 samples and had a coefficient of variation of 10%. Organic carbon was calculated by subtracting percent inorganic carbon from the percent of total carbon.

B. RESULTS

METEOROLOGICAL DATA

Precipitation

In 1981, at Brooks, there was 8% more precipitation (363 mm) than the 1951 to 1980 average (335 mm) (Figure 4.1). Total precipitation in 1982 (412 mm) was 23% higher than this average and in 1983 was 5% lower (318 mm).

There were often large deviations from the long term monthly averages. In March, May, July and October 1981, the precipitation was 1.8 to 2.6 times higher than the average (Table 4.1). In January, February, April, August, September, and December 1981, the precipitation was less than 50% of the average. In 1982, precipitation in January, March, May, July, September and October was nearly twice that of the average and in February, June, August and December was less than 70% of the average. In 1983, March and April precipitation was at least 1.5 times higher and January, February, May, June and September precipitation was approximately 50% of the average. October 1983, had extremely low total precipitation with

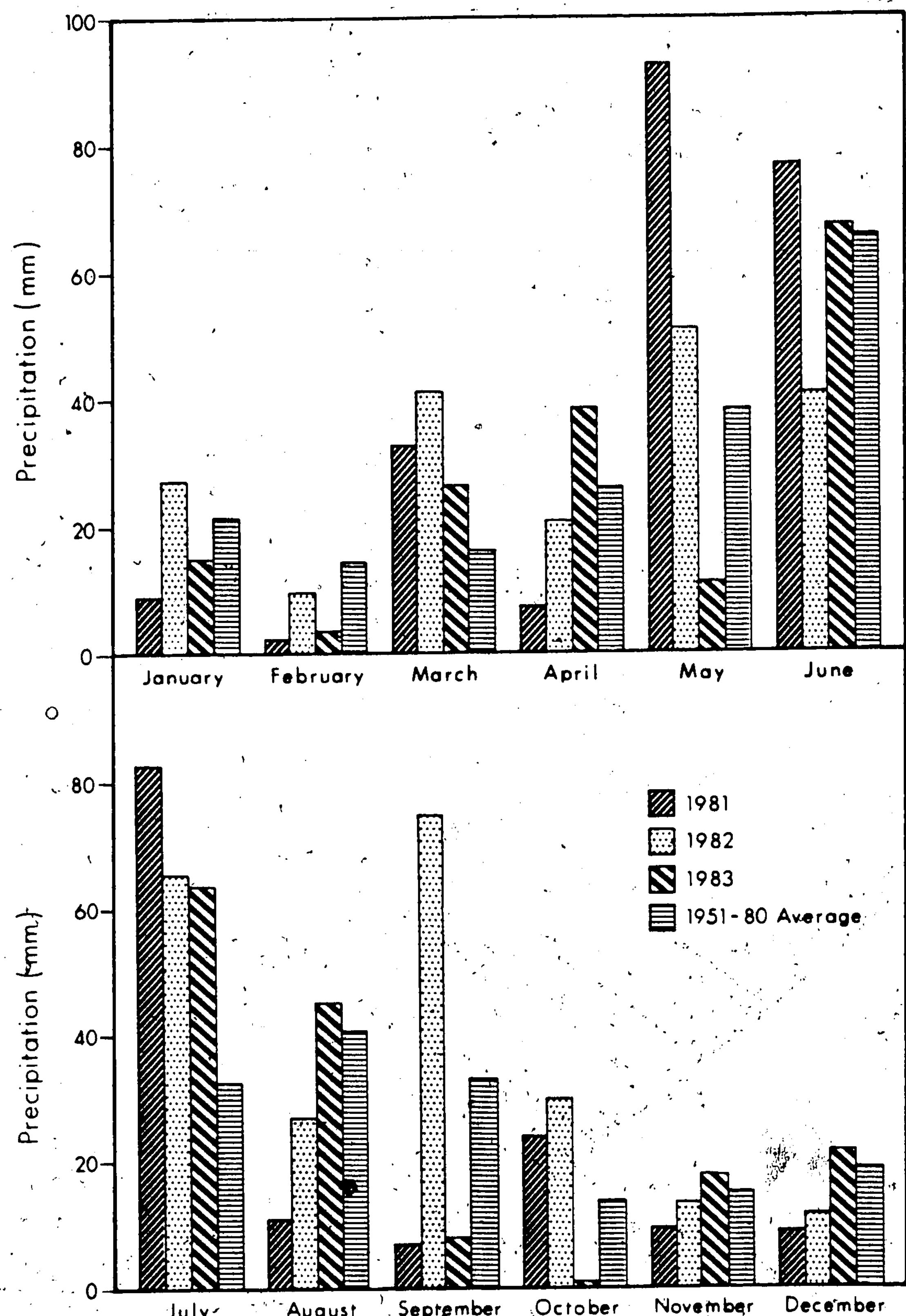

Figure 4.1. Monthly precipitation for Brooks (AHRC).
Data from Atmospheric Environment Services.

only 4% of the average. Near average precipitation occurred in the first four months of 1984, with the exception of February, which had 4% of the average total.

During springmelt of 1982 and 1983, ponding near the 1981 trench, on the working side of the r-o-w, was evident for several weeks and resulted in saturated soils. In 1982, ponding was greatest at sites 2 and 3 and in 1983 was most pronounced at site 1.

Temperature

In 1981, the mean air temperature for Brooks AHRC (6°C) was higher than the long term average (4°C). The 1983 mean temperature (4°C) was similar to the long term average and the 1982 mean (2°C) was lower. The highest long term average temperature occurs in July and the lowest in January (Figure 4.2). The trend in 1982 followed that of the long term average. In 1981 and 1983, however, August was the hottest month and December was the coldest.

SOIL PHYSICAL PROPERTIES

Particle Size Distribution

Soil textures to a depth of 7.6 cm were loam, clay loam and silt loam (Table 4.2). In all transects, at all sites, sand and silt contents averaged 39% (SD 2%) and 42% (SD 8%), respectively. Clay contents were relatively low, averaging 18% (SD 7%). All disturbed areas had higher amounts of clay than the undisturbed prairie. The trench transects had highest clay contents and lowest silt contents. Sand contents were similar over all transects.

Samples below 7.6 cm were analyzed only for the undisturbed transects. Clay content increased with depth, silt content decreased and sand content remained relatively constant. The texture was clay loam for all samples analyzed.

Table 4.1. **Precipitation as a percentage of the 1951 to 1980 average.**

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
	Percentage												
1981	39	17	207	30	242	117	255	27	20	178	62	45	108
1982	126	67	254	81	132	62	202	68	220	222	93	63	123
1983	65	26	164	148	28	102	51	113	24	4	117	116	95
1984	111	4	106	97									

Table 4.2. **Particle size distribution (0 to 7.6 cm).**

Site	Transect	Particle size distribution % sand	% silt	% clay	Texture
1	undisturbed	33	54	13	silt loam
2	undisturbed	41	49	10	loam
3	undisturbed	41	51	8	silt loam
1	work	38	50	12	loam
2	work	37	38	25	loam
3	work	39	51	10	silt loam
1	pipelay	38	40	22	loam
2	pipelay	35	47	18	loam
3	pipelay	41	41	18	loam
1	1981 trench	41	31	28	clay loam
2	1981 trench	39	33	28	clay loam
3	1981 trench	40	29	11	loam
1	stockpile	39	44	17	loam
2	stockpile	37	51	12	loam
3	stockpile	39	36	25	loam
1	1957 trench	40	35	25	loam
2	1957 trench	41	38	21	loam
3	1957 trench	42	36	22	loam

. **Precipitation as a percentage of the 1951 to 1980 average.**

Percentage												
an	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
39	17	207	30	242	117	255	27	20	178	62	45	108
26	67	254	81	132	62	202	68	220	222	93	63	123
55	26	164	148	28	102	51	113	24	4	117	116	95
11	4	106	97									

Particle size distribution (0 to 7.6 cm).

Transect	Particle size distribution % sand	% silt	% clay	Texture
undisturbed	33	54	13	silt loam
undisturbed	41	49	10	loam
undisturbed	41	51	8	silt loam
work	38	50	12	loam
work	37	38	25	loam
work	39	51	10	silt loam
pipelay	38	40	22	loam
pipelay	35	47	18	loam
pipelay	41	41	18	loam
1981 trench	41	31	28	clay loam
1981 trench	39	33	28	clay loam
1981 trench	40	29	11	loam
stockpile	39	44	17	loam
stockpile	37	51	12	loam
stockpile	39	36	25	loam
1957 trench	40	35	25	loam
1957 trench	41	38	21	loam
1957 trench	42	36	22	loam

Bulk Density

Bulk density of the undisturbed transects had a mean of 1.05 Mg/m^3 for the uppermost 7.6 cm and ranged from 1.30 to 1.75 Mg/m^3 with depth. Surface bulk density increased in all disturbed transects by 51 to 82% compared to the undisturbed transects, with the highest increases in the 1981 trench (Figure 4.3). There were no significant differences in surface bulk density among sites for a given transect. Data in Figure 4.3 were analyzed using SNK multiple range test. When data were analyzed using a less conservative test (Duncan's MRT) values for the 1981 trench were significantly higher than values for all other transects.

Trends in bulk density with depth were similar for all three sites within a given transect. Site 1 had significantly higher bulk density below 60 cm in the 1981 trench than did either sites 2 or 3. In the undisturbed prairie, bulk density generally increased with depth whereas it decreased with depth in the 1981 trench (Figure 4.4). Bulk densities of the undisturbed prairie and the 1981 trench were significantly different at all depths with the exception of the [illegible] nd 25 cm points, in all three sites and at 55 cm in site 2 (Figure 4.5). To a depth of approximately 25 cm, bulk density was higher in the 1981 trench, whereas at depths greater than 25 cm, it was higher in the undisturbed prairie.

Bulk density in transects of the 1981 r-o-w, with the exception of the 1981 trench, followed a trend similar to that of the undisturbed prairie (Figure 4.6). Bulk densities in these transects increased consistently with depth.

Bulk densities in the trench transects were not significantly different at all depths [illegible]gure 4.7). Below 25 cm, the work and pipelay transects had significantly higher bulk densities than any other transect except the undisturbed blowouts. Bulk density in the undisturbed prairie increased with depth, whereas for trench transects it decreased. The between trenches, stockpile, undisturbed and undisturbed blowout transects generally had significantly higher bulk densities than the 1963 and 1968 trenches but were not significantly different from the 1972, 1957 and 1981 trenches.

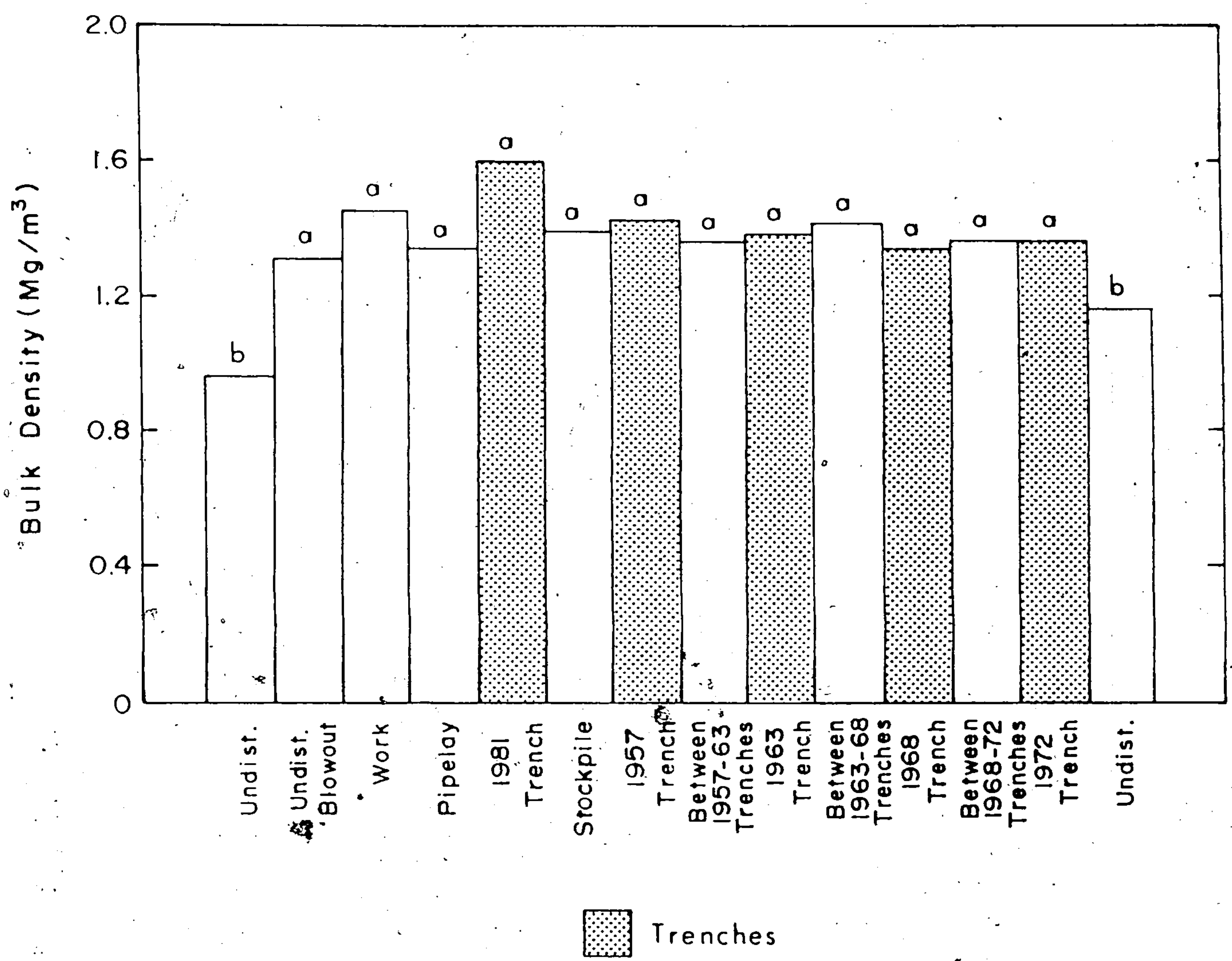

Figure 4.3. Surface bulk density (site 2, n=5).
Same letters denote no significant difference among transects.

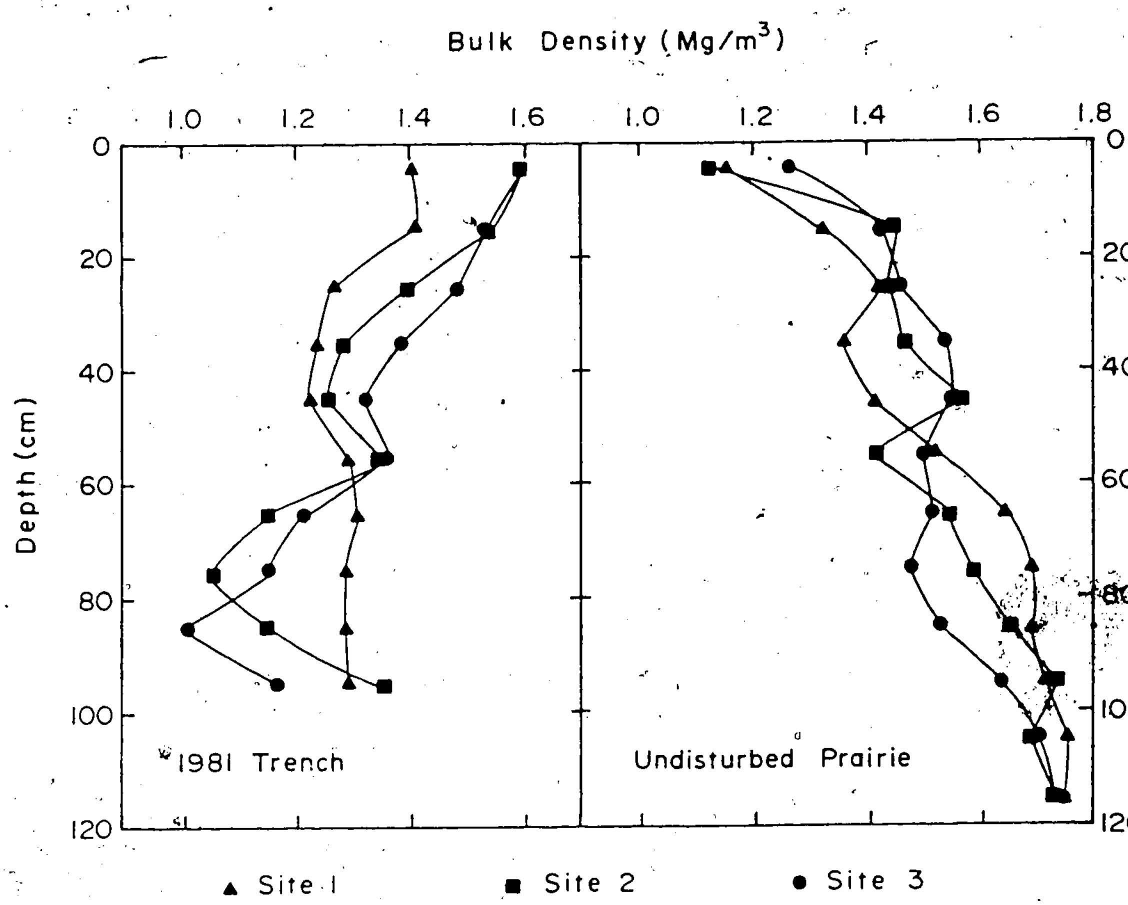

Figure 4.4. Profile bulk density among sites in the 1981 trench and the undisturbed prairie transects, August 1983.

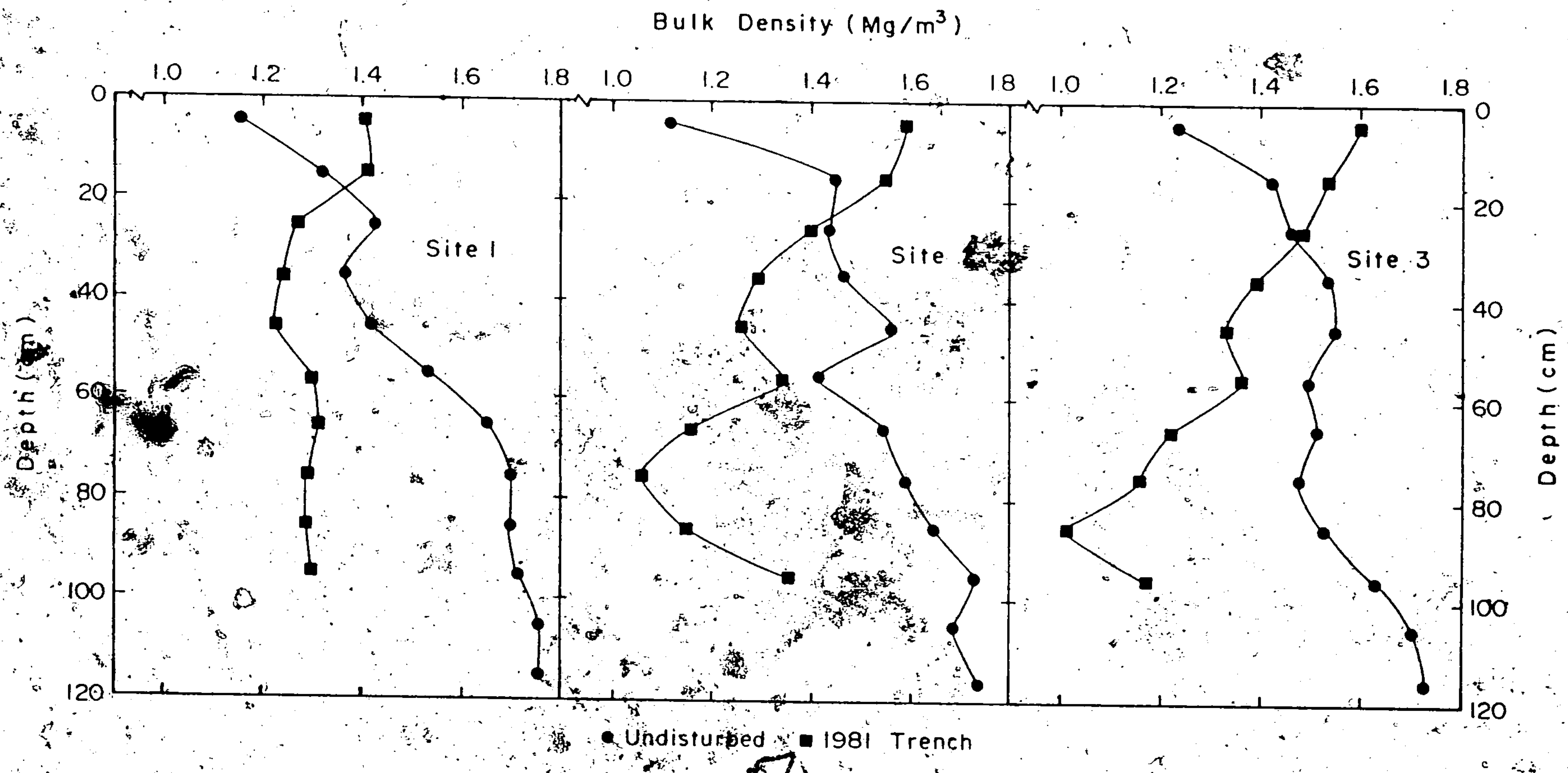

Figure 4.5. Profile bulk density in the 1981 trench and the undisturbed prairie transects, August 1983.

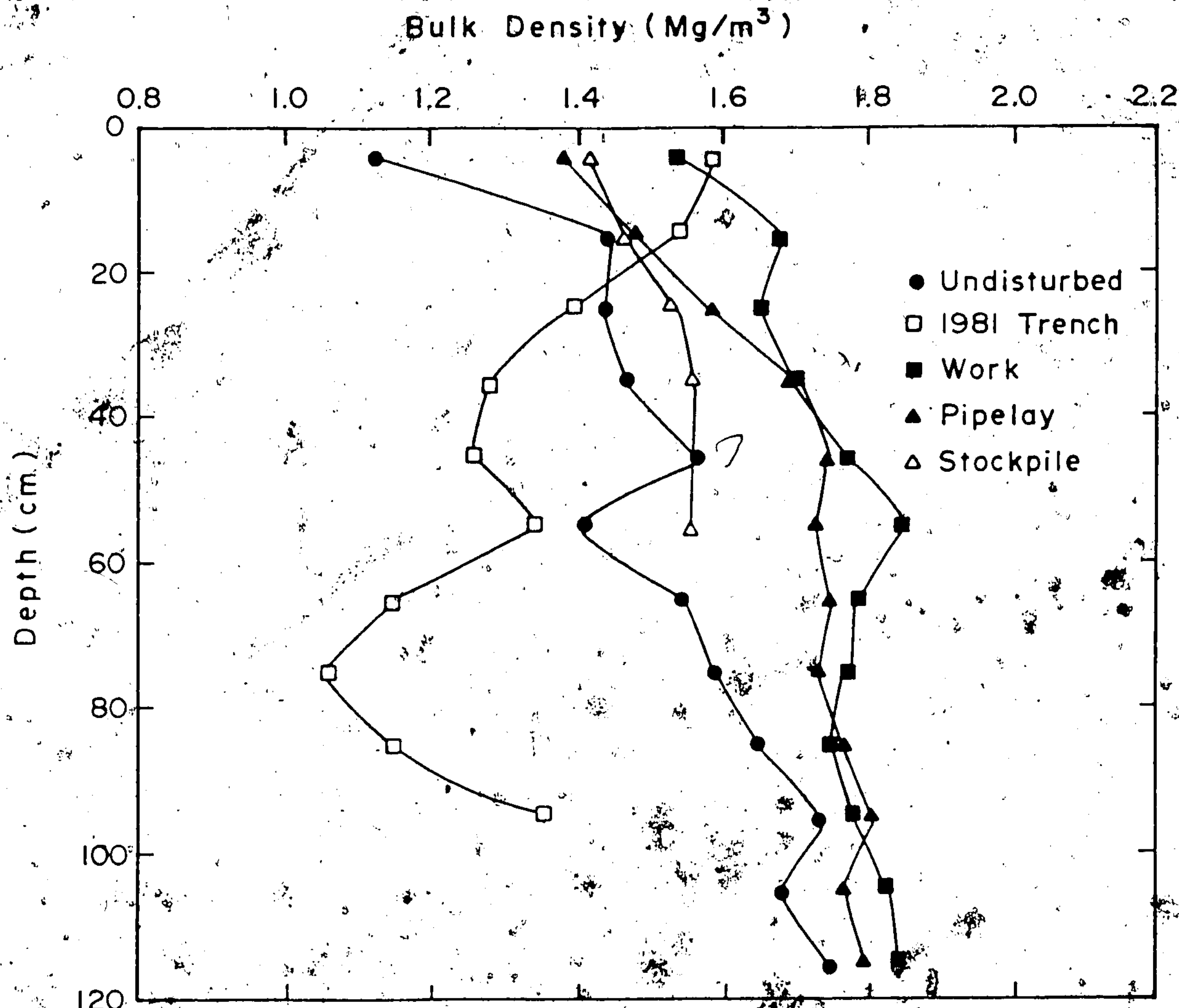

Figure 4.6. Profile bulk density in the undisturbed prairie and the 1981 right-of-way transects (site 2, August 1983).

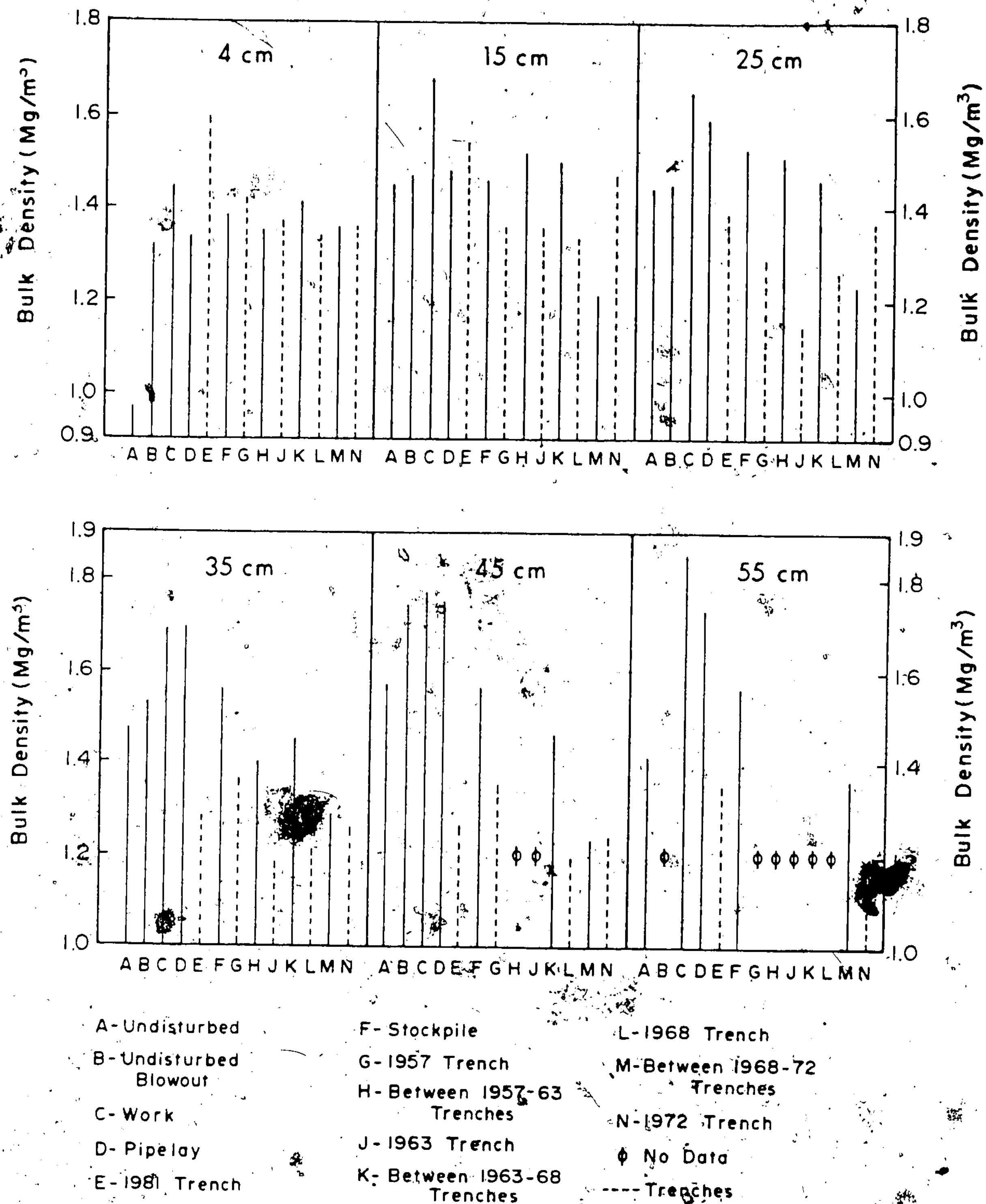

Figure 4.7. Profile bulk density (site 2, August 1983).

There were no significant differences between bulk densities for 1982 and those for 1983 at most depths in all transects except in the 1981 trench. Increases in bulk density from 1982 to 1983 in the 1981 trench were greater with depth in sites 1 and 2 but were less pronounced and more variable in site 3 (Figure 4.8). At 35 cm and lower bulk density decreased significantly in sites 1 and 2 between 1982 and 1983.

Available Water Capacity

There were no significant differences among transects for moisture retention at either -33 or -1500 kPa (Figure 4.9). There were no significant differences among sites for moisture retention at -1500 kPa but site 2 had significantly higher values at -33 kPa.

All three sites had similar trends in available water capacity of the surface soil (Figure 4.10). There were no significant differences in the available water capacity of the uppermost 7.6 cm among transects (Figure 4.10).

Soil Moisture

Monthly soil moisture status varied among sites, with differences being more pronounced between November 1982 and May 1983 in the undisturbed prairie than in the 1981 trench (Figures 4.11 and 4.12). Trends for total water in these two transects were similar. In the undisturbed prairie, soil moisture status at all three sites followed the same trend (Figure 4.11). Soil moisture was highest in site 2 for all but the November 1982 to May 1983 period where it was significantly lower than at sites 1 or 3. In the 1981 trench, soil moisture status for all three sites followed a similar trend (Figure 4.12). Total water to depths of 50 and 100 cm (data not shown) was significantly lower in site 1 than in sites 2 or 3, which did not differ significantly from each other. In the uppermost 50 cm, the 1981 r-o-w with the exception of the stockpile transect had more water than did the undisturbed prairie (Figure 4.13). Total water was lowest in the stockpile and undisturbed prairie. Annual trends were similar for all transects and sites.

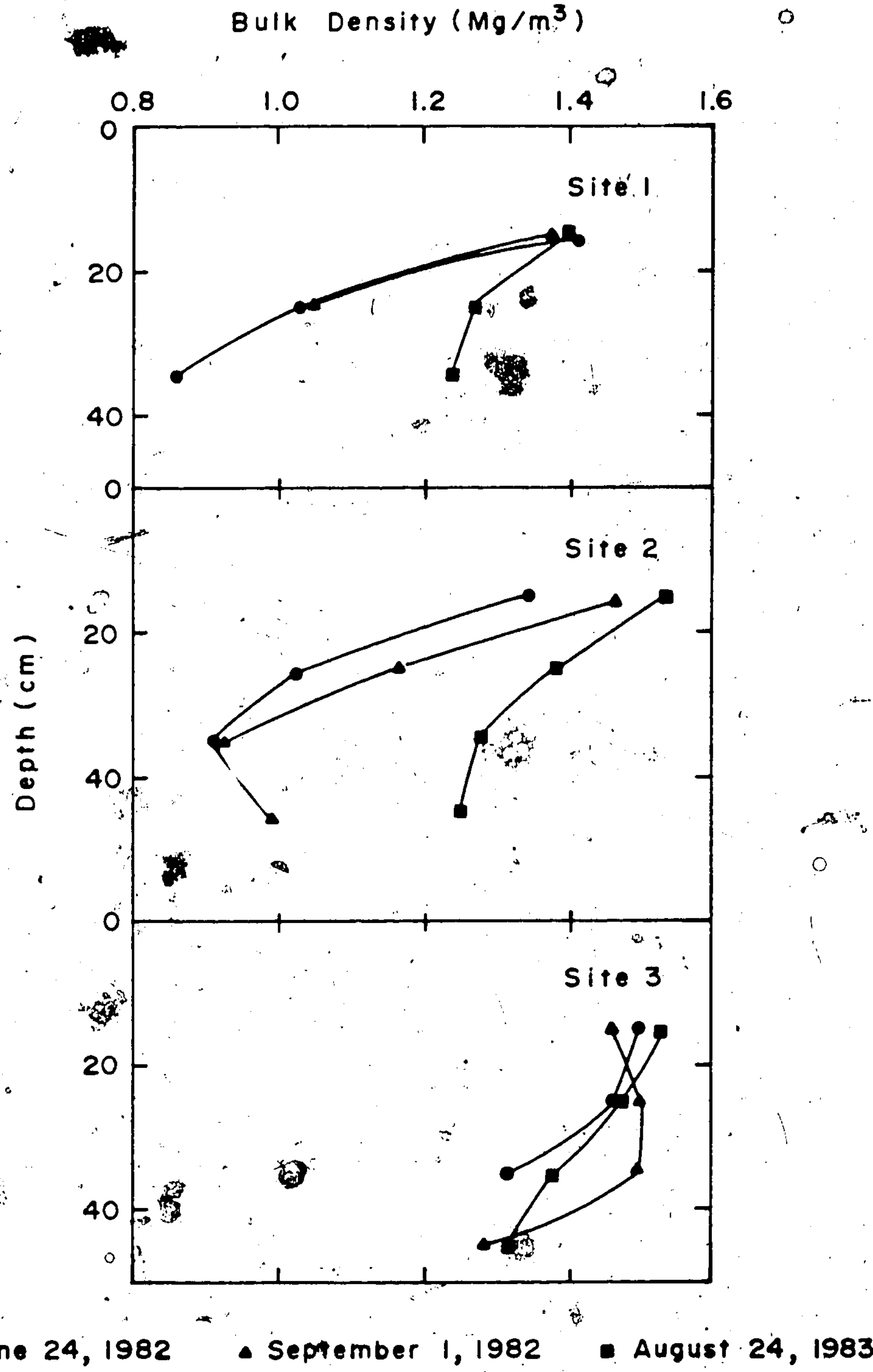

Figure 4.8. Bulk density in the 1981 trench with depth, site and sampling time.

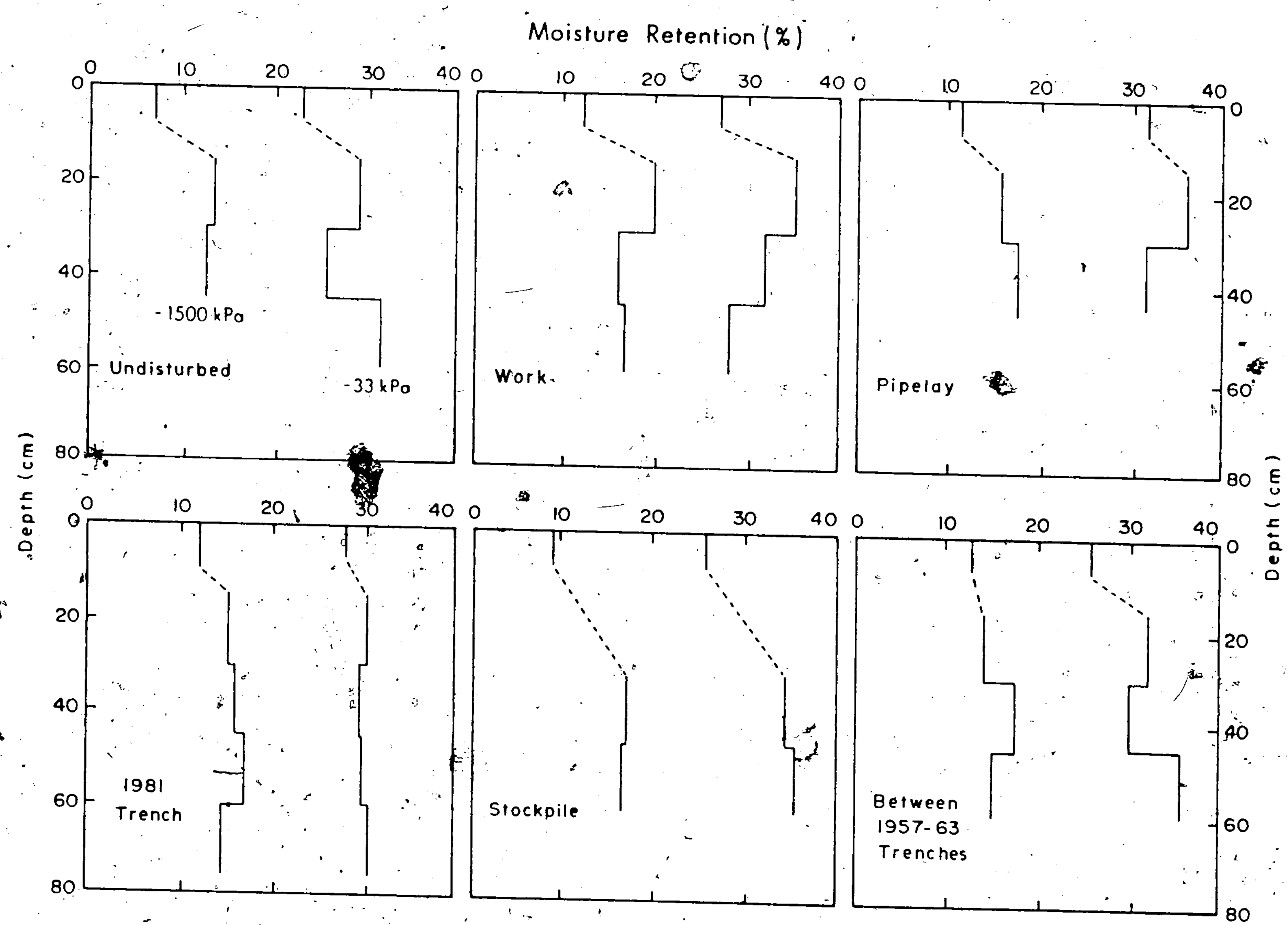

Figure 4.9. Profile moisture retention (site 2, 1983).

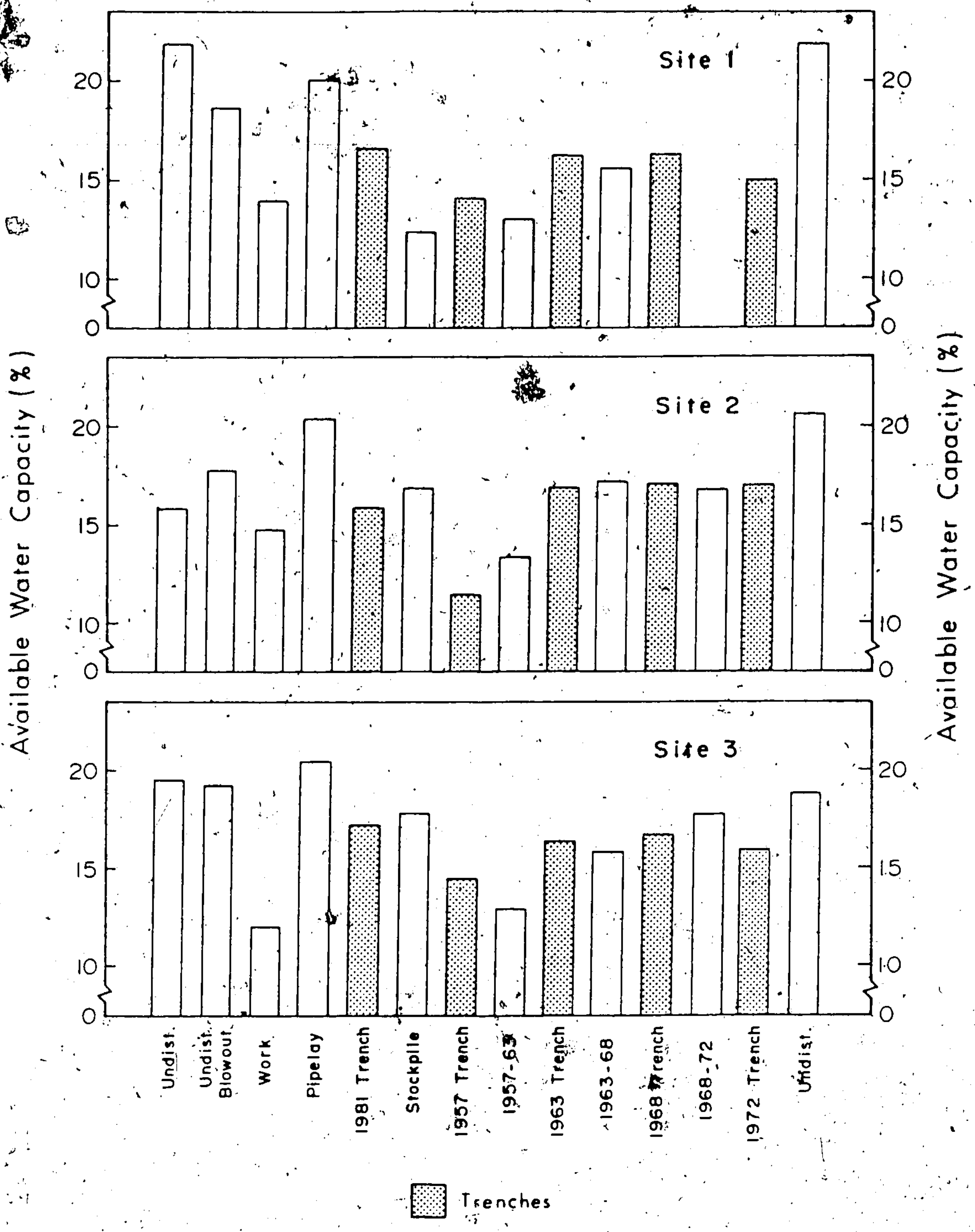

Figure 4.10. Available water capacity (0-7.6 cm, 1983).
There were no significant differences among transects.

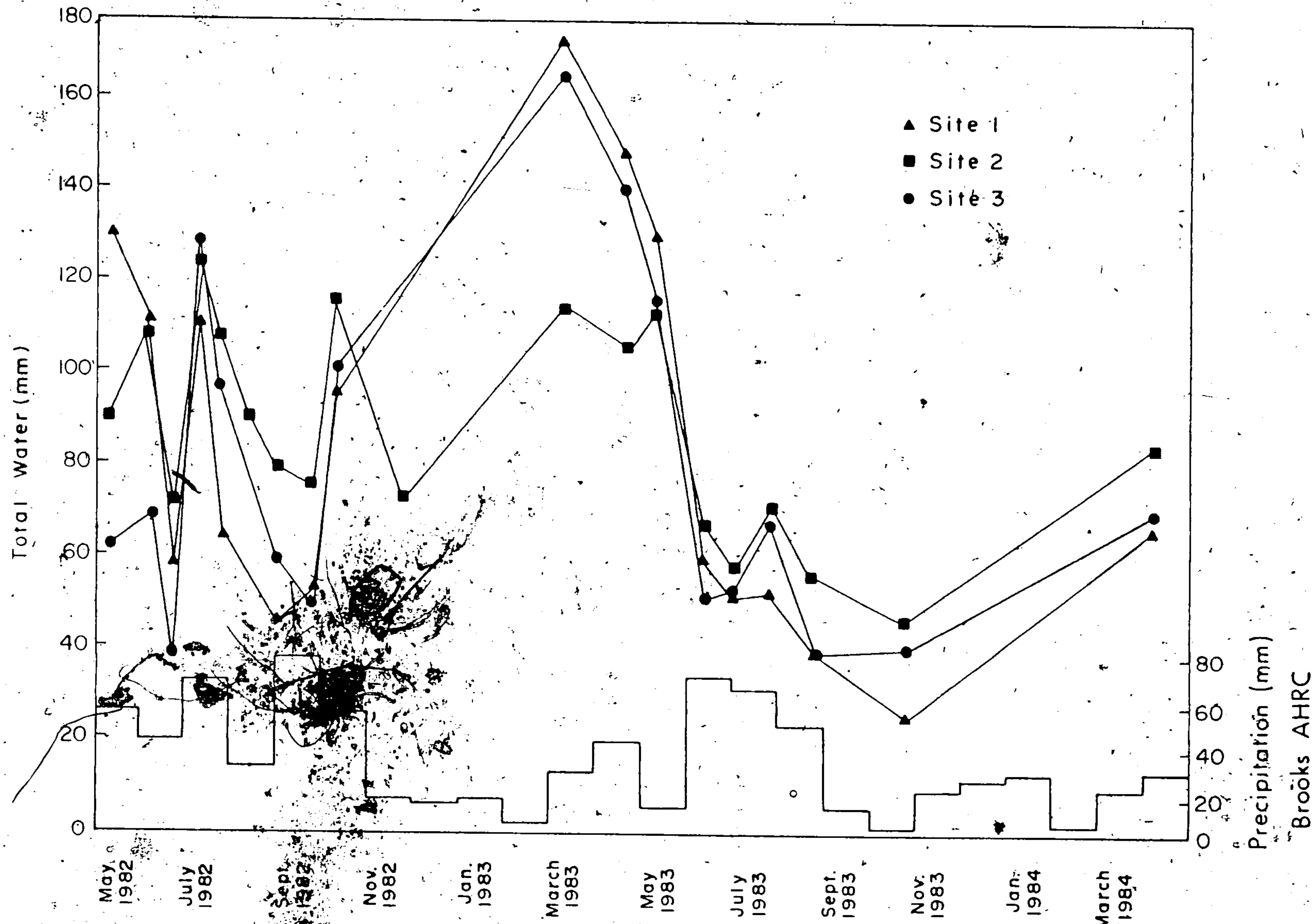

Figure 4.11. Temporal soil moisture status in the undisturbed prairie among sites (0-50 cm).

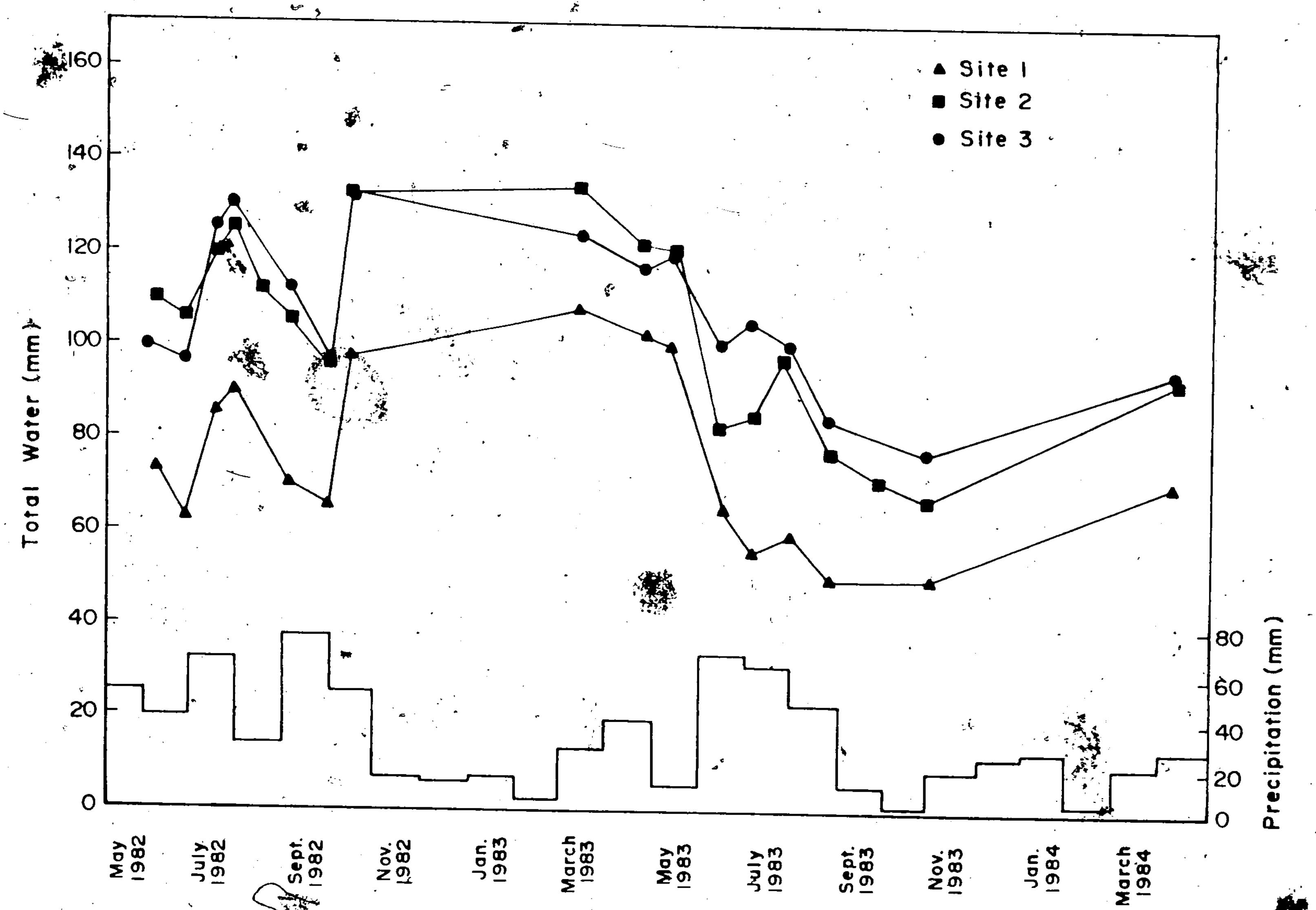

Figure 4.12. Temporal soil moisture status in the 1981 trench among sites (0-50 cm).

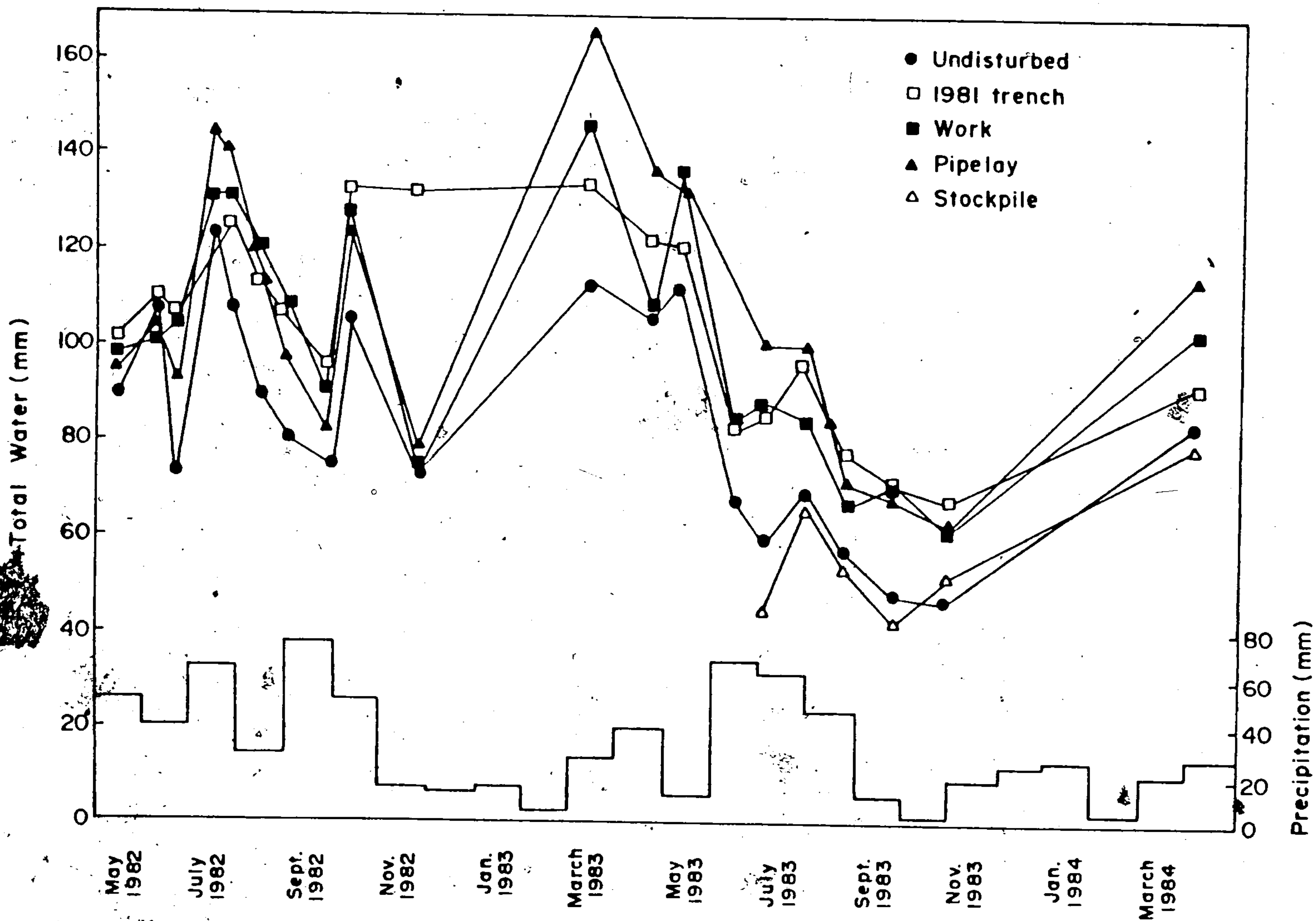

Figure 4.13. Temporal soil moisture status in the 1981 right-of-way and the undisturbed prairie (site 2, 0-50 cm).

In both spring and autumn, to a depth of 50 cm, the total water did not vary significantly with transect (Figure 4.14). If Duncan's MRT was used to analyze the data, the 1981 trench in autumn and the pipelay transects had significantly higher values than all other transects. In all transects total water was higher in spring than in autumn.

In autumn, in all three sites, in the undisturbed prairie and in the 1981 trench, moisture content generally increased with depth (Figure 4.15). In spring moisture contents were highest at the surface, decreased to a depth of 25 to 35 cm and generally increased with depth thereafter. Moisture contents in the trench were more uniform with depth than were those of the undisturbed prairie in both spring and autumn. Volumetric moisture content to 50 cm was significantly higher in the 1981 trench than in all other transects except the stockpile and pipelay transects (Duncan's MRT).

Overwinter soil moisture changes in the undisturbed prairie and in the 1981 trench followed similar trends for all three sites (Figures 4.16 and 4.17). At depths less than 35 cm, spring moisture contents were higher than those of autumn; at depths greater than 35 cm they were similar.

Overwinter soil moisture gain was higher for the undisturbed transects than for the 1981 trench transects (Table 4.3). Mean moisture gain in the 1981 trench was 21 mm (SD 3 mm) and in the undisturbed prairie it was 35 mm (SD 5 mm). The 1968 and 1972 trenches and 1981 r-o-w had low gains relative to the older lines but similar to the gain in the undisturbed prairie (Table 4.3). The pipelay transect was an exception, having the highest gains of all the transects. Depth of gain was highest for the older r-o-w and lowest for the undisturbed prairie, the 1972 trench and the 1981 r-o-w. In the pipelay and work transects, 1982 to 1983 overwinter moisture gains in site 2 were significantly higher than those in sites 1 and 3 (Table 4.4). In the undisturbed and 1981 trench transects there were no significant differences among sites.

Table 4.3. Overwinter moisture gains: October 27, 1983 to April 13, 1984.

Site	Transect	Moisture Gain (mm)	Depth of Gain (cm)
1	undisturbed	29	35
2	undisturbed	38	45
3	undisturbed	38	55
1	1981 trench	20	35
2	1981 trench	24	45
3	1981 trench	19	45
2	work	41	40
2	pipelay	66	40
2	stockpile	29	30
2	1957 trench	49	50
2	between 1957-1963	52	60
2	1963 trench	48	50
2	between 1963-1968	51	60
2	1968 trench	28	60
2	between 1968-1972	55	60
2	1972 trench	32	30

Table 4.4. Overwinter moisture gains: 1982 to 1983.

Site	Transect	Moisture Gain (mm)	Depth of Gain (cm)
1	work[1]	18	20
2	work[2]	100	110
3	work[1]	11	20
1	pipelay[1]	31	40
2	pipelay[2]	105	90
3	pipelay[1]	11	20
1	1981 trench[1]	4	20
2	1981 trench[2]	5	50
3	1981 trench[1]	4	10
1	undisturbed[1]	77	50
2	undisturbed[2]	64	100
3	undisturbed[1]	67	60

[1] October 11, 1982 to March 12, 1983
[2] November 25, 1982 to March 13, 1983

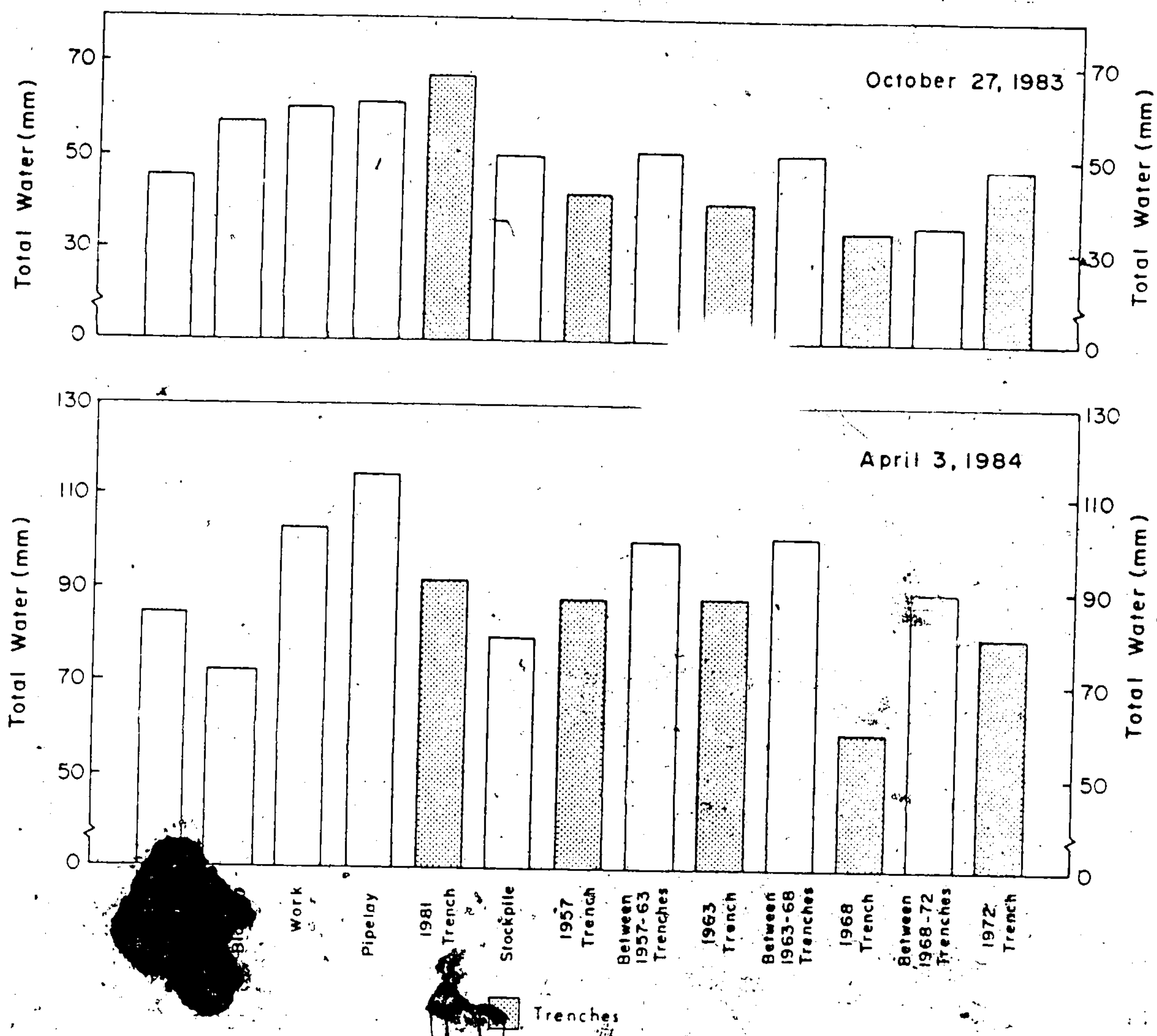

Figure 4.14. Total water in autumn 1983 and spring 1984 (site 2, 0-50 cm). There were no significant differences among transects.

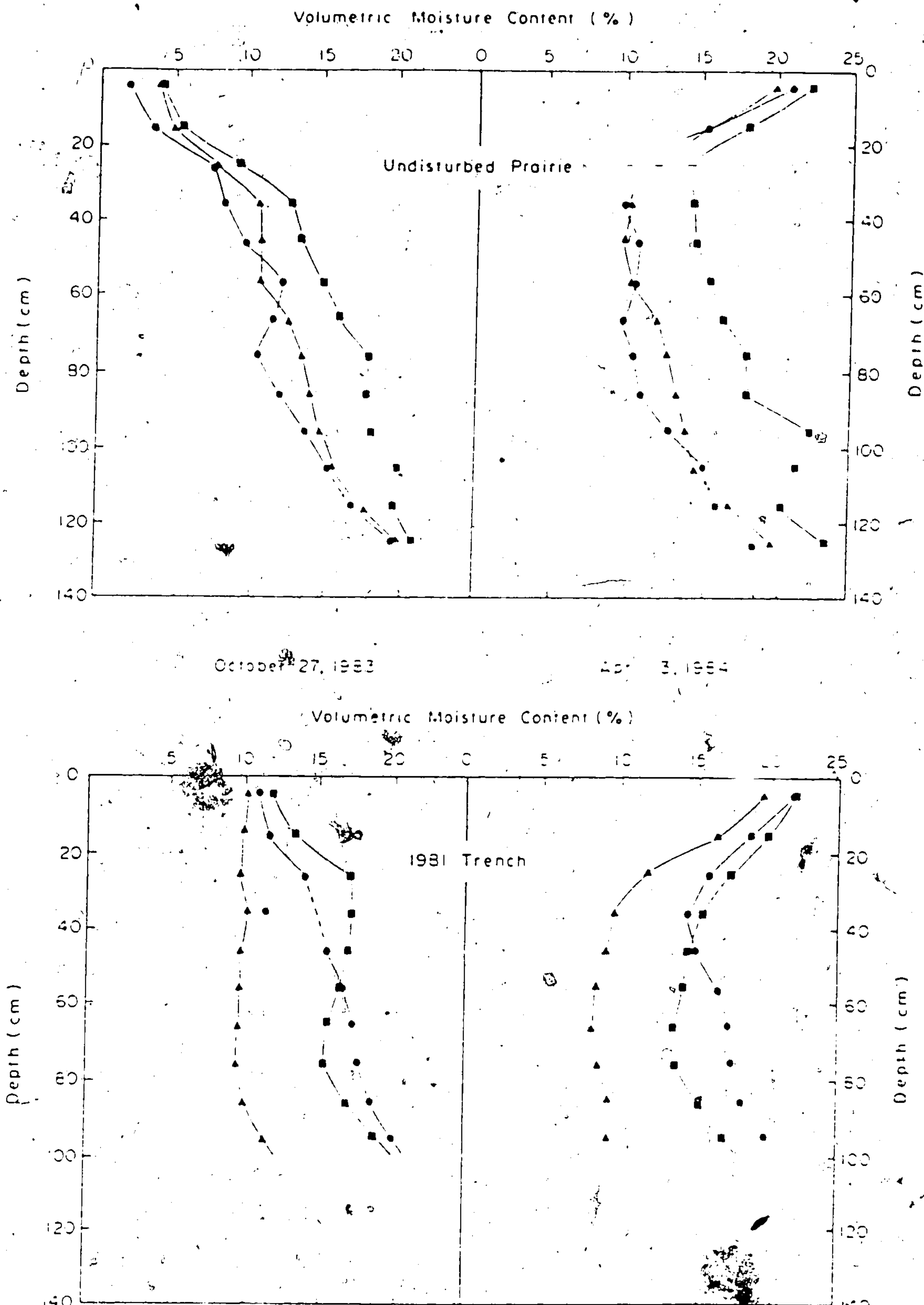

Figure 4.15. Profile moisture in the undisturbed prairie and the 1981 trench, autumn 1983 and spring 1984.

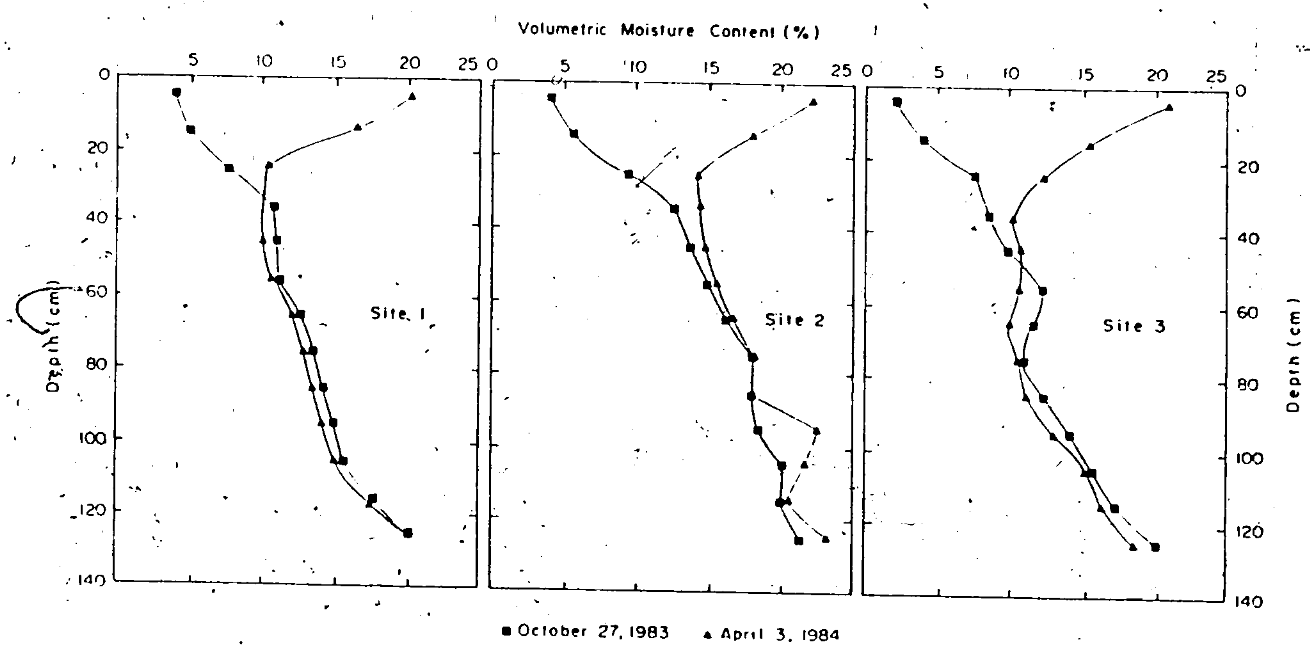

Figure 4.16. Overwinter profile moisture in the undisturbed prairie (site 2).

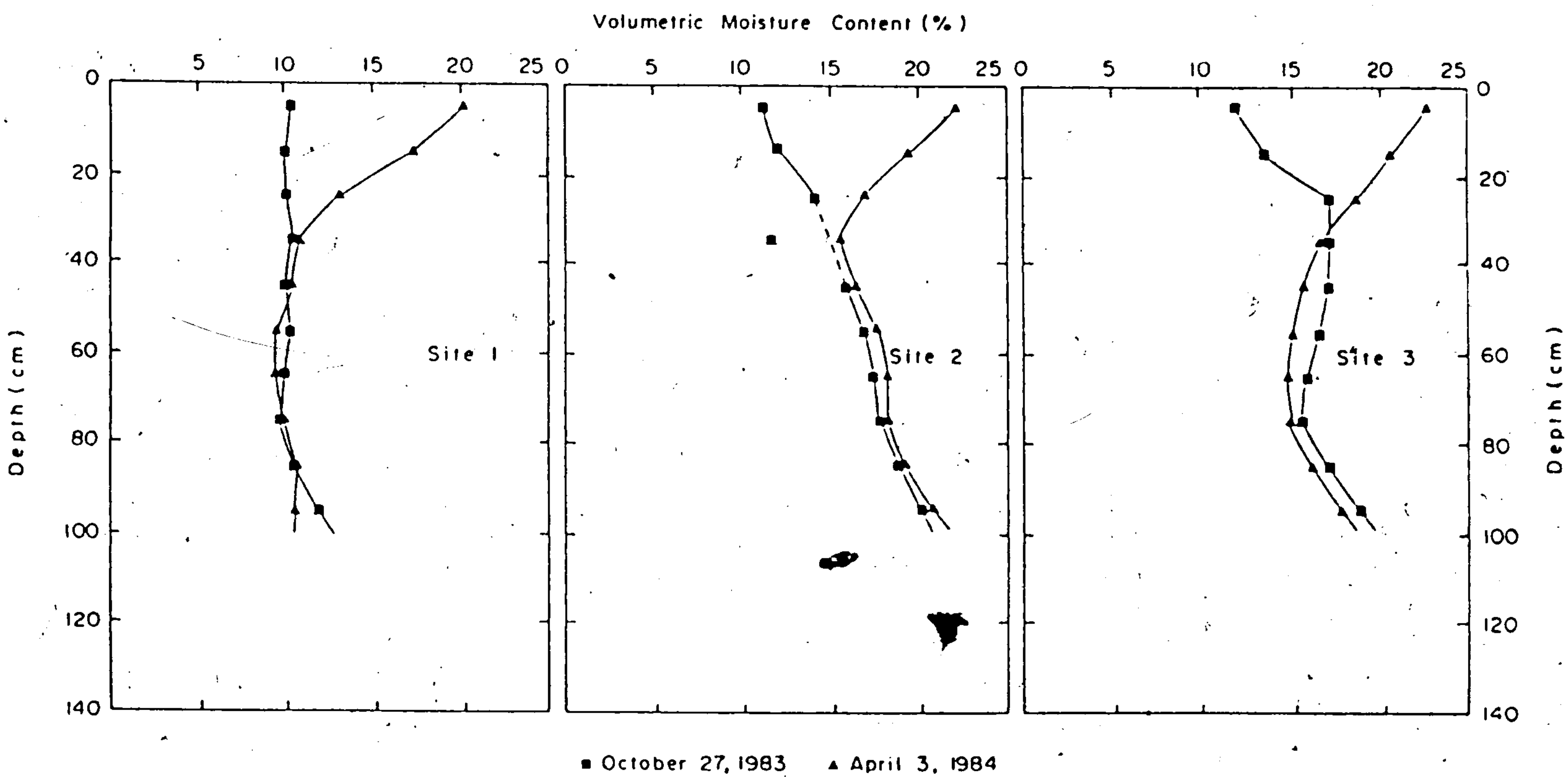

Figure 4.17. Overwinter profile moisture in the 1981 trench (site 2).

Temperature

Temperatures at depths of 5 and 15 cm varied with site and transect (Figures 4.18 and 4.19). Soil temperatures on January 25, 1983 at 5 and 15 cm depths were between -5 and -15 °C in sites 1 and 2. Site 3 displayed a different temperature distribution, showing opposite gradients for the 1981 trench and the pipelay transect. No trends were evident among transects for a given site.

On July 25, soil temperatures at 5 cm were between 25 and 29°C, except for the pipelay transect where temperatures were 33 to 35°C at sites 1 and 2 (Figure 4.18). Temperatures at 15 cm were generally 3°C lower than those at a depth of 5 cm. The highest temperatures at both depths on this date were found in the pipelay transect and the lowest in the undisturbed prairie (Figure 4.18).

In transects of the 1981 r-o-w, the 1957 trench and the undisturbed prairie, temperatures varied with depth (Figures 4.20a and 4.20b), increasing in January and decreasing in July. Temperatures varied little among transects, with the exception of the 1981 trench in January when temperature was approximately 6°C higher than that of any other transect at a depth of 110 cm. At this time of year, temperatures were consistently highest in the 1981 trench at depths between 30 and 110 cm (Figure 4.21a). Daily temperature fluctuations at a depth of 5 cm followed a similar trend for both the undisturbed and 1981 trench transects (Figures 4.21a and 4.21b). At 110 cm, temperature in the undisturbed prairie fluctuated less with time than that in the 1981 trench. The temperature at 110 cm in the 1981 trench was higher in winter and lower in summer than that of the undisturbed prairie. Temperatures at a depth of 5 cm followed a similar trend to that of mean air temperature in winter and that of maximum air temperature in summer.

At depths of 60 and 110 cm, the temperature in the 1981 trench, compared to that of the undisturbed prairie, was higher in winter (maximum 2.8°C at a depth of 60 cm in January and 7.3°C at a depth of 110 cm in December) but lower in summer (maximum 1.4°C at a depth of 60 cm and 1.9°C at a depth of 110 cm, both in August) (Table 4.5).

Table 4.5. Profile soil temperature (°C) between the 1981 trench and the undisturbed prairie on the 25th of each month, site 2.

Date	Depth 60 cm	Depth 110 cm
October 1982	+0.6	+3.2
November 1982	+1.2	+5.8
December 1982	+2.1	+7.3
January 1983	+2.8	+6.3
February 1983	+0.9	+5.0
March 1983	+0.8	+2.9
April 1983	+1.4	+1.8
May 1983	+0.7	+0.2
June 1983	+0.1	-0.3
July 1983	-0.3	-1.6
August 1983	-1.4	-1.9

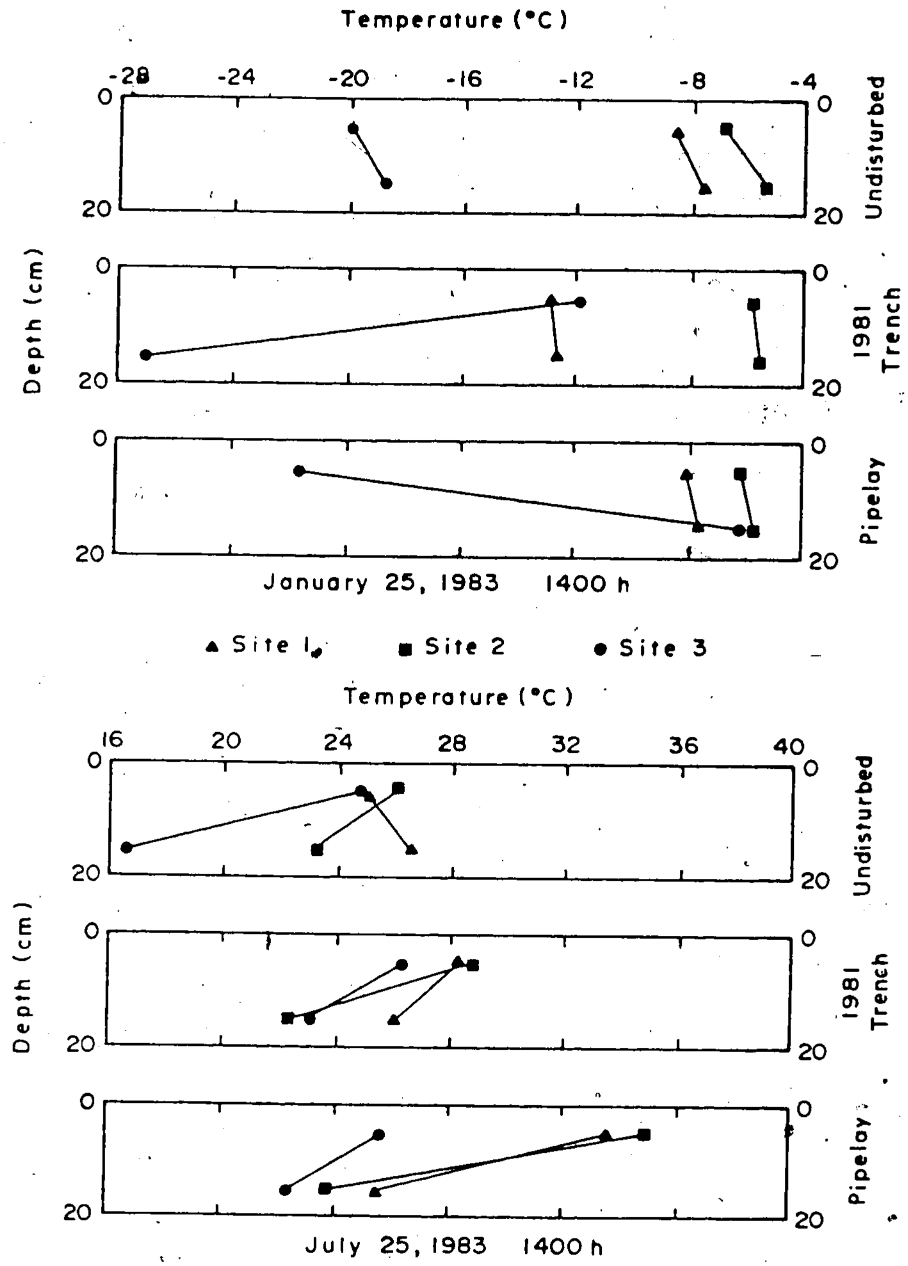

Figure 4.18. Profile temperature among sites, January and July 1983.

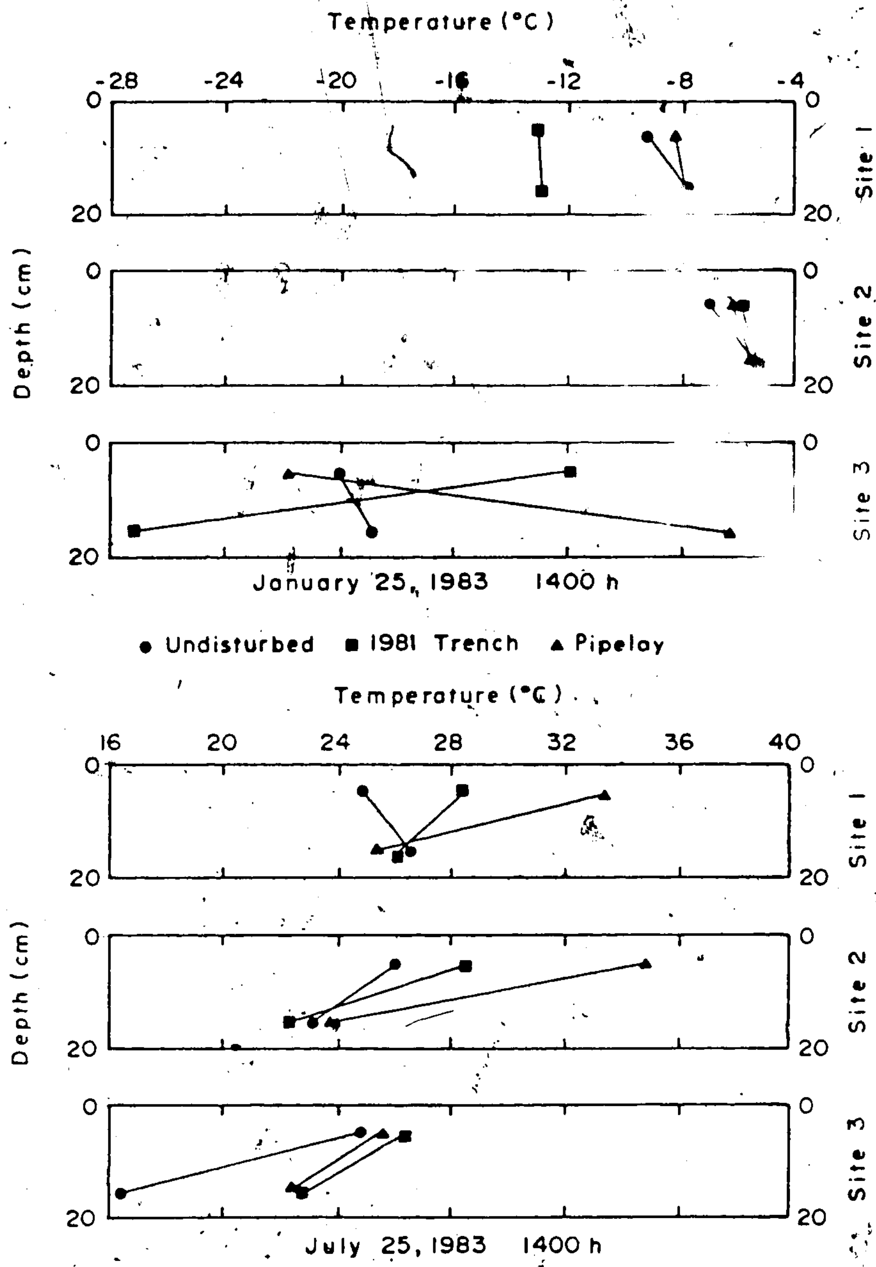

Figure 4.19. Profile temperature among transects, January and July 1983.

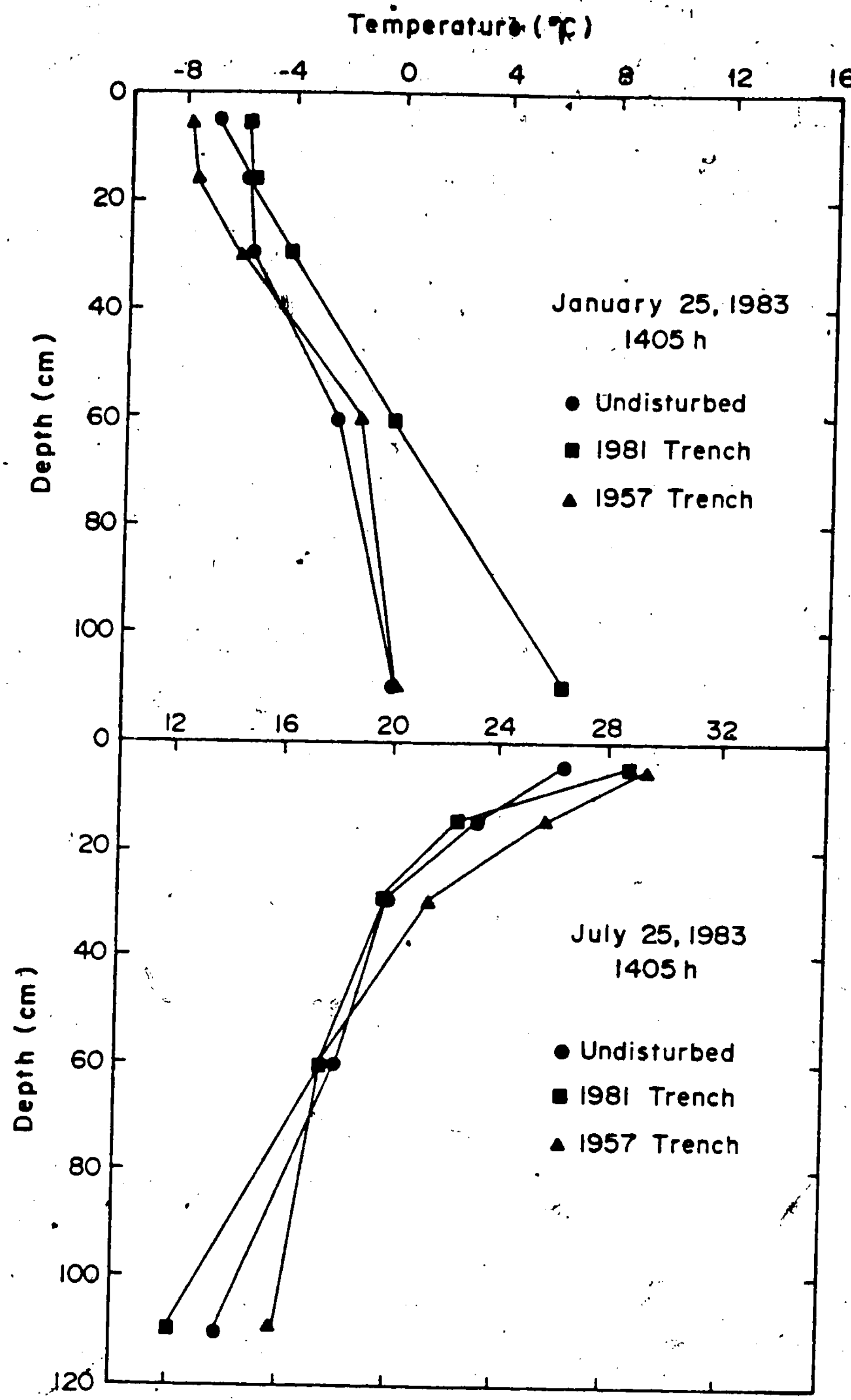

Figure 4.20a. Profile temperature in the 1981 trench, 1957 trench and undisturbed prairie, January and July 1983 (site 2).

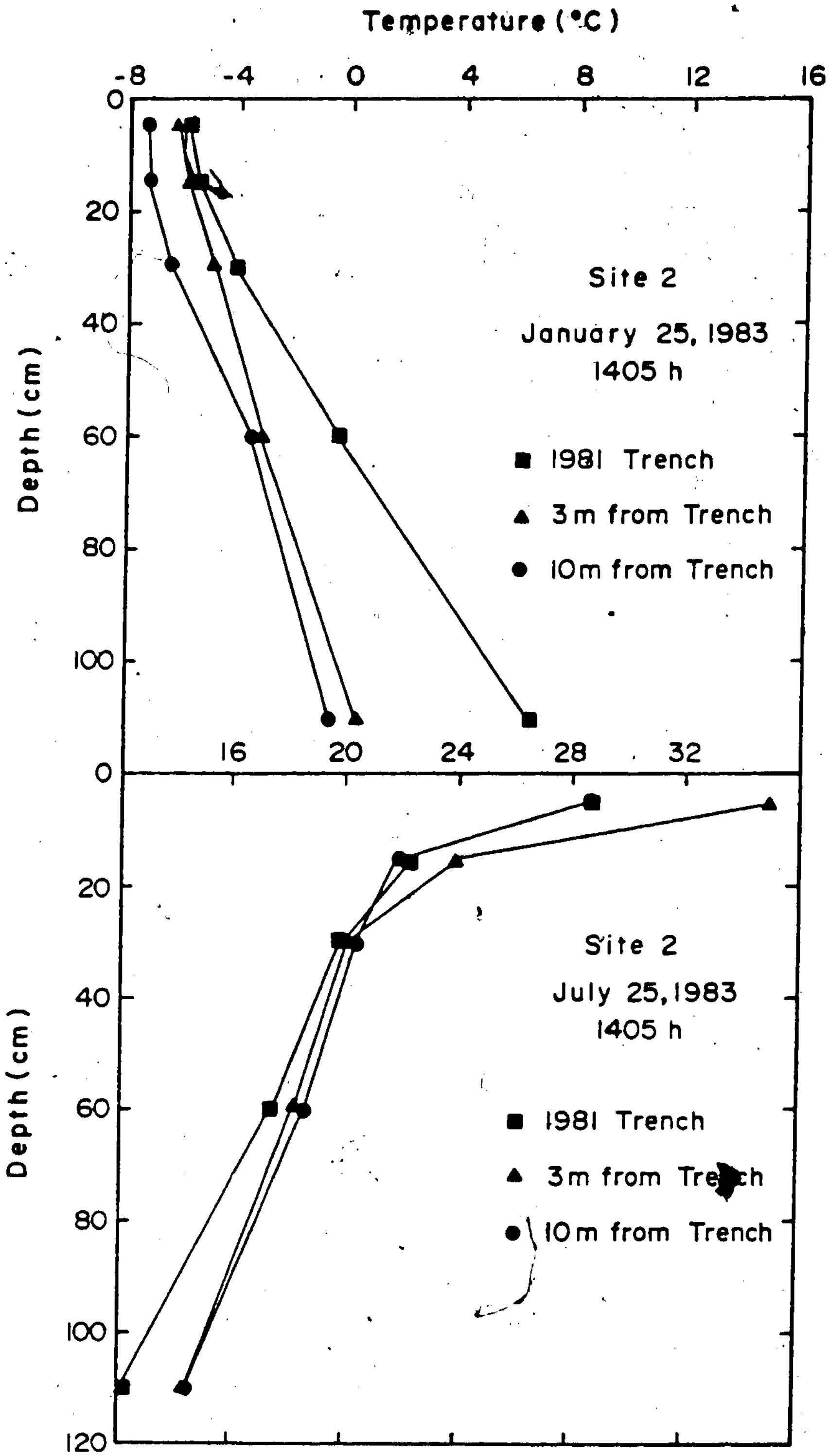

Figure 4.20b. Profile temperature in the 1981 right-of-way, January and July 1983 (site 2).

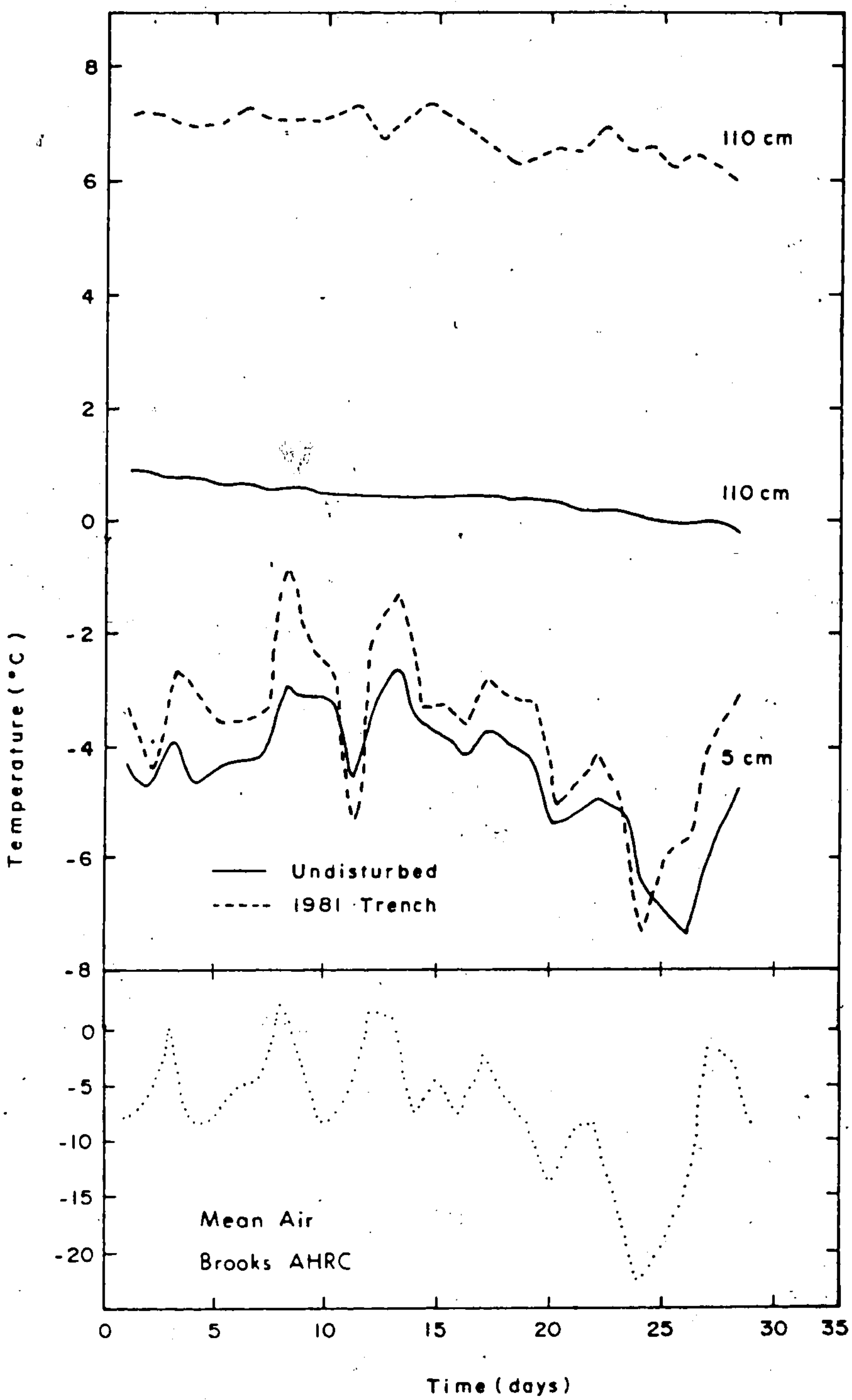

Figure 4.21a. Daily temperature at depths of 5 and 110 cm in the 1981 trench and the undisturbed prairie, January 1983 (site 2).

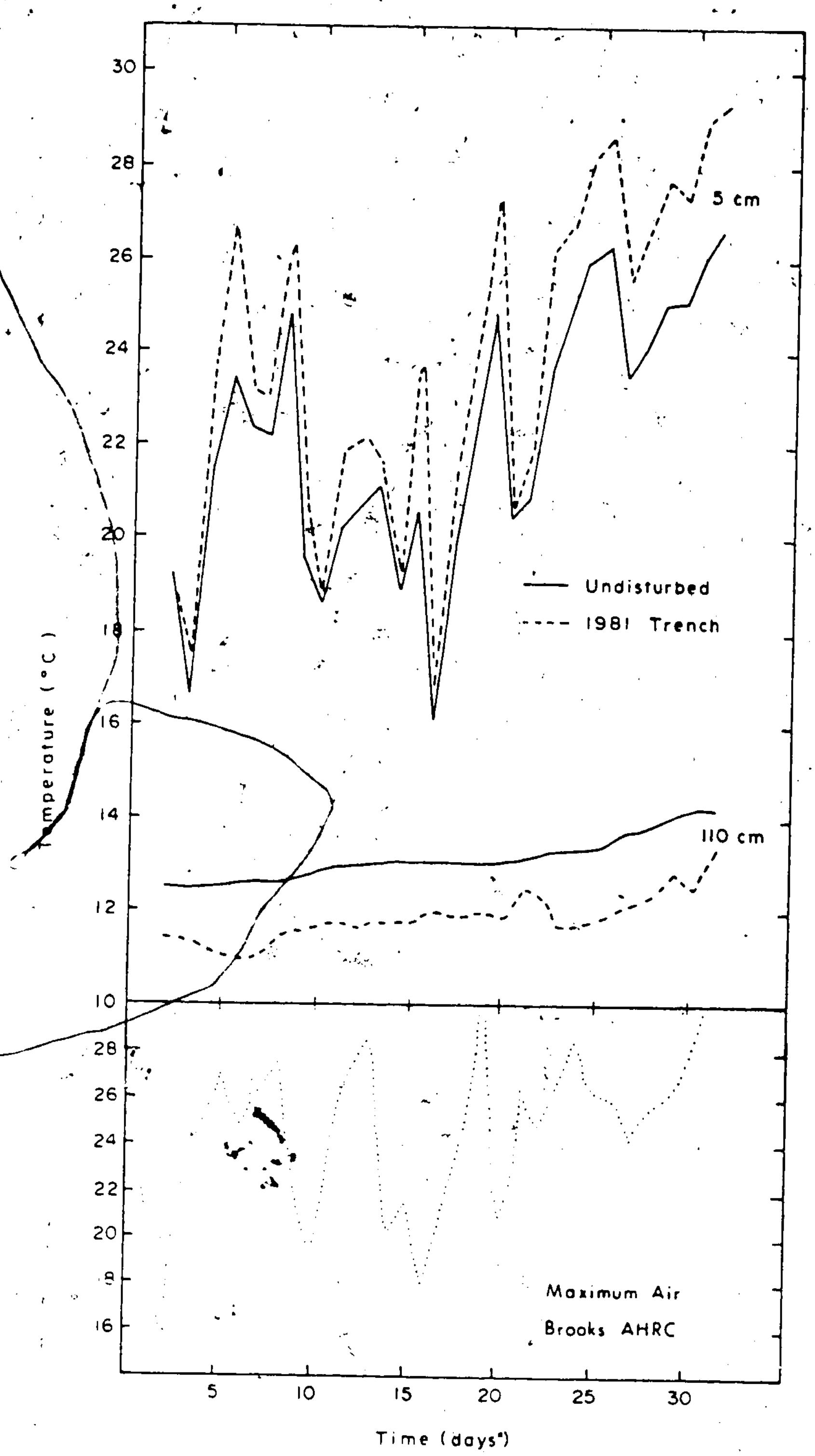

Figure 4.21b. Daily temperature at depths of 5 and 110 cm in the 1981 trench and the undisturbed prairie, July 1983 (site 2).

SOIL CHEMICAL PROPERTIES

Duagh Soil Samples

Standing time of the Duagh saturation pastes influenced the anion and cation values, as well as the EC of the saturation extracts (Table 4.6). All values were highest after standing times of 20 to 24 hours. Values for these times were not significantly different from each other except for HCO_3, where a standing time of 24 hours increased ion concentration 23% over that of 20 hours. For all properties, values were lowest after a 12 hour standing time, often decreasing significantly from 4 and 8 hour standing times. For most properties, the 16 hour standing time yielded values lower than 20 or 24 hour times but the differences were often not significant, with the exception of HCO_3. The data were compared with those of Alzubaidi and Webster (1982), who used the same soil for their study. All ion concentrations compared favourably, with the exception of HCO_3, which tended to have lower values than those obtained by Alzubaidi and Webster. Optimum standing time for saturation pastes, based on the above data, was determined as 20 to 24 hours.

Organic Carbon

All disturbed transects had significantly lower percent organic carbon than did the undisturbed prairie (Figure 4.22). Organic carbon contents in the undisturbed prairie were over 6.5 times higher than those in the 1981 trench, which were lower than in any other transect. Between trench transects had 0.1 to over 2 times as much organic carbon as did the trench transects. The undisturbed prairie had 2 and 3 times as much organic carbon as the between trench transects of the 1981 and older r-o-w respectively. The 1957 trench had significantly higher organic carbon than did the 1981 trench but 2.5 times less than the undisturbed prairie. Organic matter contents of the 1963, 1968 and 1972 trenches did not differ significantly but had less than 1/4 the organic carbon of the undisturbed prairie. Values did not differ significantly

Table 4.6. **Soluble ions in a Duagh Ap horizon.**

Time of standing for saturation paste (hours)	Ca^{++}	Mg^{++}	K^{+}	Na^{+}	HCO_3^{-}	SO_4^{--}
	mmol/L					
4	0.8	1.5	0.5	35.4	2.0	10.8
4	0.7	1.5	0.5	34.4	2.4	10.6
4	0.8	1.5	0.5	35.9	2.4	10.7
4	0.7	1.4	0.4	34.4	2.7	9.9
4	0.7	1.5	0.5	34.4	2.1	10.2
8	0.8	1.5	0.4	35.9	2.9	10.6
8	0.8	1.7	0.4	37.4	3.0	11.8
8	0.8	1.6	0.4	33.0	2.7	10.6
8	0.8	1.6	0.4	33.5	2.6	10.6
8	0.7	1.9	0.4	33.0	2.7	10.2
12	0.6	1.3	0.4	35.0	2.5	10.0
12	0.6	1.9	0.4	35.4	2.1	10.0
12	0.6	1.2	0.4	30.7	2.6	8.7
12	0.6	1.3	0.4	34.4	2.9	9.4
12	0.6	1.3	0.4	34.4	2.6	9.7
16	0.7	1.4	0.4	32.5	3.3	9.0
16	0.7	1.4	0.4	32.5	3.4	8.9
16	0.9	1.7	0.5	36.4	3.9	10.4
16	0.9	1.7	0.4	34.4	3.6	10.0
16	0.9	1.6	0.4	34.4	3.4	10.0
20	1.0	1.7	0.4	35.0	4.1	10.0
20	1.0	1.7	0.5	35.9	4.6	10.4
20	0.9	1.8	0.5	34.4	4.6	10.1
20	1.0	1.7	0.4	35.9	4.4	10.5
20	0.9	1.7	0.4	35.0	4.2	10.2
24	0.6	1.9	0.4	35.0	4.9	9.2
24	0.7	1.4	0.4	37.4	5.4	9.6
24	0.8	1.6	0.4	37.4	5.8	10.1
24	1.0	1.7	0.5	34.4	5.1	9.6
24	1.0	1.9	0.5	37.4	5.9	10.5

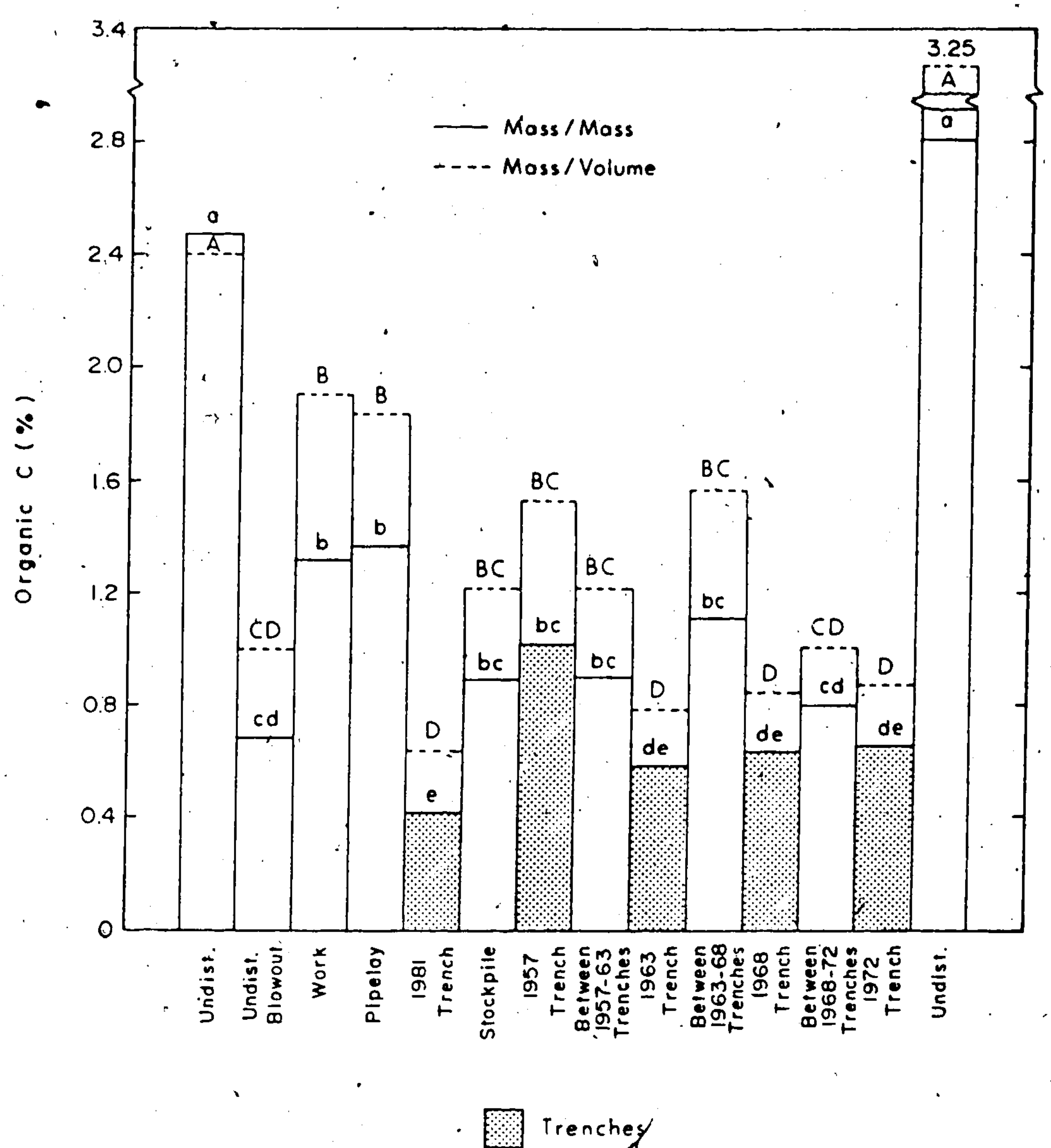

Figure 4.22. Surface (0 - 7.6 cm) organic carbon (site 2). Same letters denote no significant difference among transects.

among sites.

If organic carbon is evaluated on a mass basis, the bulk density differences in the transects partially reduce differences in mass of carbon between the transects (Figure 4.22). On a mass basis, organic carbon content of the undisturbed prairie was 4.4 times that of the 1981 trench transect, 1.8 that of the 1957 trench and 3.3 times that of the other older trenches. The between line transects had more organic carbon than did the trenches. The undisturbed prairie had 2.2 times the organic carbon of the older r-o-w and 1.7 times that of the 1981 r-o-w.

Hydrogen Ion Activity

Hydrogen ion activity decreased steadily with depth in the undisturbed prairie (Figure 4.23). In the disturbed transects pH was relatively uniform with depth (Figure 4.24). There were no significant differences among transects or sites for a given depth increment.

Electrical Conductivity

In all transects, electrical conductivities tended to increase at depths greater than 15 cm (Figures 4.25 and 4.26). This increase was least pronounced in the undisturbed prairie and most pronounced in the 1981 r-o-w. Electrical conductivities to a depth of 45 cm were consistently highest in the 1981 trench. In sites 1 versus 3 and 2 versus 3 electrical conductivities for given transects were not significantly different but values for transects in site 1 were significantly different from those in site 2.

Ion Concentration

Soluble ion concentrations (meq/L) were checked using the following formula: the sum of the cations minus the sum of the anions divided by the sum of the cations plus the sum of the anions. Eighty-four percent of the data fell within an acceptable 10% range. Of the data that exceeded this range, 86% were between 10 and 15% while 14% were between 15 and 20%. Nitrate concentration was determined in several samples that had high cation sums. Of these

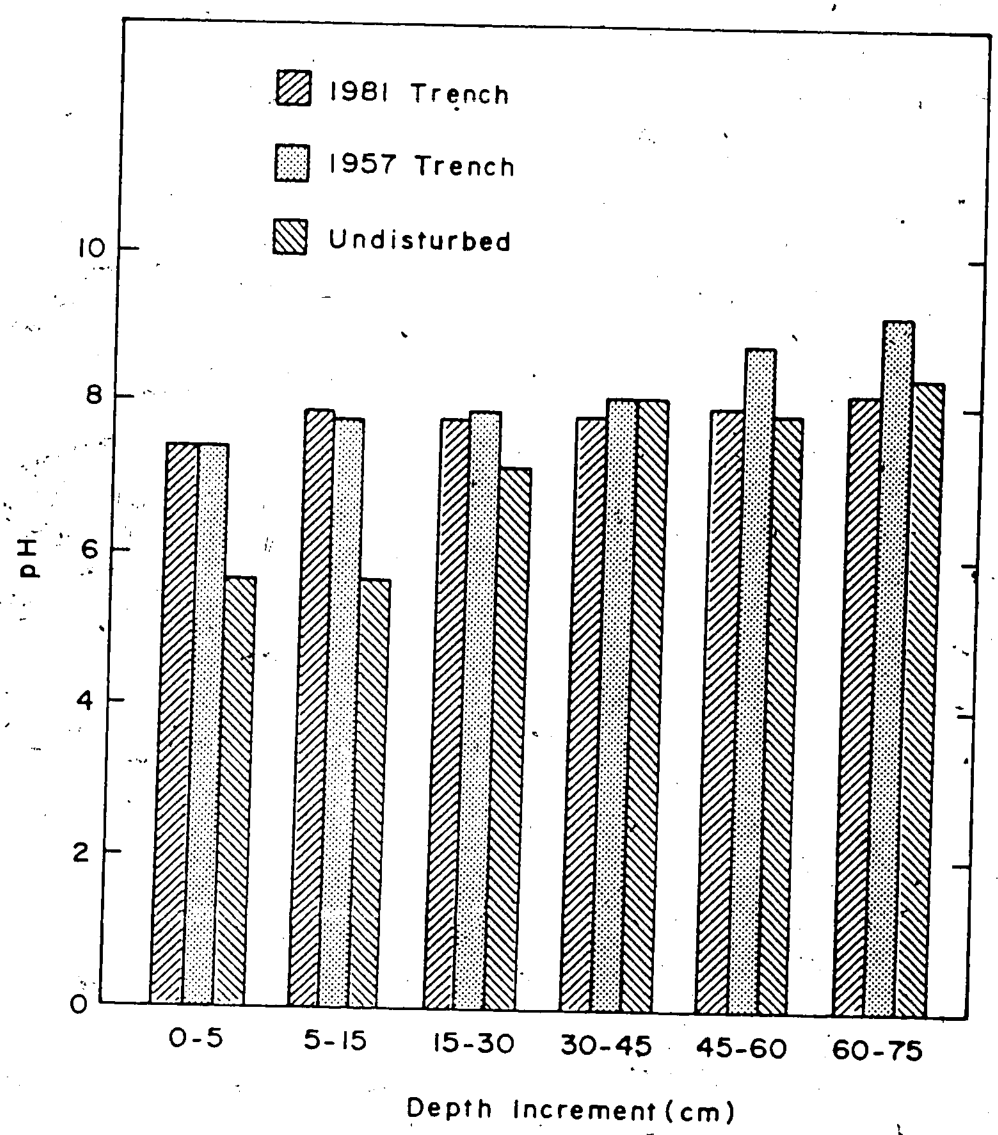

Figure 4.23. Profile pH (site 2). There were no significant differences among transects for a given depth increment.

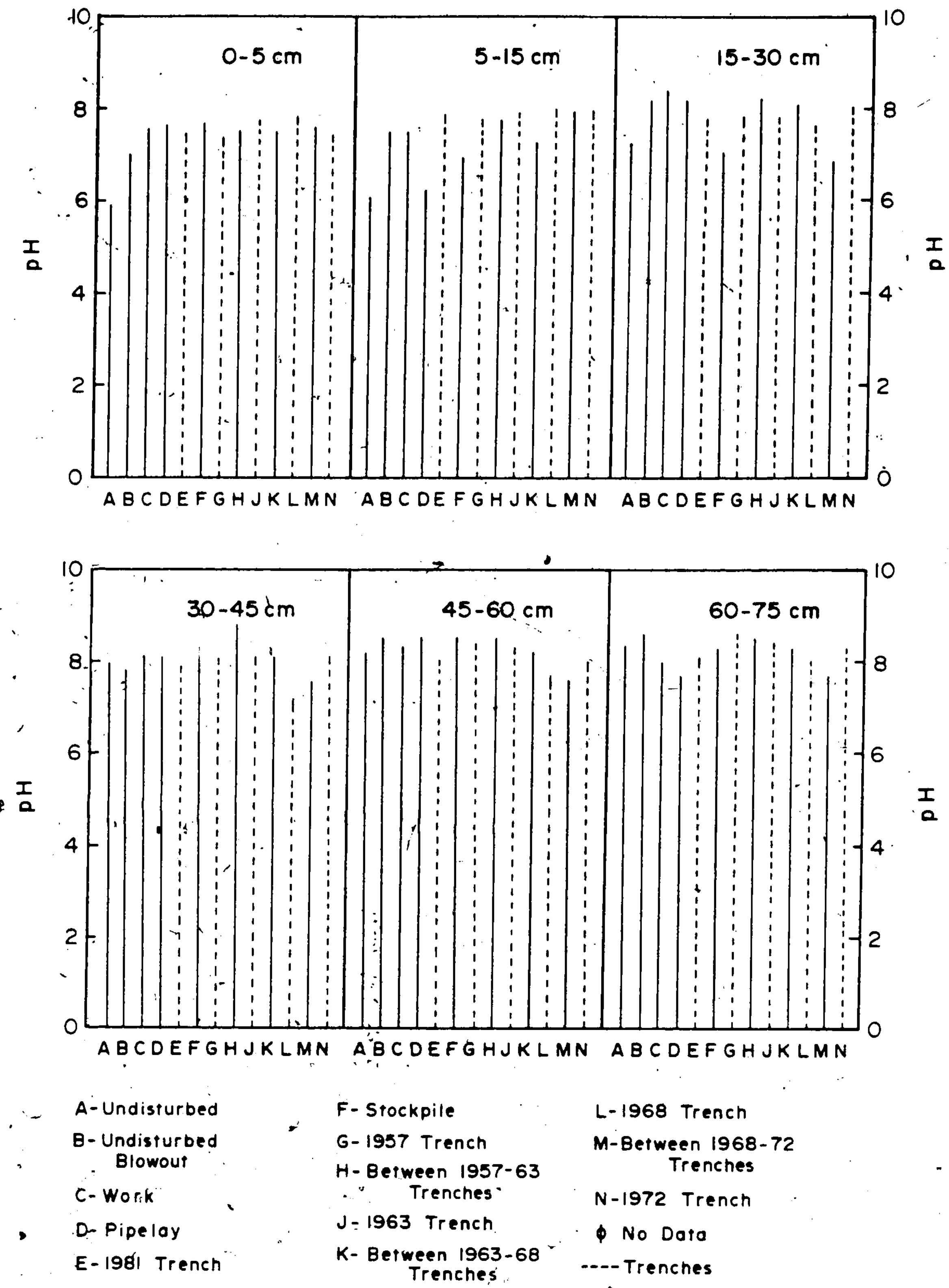

Figure 4.24. Profile pH among transects (site 2).

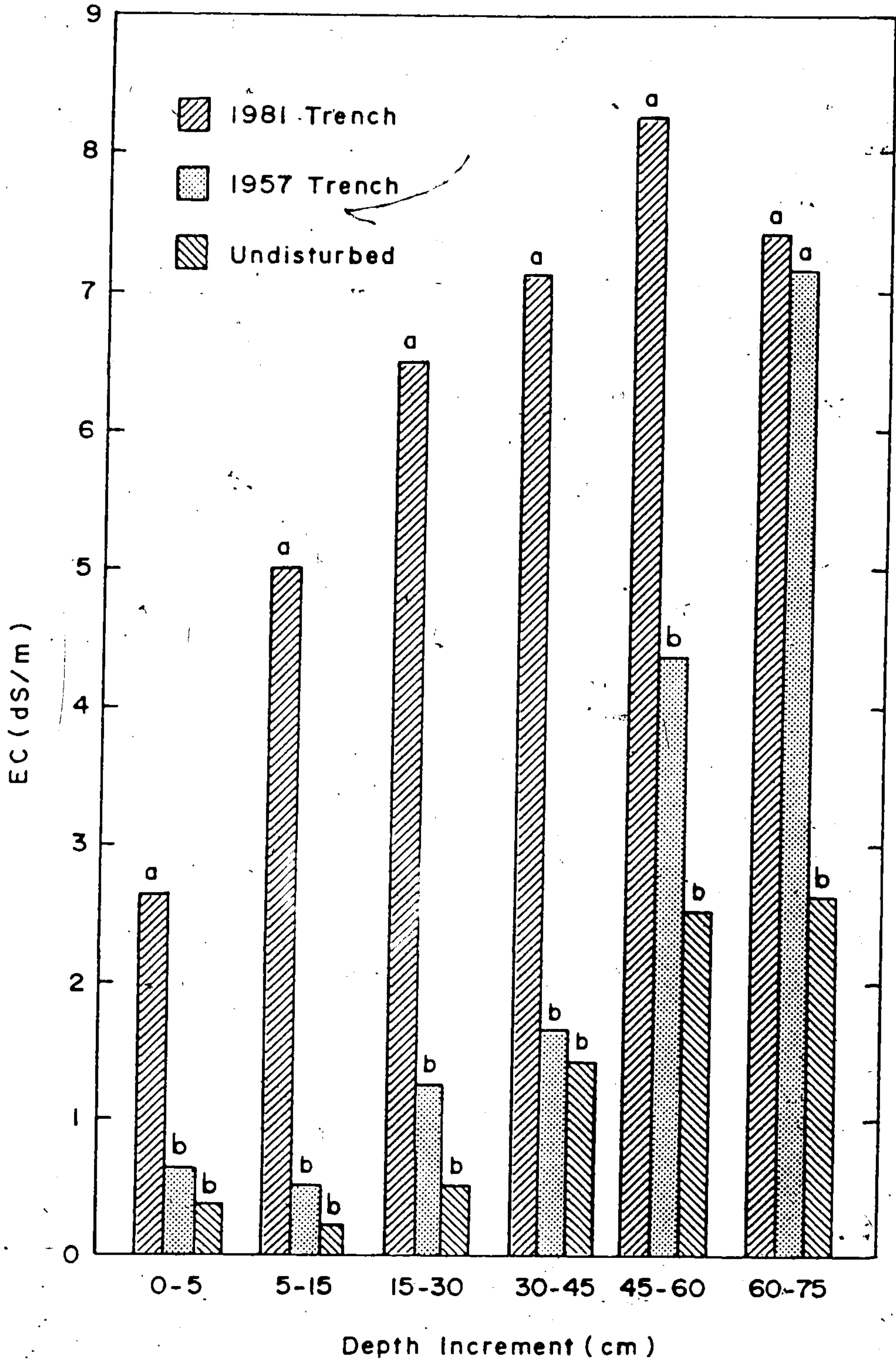

Figure 4.25. Profile electrical conductivity (site 2). Same letters denote no significant difference among transects for a given depth increment.

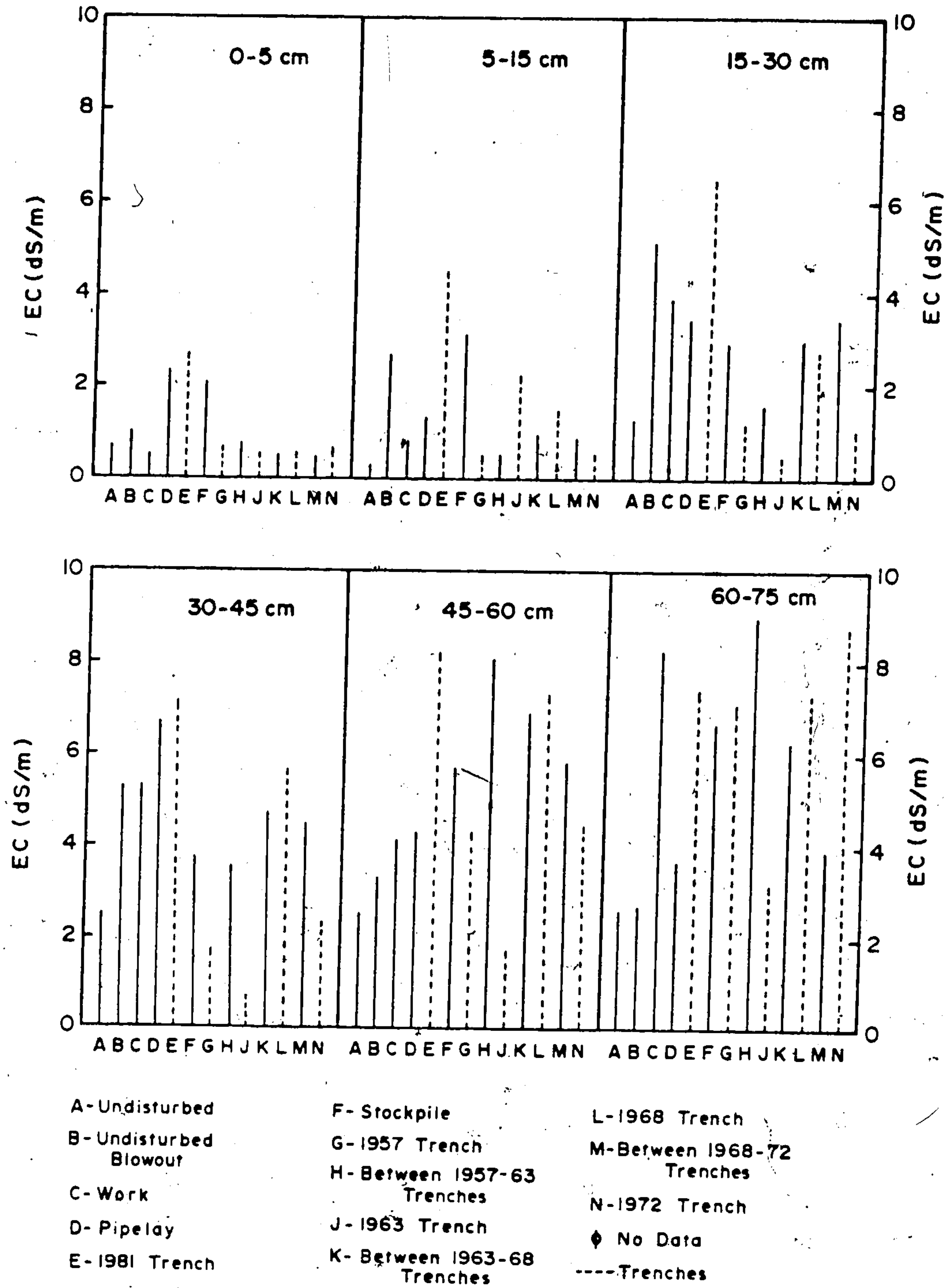

Figure 4.26. Profile electrical conductivity among transects (site 2).

samples, 88% had nitrates ranging in concentration from 0.02 to 2.84 mmol/L. Several samples that did not have nitrates had very low HCO_3^- or SO_4^{--} concentrations. Samples that had high anion sums had very high sulfate concentrations.

Sites 1, 2 and 3 had similar trends in ion concentration with depth for a given transect (data not shown). Individual ion concentrations for a given depth in sites 1 and 3 were not significantly different for a given transect, whereas those in site 2 often differed significantly from those in sites 1 and 3 except for sulfate.

In the undisturbed prairie, ion concentrations tended to increase with depth (Tables 4.7 and 4.8). These changes were least pronounced for potassium. Bicarbonates peaked at 30 to 45 cm, then decreased thereafter. All ions except sodium and magnesium had higher concentrations in the surface 5 cm than in the 5 to 30 cm depth interval. Ion concentration for the undisturbed blowout transects followed a similar trend, with a tendency to decrease slightly at depths greater than 60 cm. For all ions, concentration varied little with depth in the 1981 trench.

Calcium concentrations were higher in all disturbed transects at all depths (Tables 4.9 to 4.19). In the 1981 trench transect, Ca^{++} concentration increased from 1 to 22 times that of the undisturbed. Concentrations in the 1981 trench were higher than in all other transects except the 1963 and 1972 trenches. The Ca^{++} concentration in the older trench transects was generally less than 5 times that of the undisturbed prairie. The 1972 trench values were not significantly different from those of the 1963 and 1968 trenches and the 1968 trench values were only significantly different from those of the undisturbed prairie.

Magnesium, potassium and sodium concentrations among disturbed transects tended to follow trends similar to those of calcium. In the 1981 trench, Mg^{++} concentrations increased 4 to 27 times that of the undisturbed prairie. Potassium concentration doubled and sodium increased by 2 to 52 times. These increases were most pronounced at lower depths. Sodium concentration tended to decrease in transects in the older r-o-w more so than did potassium or magnesium. Magnesium concentration in the 1981 trench was significantly higher than values in

Table 4.7. **Soluble ions in undisturbed prairie in site 2.**

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^-	SO_4^{--}
0-5	0.8(0.3)[1]	0.5(0.2)	0.6(0.2)	0.4(0.1)	2.2(0.9)	0.4(0.1)
5-15	0.6(0.2)	0.3(0.2)	0.1(0.1)	0.8(0.5)	1.3(0.5)	0.2(0.2)
15-30	0.9(0.8)	0.4(0.4)	0.2(0.1)	0.9(0.7)	3.1(1.2)	0.6(0.6)
30-45	1.0(0.4)	0.8(0.7)	0.2(0.1)	12.7(15.7)	5.3(2.3)	4.2(6.0)
45-60	3.2(5.5)	2.8(5.3)	0.3(0.2)	20.9(30.0)	4.0(2.6)	11.5(24.3)
60+	3.1(5.0)	2.2(3.4)	0.3(0.1)	21.9(34.0)	3.5(0.9)	12.5(24.2)

Table 4.8. **Soluble ions in undisturbed prairie blowouts in site 2.**

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^-	SO_4^{--}
0-5	0.8(0.5)	0.7(0.3)	0.3(0.2)	13.5(8.3)	2.3(2.0)	5.2(6.1)
5-15	2.4(1.8)	2.8(2.9)	0.3(0.3)	23.3(14.2)	5.4(3.4)	14.6(19.0)
15-30	7.2(6.0)	11.9(10.0)	0.6(0.4)	47.5(24.0)	6.4(2.3)	28.0(25.6)
30-45	7.5(5.1)	5.7(4.3)	0.7(0.6)	59.1(21.8)	4.4(1.5)	32.9(20.3)
45-60	4.1(4.8)	3.4(3.6)	0.7(0.5)	40.5(21.2)	4.6(1.2)	23.0(20.8)

Table 4.9. **Soluble ions in 1981 work transect in site 2.**

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^-	SO_4^{--}
0-5	0.5(0.3)	0.6(0.2)	0.2(0.2)	3.6(1.5)	2.9(1.0)	0.7(0.1)
5-15	1.0(0.3)	0.6(0.4)	0.1(0.0)	8.6(6.0)	7.6(3.3)	1.1(0.4)
15-30	3.3(4.8)	4.0(7.0)	0.3(0.2)	41.0(44.6)	6.1(1.1)	23.5(23.9)
30-45	7.1(6.1)	3.9(2.3)	0.5(0.2)	41.9(21.8)	4.3(0.9)	28.3(15.6)
45-60	7.8(6.7)	4.7(5.8)	0.4(0.3)	30.6(7.5)	4.4(1.8)	20.8(16.8)
60+	10.3(0.0)	12.8(0.0)	0.6(0.0)	58.9(0.0)	2.1(0.0)	48.5(0.0)

[1]Numbers in parentheses are standard deviations preceded by mean values (n=5)(Tables 4.7 to 4.19, inclusive).

Table 4.10. Soluble ions in 1981 pipelay transect in site 2.

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^-	$SO_4^{=}$
0-5	3.8(4.4)	3.3(5.5)	0.6(0.4)	16.8(29.7)	4.1(0.4)	9.5(19.5)
5-15	1.4(1.6)	1.4(2.3)	0.2(0.1)	10.6(18.4)	2.7(1.9)	5.8(11.7)
15-30	5.0(4.7)	3.4(5.2)	0.6(0.8)	34.6(35.3)	6.3(2.5)	18.6(24.0)
30-45	9.0(4.8)	5.7(4.7)	0.5(0.1)	58.1(23.6)	3.6(0.7)	39.5(16.7)
45-60	3.7(4.0)	3.9(2.7)	0.5(0.1)	48.2(18.8	4.4(1.9)	24.9(15.3)
60+	4.5(3.7)	4.7(4.8)	0.5(0.3)	28.1(38.8)	3.1(0.7)	18,4(24.1)

Table 4.11. Soluble ions in 1981 trench transect in site 2.

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^-	$SO_4^{=}$
0-5	6.2(5.0)	2.1(2.0)	0.5(0.2)	15.3(17.1)	2.8(1.9)	15.0(15.1)
5-15	12.9(1.3)	8.0(1.1)	0.6(0.9)	37.8(20.5)	2.2(0.4)	49.6(10.7)
15-30	11.5(1.1)	7.8(2.4)	0.6(0.1)	47.0(23.0)	2.4(0.2)	40.3(10.4)
30-45	11.1(0.8)	9.2(1.1)	0.6(0.1)	54.9(15.1)	2.4(0.2)	44.6(8.5)
45-60	11.0(0.8)	9.5(0.9)	0.6(0.1)	65.6(11.9)	2.5(0.2)	44.3(8.7)
60+	8.5(5.3)	8.1(1.4)	0.6(0.1)	47.3(33.5)	2.3(0.4)	39.0(14.2)

Table 4.12. Soluble ions in 1981 stockpile transect in site 2.

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^-	$SO_4^{=}$
0-5	6.2(6.1)	2.5(2.0)	0.5(0.2)	13.0(13.2)	1.2(1.1)	12.4(7.9)
5-15	6.8(6.0)	4.3(3.4)	0.5(0.1)	20.3(16.3)	3.2(1.7)	20.7(12.8)
15-30	2.7(2.6)	2.4(2.9)	0.3(0.1)	22.4(13.2)	3.3(2.5)	12.0(10.1)
30-45	2.6(4.1)	3.1(4.8)	0.2(0.1)	35.9(27.3)	6.7(3.0)	16.5(21.3)
45-60	4.3(5.2)	5.7(4.6)	0.5(0.4)	43.6(25.9)	2.5(1.8)	29.2(22.9)
60+	4.6(4.2)	2.7(2.1)	0.6(0.3)	57.5(29.5)	5.0(0.1)	32.3(23.3)

Table 4.13. Soluble ions in 1957 trench transect in site 2.

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^-	SO_4^{--}
0-5	2.4(0.7)	1.0(0.3)	0.7(0.3)	0.5(0.2)	7.4(2.1)	0.3(0.2)
5-15	2.2(0.9)	0.8(0.2)	0.5(0.2)	0.6(0.2)	3.5(1.2)	1.7(2.8)
15-30	4.8(4.0)	1.5(1.2)	0.3(0.2)	3.1(2.3)	3.4(1.4)	5.3(6.8)
30-45	2.0(1.7)	1.3(0.9)	0.2(0.1)	13.0(11.7)	4.9(1.9)	6.2(4.7)
45-60	3.9(4.2)	3.6(3.2)	0.4(0.3)	35.0(30.8)	3.6(0.7)	20.9(21.1)
60+	3.7(3.4)	3.4(4.0)	0.4(0.3)	47.4(39.7)	3.4(0.5)	27.2(24.1)

Table 4.14. Soluble ions in between 1957-1963 trenches transect in site 2.

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^-	SO_4^{--}
0-5	2.2(0.5)	1.1(0.3)	0.8(0.2)	1.8(2.9)	7.1(1.6)	0.3(0.1)
5-15	1.3(0.6)	0.7(0.4)	0.2(0.1)	1.9(0.7)	5.2(1.9)	0.6(0.5)
15-30	1.0(0.5)	0.6(0.5)	0.1(0.0)	16.8(15.6)	5.1(2.3)	1.4(1.8)
30-45	1.8(2.0)	2.2(2.7)	0.2(0.1)	35.6(32.5)	6.4(1.8)	16.1(19.1)
45-60	3.3(4.9)	5.0(5.5)	0.3(0.3)	57.0(53.9)	3.4(2.6)	31.7(33.5)
60+	6.1(4.0)	6.8(5.2)	0.5(0.4)	81.1(53.4)	4.8(2.4)	46.0(29.9)

Table 4.15. Soluble ions in 1963 trench transect in site 2.

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^-	SO_4^{--}
0-5	2.5(1.3)	0.9(0.1)	0.9(0.4)	0.2(0.1)	5.6(0.5)	0.9(1.0)
5-15	3.5(4.4)	2.7(4.5)	0.7(0.5)	9.3(19.1)	3.3(0.4)	8.0(17.3)
15-30	1.5(0.8)	0.5(0.2)	0.3(0.1)	1.8(1.3)	3.5(0.6)	0.8(0.8)
30-45	2.9(3.2)	0.6(0.4)	0.2(0.1)	4.8(2.2)	3.8(0.9)	1.6(1.3)
45-60	4.4(5.7)	2.1(2.4)	0.3(0.2)	9.5(7.8)	3.8(1.4)	8.1(9.6)
60+	4.6(5.7)	3.9(4.1)	0.3(0.5)	22.8(22.8)	3.5(1.1)	16.3(20.8)

Table 4.16. Soluble ions in between 1963-1968 trenches transect in site 2.

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^-	SO_4^{--}
0-5	0.7(0.5)	0.7(0.3)	0.6(0.4)	2.9(2.0)	3.9(1.0)	0.4(0.2)
5-15	1.5(0.4)	0.4(0.2)	0.1(0.0)	9.8(5.7)	6.9(2.9)	1.5(1.3)
15-30	4.0(6.1)	2.5(3.8)	0.2(0.1)	26.5(14.4)	4.2(2.1)	14.2(15.1)
30-45	5.7(6.2)	4.5(4.9)	0.5(0.3)	41.3(18.1)	4.8(1.0)	25.2(19.9)
45-60	6.8(4.4)	5.8(3.5)	1.1(0.5)	51.1(15.1)	3.6(0.4)	34.1(15.7)
60+	6.4(6.4)	6.0(6.3)	0.9(1.0)	50.8(31.3)	5.2(1.0)	30.7(25.6)

Table 4.17. Soluble ions in 1968 trench transect in site 2.

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^-	SO_4^{--}
0-5	1.9(0.7)	0.9(0.1)	1.0(0.6)	0.8(0.5)	4.8(1.5)	0.8(0.9)
5-15	5.9(7.1)	1.6(1.5)	0.7(0.4)	4.7(2.9)	1.5(1.4)	11.2(14.9)
15-30	5.8(5.8)	3.6(3.5)	0.5(0.2)	15.8(11.7)	7.4(1.2)	8.3(6.8)
30-45	6.5(5.3)	7.3(6.3)	0.4(0.2)	50.1(37.6)	7.7(2.3)	32.6(29.6)
45-60	4.3(4.7)	7.6(6.0)	0.6(0.4)	67.7(58.7)	4.8(1.1)	31.5(27.9)
60+	4.5(5.2)	7.2(6.2)	0.7(0.4)	68.2(58.7)	4.5(0.9)	38.4(36.2)

Table 4.18. Soluble ions in between 1968-1972 trenches transect in site 2.

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^-	SO_4^{--}
0-5	1.0(0.5)	0.6(0.3)	0.9(0.3)	1.5(1.2)	4.4(0.3)	0.3(0.1)
5-15	2.5(3.4)	1.0(1.2)	0.5(0.3)	4.8(2.0)	4.4(0.9)	4.1(7.7)
15-30	5.3(6.2)	4.3(5.5)	0.2(0.1)	13.1(13.9)	5.7(3.0)	17.6(23.0)
30-45	4.9(4.5)	6.0(7.3)	0.4(0.3)	40.9(41.7)	4.4(1.5)	25.8(30.9)
45-60	8.5(6.5)	9.6(8.1)	0.6(0.4)	40.9(40.4)	4.0(2.8)	32.6(29.9)
60+	4.6(4.9)	4.1(5.5)	0.7(0.5)	30.5(31.8)	3.4(2.1)	19.6(21.4)

Table 4.19. Soluble ions in 1972 trench in site 2.

Depth (cm)	Ca^{++}	Mg^{++}	K^{+} (mmol/L)	Na^{+}	HCO_3^{-}	$SO_4^{=}$
0-5	2.3(2.7)	1.0(0.9)	0.9(0.4)	0.8(0.7)	3.8(0.4)	2.2(3.7)
5-15	1.7(1.2)	0.8(0.2)	0.6(0.2)	1.8(1.6)	3.2(0.6)	2.0(2.5)
15-30	2.5(2.1)	1.2(1.0)	0.6(0.3)	4.8(3.3)	3.3(0.8)	3.8(3.5)
30-45	6.2(5.3)	2.8(3.2)	0.6(0.4)	16.3(13.6)	3.6(1.1)	12.5(14.4)
45-60	6.6(5.3)	7.3(6.2)	0.7(0.4)	53.8(46.5)	3.5(1.3)	36.1(32.7)
60+	8.3(4.5)	10.4(5.7)	0.9(0.6)	73.8(40.2)	3.0(1.9)	56.0(29.3)

most other transects except the 1963 and 1972 trenches and between the 1963-1968 and 1968-1972 transects. Magnesium values for the 1972 trench were only significantly different from those of the undisturbed prairie. Potassium concentrations did not differ significantly among transects. Sodium concentrations in the 1981 trench were usually significantly higher than in all other transects except the blowout and the 1972 trench transects. Blowouts had values significantly higher than the 1957 and 1963 trenches and the undisturbed prairie.

Sulfate concentrations in the 1981 trench were 3 to 248 times higher than those in the undisturbed prairie, with the largest increase occurring at depths of 5 to 15 cm. Bicarbonate values varied with depth and transect but no discernible pattern was found. To a depth of 15 cm, $SO_4^{=}$ concentrations were higher in trench transects than they were in between trench transects. Sulfate concentrations in the 1981 trench were significantly higher in all but the 1972 trench and the blowout transects. The 1972 trench had values significantly higher than the undisturbed prairie. Bicarbonate values in the 1981 trench were significantly higher than those in all but the 1963 and 1972 trench transects. Sodium sulfate was the dominant salt in the system.

Sodium Adsorption Ratio

Sodium adsorption ratios increased with depth for all transects (Figure 4.27). To a depth of 30 cm, SAR in the 1981 r-o-w was higher than that of the undisturbed prairie. Increases to a depth of 15 cm in the 1981 trench were 9 times those of the undisturbed prairie. At depths greater than 30 cm, SAR in the 1981 trench was lower than that in the undisturbed prairie. Increases in the other transects of the 1981 r-o-w were slightly higher than those in the 1981 trench. The older r-o-w had higher SAR values than the undisturbed prairie but lower values than the 1981 r-o-w to 45 cm. Below 45 cm SAR values were variable, with no discernible trends among transects. Among site differences were not significant.

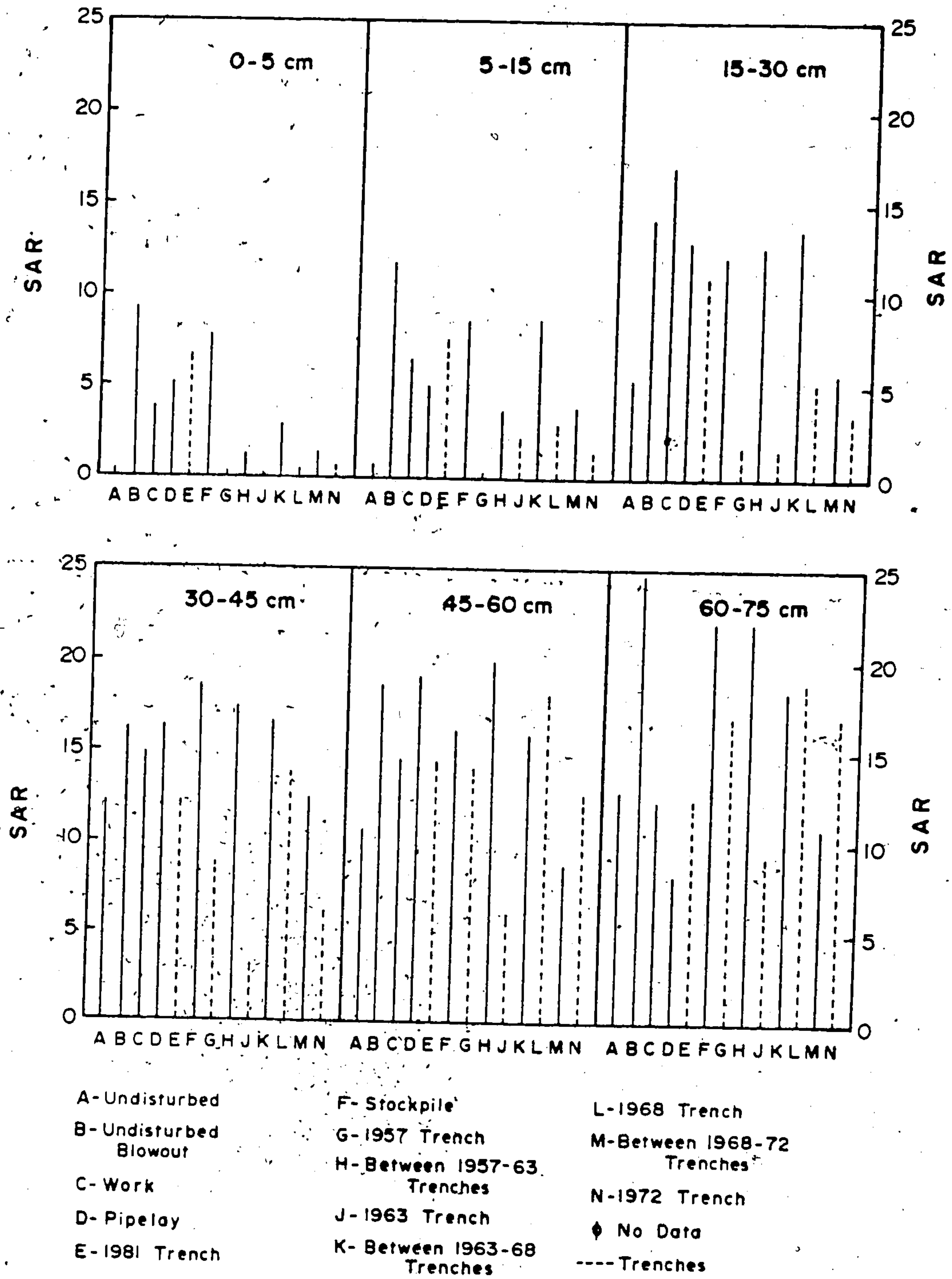

Figure 4.27. Profile sodium adsorption ratio among transects (site 2).

C. DISCUSSION

Soil Physical Properties

The soil physical properties of the study sites were altered by pipeline construction activities. Although the trenching procedure was responsible for the most profound changes, compaction associated with the use of heavy equipment also contributed to a changed edaphic environment.

Clay content was higher in the B and C horizons of the undisturbed prairie than it was in the A horizons. Incorporation of this clay material into the A horizon during trenching increased clay contents of surface material in trench transects. B and C horizon material was piled or moved about on the stockpile, work and pipelay transects during pipeline construction. Small amounts of this material were either incorporated into the surface horizon during seed-bed preparation or remained as patches on the soil surface. Similar mixing of A, B and C horizon material over the entire r-o-w was reported by Hardy Associates (1978) Ltd. (1983).

Increases in bulk density as a result of pipeline construction were mainly due to compaction by equipment. The amount of compaction is influenced by soil texture and moisture content at the time of construction as well as the weight of and the vibrations from the machinery.

Surface bulk density increased due to trenching whereas bulk density with depth decreased significantly. Highest surface bulk densities in the disturbed transects indicate that bulk density increased as a result of pipeline construction. These increases are most pronounced in the 1981 trench. Although 70 to 90% of compaction occurs with the first pass of a vehicle (Gill and Vanden Berg 1967), compaction increases with each loading cycle. The increased activity over the trench likely caused the 10 to 20% increases in bulk density compared to that of the other transects in the r-o-w. This is probably due to the increased traffic and weight over the trench during the trenching and backfilling operations, as well as increased cattle activity later. The trench material is also less heterogeneous than that of other transects and lacks the cushioning effect of vegetative cover, thereby increasing its susceptibility to compaction.

The breaking up of the Bnt horizon during trenching resulted in lower bulk densities with depth in the trench transects. These decreases in bulk density were most evident at depths greater than 15 cm. Compaction due to heavy equipment is most pronounced to a depth of 15 to 50 cm, depending on the type of equipment used and the texture of the soil in which the disturbance occurred (Soane *et al.* 1982). This is evident in other transects of the 1981 r-o-w, where bulk density increased to a depth of 55 cm but did not increase at greater depths. Assuming 1.5 Mg/m^3 is the critical bulk density for root penetration (Lutz 1952), bulk density was theoretically high enough in the 1981 trench to a 15 cm depth to impede root penetration. Bulk density below 15 cm in the other transects could pose similar problems.

Soil moisture status is a function of the water input into the soil system (precipitation, infiltration) and the amount of soil moisture loss (plant uptake, evaporation, evapotranspiration). These basic processes were affected by bulk density, ground cover and soil organic matter, which decreased as a result of pipeline construction activities.

Soil moisture retention is affected by soil texture and percent soil organic matter, both having been altered by trenching. Clay content increased and organic matter decreased but resulting higher moisture retention at both -33 and -1500 kPa was not significant. The mixing of soil by trenching created a more uniform particle size distribution possibly contributing to a more uniform moisture retention at both pressures.

The berm-like construction over trenches and the changes in vegetative cover are mainly responsible for differences in soil moisture status among transects. In the spring, higher total water in the work, pipelay and between trench transects was due to the higher amounts of snow trapped there and to the ponding of snowmelt water. The ponded water in the 1981 pipelay transect could have contributed to the high total water in the 1981 trench transect through lateral movement of water. The between trenches transects also had higher total water than the trench transects in autumn. At this time, the pipelay and 1981 trench transects had the highest total water, due to lower moisture depletion than in the older r-o-w or the undisturbed prairie. The plant cover in the recently disturbed areas was often sparse well into the second year after disturbance, contributing to this lower moisture depletion. The higher spring moisture contents in these transects thus persisted into autumn.

Wide fluctuations in surface temperature in the 1981 trench transect likely result from a lack of vegetative cover which would provide an insulating and thus stabilizing effect. More pronounced winter temperature fluctuations are attributable to lack of snow cover directly over the trench. No vegetation was present to trap snow which tended to drift over the trench leaving it bare.

Pipeline construction alters the temperature regime with depth on the r-o-w, mainly due to the heating effect from the gas in the pipeline and to the changes in vegetative cover. Temperature would also be affected by soil moisture status (heat capacity) and organic matter (surface albedo). Compression of the gas in the line was more frequent in winter, thus having a more pronounced effect on temperature above the pipeline at that time of the year. Temperature increases were most pronounced directly above the pipe where increases of 7°C compared to all other transects were recorded. These increased temperatures appeared to be localized, with no effect evident 3 m from the pipe or 50 cm above it. Bulk density influences thermal conductivity; thus higher bulk densities in the B horizon of the undisturbed prairie could facilitate heat transfer resulting in a non-uniform temperature with depth, at equal moisture contents in the horizons. The less heterogeneous nature of the trench is more conducive to relatively small temperature gradients. Temperature changes due to pipeline installation and subsequent flow of heated materials, as well as the effects of disturbance on ground cover and subsequent changes in surface temperature, are likely to affect plant growth and development.

The effect of grazing is most evident on soil moisture status and bulk density. Bulk density to a depth of 55 cm was lower in site 1 than in either sites 2 or 3, possibly indicating an effect of season of grazing. Cattle spend less time grazing the r-o-w in site 1 because plant material is often partially cured and unpalatable, thus reducing traffic and subsequent compaction. Total soil moisture in the 1981 r-o-w was lower in site 1 than sites 2 or 3, possibly due to the influence of late season grazing. Plants in the late season grazed sites used available moisture early in the spring and well into autumn, whereas plants in early season grazed sites were using less moisture due to severe defoliation early in the spring. Plants that are unpalatable late in the season are not removed from the trench transect and plant utilization of available moisture continues until the plant becomes dormant. The higher frequency of *Agropyron pectiniforme*, a high moisture requiring plant, in site 1, may also contribute to the decreased soil moisture with late season grazing. Because soil moisture was monitored in only one late season grazed site, there was no replication of this data.

The 12 to 20% reductions in suface bulk density over the older r-o-w compared to that of the 1981 r-o-w possibly indicate ameliorative effects over time, particularly over the trench transects. Bulk density tends to change less with time in the between trenches transects than it does in the trenches. This persistence may be explained by the more stable state of the between trench transects relative to that of the trench. The trench transects are influenced more by plant root penetration, and wetting and drying, with resulting shrinking and swelling that tend to reduce bulk density. Blowout areas have higher bulk densities due to the exposed B horizon material on the surface. After 24 years bulk density with depth in the trenches is still significantly lower than that of the undisturbed prairie, indicating that at least in the trenches, bulk density has not returned to predisturbed values.

Other researchers have also reported on the persistence of bulk density changes, but there are many inconsistencies in the literature, probably due to differences in soils, type of disturbance and environmental conditions. A review of the literature on compaction by agricultural vehicles (Soane *et al.* 1982) indicated that between 12 and 50 years is required to return compacted and/or loosened forest soils to predisturbed bulk densities. Surface bulk density tends to return to predisturbed conditions faster than does the bulk density with depth, often reaching predisturbed values after only five years.

Effects of pipeline construction on bulk density found in this study are similar to those of Button (1971) and de Jong and Button (1973) for Solonetzic soils in Saskatchewan. Other researchers who studied the impact of pipeline installation did not use Solonetzic soil sites. Therefore data are often not in agreement or relevant to this study. Changes in surface bulk density appear to be consistent regardless of soil type studied, with significant increases with disturbance particularly over the trench area (Button 1971; de Jong and Button 1973; Ramsay and Mackenzie 1978; Stewart and Mackenzie 1979; Shields 1979; Culley *et al.* 1981, 1982). Bulk density in non-Solonetzic soils, as reported in the above mentioned literature, tended to increase with depth. Because bulk density of Solonetzic soils is inherently higher than that for other soils, trenching reduced it by breaking the Bnt horizon.

Data from this study indicate that moisture retention at both -33 and -1500 kPa was not significantly altered with pipeline disturbance. Total soil profile water increased, but these increases did not persist with time. Button (1971) and de Jong and Button (1973) reported variable results which seemed to depend on soil type. Volumetric moisture content decreased at -33 kPa and available water either decreased or did not change. Other researchers, also named above, indicated that pipeline construction generally reduced water holding capacity. Changes were always more pronounced in the trench than they were on adjacent areas.

Only one other study reported on temperature increases due to pipeline operation (Stewart and Mackenzie 1979), although no comments were made regarding area affected by the temperature change.

Soil Chemical Properties

Pipeline construction activities altered some chemical properties of the soil on the pipeline r-o-w, particularly to a depth of 15 cm. The trenching procedure had the most profound effect on soil chemical changes. These changes were probably brought about by the incorporation of calcareous and/or alkaline material from the lower soil horizons and subsequent dilution of the surface horizons.

Although soil chemical properties were modified as a result of pipeline construction, the relatively inhospitable nature of the Solonetzic soil was not ameliorated by trenching. Soil acidity was reduced and water soluble Ca^{++}, K^{+} and Mg^{++} concentrations were increased near the soil surface, improving the plant's rooting environment. However, EC and Na^{+} concentrations increased, soil organic matter decreased considerably and pH was raised to near 8, higher than ideal for the growth of most plants.

Total soluble salt increases to a depth of 60 cm were not severe enough to restrict plant growth. In the 1981 trench to a depth of 30 cm, salinity increases would be high enough only to affect very salt sensitive species. Although SAR data indicate that no detrimental effects on either crop growth or soil structure to a depth of 15 cm are expected, the higher concentrations of Na^{+} may have detrimental effects on soil physical properties, particularly in view of the low organic matter content. The redistribution of organic matter may also contribute to a less stable soil system both physically and biologically, thereby increasing the potential for erosion. The grading procedure and the compaction of soil due to the use of heavy equipment produced an effect similar to trenching in this regard. Mixing of B and C horizon material with that of the A horizon during stockpiling and backfilling operations was responsible for these changes.

The surface organic matter loss in the work, pipelay and stockpile transects as a result of grading was less than by trenching. The grading procedure removes only part of the surface material. There was no incorporation and subsequent dilution of organic material as there was in the trenching operation.

Surface pH in the between trenches transects tended to be higher than that of the undisturbed prairie, indicating movement of subsurface material in the r-o-w and the less than complete removal of this material during the trench backfilling procedure. Increased total salt concentration over the r-o-w at all depths may be explained by the redistribution of lower horizon soil material. Higher surface EC and SAR values in these transects are probably a direct result of subsurface material remaining on the surface of these transects.

Results indicated salt concentrations decreased with time; however, EC did not decrease to less than that of the undisturbed prairie. Na^+, due to its relative ease of leaching, decreased more readily than did the other ions. Data for chemical properties and % organic matter suggest that a trend towards predisturbed chemical conditions is evident within nine years after disturbance, but more than 24 years are required for a complete return if the r-o-w are not seeded. Assuming returns to predisturbed conditions continue at the same rate and there are no other factors involved, at least 33 years are required for organic matter levels to attain predisturbed levels and at least that time period is required for salt levels to return to those of predisturbed conditions, again, assuming the r-o-w is not seeded.

Data from this study, in general, support conclusions of de Jong and Button (1973) and Culley *et al.* (1981). However, there were exceptions. In the above mentioned studies, decreases in potassium were reported for trenched areas, whereas this study found a trend of increases. Other researchers had not studied effects of pipeline installation on soil chemical properties.

V. VEGETATION

A. MATERIALS AND METHODS

Preliminary Study

A reconnaissance survey was undertaken in August 1981, prior to pipeline installation. Major plant associations were examined, a preliminary species list was compiled and study sites were selected. After pipeline installation three sites were established as described under Experimental Design (Chapter 3, Figure 3.4).

Site And Transect Groupings

The transects of the study sites were grouped into seven categories on the basis of treatment:

undisturbed native prairie (undisturbed and prairie transects),
1981 right-of-way (work, pipelay, 1981 trench and stockpile transects),
1957 right-of-way (1957 trench and between 1957 and 1963 trenches transects),
1963 right-of-way (1963 trench and between 1963 and 1968 trenches transects),
1968 right-of-way (1968 trench and between 1968 and 1972 trenches transects),
1972 right-of-way (1972 trench and between 1972 trench and roadway transects) and
roadway (roadway transect).

The three sites selected in the preliminary study were utilized in 1982. In 1983 a fourth site was established in the late season grazed section to provide a replicate to evaluate the effect of season of grazing. The sites were grouped into early season grazed sites (1 and 4) and late season grazed sites (2 and 3) (Experimental Design, Chapter 3).

Field Sampling

Sampling of both dominant and subordinate plant species is required if response to climate, soil, grazing and mechanical disturbance is to be determined. Dominant species may not react noticeably to a change in a given factor-complex but less common species may react sharply (Lodge *et al.* 1969), due to their frequently narrower ecological amplitudes (Hanson 1956). Since vegetation may react to pipeline disturbances in this manner, all species present in each site were recorded. Intensive surveys were undertaken in 1982 and 1983. In 1982 vegetation was sampled during the first two weeks of June and the last two weeks of September to compare vegetative characteristics in spring and autumn. In 1983 vegetation sampling was undertaken during the last two weeks in June. Species were identified according to Moss (1983).

Minimal area is the smallest area in which the species composition of a given community is adequately represented (Mueller-Dombois and Ellenberg 1974). For temperate zone vegetation an empirical value for minimal area in dry grassland is 50 to 100 m². This value was used as a guideline in determining size and number of quadrats in each transect.

Restricted random sampling was utilized for field data collection. Each transect was divided into subtransects; each subtransect and all parts within this subtransect had equal chances of being sampled. A coordinate system was established in each transect with the transect width as the x axis and the transect length as the y axis. Pairs of random numbers generated by a computer program were used to locate subtransects in which quadrats were to be read.

Quadrats

One m² quadrats are most often used in studies of North American prairies and ranges (Brown 1954; Mueller-Dombois and Ellenberg 1974; Chapman 1976). When a large number of species of small size are present, smaller quadrats may be appropriate (Chapman 1976). These smaller quadrats often have a larger perimeter to area ratio, thereby increasing edge effects. In this study, only species rooted in the quadrat were counted so edge effects were minimized.

In 1982, all transects at each site were subdivided into four subtransects, each 25 m in length and spanning the width of the transect. Twelve permanent 1 m² quadrats were randomly established in each transect; there were 3 per subtransect. Quadrats were divided into four 0.25 m² quadrants to facilitate readings. Quadrats were read in June and September 1982, to account for seasonal species variation.

The size of quadrats used in 1982 made readings difficult and time consuming. The number of quadrats read was not sufficient to account for several subordinate species in the study sites. In 1983, subtransect number was increased and size was decreased to enhance sampling efficiency. Individual transects were divided into 1 by 1 m subtransects to assist in quadrat location. At each site, one hundred 0.10 m² (20 cm x 50 cm) temporary quadrats were read in each of the following transects: undisturbed native prairie, 1981 trench, 1981 pipelay, 1981 stockpile, 1957 trench and between the 1957 and 1963 trenches. Quadrats were divided into ten smaller sections to facilitate cover estimates. Treatments had been reduced to include only the oldest and most recent disturbances and the control to accommodate the larger number of quadrats within the sampling time frame.

Basal Area

Canopy cover is considered a reliable measure to record changes in vegetation resulting from a change in management or biotic influences (Chapman 1976). Basal area, the area occupied by the plant in a horizontal position approximately half an inch above the ground, was used to assess ground cover. Basal area varies less than canopy coverage from year to year (Poulton and Tisdale 1961) and is based on a more practical height for use in grazed areas (Hanson 1956).

Basal area cover classes (modified after Braun-Blanquet 1932; Raunkiaer 1934; Daubenmire 1959) were established that would be sensitive to both the lower and the higher frequency species (Table 5.1).

Table 5.1. Cover classes for the determination of basal area.

Class	Range	Midpoint
1	+	+
2	+ -1	0.5
3	2-5	3.5
4	6-10	8.0
5	11-25	18.0
6	26-50	38.0
7	51-75	63.0
8	76-95	85.0
9	96-100	98.0

Ocular estimates of basal area were facilitated by the use of a ruler. In each quadrat, individual plant species, total live vegetation (included only green vegetation), total dead vegetation and bare ground were assigned to a cover class. Voucher specimens from all unknown species were assigned a number and collected for future identification.

Frequency

Frequency of each species in a quadrat was recorded. To calculate percent frequency, the number of quadrats in which a species occurred was divided by the total number of quadrats and multiplied by one hundred. From frequency data a presence list of species at all four sites was compiled (Appendix II, Table 1).

Density

Plant density over the 1981 r-o-w was determined to quantify the establishment of introduced species and invasion by native species. At each site, four seeded rows were randomly selected in each of the following transects: 1981 trench, pipelay, work and stockpile. Twenty-five, 1 m segments were randomly selected along each seeded row and the number of introduced and native plants were counted in each row segment.

Data Analysis

Data were analyzed separately for each transect, in each site, for 1982 spring, 1982 autumn and 1983 spring recordings. Within each site data were first analyzed for among transect differences then data from each transect were analyzed for among site differences. Data from 1982 were analyzed for between season differences. Analyses were performed at the 5% level of significance.

Mean basal area was determined by obtaining the midpoint of the basal area of each species in each quadrat; these midpoints were then added and the total divided by the number of quadrats sampled. For calculation purposes, the + basal area midpoint was assigned a value of 0.001%.

Contingency tables and Chi square may be used to compare frequencies and covers of species, to determine if they can be regarded as estimates of a single value (Sokal and Rohlf 1981; Greig-Smith 1983). The analysis of contingency tables is the qualitative equivalent of both the ANOVA and the correlation analysis (Legendre and Legendre 1983). The hypothesis tested in this study was that the frequency and cover distribution of a given species were the same among various groups (quadrats were samples from homogeneous groups; transects were samples from homogeneous sites; and sites were samples from homogeneous areas).

Chi square was used to test departure from expected values and to determine the homogeneity of two species with respect to frequency and basal area. The number of occurrences for many species was often small, resulting in a discontinuous distribution. This inaccuracy was corrected for by using Yates' correction for continuity (Steel and Torrie 1980; Greig-Smith (1983).

In the analysis of data, emphasis was initially placed on frequency and basal area data. Species were evaluated for consistency in all sites over the two years that data were collected. Species occurring only in specific transects or sites were further examined for patterns of occurrence. All species were evaluated for seasonal variation in frequency and basal area.

To facilitate comparison of species a figure combining abundance or cover and frequency or constancy is desirable (Hanson 1956, Chapman 1976). To compare species composition of the different transects, frequency of each species was multiplied by basal area of that species. This value was termed an FB index and was then used to compare combinations of two transects. For each set of two transects being compared, the FB index of each species in each transect was evaluated for consistency between the two transects using Chi square analysis. The number of species with statistically different values was then recorded. Transects with few species having statistically different values were considered similar to each other in botanical composition.

B. RESULTS

Undisturbed Native Prairie

The basal area of the undisturbed prairie consisted of approximately 50% live vegetation (green growth), 30% dead vegetation (litter) and 20% bare ground (Figure 5.1). Over 99% of the live vegetation was composed of native species. Significance in Figure 5.1 was determined using Chi square. Results from a more conservative test, ANOVA, followed by SNK for significant F values, were similar.

Selaginella densa was the dominant species throughout the year, in all four sites, often comprising over 70% of the vegetation in 1982 (Figure 5.2, Table 5.2) and over 30% in 1983 (Tables 5.2 and 5.3). In the undisturbed transects both frequency and basal area of this species were significantly higher than those in any other transect. *Selaginella densa* did not occur in the disturbed transects.

The most abundant grasses were *Bouteloua gracilis, Koeleria macrantha* and *Stipa* species (predominantly *Stipa comata*, with smaller amounts of *Stipa curtiseta*). Together these three grasses represented up to 10% of the total vegetation of the sites and had mean frequencies of 46 to 92% (Tables 5.3 and 5.4).

Forbs and half shrubs were abundant at all four sites. The major species were *Artemisia frigida* (a half shrub), *Phlox hoodii* and *Sphaeralcea coccinea*. *Artemisia frigida* had the highest frequency and basal area (Table 5.4). *Opuntia polyacantha* comprised only 1% of the total basal area (Table 5.3) but was the most abundant species on all blowouts. *Carex* species had a high frequency but a very low basal area in all undisturbed transects (Table 5.3). These values were, however, significantly higher than for disturbed areas within each site.

Common grasses at all four sites were *Poa* species (predominantly *Poa sandbergii*) and *Agropyron smithii*. Common forbs included *Achillea millifolium, Antennaria parvifolia, Astragalus* species, *Cerastium arvense* and *Gutierrezia sarothrae*, which had frequency values less than 10% and basal area values of over 1% (Appendix II, Table 2). *Plantago patagonica,*

Table 5.2. **Percentage composition of vegetation classes on undisturbed mixed prairie (n=100).**

Cover Characteristic	Sampling Date	Site 1	Site 4	Site 2	Site 3	Mean
Grasses	Sept. 1982	25a	-	7b	4b	12
Forbs[1]		15ab	-	11b	18a	15
Moss[2]		60b	-	77a	78a	72
Sedges		+	-	-	+	+
Shrubs		-	-	5	-	2
Grasses	June 1982	36a	-	10b	7b	18
Forbs[1]		9b	-	10ab	17a	12
Moss[2]		55b	-	76a	76a	69
Sedges		+	-	-	+	+
Shrubs		-	-	4a	+b	1
Grasses	June 1983	13b	18a	12b	10b	13
Forbs[1]		49b	58a	38c	37c	46
Moss[2]		36b	24c	33b	53a	37
Sedges		+	+	+	+	+
Shrubs		1b	17a	1b	-	5

\+ Less than 1%
[1] Includes half shrubs
[2] *Selaginella densa*
Sites 1 and 4 are late season grazed
Sites 2 and 3 are early season grazed
Significant differences among sites denoted by different letters

Table 5.3. **Mean frequency, basal area and percentage composition of common species at four sites of undisturbed mixed prairie, June 1983 (n=400).**

Species	Frequency %	Basal Area %	Composition %
Koeleria macrantha	92	3	4
Selaginella densa	87	26	37
Artemisia frigida	69	6	8
Bouteloua gracilis	69	2	2
Carex species	55	+	+
Stipa species	46	3	4
Sphaeralcea coccinea	40	1	1
Phlox hoodii	30	3	4
Plantago species	26	2	2
Erysimum inconspicuum	22	+	+
Agropyron smithii	12	+	1
Poa species	10	1	1
Vicia americana	10	+	+
Artemisia cana	6	3	4
Opuntia polyacantha	3	1	1

+ Less than 1%

Table 5.4. Seasonal and year to year variation in frequency and basal area of common species in undisturbed mixed prairie (1982 data are means from three sites, n=72; 1983 data are from four sites, n=400).

Species	Frequency %			Basal Area %		
	Sept 1982	June 1982	June 1983	Sept 1982	June 1982	June 1983
Koeleria macrantha	9	96*	92	+	5*	3
Stipa species	21	59*	46	1	1	3
Phlox hoodii	7	43*	30	+	1	3
Carex species	10	18*	55	+	+	+
Bouteloua gracilis	98	93	69	5	2	2
Opuntia polyacantha	15	16	3	18	7*	1
Artemisia frigida	91	91	69	3	3	6
Selaginella densa	92	92	85	58	55	26
Sphaeralcea coccinea	67	67	40	+	+	1

\+ Less than 1%
* Significant differences between September and June 1982 data

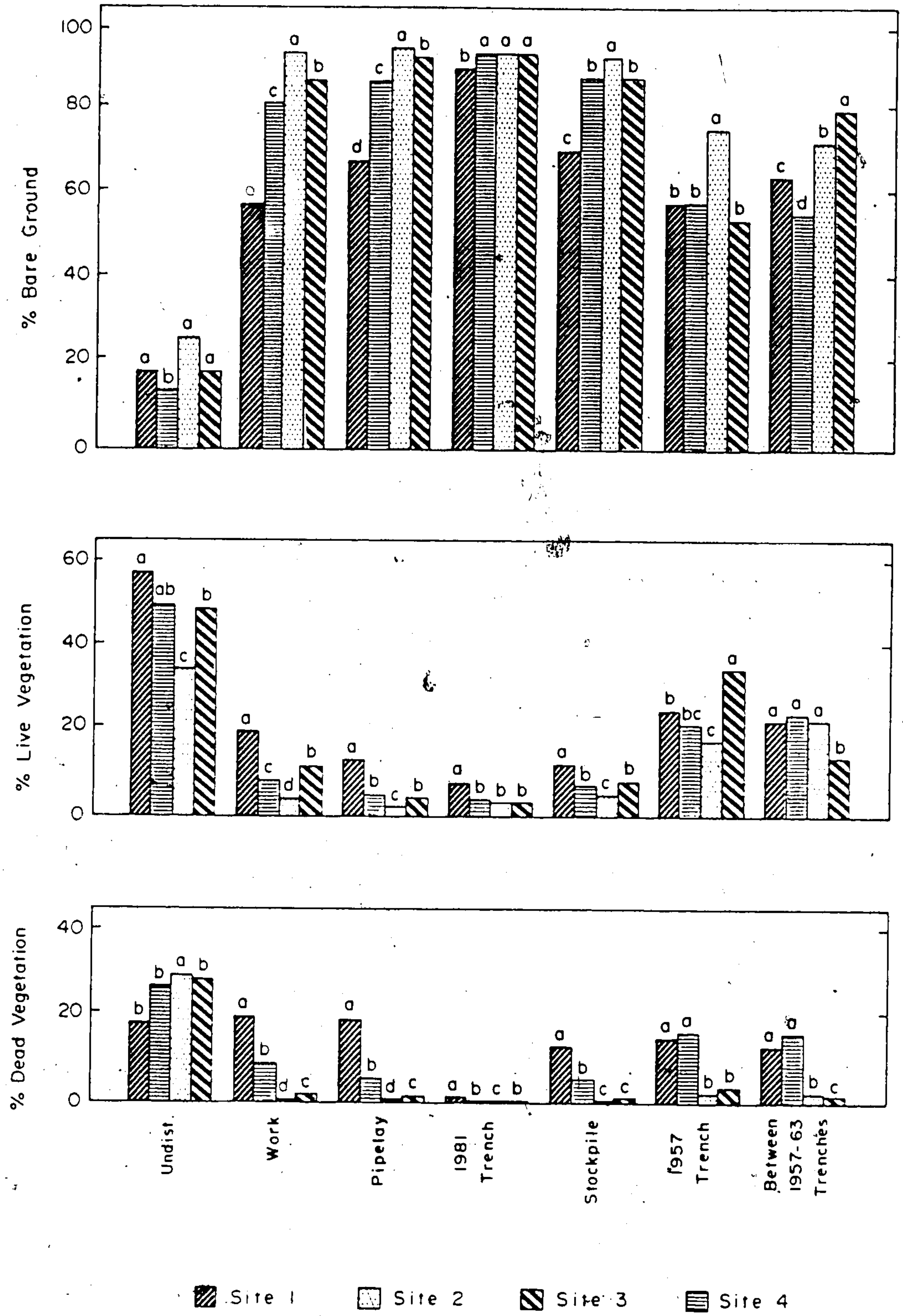

Figure 5.1. Ground cover, June 1983. Same letters denote no significant difference among sites for a given transect. (Sites 1 and 4 = late season grazed; sites 2 and 3 = early season grazed).

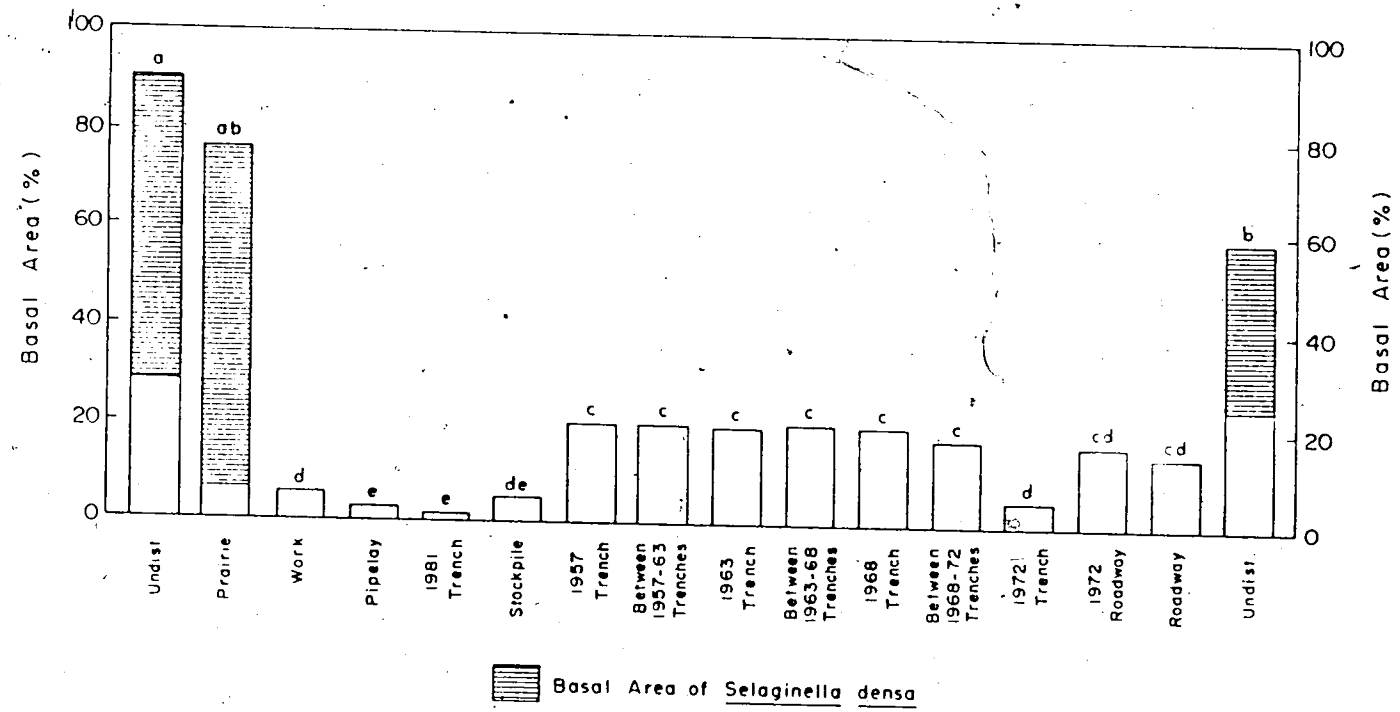

Figure 5.2. Basal area of live vegetation and *Selaginella densa*, June 1982. Data are means of three sites. Same letters denote no significant difference among transects.

Erysimum inconspicuum and *Vicia americana* had a frequency greater than 10% and had a very low basal area. *Artemisia cana* had a high basal area but a low frequency and was the most common shrub on all sites (Table 5.4).

Numerous species with low basal area (<1%) and frequency (<10%) occurred in all sites (Appendix II, Tables 2, 9 and 24). Approximately 95% of these species were not significantly different among sites in either basal area or frequency.

Introduced species from adjacent pipeline r-o-w had not successfully invaded the undisturbed native prairie. *Agropyron pectiniforme* was present but was generally a minor component of the vegetation. *Agropyron smithii*, which is also native to the area and *Onobrychis viciifolia* were the only other introduced species in the undisturbed transects. These species had very low basal area and frequency values (Appendix II, Tables 2, 9 and 24).

During both June and September 1982 grass composition was significantly higher in site 1 than in sites 2 or 3 while *Selaginella densa* was significantly higher in sites 2 and 3. 1983 data were significantly higher for forbs in sites 1 and 4 than in sites 2 and 3.

Seasonal Variation

Frequency and basal area of some species varied with season. Early maturing species dominating the vegetative composition at the time of spring sampling had been replaced by later maturing species at the time of autumn sampling (Table 5.4). Only green growth was considered, with standing dead vegetation considered as litter.

Of the grasses, *Koeleria macrantha* and *Stipa* species were more plentiful in the spring with low frequencies and basal areas in autumn (Table 5.4). *Phlox hoodii* and *Carex* species had significantly higher basal area and frequency values in spring than in autumn. Unpalatable species such as *Opuntia polyacantha, Artemisia frigida, Selaginella densa* and *Sphaeralcea coccinea* were not affected by season of sampling.

Year to Year Variation

Year to year variation in the composition of plant groupings and species were also encountered and were most common for forbs and mosses (Tables 5.2 and 5.4). These variations could not be analyzed statistically because quadrat size differed between 1982 and 1983 samplings.

Variation Due to Season of Grazing

Season of grazing had a substantial effect on vegetative composition and ground cover. Live vegetation and litter declined and bare ground increased under an early season grazing regime (Figure 5.1). Both frequency and basal area were affected by season of grazing with most significant differences observed for frequency data. Late season grazing resulted in increased basal area of many grasses and palatable forbs whereas early season grazing depressed basal area by up to 50%. Early maturing species were least affected by early season grazing.

In 1982 grasses were a significantly higher component of the total vegetation (frequency and basal area) under a late season grazing regime than under an early season grazing regime (Table 5.5). *Selaginella densa* significantly decreased under late season grazing compared to early season grazing. In 1983 forbs were significantly more abundant under late season grazing (Table 5.6).

Frequency of *Stipa* species was reduced by 23% with early season grazing (Table 5.5) while that of *Agropyron smithii* was reduced by 6%. Frequency values of most forbs were significantly affected by season of grazing with changes ranging from 6 to 35% (Table 5.7).

Season of grazing significantly affected the frequency of *Agropyron pectiniforme* (Table 5.7). Under a late season grazing regime (Site 1) in the undisturbed transect near the seeded r-o-w (1968 and 1972), *Agropyron pectiniforme* was abundant (Figures 5.3 and 5.4). In site 1, spring frequency was 83% and spring basal area was 12%. Autumn frequency was 8% and basal area was less than 1%. *Agropyron pectiniforme* did not occur in this undisturbed transect in early season grazed sites.

Table 5.5. **Composition of selected species in undisturbed transects, June 1982.**

Species	Percentage Composition					
	Frequency			Basal Area		
	Site					
	1	2	3	1	2	3
Grasses						
Agropyron pectiniforme	8a	-b	+b	1	-	+
Agropyron smithii	+	-	+	1	-	+
Bouteloua gracilis	+	3	2	18a	7b	3b
Koeleria macrantha	25a	6b	5b	3	+	1
Stipa species	3	1	+	1	+	+
Other grasses	+	-	+	+	+	+
Forbs and half shrubs						
Artemisia frigida	+b	4a	5a	6	4	6
Opuntia polyacantha	5b	3b	11a	8	6	10
Phlox hoodii	+	1	1	+	-	+
Sphaeralcea coccinea	+	+	+	+	+	+
Other forbs	+b	3a	+b	1	1	2
Moss, sedges and shrubs						
Selaginella densa	55b	76a	76a	60b	77a	78a
Carex species	+	-	+	+	-	+
Shrubs	-b	4a	+b	-	5	-
Total grasses	36a	10b	7b	25a	7b	4b
Total forbs	9b	10b	17a	15a	11b	18a
Total others	55b	80a	76a	60c	82a	78b

\+ Less than 1%
Site 1 = late season grazed
Sites 2 and 3 = early season grazed
Same letters denote no significant differences among sites

Table 5.6. Composition of selected species in undisturbed transects, June 1983.

Species	Percentage Composition: Late Season Grazed Sites 1	Late Season Grazed Sites 4	Early Season Grazed Sites 2	Early Season Grazed Sites 3	Mean Of Sites 1+4		Mean Of Sites 2+3
Grasses							
Agropyron pectiniforme	-	1	+	+	1		+
Agropyron smithii	+	1	+	+	1		+
Bouteloua gracilis	3	3	2	1	3		2
Koeleria macrantha	4	3	6	4	4		5
Stipa species	3	8	2	1	6		5
Other grasses	2	-	2	3	1		1
Forbs and half shrubs							
Artemisia frigida	9	8	8	9	9		9
Opuntia polyacantha	+	+	8	1	+		5
Phlox hoodii	3	3	6	3	3	*	6
Sphaeralcea coccinea	1	+	2	+	1		1
Other forbs	36	47	15	21	42	*	18
Moss, sedges and shrubs							
Selaginella densa	36	24	33	53	30	*	43
Carex species	+	+	+	+	+		+
Shrubs	1	17	1	-	1	*	9
Total grasses	13	18	12	10	16		15
Total forbs	49	58	39	37	54	*	38
Total others	38	40	34	53	30	*	52
Total vegetation	100	100	100	100	100		100

+ Less than 1%

* Significantly different means

Table 5.7. **Effect of season of grazing on frequency and basal area of common species in undisturbed mixed prairie, June 1983 (Data are means for two sites each, n=200).**

Species	Frequency % L		Frequency % E	Basal Area % L		Basal Area % E
Early Season Grazed Increasers						
Phlox hoodii	21	*	39	2		4
Carex species	46	*	64	+		+
Gutierrezia sarothrae	2	*	13	3		1
Artemisia frigida	64	*	74	7		5
Agropyron pectiniforme	2	*	8	+		1
Grindelia squarrosa	4		10	+		+
Late Season Grazed Increasers						
Sphaeralcea coccinea	58	*	23	1		+
Erysimum inconspicuum	38	*	6	+		+
Stipa species	58	*	35	4	*	1
Arnica species	12	*	+	1		+
Astragalus species	14	*	4	9	*	+
Artemisia cana	11	*	1	1	*	5
Achillea millifolium	8	*	1	3		2
Agropyron smithii	15	*	9	1		+
Lappula species	6	*	+	+		+
Cerastium arvense	7		1	2		3
Bouteloua gracilis	69		64	3		1

\+ Less than 1%
L Late season grazed
E Early season grazed
* Significant differences between early and late season grazing

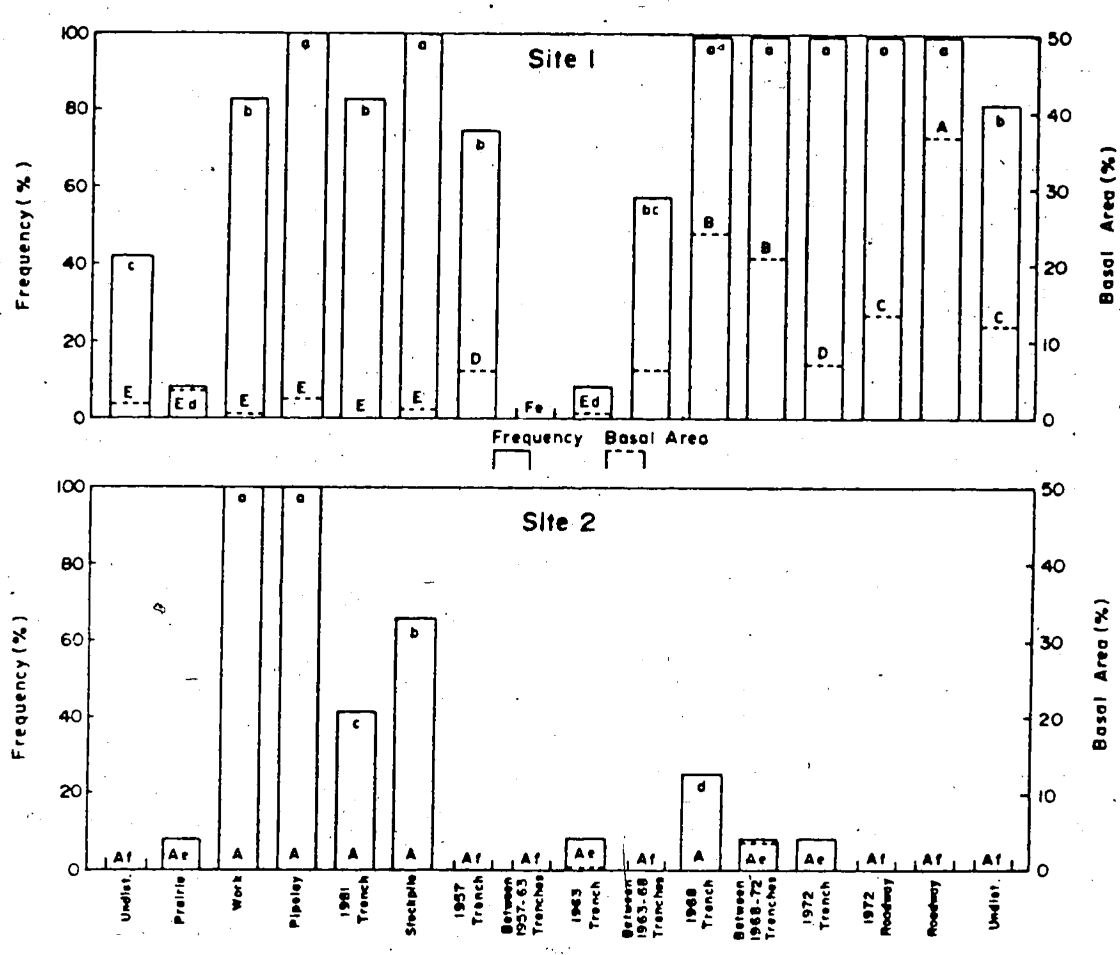

Figure 5.3. Frequency and basal area of *Agropyron pectiniforme*, June 1982. Same letters denote no significant difference among transects. (Site 1 = late season grazed; site 2 = early season grazed).

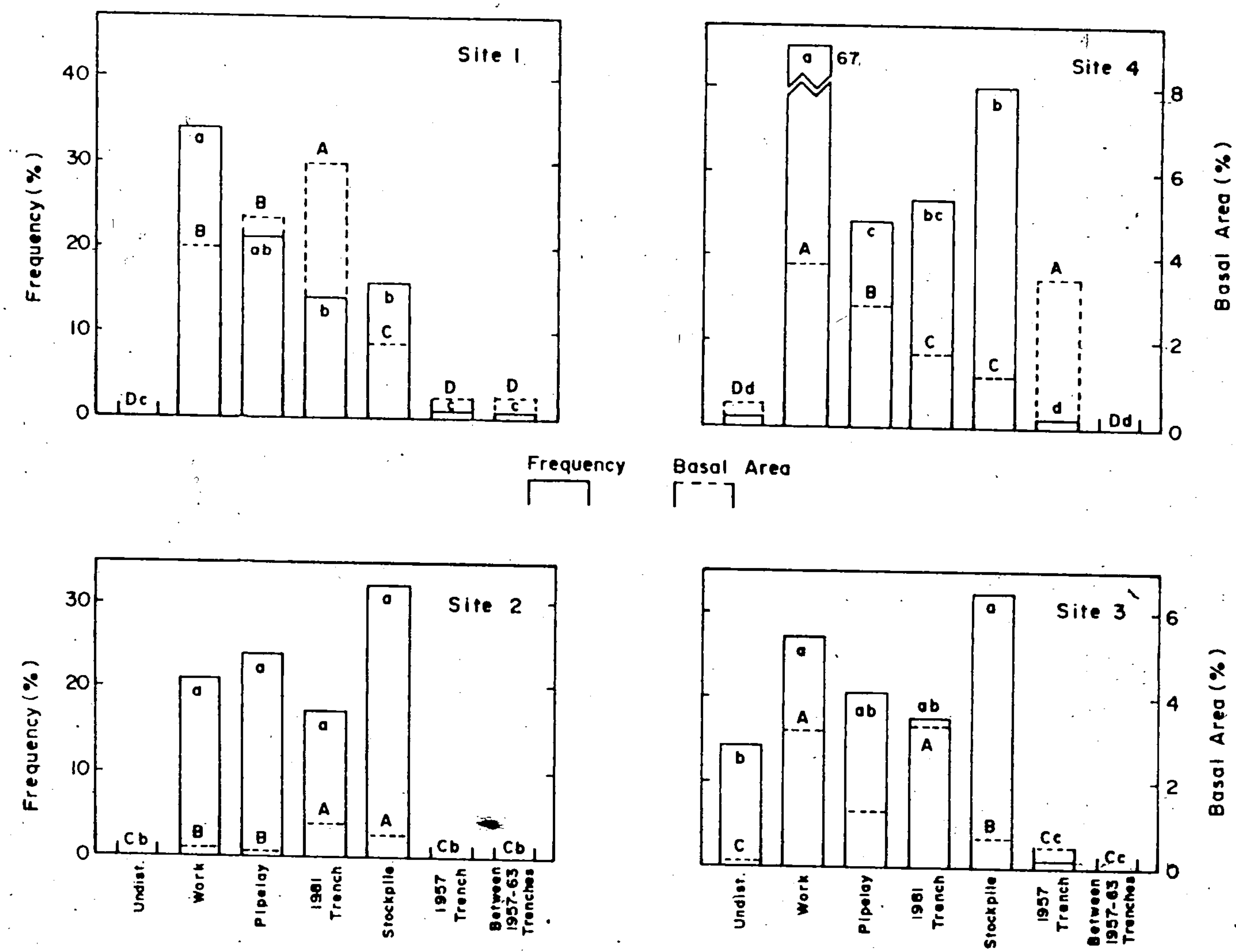

Figure 5.4. Frequency and basal area of *Agropyron pectiniforme*, June 1983 (site 2). Same letters denote no significant difference among transects. (Sites 1 and 4 = late season grazed; sites 2 and 3 = early season grazed).

Disturbed Transects

With pipeline disturbance, botanical composition and ground cover changed significantly from that of the undisturbed prairie. The trenching disturbance was the most disruptive compared to the grading and stockpiling operations of the other r-o-w transects.

1981 Right-Of-Way

Immediately following pipeline construction, vegetation declined to nearly 0% of the ground cover over the trench and to nearly 0.5% over the other disturbed transects. During the first year, vegetative cover over the trench increased to approximately 2% of the ground cover while it was approximately 5% on the other transects of the r-o-w (Figure 5.1). In 1982, species in all transects of the 1981 r-o-w had very low basal area and frequency values. Over 95% of the species present had a mean basal area of less than 1% and approximately 60% had a frequency of less than 10% (Appendix II, Tables 11, 12, 13 and 14).

The most abundant species were either introduced such as *Agropyron pectiniforme*, *Medicago* species and *Astragalus* species or pioneers, such as *Polygonum arenastrum*, *Chenopodium* species and *Monolepis nuttalliana* (Tables 5.8 and 5.9). Native species were more common in transects other than the trench transect and included *Bouteloua gracilis*, *Artemisia frigida*, *Sphaeralcea coccinea* and *Stipa* species (Tables 5.8 and 5.9). *Artemisia frigida*, *Grindelia squarrosa*, *Gutierrezia sarothrae*, *Descurainia sophia*, *Sphaeralcea coccinea*, *Stipa* species and *Plantago* species were significantly more abundant on the work transect than on either the pipelay, stockpile or trench areas. Most common species had the highest frequency and basal area in the spring (Tables 5.10 and 5.11). In autumn, only *Agropyron pectiniforme* and *Artemisia frigida* had a basal area greater than 1%. In general, sites 1 and 4, which were late season grazed, had significantly higher frequency and basal area values than sites 2 and 3. These higher values were usually found for species on the pipelay, work and stockpile transects.

Table 5.8. **Mean frequency of common species at four sites of the 1981 right-of-way, June 1983 (n=400).**

Species	Frequency (%) Transects			
	Trench	Pipelay	Work	Stockpile
Native/Naturalized				
Polygonum arenastrum	34c	51a	45b	49ab
Descurainia sophia	31c	40b	47a	41b
Sphaeralcea coccinea	1c	26b	33a	28ab
Stipa species	2d	8c	30a	20b
Lappula species	8c	14b	17ab	19a
Monolepis nuttalliana	12b	4c	2c	17a
Lepidium densiflorum	+c	6b	8ab	10a
Koeleria macrantha	+d	1c	9b	13a
Vicia americana	4b	14a	5b	12a
Artemisia frigida	+c	12b	35a	7b
Grindelia squarrosa	1c	7b	16a	4b
Plantago species	-c	6b	19a	3b
Gutierrezia sarothrae	+b	+b	12a	1b
Phlox hoodii	-c	1bc	6a	4ab
Seeded				
Agropyron pectiniforme	20c	23c	37a	30b
Medicago species	8c	14ab	16a	12b
Elymus species	25a	13b	11b	11b
Agropyron trichophorum	5a	6a	1b	+
Agropyron elongatum	-b	5a	-b	+b
Native/Seeded				
Agropyron smithii	27c	36b	33bc	48a
Astragalus species	1b	1b	6a	3b

\+ Less than 1%
Same letters denote no significant differences among transects for a given species

Table 5.9. **Mean basal area of common species at four sites of the 1981 right-of-way, June 1983 (n=400).**

Species	Basal Area (%) Transects Trench	Pipelay	Work	Stockpile
Native/Naturalized				
Artemisia frigida	+b	1b	3a	3a
Descurainia sophia	1b	2ab	3a	1b
Grindelia squarrosa	+b	1b	3a	1b
Koeleria macrantha	+	2	1	2
Phlox hoodii	-	+	3	2
Stipa species	1	1	2	1
Gutierrezia sarothrae	+	1	1	2
Polygonum arenastrum	1	1	1	1
Sphaeralcea coccinea	+	1	1	1
Lepidium densiflorum	+	+	1	1
Vicia americana	+	1	1	+
Monolepis nuttalliana	1	+	+	+
Plantago species	-	1	+	+
Lappula species	+	+	+	+
Seeded				
Agropyron pectiniforme	4a	2b	3ab	2b
Elymus species	3	3	2	3
Medicago species	1	1	1	1
Agropyron trichophorum	2	1	+	+
Agropyron elongatum	-	1	-	1
Native/Seeded				
Agropyron smithii	2	2	2	1
Astragalus species	+	+	+	+

\+ Less than 1%
Same letters denote no significant differences among transects

Table 5.10. **Seasonal and year to year variation in basal area of common species in the 1981 right-of-way (1982 data are means of three sites, n=72; 1983 data are means of four sites, n=400).**

Species	Basal Area (%)											
	Transect											
	Trench			Pipelay			Work			Stockpile		
	Sept 1982	June 1982	June 1983	Sept 1982	June 1982	June 1983	Sept 1982	June 1982	June 1983	Sept 1982	June 1982	June 1983
A. pectiniforme	+	+	4	+	1	2	1	+	3	1	+	2
Gutierrezia sarothrae	+	+	+	2	+	1	+	+	1	+	+	2
Agropyron smithii	-	-	2	-	-	2	+	+	2	+	+	1
Astragalus species	+	+	+	+	+	+	+	+	+	+	+	+
Descurainia sophia	-	-	1	+	+	2	+	1	3	+	+	1
Plantago species	+	+	-	+	+	1	1	+	+	+	+	+

\+ Less than 1%

Table 5.11. **Seasonal and year to year variation in frequency of common species in the 1981 right-of-way (1982 data are means of three sites, n=72; 1983 data are means of four sites, n=400).**

Species	Frequency (%)											
	Transect											
	Trench			Pipelay			Work			Stockpile		
	Sept 1982	June 1982	June 1983	Sept 1982	June 1982	June 1983	Sept 1982	June 1982	June 1983	Sept 1982	June 1982	June 1983
Chenopodium species	8	17	3	25	53	1	25	86	4	6	22	6
Artemisia frigida	3	3	+	42	17	12	58	4	35	19	42	7
A. pectiniforme	72	75	20	56	97	23	56	86	37	56	72	30
Koeleria macrantha	-	-	+	+	19	1	+	17	9	+	42	13
Lappula species	+	6	8	+	25	14	+	31	17	+	3	19
Bouteloua gracilis	3	3	1	33	3	1	14	8	+	50	22	4
Descurainia sophia	-	-	31	+	17	40	+	33	47	+	11	41
Monolepis nuttalliana	3	17	12	19	28	4	31	50	2	3	19	17
Stipa species	8	+	2	11	+	8	31	+	30	+	3	20
Polygonum arenastrum	31	42	34	45	67	51	56	69	45	25	22	49
Gutierrezia sarothrae	+	3	+	+	3	+	3	6	12	+	33	1
Medicago species	39	39	8	28	42	14	28	28	16	17	50	12
Sphaeralcea coccinea	3	+	1	47	25	26	56	42	33	56	58	28
Astragalus species	22	28	1	44	39	1	31	39	6	36	17	3
Lepidium densiflorum	-	-	+	8	17	6	11	25	8	3	8	10
Grindelia squarrosa	8	3	1	17	25	7	31	39	16	6	4	4
Phlox hoodii	-	-	-	+	8	1	8	19	6	-	-	4
Plantago species	6	+	-	19	19	6	39	31	19	3	3	3
Agropyron smithii	-	-	27	-	-	36	17	19	33	+	8	48

\+ Less than 1%

By 1983 the basal area of live vegetation over the trench had increased to approximately 5% and there was more litter cover but the outstanding feature was still the large amount of bare ground (Figure 5.1).

In most sites, other disturbed transects of the 1981 r-o-w had less bare ground than did the trench. The work and stockpile transects often had nearly twice as much vegetative cover as the trench did. The pipelay transect tended to have values between those of the trench and the other disturbed transects. Litter (dead vegetation) was significantly higher over these transects than it was over the trench, particularly in the late season grazed sites (Figure 5.1).

Both the frequency and basal area of most species present on the r-o-w increased from 1982 to 1983 and significant differences were observed between late and early season grazed sites (Tables 5.12 and 5.13). In all sites, over all 1981 transects except the trench, native species diversity was greater than introduced species diversity. A similar number of native and introduced species were present over the trench but lower than over any other transect. Over the trench and pipelay transects, introduced species comprised 63% and 41% of the common species, respectively. The work and stockpile transects each had 35% introduced common species.

In 1983, common species on the 1981 r-o-w were similar to those found in 1982. Introduced species tended to dominate the trench transect, particularly *Agropyron pectiniforme, Elymus* species and *Agropyron smithii* (Tables 5.6 and 5.7). The native (naturalized) species present were mostly pioneers such as *Polygonum arenastrum, Descurainia sophia* and *Monolepis nuttalliana*.

The pipelay transect was most similar in species composition to the trench transect but it had a larger number of native forbs and grasses. Most common species in the pipelay transect included *Sphaeralcea coccinea, Artemisia frigida* and *Vicia americana* (Tables 5.6 and 5.7). *Descurainia sophia* and *Koeleria macrantha* were also common.

The stockpile and work transects had a similar species composition (Tables 5.6 and 5.7). Pioneers were common but introduced species were limited to *Agropyron pectiniforme,*

Table 5.12. Effect of season of grazing on frequency of common species in the 1981 right-of-way, June 1983 (data are means of two sites, n=200).

Species	Frequency (%)							
	Transect							
	Trench		Pipelay		Work		Stockpile	
	L	E	L	E	L	E	L	E
Early Season Grazing Increasers								
Artemisia frigida	-	1	1 *	23	15 *	56	3 *	12
Elymus species	21	29	8 *	18	2 *	19	5 *	17
Grindelia squarrosa	-	2	2 *	13	5 *	27	2	6
Plantago species	-	-	3 *	10	14 *	25	- *	6
Late Season Grazing Increasers								
Descurainia sophia	63 *	-	80 *	1	93 *	1	79 *	2
Lappula species	15 *	-	28 *	-	38 *	1	39 *	-
Medicago species	13 *	4	29 *	10	25 *	7	14	10
A. trichophorum	7	4	12 *	-	2	-	1	-
Varied Responses To Grazing								
Sphaeralcea coccinea	2	-	42 *	10	49 *	17	36 *	20
Polygonum arenastrum	36	31	47 *	56	25 *	65	48	51
Agropyron smithii	26	28	40	32	41 *	25	54 *	42
Monolepis nuttalliana	18 *	6	4	7	1	5	26 *	8
A. pectiniforme	21	19	23	23	51 *	24	27	32
Gutierrezia sarothrae	-	1	-	2	20 *	3	-	3
Lepidium densiflorum	-	1	9	4	9	8	- *	5

\+ Less than 1%
L Late season grazed
E Early season grazed
* Significant differences between early and late season grazed sites

Table 5.13. **Effect of season of grazing on basal area of common species in the 1981 right-of-way, June 1983 (data are means of two sites, n=200).**

Species	Basal Area (%)							
	Transect							
	Trench		Pipelay		Work		Stockpile	
	L	E	L	E	L	E	L	E
Early Season Grazing Increasers								
Gutierrezia sarothrae	-	-	-	2	+	2	-	* 5
Artemisia frigida	-	+	+	2	2	3	2	3
Grindelia squarrosa	-	+	-	1	2	* 2	+	1
Late Season Grazing Increasers								
Descurainia sophia	2	-	3	* +	5	* +	2	1
Agropyron smithii	3	2	3	1	3	1	2	1
A. trichophorum	4	1	2	-	1	-	+	-
Elymus species	4	3	3	2	2	2	5	1
Polygonum arenastrum	2	+	1	+	1	1	1	+
Medicago species	1	+	1	1	1	+	1	+
Monolepis nuttalliana	2	+	+	+	+	+	1	+
Sphaeralcea coccinea	-	-	2	+	1	1	1	+
Lappula species	+	-	1	-	+	+	1	-
Varied Responses To Grazing								
A. pectiniforme	4	4	4	1	4	2	1	2
Plantago species	-	-	2	+	+	+	-	1
Lepidium densiflorum	-	+	+	+	5	+	1	+

+ Less than 1%
L Late season grazed
E Early season grazed
* Significant differences between early and late season grazing

Medicago species, *Elymus* species and *Agropyron smithii*. The main difference between these two transects was the higher frequency of *Artemisia frigida* in the work transect.

There were few significant differences in species composition between the four sites. Among treatments the within site differences were significant and occurred most often between the trench transect and the other three transects.

The effect of grazing was most obvious on *Descurainia sophia*. Under a late season grazing regime *Descurainia sophia*, with high frequency and basal area, dominated the vegetative composition but under an early season grazing regime it was often eliminated (Figure 5.5, Tables 5.12 and 5.13).

Significant increases under a late season grazing regime were noted for frequency of *Lappula* species, *Medicago* species and *Agropyron trichophorum*. Significant increases under early season grazing were noted for *Grindelia squarrosa, Plantago* species, *Artemisia frigida* and *Elymus* species (Tables 5.12 and 5.13). Many species did not appear to respond directly to grazing but rather to the type of disturbance. Basal area changed little with grazing regime.

Under late season grazing, the density of native species was higher than the density of introduced species in all transects but the 1981 trench transect of site 4 (Table 5.14). Under early season grazing, density of introduced species was higher in all transects except the work transect of both sites. Early season grazing significantly depressed the density of native species but had a variable effect on introduced species in all transects except the stockpile. The work transect had the highest native species density and the trench transect had the lowest under both grazing regimes. The stockpile transect had the largest number of introduced species, with the 1981 trench having the lowest.

1957 Right-Of-Way

Vegetative cover over the 1957 r-o-w was approximately 40%, with 60% bare ground. Species on the between trenches transect and the trench transect had similar basal areas (Figures 5.1 and 5.2).

Table 5.14. Variation in density of introduced and native species with site and transect in the 1981 right-of-way.

Transect	Number of plants/100 m transect									
	Introduced species					Native species				
	Late Grazed		Early Grazed			Late Grazed		Early Grazed		
	1	4	2	3	Mean	1	4	2	3	Mean
Work	424	533	395	318	417	3161	3330	596	466	1888
Pipelay	432	374	533	285	406	1081	643	345	149	554
1981 Trench	293	365	451	358	366	590	127	152	94	240
Stockpile	349	884	365	453	512	1543	433	368	340	671
Mean/site	374	539	436	353	539	1593	1133	365	262	784

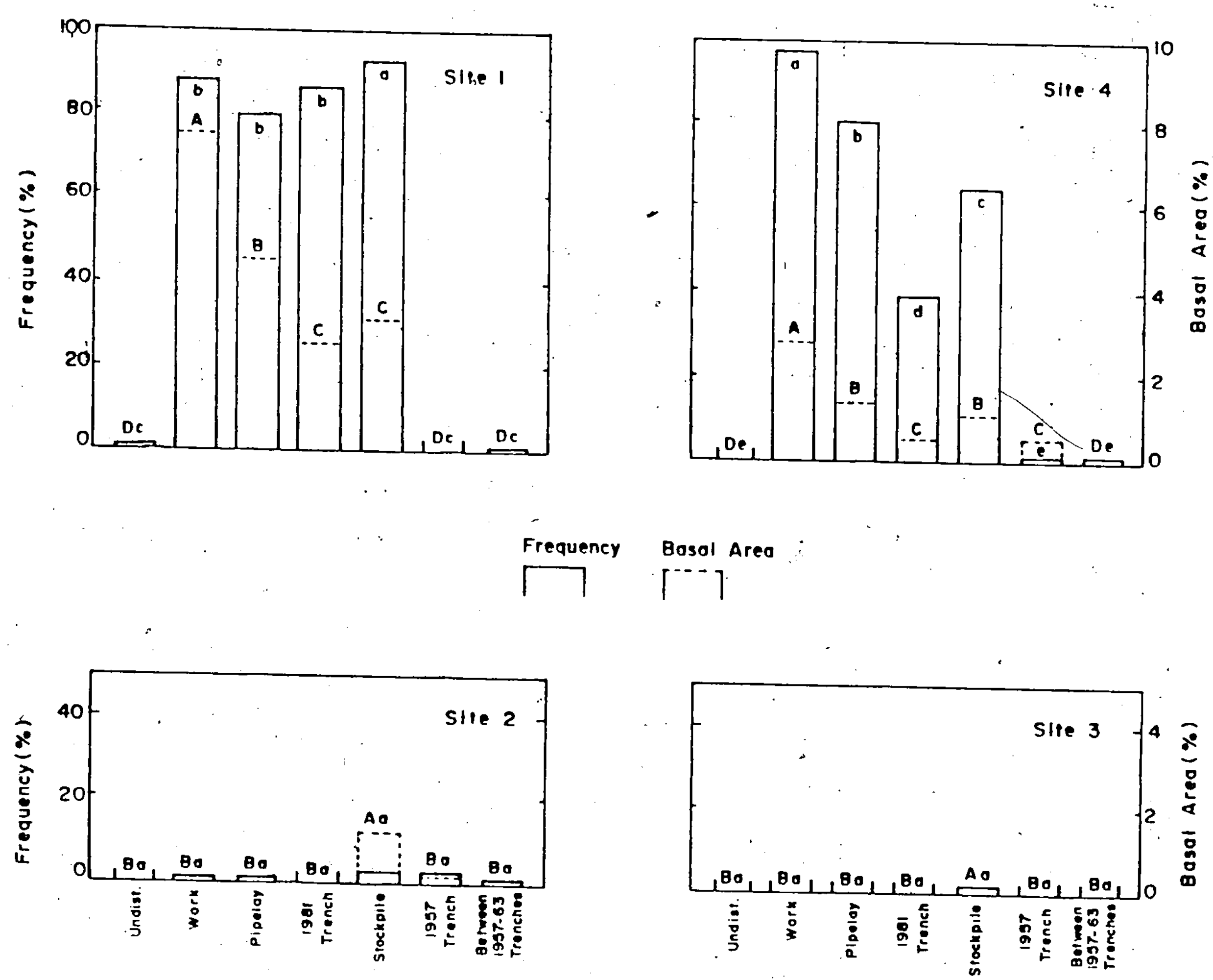

Figure 5.5. Frequency and basal area of *Descurainia sophia*, June 1983. Same letters denote no significant difference among transects. (Sites 1 and 4 = late season grazed; sites 2 and 3 = early season grazed).

Few introduced species were present on the 1957 r-o-w but large numbers of native species, particularly forbs, were present with both high basal area and frequency values (Table 5.15). Dominant grasses in both transects were *Koeleria macrantha, Stipa* species, *Poa* species, *Bouteloua gracilis* and *Agropyron smithii* (Table 5.15). The dominant half shrub was *Artemisia frigida*. Other species commonly found in these transects were most similar to those of the undisturbed mixed prairie.

Variations in frequency due to season of grazing were observed for late maturing species such as *Bouteloua gracilis Vicia americana* and *Agropyron smithii* which increased with late season grazing (Table 5.16). *Poa* species, *Artemisia frigida* and *Taraxacum officinale* increased under early season grazing.

1963, 1968 and 1972 Rights-Of-Way

Over time vegetative cover increased on disturbed areas. The 1972 trench had approximately 10% vegetative cover and 90% bare ground (Figure 5.2). Vegetative cover of the 1963 and 1968 r-o-w was approximately 20% which compares with 60% bare ground for the undisturbed native prairie (Figure 5.2). The between trenches transect near the 1972 r-o-w had more vegetation than did the 1972 trench. Areas between the 1963 and 1968 trenches had basal areas similar to those of the adjacent trenches.

With time the effect of grazing had a compounding effect with that of the pipeline disturbance. Older r-o-w under late season grazing tended to have less bare ground and more live vegetation and litter than did the early season grazed sites (Figure 5.1). Late season grazed sites had approximately four times as many native species over the 1981 r-o-w as did the early season grazed sites. Although introduced species numbers were higher in late season grazed sites as well, the variability was high making the differences non-significant.

These transects are similar in native species composition to that of the 1957 r-o-w. However, the number of introduced species is dramatically increased.

Table 5.15. Frequency and basal area of common species at four sites of the 1957 right-of-way, June 1983 (n=400).

Species	Frequency (%)		Basal Area (%)	
	1957 Trench	Between 1957-1963 Trenches	1957 Trench	Between 1957-1963 Trenches
Koeleria macrantha	95	97	4	5
Artemisia frigida	59	63	4	3
Gutierrezia sarothrae	50	49	3	2
Stipa species	37	32	3	4
Sphaeralcea coccinea	30	28	1	1
Vicia species	34	17	1	1
Poa species	19	22	+	2
Achillea millifolium	18	21	4	* 2
Taraxacum officinale	16	23	5	* 2
Agropyron smithii	12	22	1	1
Bouteloua gracilis	20	12	1	+
Astragalus species	13	14	1	+
Grindelia squarrosa	9	* 16	1	1
Plantago species	10	11	1	+
Aster species	-	* 14	-	+
Gaura coccinea	12	* 2	2	2

\+ Less than 1%

* Significant differences between transects

Table 5.16. Effect of season of grazing on frequency and basal area of common species in the 1957 right-of-way, June 1983 (n=200).

Species	Frequency (%)						Basal Area (%)				
	1957 Trench			Between 1957-1963 Trenches			1957 Trench		Between 1957-1963 Trenches		
	L		E	L		E	L	E	L		E
Early Season Grazing Increasers											
Poa species	4	*	34	6	*	38	+	1	3		2
Taraxacum officinale	10	*	22	12	*	35	9	2	2		2
Artemisia frigida	48	*	69	65		63	3	6	3		3
Achillea millifolium	13	*	24	16	*	26	3	5	2		2
Grindelia squarrosa	5		14	42		55	1	1	+		1
Gutierrezia sarothrae	48		53	42	*	55	3	4	2		2
Cerastium arvense	5		5	2	*	12	2	1	9	*	5
Late Season Grazing Increasers											
Bouteloua gracilis	36	*	3	17	*	7	1	+	+		+
Agropyron smithii	18	*	7	36	*	8	1	1	1		1
Gaura coccinea	22	*	2	4		2	3	1	3		+
Vicia americana	37	*	32	23	*	12	1	1	1		1
Varied Responses To Grazing											
Plantago species	5	*	15	15	*	8	+	2	+		+
Stipa species	36		39	38	*	25	3	3	6	*	1
Ratibida columnifera	6	*	4	2	*	14	3	+	1		+

\+ Less than 1%
L Late season grazed
E Early season grazed
* Significant differences between early and late season grazing

Under late season grazing, *Agropyron pectiniforme* dominated the 1968 and 1972 r-o-w and was prominent in the 1963 r-o-w (Figure 5.3). No other introduced species had persisted and native species invasion had been accomplished by only a few ruderals. When early season grazed, *Agropyron pectiniforme* had lower frequencies and basal areas less than 1%.

In the 1963 r-o-w, common species were *Koeleria macrantha, Artemisia frigida, Stipa* species, *Taraxacum officinale, Gutierrezia sarothrae, Grindelia squarrosa* and *Bouteloua gracilis* (Table 5.17). *Agropyron pectiniforme* was the only common introduced species. Native invaders were still common but perennial forbs and perennial native grasses were beginning to dominate. *Hordeum jubatum, Achillea millifolium, Agropyron smithii,* and *Polygonum arenastrum* had significantly increased frequency under an early season grazing regime. Late season grazed sites had increased frequency values for *Stipa* species, *Bouteloua gracilis, Plantago* species, *Gaura coccinea, Ratibida columnifera* and *Astragalus* species (Table 5.18).

In the 1968 r-o-w native invaders and opportunists such as *Artemisia frigida* were common (Table 5.19). Significant differences in frequency values with season of grazing were found for many species (Table 5.20).

Species on the 1972 r-o-w responded similarly to those on the 1968 r-o-w and the data are presented in Tables 5.21 and 5.22.

Roadway

Only nine species were found on the roadway transect (Appendix II, Table 24). These species were: *Agropyron pectiniforme, Artemisia frigida, Polygonum arenastrum, Grindelia squarrosa, Sphaeralcea coccinea, Taraxacum officinale, Gutierrezia sarothrae, Hordeum jubatum* and *Koeleria macrantha.* Plant growth was concentrated on the least travelled portions of the roadway such as the centre area and the edges.

In all sites, *Agropyron pectiniforme*, with a mean frequency of 50% and a mean basal area of 10% was the dominant species. *Polygonum arenastrum* and *Artemisia frigida*, were the only other common species.

Table 5.17. **Frequency and basal area of common species at three sites of the 1963 right-of-way (n=36).**

Species	Frequency (%)			Basal Area (%)		
	1963 Trench		Between 1963-1968 Trenches	1963 Trench		Between 1963-1968 Trenches
Native/Naturalized						
Koeleria macrantha	85		96	1	*	17
Artemisia frigida	81		85	1		2
Stipa species	59	*	78	3	*	1
Taraxacum officinale	60		60	+		1
Gutierrezia sarothrae	73	*	46	1		1
Grindelia squarrosa	63		36	+		+
Bouteloua gracilis	35	*	63	+		+
Sphaeralcea coccinea	38		38	+		+
Achillea millifolium	40	*	29	2		+
Ratibida columnifera	33	*	15	+		+
Plantago species	8	*	40	+		+
Hordeum jubatum	21		23	1		+
Polygonum arenastrum	19		25	+		1
Antennaria parvifolia	23		13	3	*	1
Gaura coccinea	19	*	9	+		1
Artemisia cana	19	*	80	1		2
Lappula species	2	*	13	+		+
Seeded						
Agropyron pectiniforme	14	*	31	1	*	3
Introduced/Seeded						
Astragalus species	48	*	27	+		1
Agropyron smithii	17	*	6	+		+

\+ Less than 1%

* Significant differences between transects

Table 5.18. Effect of season of grazing on frequency and basal area of common species in the 1963 right-of-way (n=12 for late season grazing and n=24 for early season grazing treatments).

Species	Frequency %						Basal Area (%)					
	1963 Trench			Between 1963-1968 Trenches			1963 Trench			Between 1963-1968 1968		
	L		E	L		E	L		E	L		E
Early Season Grazing Increasers												
Hordeum jubatum	8	*	34	+	*	46	1		1	+		+
Agropyron smithii	+	*	33	58	*	4	+		+	7		+
Achillea millifolium	33	*	46	33		25	2		1	+		+
Polygonum aviculare	8	*	29	25		25	+		+	+		1
Artemisia cana	17		21	+	*	17	+		1	+		5
Late Season Grazing Increasers												
Stipa species	92	*	25	92	*	63	3		3	1		2
Bouteloua gracilis	58	*	13	83	*	42	+		+	+		+
Astragalus species	75	*	21	33	*	21	+		+	2		+
Plantago species	8		8	67	*	13	+		+	+		+
Koeleria macrantha	100	*	71	100		92	11	*	5	3		1
Gaura coccinea	25	*	13	17	*	+	+		+	2		+
Ratibida columnifera	42	*	25	17		13	+		+	+		+
Cerastium arvense	-		-	17	*	+	-		-	+		+
E. inconspicuum	-		-	17	*	+	-		-	+		+
Varied Responses To Grazing												
Gutierrezia sarothrae	75		70	8	*	83	+		1	+		2
A. pectiniforme	8	*	20	58	*	4	1		1	7	*	+
Antennaria parvifolia	8	*	38	25	*	+	4		1	1		+
Sphaeralcea coccinea	50	*	25	25	*	50	1		+	+		+
Lappula species	+		4	25	*	+	+		+	+		+

\+ Less than 1%
L Late season grazed
E Early season grazed
* Significant differences between early and late season grazing

Table 5.19. **Frequency and basal area of common species at three sites of the 1968 right-of-way, June 1982 (n=36)**

Species	Frequency (%) 1968 Trench		Frequency (%) Between 1968-1972 Trenches	Basal Area (%) 1968 Trench	Basal Area (%) Between 1968-1972 Trenches
Native/Naturalized					
Koeleria macrantha	73	*	52	2	2
Artemisia frigida	67		56	2	2
Grindelia squarrosa	60		60	+	+
Polygonum arenastrum	19		25	+	1
Stipa species	63	*	31	2	1
Gutierrezia sarothrae	50	*	39	1	2
Taraxacum officinale	57	*	29	+	+
Hordeum jubatum	29		33	1	1
Sphaeralcea coccinea	[illegible]	*	4	+	+
Achillea millifolium	11		13	+	1
Tragapogon dubius	15		8	+	+
Seeded					
Agropyron pectiniforme	71	*	56	+	11
Introduced/Seeded					
Astragalus species	29	*	4	+	+

\+ Less than 1%
* Significant differences between transects

Table 5.20. **Effect of season of grazing on frequency and basal area of common species in the 1968 right-of-way, June 1982. (n=36).**

Species	Frequency (%)						Basal Area (%)					
	1968 Trench			Between 1968-1972 Trenches			1968 Trench			Between 1968-1972 Trenches		
	L		E	L		E	L		E	L		E
Early Season Grazing Increasers												
Artemisia frigida	33	*	100	17	*	96	1		3	+		3
Hordeum jubatum	+	*	58	+	*	67	+		2	+		2
Gutierrezia sarothrae	25	*	75	8	*	72	+		2	+	*	3
Stipa species	42	*	83	+	*	62	1		3	+		1
Koeleria macrantha	67	*	79	17	*	88	2		1	4	*	1
Taraxacum officinale	42	*	71	8	*	50	+		1	+		+
Achillea millifolium	+	*	21	+	*	25	+		1	+		1
Grindelia squarrosa	58		62	50	*	71	+		+	+		+
Artemisia cana	+	*	13	17	*	96	+	*	11	+	*	3
Late Season Grazing Increasers												
A. pectiniforme	100	*	42	100	*	12	24	*	+	21	*	2
Polygonum arenastrum	50	*	41	83	*	29	+		+	+		3
Sphaeralcea coccinea	67	*	13	8	*	+	1		+	+		+
Astragalus species	50	*	8	8	*	+	+		+	+		+
Tragapogon dubius	25	*	4	8		8	+		+	+		+

\+ Less than 1%
L Late season grazed
E Early season grazed
* Significant differences between transects

Table 5.21. **Frequency and basal area of common species on three sites of the 1972 right-of-way, June 1982 (n=36).**

Species	Frequency (%) 1972 Trench		Frequency (%) Between 1972-Road	Basal Area (%) 1972 Trench		Basal Area (%) Between 1972-Road
Native/Naturalized						
Grindelia squarrosa	73	*	48	+		+
Artemisia frigida	40	*	73	+	*	4
Koeleria macrantha	23	*	75	+		2
Hordeum jubatum	30		36	1		1
Sphaeralcea coccinea	4	*	57	+		+
Polygonum arenastrum	14	*	42	1		1
Gutierrezia sarothrae	27		25	1		1
Taraxacum officinale	25		23	+		+
Stipa species	12		23	+		1
Plantago species	8	*	21	+		+
Ratibida columnifera	17	*	6	+		+
Erigeron glabellus	6		11	+		+
Chenopodium species	6	*	15	+		+
Seeded						
Agropyron pectiniforme	69		58	4	*	7
Introduced/Seeded						
Astragalus species	33	*	11	+		+

\+ Less than 1%
* Significant differences between transects

Table 5.22. Effect of season of grazing on common species in the 1972 right-of-way, June 1982 (n=36).

Species	Frequency (%)				Basal Area (%)			
	1972 Trench		Between 1972-Road		1972 Trench		Between 1972-Road	
	L	E	L	E	L	E	L	E
Early Season Grazing Increasers								
Hordeum jubatum	+	* 59	+	* 71	+	2	+	1
Artemisia frigida	8	* 71	50	* 96	+	1	+	* 7
Gutierrezia sarothrae	8	* 46	8	* 41	+	2	+	1
Stipa species	+	* 25	+	* 45	+	1	+	1
Taraxacum officinale	8	* 42	17	* 29	+	+	+	1
Achillea millifolium	+	* 16	+	* 21	+	+	+	+
Phlox hoodii	+	* 13	+	* 13	+	2	+	+
Plantago species	8	8	8	* 33	+	+	+	+
Late Season Grazing Increasers								
A. pectiniforme	100	* 37	100	* 16	7	+	14	* +
Chenopodium species	8	4	25	* 4	+	+	+	+
Erigeron glabellus	8	4	17	* 4	+	+	+	+
Varied Responses To Grazing								
Grindelia squarrosa	92	* 54	33	* 62	+	+	+	+
Sphaeralcea coccinea	+	* 8	75	* 38	+	+	+	+
Astragalus species	42	* 66	17	* 4	+	+	+	+
Polygonum arenastrum	17	13	33	* 50	+	1	+	1

+ Less than 1%
L Late season grazed sites
E Early season grazed sites
* Significant differences between early and late season grazing

Species Composition

The similarity of species composition in the various transects is compared in Figures 5.6 to 5.8. The percentage of species having a different FB (frequency x basal area) index among transects is presented in Figure 5.6 as the mean of four sites. The undisturbed native prairie is least similar to the 1981 disturbed transects (work, pipelay, trench and stockpile). The undisturbed native prairie is more closely related in species composition to older disturbed transects such as the 1957 trench and between the 1957 and 1963 trenches. Using the Chi square test, the 1981 trench and 1981 pipelay transects had a significantly lower percentage of species with different FB indices than any other transect pair comparison. This indicates that the 1981 trench and the 1981 pipelay transects had the most similar species composition.

Figure 5.7 can be used to determine significant differences in the percentage of species having a different FB index among transects for individual sites. The undisturbed prairie was most closely related to the 1957 trench and the between 1957 and 1963 trenches in sites 1 and 4. No clear trend was discernible in sites 2 and 3. In all sites, species composition of the 1957 r-o-w was not significantly different from that of the undisturbed transects. The 1981 trench transect was most similar to the 1981 pipelay transect. The stockpile and work transects more closely resembled the undisturbed and 1957 r-o-w transects than did the pipelay or 1981 trench transects. Under an early season grazing regime, the 1963, 1968 and 1972 r-o-w were more similar in botanical composition to the 1957 r-o-w than to the 1981 r-o-w or to the undisturbed prairie (data not shown). Under a late season grazing regime, these transects were not significantly different from all other transects.

In Figure 5.8 the percentage of species having significantly different FB indices are compared within a given transect between sites. The mean percentage of species of combined transects that had significantly different FB indices ranged from 18 to 20 (column 1, Figure 5.8), indicating similarities in beween site comparisons across all transects. However, within specific transects there were great differences. The most uniform species composition between any two given sites was in the 1981 trench where an average 11% of the species had significantly

Mean of 4 Sites

	Work	Pipelay	1981 Trench	Stockpile	1957 Trench	Between 1957-1963 Trenches
Undisturbed	28	29	30	30	26	23
Work		18	19	19	28	28
Pipelay			14	19	31	32
1981 Trench				20	32	30
Stockpile					31	28
1957 Trench						20

Significance Between Rows

a	a	a	a	a
a	a	a	a	a
	b	ab	a	a
		a	a	a
			a	a

Significance Between Columns

a	a	a	a	a
a	ab	a	a	a
	b	a	a	a
		a	a	a
			a	a
				a

Figure 5.6. Percent of species with significantly different FB (frequency x basal area) indices. Same letters denote no significant difference among transects.

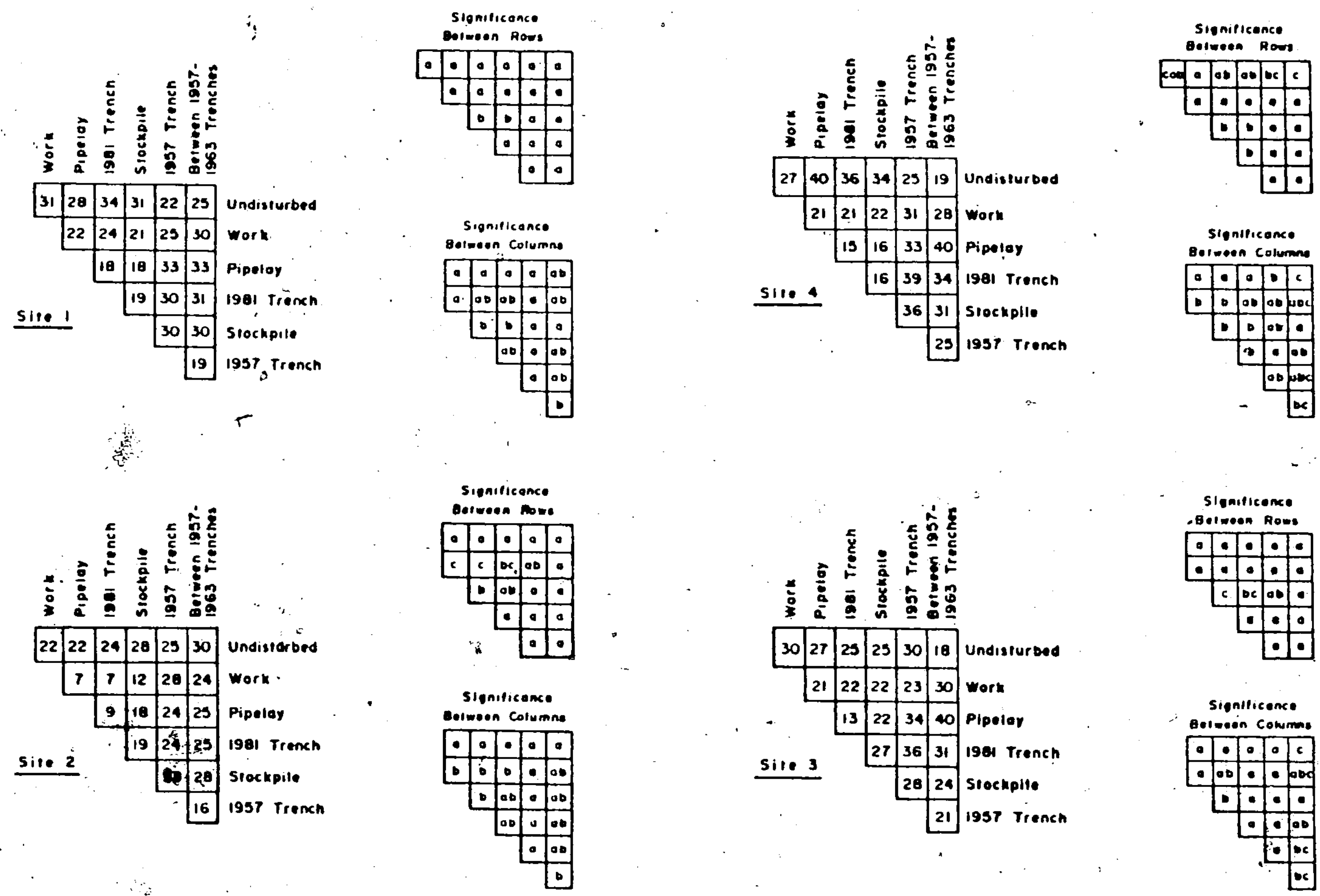

Figure 5.7. Percent of species with significantly different FB (frequency x basal area) indices. Same letters denote no significant difference among transects.

Mean (sd) of Combined Transects	Undisturbed	Work	Pipelay	1981 Trench	Stockpile	1957 Trench	Between 1957-1963 Trenches	
21(3)	24	22	22	15	24	19	21	Site 1-2
19(5)	19	24	22	10	25	21	15	Site 1-3
20(4)	21	21	21	13	15	24	24	Site 1-4
18(7)	21	21	10	7	21	27	16	Site 2-3
20(5)	19	16	22	12	21	28	24	Site 2-4
20(6)	19	25	24	7	19	27	19	Site 3-4
20(1)	21(2)	22(3)	20(5)	11(3)	21(4)	24(4)	20(4)	Mean (sd) of Combined Sites

Figure 5.8. A comparison among sites of the percent of species with significantly different FB (frequency x basal area) indices.

different FB indices. In contrast, the most variable transect was the 1957 trench, where an average 24% of the species had significantly different FB indices. Most transects averaged 20 to 22% of species with different FB indices between given sites.

C. DISCUSSION

Grazing history had a marked effect on the vegetation composition in the study area. In the undisturbed transects there were generally nine times more forbs and 30% fewer grasses (Tables 5.5 and 5.6) than reported by Coupland (1950, 1961) for the same community type. However, Coupland studied areas that were mainly ungrazed or lightly grazed. Botanical composition of the study sites and frequency and basal area of individual species were similar to those reported for grazed mixed prairie sites in both Alberta and Saskatchewan (Clarke 1930; Clarke and Tisdale 1936; Clarke *et al.* 1942, 1943; Smoliak *et al.* 1972; and Wroe *et al.* 1979). Basal area data from this study are in agreement with mean percentage composition for grasses of 7% reported by Smoliak (1965) but the value of 3% for forbs is much lower than found in this study. Values for many individual species were in close agreement to those found by Smoliak (1965).

Differences due to grazing included a decrease in frequency of the midgrasses and an increase in unpalatable species, many of which are forbs or half shrubs.

The majority of the species present have a cool season growth habit. They begin growth in late March or early April, are heading or flowering by June and have completed seed maturation by July. Most vegetation will be dormant or cured by August. These species will be most affected by early season grazing. Severe defoliation during early stages of phenological development is often detrimental to seed production and even to the survival of species whose primary means of reproduction is seed. Species that can reproduce vegetatively are also stunted following severe defoliation because energy must be put into building photosynthetic parts and carbohydrate reserves necessary for winter survival.

Early maturing species that are late season grazed have a distinct advantage for survival over those that are grazed early in the season. By July and August, most early maturing species are nearing the end of their growing season. Some species, such as those of the genus *Stipa*, have awned seeds which are unpalatable to cattle. Mature *Agropyron pectiniforme* is coarse and unpalatable due to large seed heads, many stems and the high content of structural components in leaves and stems. Many of the forbs have matured and become unpalatable by the time late season grazing begins. Thus only later maturing species and those that regrow in autumn will be most palatable. Late season grazing will likely detrimentally affect these palatable species.

In spite of a high frequency and basal area, *Selaginella densa* is not considered a dominant species due to its low growth form and low moisture requirements (Clarke *et al.* 1943). Its contribution to the forage component of the range is negligible but it is considered important due to its high ground cover (Ryerson 1970). In this study, basal area of *S. densa* was higher than the 50% reported by Clarke *et al.* (1942), the 10 to 25% by Ryerson (1970) and the 6 to 25% by Coupland (1950). This reflects the lower range condition of the study area since *S. densa* increases with grazing. When *S. densa* is present in high concentrations, it often forms a mat 6 to 7.5 cm thick which intercepts precipitation, holding it in a sponge-like manner. Moisture cannot easily penetrate this layer and is relatively unavailable for more desirable vegetation (Ryerson 1970). Since *S. densa* generally occurs in climax communities and increases with grazing pressure, it would not likely be found in the relatively early successional stage of the disturbed transects. Although Ryerson (1970) reported that it often increases in abundance when competing vegetation is weakened or removed, there was no re-invasion even 50 to 75 years after plowing, cropping and subsequent return to grassland. In the same study, mechanical treatments such as pitting reduced cover 25 to 70% indicating that the removal of a 4 to 5 cm deep layer was critical to successful cover reduction, however, conditions for re-establishment of *S. densa* are unknown. The pipeline disturbance is similar to those studied by Ryerson (1970). The trenched and graded areas of the r-o-w have at least 5 cm of soil removed, thus predisposing the area to a reduction or elimination of *S. densa*.

Bouteloua gracilis begins growth up to a month later than either *Koeleria macrantha* or *Stipa* species (Coupland 1950). Thus higher frequency and basal area values in autumn are to be expected. *Bouteloua gracilis* is low growing and is therefore relatively resistant to grazing. Thus it may increase under early season grazing. Even though *Bouteloua gracilis* may be palatable in the late summer and autumn, its chief means of reproduction is through tillering, so any reduction in seed production would not be seriously detrimental to its survival. *Stipa* species are most affected by defoliation from the boot stage to the complete maturation of fruit (Pearson 1964; Wright 1967). Seed is cast in June and the plant remains relatively green and high in moisture content. By the time late season grazing begins *Stipa* species have increased tolerance to grazing.

The low autumn values for *Sphaeralcea coccinea* and *Phlox hoodii* are due to the early season growth habit of these forbs. By the time the autumn readings were taken these forbs would have been dormant.

Carex species complete their growth cycle long before any of the grasses do. Seeds are usually ripe by June (Coupland 1950), accounting in part, for the very low spring and autumn basal area estimates in this study compared to those found in other studies (Clarke *et al.* 1943; Coupland 1950, 1961).

The differences between 1982 and 1983 data probably reflect differences in quadrat size, shape and number. Frequency, in particular, is a function of quadrat shape and size, especially for species of intermediate abundance (Mueller-Dombois and Ellenberg 1974). It is unlikely that these differences are attributable only to the year to year variation in climate.

The trench area had a greater number of introduced species with lower basal area and frequency compared to other transects. Other disturbed transects were not trenched but only graded and therefore were more conducive to regrowth from species having intact or partially buried roots. This was particularly true for the forbs and half shrubs. *Artemisia frigida* appears to endure trampling and compaction but not burying, thus accounting for high values over the work area relative to pipelay, stockpile or trench areas. Similar responses were observed for *Gutierrezia sarothrae, Plantago* species and *Grindelia squarrosa*.

The higher basal area and frequency for many species in sites grazed late in the summer reflect the susceptibility of some species to early season grazing. This is particularly evident with *Agropyron pectiniforme* and *Descurainia sophia*. The increased competitiveness of *Agropyron pectiniforme* under a late season grazing regime has been reported by Coupland and Piemeisel (see Chapter 2). *Descurainia sophia* is not native to the mixed prairie but its seeds appear to be ubiquitous. On newly abandoned lands, part of the seed supply for most native species is already on the ground (Piemeisel 1951). Johnston *et al.* (1969) found 204 to 12342 seeds/m^2 in mixed prairie sites. Mustards such as *D. sophia* are particularly adapted to take advantage of any unutilized ground (Piemeisel 1951). Thus the high frequency and basal area of *D. sophia* in sites 1 and 4 are a result of dormant seed that had found favourable conditions to germinate. *D. sophia* is not resistant to grazing, even in early spring. Although it is relatively unpalatable (Piemeisel 1938, 1951), it has broad leaves and brittle stems making it highly susceptible to trampling. *D. sophia* germinates in the fall as soon as moisture is sufficient. Thus if seed is available on disturbed sites hospitable to growth, *D. sophia* may likely be one of the first species to germinate. Mustard seeds are small and smooth and have a high specific gravity making them conducive to easy burial in soil and for favourable contact with the soil surface (Evans and Young 1970). Furthermore, when moistened, a small amount of mucilage forms around the seeds promoting better soil contact and preventing moisture loss to the atmosphere (Young *et al.* 1970). Compared to perennial rangeland grasses, *D. sophia* germinates more rapidly and at much lower temperatures giving it another advantage in establishment (Young *et al.* 1970). It can easily form a dense cover the first spring following disturbance. If late season grazed, the seed matures and the process continues until it is outcompeted or seeds the ground so heavily that individual plants do not mature. If early season grazed, *D. sophia* probably does not survive heavy trampling and grazing by cattle.

Species such as *Hordeum jubatum* appeared most prevalent under early season grazing. Because of its low growing point and low palatability *Hordeum jubatum* is less susceptible to grazing and will likely thrive when other species such as *Elymus junceus* and *Agropyron pectiniforme* are reduced by grazing pressures. However, in late grazed sites, *Hordeum jubatum* is likely reduced through competition by species such as *Agropyron pectiniforme* and *Descurainia sophia* which have readily established. *Elymus junceus* has a weak seedling vigor due to a low net assimilation rate (Smoliak *et al.* 1970) and would likely be negatively affected by strong competitors like *Agropyron pectiniforme* and *Descurainia sophia*.

Koeleria macrantha is a vigorous native increaser as its prominence in the disturbed transects indicates. *K. macrantha* reseeds bared areas and because it begins growing early in the spring, can readily take advantage of any moisture reserves (Coupland 1950).

Species that tended to have high localized frequency and basal area were likely occupying favorable microsites created by the disturbance. The large number of forbs present perhaps indicates the efficiency of these species in secondary succession. Forbs are generally more efficient than grasses in using environmental resources, such as wind, for the dissemination of seeds and soil moisture and nutrients for germination and growth. Perhaps, most importantly, forbs are generally unpalatable and thus have a distinct advantage in heavily grazed systems. Piemeisel (1951) reported that the aggressiveness often associated with annual weeds can often be attributed to their entering a void in the native vegetation. Thus species such as *Descurainia sophia* and *Salsola kali* can dominate the vegetation initially until perennial species have become established.

The 1957 r-o-w was not seeded to an introduced mixture but was left abandoned and readily accessible to native species. The species that were present in any large number tended to be pioneer species, many of which were discussed by Coupland (1950). Others, such as *Artemisia cana*, readily appropriate areas under a heavy grazing regime that are covered by grass or bare soil. Many species which reproduce chiefly by means of seed, such as *Achillea millifolium* tended to be more prominent in the late season grazed sites, where the seedlings had a chance to mature.

During the final stages of pipeline construction, the 1968 and 1972 r-o-w were seeded to a mixture containing *Agropyron pectiniforme* whose most active growth period is in early spring. Dormancy occurs during summer (Smoliak *et al.* 1967). It generally does not suffer frost damage nor winter kill and is highly drought resistant due to its extensive root system. As a seedling it has the ability to produce a greater total root length than any other species (Plummer 1943). It is also an excellent weed competitor. All of these characteristics make *Agropyron pectiniforme* a species well suited to eventual dominance of a disturbed area. Hubbard (1949) indicated that when *A. pectiniforme* is grazed early in the spring, native dominants advance and compete successfully. Allred (1940) noted that *A. pectiniforme* rarely invaded climax stands of grass but can successfully outcompete even *Artemisia frigida* in disturbed areas.

In this study it was observed that *Agropyron pectiniforme* did invade adjacent undisturbed prairie but it never became a major component of the communities that it invaded. *A. pectiniforme* that had been seeded during pipeline revegetation usually responded to early season grazing by decreasing in both basal area and frequency. However, it appeared that *A. pectiniforme* which had invaded native prairie adjacent to the r-o-w did not respond in this manner. If self-seeded, *A. pectiniforme* tended to become a minor component of the vegetation. Under early season grazing it tended to increase in basal area and frequency while it declined under late season grazing. Although these differences were not significant they show a consistent trend. Most of the *A. pectiniforme* in early season grazed sites was on the periphery of blowout areas. These areas were dominated by *Opuntia polyacantha*. This could possibly make it less accessible by cattle and therefore contribute to its increased frequency and basal area.

Koeleria macrantha responded in a similar pattern to *Agropyron pectiniforme* under early season grazing. This species was higher in the 1963 r-o-w which is not dominated by *A. pectiniforme*. In the 1968 and 1972 r-o-w, where *A. pectiniforme* was seeded, *Koeleria* *macrantha* was apparently unable to compete. The lower values for *Bouteloua gracilis* in site 1 also reflect its inability to outcompete *A. pectiniforme* under a late season grazing regime. Similarly, *Hordeum jubatum* is a leading invader only where it is not competing with *A. pectiniforme* or other rapidly establishing, aggressive, deep-rooted perennials.

All of the species growing on the roadway were invaders, highly capable of colonizing eroded, inhospitable areas.

Pipeline disturbance in the study sites is similar to other types of disturbances documented by Coupland (1950, 1961) and Piemeisel (1940). The trench areas were most severely disturbed and were most similar to abandoned, cultivated lands. This is particularly true for the 1957 and 1963 trenches which were not seeded to introduced species. Other areas of the r-o-w were more closely related to bare ground areas found in undisturbed mixed prairie. Many of the species, or species of the same genus, noted by Coupland were found on the disturbed transects of the study sites. Similar stages of succession are evident in these disturbed transects with species composition significantly different from that of the undisturbed transects. Transects disturbed in 1981 were dominated by pioneer species. The older pipeline disturbances had more native species and there was a loss of dominance by the introduced species. With time, the disturbed areas appeared to be approaching the climax vegetation of the undisturbed transects but even after 24 years there were still significant differences in botanical composition between the disturbed and undisturbed transects. This slow return to predisturbed conditions was affected not only by the introduction of non-native species but also by the presence of a grazing factor. In Idaho, on sagebrush rangeland, Piemeisel (1951) also reported a longer period of time to reach climax conditions under grazing. Abandoned lands not subjected to grazing produced a grass cover that reflected the climax vegetation within five years.

The large number of native species in late season grazed sites is likely due to the influence of grazing. Under late season grazing, the surviving native species on the work and stockpile areas would have a chance to recuperate from the disturbance prior to grazing. Viable dormant seeds would germinate and mature. Johnston *et al.* (1969) reported that for the mixed prairie the number of viable seeds of grasses that germinated and emerged was greatest in ungrazed fields and lowest in heavily grazed fields. Species in the early season grazed sites would be defoliated and trampled at a time when they were most vulnerable to depletion of energy and nutrient reserves. Thus many species in sites 2 and 3 would not survive, whereas those in sites 1 and 4 would have time to recover from the pipeline disturbance before being subjected to the pressures of grazing. The trench area would take longer to recover because of the more severe disturbance. Plant roots and seeds were likely not on the trench and only introduced seeds were present. Seedlings would not grow and establish as rapidly as plants whose roots and crowns were already present, thus accounting for the smaller number of plants in the trench transect. The number of viable seeds near the surface would also decrease over the trench where mixing of soil horizons occurred. It has been reported that new seedlings will emerge from depths greater than 7.5 cm (Chippendale and Milton 1932). Where only the surface was graded these viable seeds would be larger in number and more likely to germinate.

Density was only determined for species growing on the seeded rows. Although native species may have been more numerous between these seeded rows in some areas, it was noted that the between row areas were not heavily populated. The seeding process had likely created a more favorable seedbed in the row spaces, as opposed to the between row spaces.

As live and dead vegetation increased bare ground decreased. The amount of bare ground was mainly a function of treatment, age of disturbance and season of grazing. The 1981 r-o-w, as the most recently disturbed area, had little chance to produce live ground cover or to accumulate litter prior to being sampled in 1982. The higher litter cover in late season grazed sites was related to the lower palatability of some vegetation at the time of grazing with subsequent non-use and trampling by cattle (Currie 1970).

Data such as those presented in Figure 5.1 can be somewhat misrepresentative. If *Selaginella densa* was removed from the undisturbed prairie, then the amount of live vegetation provided by other species was similar to that for older disturbed transects. Since *S. densa* is unpalatable, the productivity of the area may not have been dramatically reduced by pipeline disturbance, except over the 1981 r-o-w. Within 15 years the amount of live vegetation in the trenches had returned to near predisturbed conditions. The non-trench transects of the r-o-w appear to approach these conditions within 10 years. Even with the limited data available it is possible to speculate that there is a fairly rapid return to predisturbed levels of palatable forage under late season grazing. Although *S. densa* is an unpalatable species, it does provide protection from erosion. The time required for *S. densa* to invade these areas is not known. If many years are required, perhaps the protection against erosion would be provided by increased cover from the more palatable species that could increase in basal area under proper range management, making *S. densa* an undesirable species from a livestock grazier's point of view and unnecessary from a soil conservation point of view.

VI. ECOSYSTEM RECONSTRUCTION DYNAMICS

Ecosystem Reconstruction

Pipeline construction activities and subsequent operation of the pipeline had a profound effect on the range ecosystem. The most visible effects were the reduction or removal of vegetative cover in the r-o-w, construction of the berm which disrupted overland water flow and leveling of the land surface to fill in blowouts. Effects on the edaphic environment were less visible although some were longer lasting. Major ecological interactions which govern the interrelationships of microclimate, soils and plants were thus altered, at least temporarily, by pipeline construction.

The effects of pipeline construction on the range ecosystem were dependent on the type of disturbance. The trenching operation caused the most extensive disruption of the ecosystem whereas grading, compaction by heavy equipment and stockpiling soil were less disruptive.

Changes in vegetative and edaphic factors due to pipeline construction were compounded by the grazing regime imposed on the ecosystem. The early and late season grazing regimes had different effects on the vegetative composition. These vegetative changes may have affected soil properties such as bulk density and soil moisture but the lack of replication of soil parameters evaluated under different grazing regimes did not allow such comparisons.

Based on the literature it is likely that the increase in soil temperature as a result of moving heated natural gas through the pipeline could have an effect on plant growth in the trench although it is not within the scope of this study to evaluate this effect. Mixed prairie species root to depths ranging from 33 to 400 cm (Coupland and Johnson 1965), well within the depth range affected by the heated pipeline (60 to 110 cm). Any significant increase in soil temperature at rooting depths could also affect plants adjacent to the trench since lateral spread of roots is 2 to 36 cm for some mixed prairie grasses and forbs.

Soil temperatures over the pipeline at depths below 60 cm were between 0 and 6°C during the coldest parts of the winter. These temperatures were theoretically high enough to stimulate root tip growth (Hanson and Juska 1961). Root growth depends on auxins such as indole acetic acid, which are contained in roots in sufficient amounts to meet requirements for the entire growth period (Salisbury and Ross 1978). Thus root growth due to elevated temperatures in the rooting zone when the plant is dormant may be possible and only limited by the amount of labile carbohydrates present in the roots. Increased root activity in the winter months may enhance the plant's survival by increasing root length, lateral spread and biomass. However, elevated temperatures mean more rapid respiration in the roots and subsequently more rapid depletion of labile carbohydrates. If carbohydrate reserves are depleted too early in the winter, spring growth will be reduced or there will be detrimental effects on the plant's ability to survive.

Surface soil temperature changes resulting from pipeline construction may also affect vegetation. During the hottest parts of the summer surface temperatures in the 1981 trench were 30 to 35°C, higher than optimum for plant growth as reported in the literature. These temperatures could reduce dr matter production. Surface temperatures in the trench increased earlier in the spring and remained higher later in autumn, encouraging early and late season plant growth. Phenological growth is thus accelerated, facilitating seed set and carbohydrate storage before summer droughts. This could enhance survival rates for plants in arid environments, particularly those dependent on seed production. Late autumn growth may, however, be detrimental to the plants' survival, increasing the likelihood of winterkill in plants that are not in a dormant state at the time of the first severe frosts. Temperatures were often higher than optimum for efficient water use (Morrow and Power 1979) over the 1981 r-o-w during the hottest parts of the growing season. In an ecosystem that already has limited water, the decreased efficiency can be potentially detrimental to plant growth. These potential effects of soil temperature changes due to pipeline construction may be compensated for by the wide range of adaptability of cool season grasses to soil temperatures as reported by Morrow and Power (1979).

Increased soil surface temperatures in spring, decreased temperatures in winter and increased moisture in the r-o-w are expected until a vegetative cover is established. Higher temperatures and increased radiation on the bare soil surface will increase evaporation rate resulting in lower soil moisture (Moody *et al.* 1963; Blevins *et al.* 1971; Hay 1977). However, lower vegetation density over the disturbed areas decreases water use by plants, thereby increasing the amount of soil moisture in the total profile.

The berm over the pipeline served as an artificial barrier which trapped snow and impeded natural drainage during springmelt. Large amounts of snowmelt water may pond beside the berm early in the spring possibly affecting plant growth. Although soil water recharge from snow water is considered less efficient in the northern parts of the Great Plains where little snowmelt occurs until spring (Wight *et al.* 1975), higher surface temperatures in the r-o-w in the spring due to the lack of vegetative cover may increase the potential for infiltration of snowmelt water and subsequent increases in available water for spring plant growth.

Agropyron pectiniforme trapped snow very effectively because of its upright growth habit. This could contribute to less dynamic winter temperature fluctuations (Rauzi 1968; Schneider *et al.* 1978) and reduce frost damage and winterkill (Piemeisel 1938). Snow may also accumulate early and deeply enough to reduce the depth of frost penetration.

Chemical changes in the soil due to trenching and handling of subsurface material may contribute to reduced plant growth. Increased concentrations of sodium in the 1981 trench may have a direct toxic effect on sensitive species and change the balance of nutrients in relatively tolerant plants (Brady 1974). High sodium concentrations relative to those of calcium and magnesium may result in aggregate instability and dispersion of colloids, creating conditions that can indirectly affect seed germination, seedling emergence, crop growth and moisture transmission. Electrical conductivities were higher than 4 dS/m in the 1981 trench and could reduce growth and productivity of salt sensitive species by increasing osmotic pressure in the soil solution and reducing the amount of available water. Electrical conductivities at depths greater than 45 cm in all disturbed transects were also high enough to be a potential problem (Alberta Agriculture 1981). High EC and SAR values in disturbed areas did not persist above 30 cm and at lower depths have returned to predisturbed conditions within 15 years thereby reducing their impact on the long-term establishment of a vegetative cover in the r-o-w.

The increased surface pH resulting from pipeline construction activity probably did not restrict plant growth because most species can grow at a pH between 5 and 8, the pH after disturbance in the 0 to 30 cm zone was rarely higher than 8. Increased soil pH is theoretically high enough to influence the availability of some plant nutrients by affecting the absolute solubility of nutrient elements as well as their relative abundance (Brady 1974). However, pH had not increased significantly with disturbance and will therefore have no greater effect than did the soil pH prior to disturbance.

Increased surface bulk density due to compaction may pose a problem for seedling emergence and root establishment; it may also contribute to reduced root penetration and plant top growth (Adams *et al.* 1960; Rosenburg and Willits 1962; Wittsell and Hobbs 1964) in most of the disturbed transects. Associated reductions in pore size may restrict aeration thereby limiting development of a root system. Through the reduction of porosity, increased surface bulk density may affect the availability of nutrients and soil moisture. These problems may be partially compensated for by the increased water retention caused by increases in the number of small diameter pores. Compaction of surface soil may increase available soil water sufficiently to facilitate seed germination. Warkentin (1971) reported that compacted soils retained less water at low tension and more water at high tension due to the reduction in soil pore size.

Pipeline construction may cause infiltration problems by enhancing splash erosion, puddling and surface crusting because of reduced plant biomass. The compaction of soils after disturbance may reduce wind erosion, but because it reduces infiltration it can increase water erosion.

Changes in texture and organic carbon content associated with pipeline construction may also affect plant growth, most likely through reduced nutrient supply and poor soil structure.

The lack of vegetative cover can contribute to the persistence of soil physical and chemical changes resulting from pipeline installation. Elevated pH values are associated with a lack of vegetative cover. The rooting action of plants and subsequent microbial and faunal interactions in the rooting zone can improve aeration and permeability of the soil. These edaphic factors in turn contribute to changes in vegetation. These cause and effect processes are not always easily separated.

Revegetation practices must be based on the assumption that erosion, either by wind or water, will be a major problem following pipeline construction. Therefore the immediate objective is to provide a rapidly establishing, self-sustaining ground cover. Erosion, even on gently undulating surfaces, can be a problem if natural drainage patterns are impeded. The traditional berm-like construction over the trench resulted in local erosion problems particularly during the springmelt period at the study sites. The size of the berm increases with the size of the pipeline and is likely to be more of a problem with large diameter pipes. The natural drainage patterns of the area should be identified before pipeline installation. If the pipeline crosses a drainage way, berm height should be reduced and/or drainage bypasses set up so as not to disturb this drainage pattern. The berm usually settles within ten years and no longer poses any serious water erosion threats. Thus bypasses are only temporary but essential to reduce water erosion initially.

Wind erosion can be a serious problem in rangeland and once it begins, many factors converge to prevent plant re-establishment. Smooth hard surfaces offer only slight opportunity for seeds to lodge, the soil dries out rapidly, seedlings do not survive soil particle abrasion and erosion continues (Piemeisel 1938). Plant cover can reduce windspeed by as much as 70%, especially if the plant cover is tall as in the genus *Agropyron* (Aase *et al.* 1976). Stripcropping breaks large fields into smaller, less erodible fields (Aase *et al.* 1976); therefore, pipeline r-o-w, surrounded by undisturbed prairie, pose less of an erosion hazard than do disturbances of a greater width. Erosion can lead to heavy thinning of the climax community especially if it is accompanied by a soil disturbance resulting in readmittance of weedy annuals and changes in community structure (Piemeisel 1938).

The accumulation of litter is an important consideration in the prevention of erosion over recently disturbed sites. Vegetative ground cover, whether live or dead, determines the effectiveness of a vegetative cover for protecting the ground surface. Thus the litter component of the ground cover is as important as the density of the plant species forming the live vegetation component. Although *Selaginella densa* is an unpalatable species it is important for its erosion reducing properties. If it is removed from the disturbed ecosystem, care must be taken to ensure that its absence does not diminish the erosion reducing potential of the vegetation. Species selection for the r-o-w must include compensatory measures for the replacement of *Selaginella densa*.

When selecting species for revegetation, the ease of establishment is of primary importance. Larger seeded species, such as those from the genus *Agropyron*, have been successful on revegetating coal mined areas in Alberta due to superior seedling emergence. Native species, due to smaller seed size, exhibited poorer seedling emergence and poorer plant cover than introduced species (Tomm and Russell 1981). Percent plant cover was highly correlated with a high percentage of viable seed. The selection of species must be based on a knowledge of the germination, growth and developmental response of the grass species to different kinds of environmental situations. Ease of establishment is an important consideration but it cannot override the fact that species considered for reclaiming rangeland must also withstand drought and grazing pressures. Species which germinated well under wide temperature ranges and moisture conditions and were easy to establish often did not withstand drought when mature (McGinnies 1960). Speed of germination has, however, been singled out as a key factor in stand establishment in difficult situations (Johnston 1961b; Whalley *et al.* 1966). Smoliak and Johnston (1967) found that introduced species were superior to native species in percent germination and speed of emergence at various temperatures (7, 13, 18 and 27°C). Introduced species emerged and grew more rapidly under lower soil moisture conditions and had ten times more leaf area and eight times more roots than native seedlings. However, native species were considered more adapted to southern Alberta conditions of cool, moist springs and early summers followed by heat and drought in midsummer.

Seeding rate for native ranges must be considered before revegetation. Percent establishment of total plants in relation to number of seeds planted diminishes with seeding rates (Launchbaugh and Owensby 1970). Plant numbers increased significantly with increased seeding rates for many common native and introduced species but populations were always low compared to the amount of seed planted. The greatest plant survival was found for seeding rates of four pure live seed per 30 cm which resulted in a 9.3% plant establishment rate. Many factors influencing germination and emergence under field conditions preclude prescribing seeding rates of mixtures or single species that would result in a given number of plants per year. However, research indicates that relatively high seeding rates compared to agriculture will be required to produce stands of ten or more plants per 1.0 m^2 of native grasses seeded. Consistent relative behaviour of species and their independent performance in a mixture indicated that first year stand composition may be controlled to a large extent by formulating seed mixtures in terms of viable seed numbers rather than arbitrarily proportioning kg/ha in seedling mixtures.

Species must also be selected to reduce the attraction of cattle to the r-o-w. While an important objective of revegetation can be to provide forage for grazing, any treatment that encourages overgrazing will likely be unsuccessful in the long term. Treatments must in turn facilitate invasion by native species to replace the introduced species without negatively influencing the physical stability of the pipeline r-o-w. If an altered vegetative cover is desired on a long term basis, then the effect of grazing and season of grazing on individual species contained in the seed mixture must be considered. The implications of reclaiming a linear site to better than predisturbed conditions must be considered seriously. Creating a small section of the range that is much more productive and palatable will likely only lead to overuse of that particular section and result in unsuccessful revegetation. However, the advantage of having such a disturbance to use as a research site for range improvement cannot be overlooked.

Ecosystem Dynamics

After pipeline installation and revegetation of the r-o-w, the ecosystem moves towards a new equilibrium. Vegetation changes most rapidly and bare ground decreases substantially within a few years. Decreases in bare ground are attributed to litter accumulation, the successful germination and growth of introduced species and the invasion by ruderals.

Soil properties will change more slowly. Many years are necessary before soil texture will change as a result of pedogenesis. The only notable change will be attributed to selective redistribution of soil particles by wind and water transfer. Soil organic matter will increase slowly as plant debris and roots are broken down through microbial decomposition and erosion losses are reduced. Caspall (1975) indicated that if erosion is controlled under a good cover of grasses and legumes, normal pedogenic development will produce a soil with sufficient organic matter and other desirable properties to give it a characteristic A horizon in 20 to 30 years. It must be kept in mind that this time frame will vary with type of soil, rate of vegetation establishment and climatic conditions. A decrease in soil pH is expected as vegetation becomes more stabilized and leaching occurs. Leaching and water movement through the soil profile will also facilitate the reduction of salt concentration near the soil surface. Soil moisture retention will be increased by increased organic matter content. As the litter and vegetative cover increase, soil loss through wind and water erosion will be reduced. Decreased bulk density will result in increased hydraulic conductivity and soil porosity will continue to increase due to the activity of soil fauna and plant roots. At the same time the increase in vegetative cover will result in increased water use and therefore increased evapotranspiration.

Stable vegetative communities are expected to develop over time. Although soil properties change slowly, vegetative characteristics are likely to change rapidly due to population diversity and the short maturation time required for many species present in the area. Successional changes will result from the modification of the physical environment. The pioneer species, in this case the invaders and the introduced species, will thrive until restricted by rapidly growing dominant species common in the area. This dominance by pioneer species is likely to last for the first one to five years and the replacement by dominant native species will occur over the next ten to eighty years (Piemeisel 1938). Data from this study indicate that the dominance of pioneer species has been removed within ten years if introduced species are seeded following pipeline construction. Within 20 years, pioneer species with low frequency and basal area will be present if no introduced species have been seeded. Site specific extrapolations of such predictions must, however, be made with caution.

The capability of an ecosystem to adapt to a disturbance has been related to the stability of key parameters and their tendencies to evolve under changed circumstances (Walker *et al.* 1981). In the solonetzic mixed prairie it is assumed that these key parameters would revolve around the establishment of a stable ground cover with subsequent soil development, erosion reduction and succession of species to approach the desired stable climax of the undisturbed prairie. The parameters most negatively affecting the ground cover establishment appear to be spring erosion problems associated with the berm, grazing intensity and season of grazing.

Grazing of the area will be a major detriment to the establishment of a stable ground cover, yet plant-animal interactions are probably one of the most critical and least understood aspects of revegetation (Hernandez 1973). Successful revegetation after pipeline construction in native rangeland requires an effective range management program to expedite a self-sustaining, erosion reducing ground cover. Forage residues can be manipulated through grazing management by adjusting the season of grazing and stocking rate, thus increasing the amount of litter present at the end of the grazing season as well as decreasing the amount of live vegetation removed. The effect of grazing on germination and emergence must also be considered. Without trampling, only cracks will provide a suitable microclimate for germination, emergence and establishment (Eckert *et al.* 1978). With trampling, cracks may be filled too deeply with soil for seedling emergence or crusting depth and soil strength may increase by powdering soil on polygon surfaces. Larger seeds will emerge, smaller ones may not. Thus surface soil conditions as affected by grazing must be considered.

Grazing the r-o-w before seedlings can become well established will likely reduce their survival rate. It is often economically detrimental to the rancher to eliminate grazing during the first few years after revegetation. Grazing to aid in weed control and species selection is desirable but only once a good ground cover has been established. Fencing and weed control would likely be the most effective means of establishing a ready ground cover. However, the high costs of this reclamation step impose more pr[illegible]iderations. Nevertheless, the use of temporary fencing, such as the electric fence, c[illegible] promise: The most economical alternative appears to be a properly managed grazing [illegible].

Cattle are attracted to the r-o-w early in spring each year and tend to use it as a resting area. This must be taken into account when determining the grazing routine for the few years immediately following the disturbance. Cattle also tend to congregate at watering or feeding areas. Therefore locating dugouts and salt licks as well as feeding at a distance from the r-o-w is another passive means that can be employed to keep the cattle away from the r-o-w.

[illegible]reased productivity or dramatic changes in species composition over the r-o-w are inc[illegible]vergrazing, particularly if the productivity of the undisturbed range is low. Thus it is [illegible] to establish not only what the end land use will be but also what grazing management regime should be [illegible]ed. Early season grazing eliminated or reduced weeds such as *Descurainia sophia* that readily colonized disturbed areas. It also reduced the dominating influence of *Agropyron pectiniforme*, decreased vegetative cover and increased the amount of bare ground, increasing the erosion hazard. *Agropyron pectiniforme* has been considered to be a desirable species capable of increasing native range productivity. If so, it must be grazed early in the season to ensure its palatability but not grazed so heavily that it is eliminated. An appropriate grazing regimemst be chosen to accomplish these objectives once the seed mixture has been determined. Reducing both the stocking rate and the period of grazing for the first few years following revegetation would be be[illegible]. Rangeland should not be only autumn or spring grazed but these regimes should be rotated periodically.

Solonetzic soils are often deficient in nitrogen and phosphorus (Alberta Agriculture 1981), limiting plant growth. Continued fertilizing could result in increased productivity on the r-o-w compared to the native prairie and subsequent overutilization by cattle. Thus fertilization to any great extent is not recommended, other than to ensure available nutrients for initial plant growth. Mulching can be a key to establishing a desired plant cover (Curry 1975; Macyk and Stewart 1977; McKell 1978; Schumacher *et al.* 1977) but it may be too costly for serious consideration unless erosion is a major problem.

Revegetation encourages the establishment of a plant nutrient cycle and can enhance the development of a soil medium with more productive physical, chemical and biological characteristics. In this manner revegetation can accelerate the restoration of disturbed lands to their original condition. Under favourable environmental conditions, loss of plant cover as a result of developmental activities can be of short duration and can often be mitigated by natural succession.

VII. CONCLUSIONS

Pipeline construction in solonetzic mixed prairie had significant effects on soil chemical and physical properties and vegetative components of the ecosystem. These effects and their changes over time were compounded by the different construction activities and the grazing regime imposed on the system.

The most extensive disruptions resulted from the trenching operation. Immediately following the disturbance bare ground in the trench increased and vegetative cover decreased to near zero. Clay content and near surface bulk density increased and bulk density with depth decreased as a result of trenching. Total soil water in the trench increased from that in the undisturbed prairie and water retention became more uniform with depth. Available water capacity was not significantly affected by the pipeline disturbance. Surface soil temperature decreased in the winter and increased in the summer and soil temperature to 30 cm above the pipe increased in the winter. Total soluble salts increased in the trench, particularly near the surface. Surface organic carbon decreased, but there was no significant effect on pH.

Grading and compaction by heavy equipment were less destructive than the trenching operation. On the pipelay, work and stockpile transects, bulk density increased to a depth of approximately 55 cm and vegetative cover decreased significantly.

Ground cover of the older pipeline r-o-w was most similar to that of the undisturbed prairie, indicating a return to predisturbed conditions. This return was most rapid for transects other than the trench. Species composition also showed a trend towards predisturbed conditions. Bare ground increased observed wind erosion but the rapid revegetation by pioneer species appeared to reduce the problem. Berm construction impeded drainage during the springmelt with subsequent erosion problems which could be improved through construction of bypasses.

Changes in bulk density with depth due to pipeline construction persisted with time. Surface bulk density declined over the trench within ten years but there was no further decline towards predisturbed conditions. Soil moisture status was affected for a short period of time with a rapid movement towards predisturbed conditions within 25 years. For all chemical changes due to disturbance there was a definite trend towards predisturbed conditions.

Species composition followed successional trends common to the mixed prairie after a disturbance. Pioneer and introduced species dominated the trench but after 26 years species composition was not significantly different from that of the undisturbed prairie when early season grazed. Species composition was not altered in a negative manner. The elimination of *Selaginella densa* did not reduce the overall productivity of the vegetation since *S. densa* is unpalatable. Pioneer species invasion of the r-o-w did not persist beyond ten years and served as a deterrence for cattle if late season grazed.

Late season grazing favored the establishment of introduced species such as *Agropyron pectiniforme* as a monoculture and the dominance of pioneer species such as *Descurainia sophia*. Early season grazing reduced the dominance of pioneer and introduced species but resulted in more bare ground over a longer period of time. Pipeline disturbance completely eliminated *Selaginella densa* which had previously comprised 50% of the ground cover.

Changes in soil temperature, moisture availability, soil structure, organic matter content, soil bulk density and soil chemical properties as a result of pipeline construction each have the potential to affect plant growth. Combinations of these factors tend to reduce the negative or positive effects produced by an individual factor. A damping of factor effects is further enhanced by the ability of plant species to adapt to a changed environment. Many factors are not significantly altered by the disturbance over the long term and therefore may only be detrimental to the ecosystem over the short term, if at all.

Following the present pipeline construction technique and revegetation practices, the most significant factor that must be considered in revegetation is the grazing regime imposed on the solonetzic mixed prairie ecosystem. A thorough evaluation of the effects of the grazing regime on individual species must be considered in the determination of seed mixtures used in revegetation.

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APPENDIX I

Table 1. Location of neutron probe access tubes in sites 1 and 3.

Number of Tubes	Location (transect)	Distance From 1981 Trench (m)	Installation Date
5	1981 trench	-	November 1981
1	pipelay	3	November 1981
1	work	12	November 1981
1	undisturbed	22	November 1981
3	undisturbed	22	June 1983

Table 2. Location of neutron probe access tubes in site 2.

Number of Tubes	Location (transect)	Distance From 1981 Trench (m)	Installation Date
5	1981 trench	-	November 1981
3	pipelay	3	November 1981
3	work	12	November 1981
3	undisturbed 1	22-32	November 1981
3	stockpile	5	June 1983
3	1957 trench	10	June 1983
3	between 1957-1963	16.5	June 1983
3	1963 trench	19.5	June 1983
3	between 1963-1968	23.5	June 1983
3	1968 trench	33.5	June 1983
3	between 1968-1972	39.5	June 1983
3	1972 trench	44.5	June 1983
1	near roadway	49.5	June 1983
3	undisturbed 2	66	June 1983
4	undisturbed 1 blowout	22-32	June 1983

Table 3. Depth and location of thermistors in sites 1 and 3.

Depth (cm)	Location (transect)
5	1981 trench
15	1981 trench
5	pipelay
15	pipelay
120	pipelay
5	undisturbed (3 m from edge of r-o-w)
15	undisturbed (3 m from edge of r-o-w)

Microloggers located 9 m from 1981 trench in the work transect

Table 4. Depth and location of thermistors in site 2.

Depth (cm)	Location (transect)
5, 15, 30, 60, 80	1981 trench (2 replicates)
5, 15, 30, 60, 120	pipelay
5, 15, 30, 60, 120	work
5, 15, 30, 60, 120	undisturbed
5, 15, 30, 60, 110	1957 trench
5, 15, 30, 60, 100	between 1957-1963 trenches
approximately 100	inside shelter

Micrologger located 9 m from the 1981 trench in the work transect

APPENDIX II

Table 1. List of plant species in the study sites.

Botanical Name	Common Name
Achillea millifolium	woolly yarrow
Agoseris glauca	false dandelion
Agropyron pectiniforme	crested wheatgrass
Agropyron elongatum	tall wheatgrass
Agropyron intermedium	intermediate wheatgrass
Agropyron repens	quackgrass
Agropyron dasystachyum var *riparium*	northern wheatgrass
Agropyron smithii	western wheatgrass
Agropyron species	wheatgrass
Agropyron trachycaulum	slender wheatgrass
Agropyron trichophorum	pubescent wheatgrass
Allium textile	prairie onion
Amaranthus graecizans	prostrate amaranth
Amaranthus species	amaranth
Androsace septentrionalis	pygmy flower
Antennaria parvifolia	pussytoes
Arnica fulgens	arnica
Artemisia cana	hoary sagebrush
Artemisia frigida	pasture sage
Aster ericoides var *pansus*	tufted white prairie aster
Astragalus dasyglottis	milk-vetch
Astragalus bisulcatus	two-grooved milk-vetch
Astragalus cicer	cicer milk-vetch
Astragalus drummondii	Drummond's milk-vetch
Astragalus species	milk-vetch
Atriplex nuttallii	Nuttall's atriplex
Atriplex prostrata	orache
Bouteloua gracilis	blue grama grass
Campanula rotundifolia	harebell
Carex eleocharis	sedge
Carex filifolia	thread-leaved sedge
Carex species	sedge
Cerastium arvense	field chickweed
Chenopodium album	lamb's quarters
Chenopodium salinum	saline goosefoot
Chenopodium leptophyllum	narrow leaved goosefoot
Chenopodium species	goosefoot
Circium arvense	Canada thistle
Collomia linearis	narrow leaved collomia
Compositae species	composite species
Coryphantha vivipara	cushion cactus
Cruciferae species	mustard

Table 1. **List of plant species in the study sites (cont'd).**

Botanical Name	Common Name
Descurainia sophia	flixweed
Distichlis stricta	alkali grass
Elymus angustus	Altai wild rye
Elymus junceus	Russian wild rye
Elymus species	wild rye
Erigeron glabellus	rough fleabane
Erigeron canadensis	horseweed
Erysimum inconspicuum	small-flowered prairie-rocket
Festuca species	fescue
Gaillardia aristata	gaillardia
Gaura coccinea	scarlet gaura
Geum triflorum	three-flowered avens
Gramineae species	grass
Grindelia squarrosa	gumweed
Gutierrezia sarothrae	broomweed
Helianthus villosa	hairy golden aster
Hordeum jubatum	wild barley
Koeleria macrantha	junegrass
Lactuca species	lettuce
Lappula squarrossa	blueburr
Lappula occidentalis	burr
Lepidium densiflorum	common peppergrass
Linum lewisii	wild blue flax
Linum rigidum	large-flowered yellow flax
Lithospermum ruderale	yellow poccoon
Lolium perenne	rye species
Medicago falcata	alfalfa
Medicago sativa	alfalfa
Mellilotus officinalis	yellow sweet clover
Monolepis nuttalliana	spear leaved goosefoot
Onobrychis viciifolia	sainfoin
Onograceae species	evening primrose
Opuntia polyacantha	prickly-pear cactus
Oxytropis sericea	early yellow locoweed
Oxytropis species	locoweed
Parmelia chlorochroa	lichen
Phlox hoodii	moss phlox
Plantago elongata	linear-leaved plantain
Plantago lanceolata	ribgrass
Plantago patagonica	Pursh's plantain
Poa pratensis	Kentucky blue grass
Poa sandbergii	Sandberg's blue grass

Table 1. List of plant species in the study sites (cont'd).

Botanical Name	Common Name
Polygonum arenastrum	common knotweed
Portulaca oleracea	purslane
Potentilla anserina	silverweed
Potentilla bipinnatifida	plains cinquefoil
Potentilla fruticosa	shrubby cinquefoil
Ratibida columnifera	long-headed coneflower
Rosa acicularis	prickly rose
Salsola kali	Russian thistle
Schedonnardus paniculatus	tumblegrass
Selaginella densa	little club moss
Setaria viridis	green foxtail
Sisyrinchium montanum	blue-eyed grass
Solanum triflorum	wild tomato
Sonchus arvensis	perennial sow thistle
Sphaeralcea coccinea	apricot mallow
Stipa comata	spear grass
Stipa curtiseta	western porcupine grass
Stipa species	needle grass
Stipa viridula	green needle grass
Symphoricarpus occidentalis	western snowberry
Taraxacum officinale	dandelion
Thermopsis rhombifolia	golden bean
Thlaspi arvense	stinkweed
Tragopogon dubius	goat's beard
Veronica peregrina	hairy speedwell
Vicia americana	American vetch
Vicia species	vetch
Xanthium strumarium	cockleburr

Table 2. Mean frequency(%) and basal area(%) of species in the undisturbed prairie (n=100; June, 1983).

	Late season grazed				Early season grazed			
	Site 1		Site 4		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	8	4.8	8	1.2	-	-	1	3.5
Agropyron pectiniforme	2	+	1	0.5	2	+	14	0.1
Agropyron repens	5	0.8	-	-	-	-	-	-
Agropyron smithii	13	0.4	17	0.8	11	0.2	7	0.4
Allium textile	-	-	-	-	-	-	1	+
Androsace septentrionalis	-	-	-	-	-	-	6	+
Antennaria parvifolia	4	7.1	4	2.1	2	0.5	5	4.4
Arnica species	13	0.5	11	0.7	-	-	-	-
Artemisia cana	1	0.5	21	1.4	2	8.0	-	-
Artemisia frigida	78	7.5	51	5.5	68	4.1	78	8.0
Astragalus species	25	2.3	3	18.2	2	0.3	5	0.3
Atriplex species	-	-	-	-	1	+	-	-
Bouteloua gracilis	74	2.7	64	3.2	80	0.5	77	0.8
Campanula rotundifolia	2	2.0	1	+	-	-	-	-
Carex species	48	0.1	44	0.1	58	0.4	88	0.1
Cerastium arvense	8	3.4	4	1.1	-	-	2	4.3
Chenopodium species	2	0.3	1	+	-	-	-	-
Coryphantha vivipara	1	3.5	-	-	-	-	-	-
Descurainia sophia	1	+	-	-	-	-	-	-
Erigeron asper	1	0.5	-	-	-	-	-	-
Erysimum inconspicuum	50	+	26	+	1	+	10	+
Gaura coccinea	-	-	3	1.5	1	0.5	-	-
Grindelia squarrosa	5	0.2	2	+	8	0.1	11	0.2
Gutierrezia sarothrae	1	0.5	3	5.5	11	0.2	14	1.9
Helianthus villosa	1	0.5	-	-	-	-	-	-
Hordeum jubatum	-	-	-	-	2	+	-	-
Koeleria macrantha	88	3.8	83	2.1	81	2.5	95	2.7
Lappula species	11	0.4	1	+	-	-	-	-
Linum species	4	+	1	+	1	+	-	-
Lithospermum ruderale	-	-	-	-	1	+	1	+
Opuntia polyacantha	3	0.2	2	+	5	3.8	1	0.5
Onobrychis viciifolia	-	-	-	-	-	-	4	+
Oxytropis sericea	3	0.5	-	-	-	-	1	+
Phlox hoodii	25	2.8	17	1.6	33	3.0	45	4.2
Plantago species	40	0.2	11	+	33	6.0	18	+
Poa species	18	0.7	-	-	1	0.5	21	2.2
Polygonum arenastrum	2	+	1	+	1	+	-	-
Potentilla species	1	0.5	2	+	-	-	1	+
Selaginella densa	93	31.8	87	17.8	80	15.9	89	38.0
Sphaeralcea coccinea	82	1.3	54	0.4	16	0.7	28	0.1
Stipa species	54	2.8	61	5.7	50	1.0	20	0.7
Taraxacum officinale	1	3.5	2	5.8	2	+	-	-
Tragopogon dubius	3	0.2	2	0.3	-	-	-	-
Vicia americana	-	-	23	0.2	2	+	15	0.1

Table 3 Mean frequency(%) and basal area(%) of species in the work transect (n=100, June, 1983).

	Late season grazed				Early season grazed			
	Site 1		Site 4		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	3	1.3	-	-	-	-	4	1.6
Agropyron pectiniforme	34	4.0	57	3.8	21	1.0	27	3.1
Agropyron repens	-	-	-	-	-	-	11	3.1
Agropyron smithii	51	3.7	21	2.2	31	0.5	18	1.5
Agropyron trachycaulum	1	3.5	-	-	-	-	-	-
Agropyron trichophorum	4	2.0	-	-	-	-	-	-
Allium textile	-	-	-	-	3	+	1	+
Androsace septentrionalis	-	-	-	-	4	+	1	+
Antennaria parvifolia	1	3.5	-	-	-	-	-	-
Arnica species	-	-	-	-	-	-	-	+
Artemisia frigida	11	3.0	19	1.1	50	0.4	61	5.9
Astragalus species	9	0.1	3	+	3	0.2	11	+
Atriplex species	-	-	-	-	11	0.5	-	-
Bouteloua gracilis	-	-	-	-	-	-	3	0.2
Carex species	-	-	-	-	-	-	3	+
Cerastium arvense	-	-	-	-	-	-	2	1.6
Chenopodium species	2	+	3	+	4	+	5	+
Collomia linearis	1	+	-	-	-	-	-	-
Descurainia sophia	88	7.5	88	2.8	1	+	-	-
Elymus species	3	1.3	1	3.5	28	0.9	12	3.2
Erigeron asper	-	-	-	-	1	+	-	-
Erysimum inconspicuum	2	+	1	+	-	-	2	+
Gaura coccinea	-	-	-	-	-	-	1	+
Gramineae species	-	-	-	-	2	0.3	-	-
Grindelia squarrosa	5	4.4	6	0.3	16	0.2	37	5.9
Gutierrezia sarothrae	2	+	38	0.6	4	0.1	2	3.5
Hordeum jubatum	4	0.4	-	-	1	+	2	2.0
Koeleria macrantha	14	3.7	-	-	11	1.2	10	0.4
Lappula species	41	0.4	24	0.5	1	+	1	+
Lepidium densiflorum	17	1.3	-	-	13	0.1	2	4.3
Lithospermum ruderale	-	-	-	-	-	-	5	2.8
Lolium perenne	-	-	-	-	-	-	2	4.0
Medicago species	13	0.[illegible]	37	1.0	7	0.1	7	0.6
Melilotus officinalis	5	0.8	-	-	-	-	2	1.8
Monolepis nuttalliana	1	0.5	-	-	8	0.1	1	+
Opuntia polyacantha	-	-	-	-	1	+	-	-
Onobrychis viciifolia	1	0.5	-	-	-	-	1	0.3
Phlox hoodii	4	7.1	7	0.7	7	0.3	5	3.0
Plantago species	17	0.2	11	+	38	+	10	0.2
Poa species	5	0.3	-	-	5	0.8	3	+
Polygonum arenastrum	47	1.3	2	+	67	0.2	63	1.0
Salsola kali	-	-	-	-	-	-	1	0.5
Schedonnardus paniculatus	-	-	-	-	-	-	1	+
Selaginella densa	-	-	-	-	-	-	1	0.5
Sphaeralcea coccinea	32	0.6	55	0.8	13	0.1	21	0.9
Stipa species	35	2.4	19	2.5	34	0.1	31	3.3
Taraxacum officinale	-	-	-	-	1	+	2	1.8
Tragopogon dubius	-	-	1	+	-	-	-	-
Vicia americana	10	1.7	2	0.3	-	-	8	0.4

Table 4. Mean frequency(%) and basal area(%) of species in the pipelay transect (n=100; June, 1983).

	Late season grazed				Early season grazed			
	Site 1		Site 4		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	-	-	-	-	1	+	1	0.5
Agropyron pectiniforme	21	4.7	24	2.8	24	0.7	21	1.3
Agropyron elongatum	2	0.3	17	1.2	1	0.6	-	-
Agropyron intermedium	-	-	7	1.4	-	-	-	-
Agropyron repens	9	2.5	4	0.5	-	-	17	0.4
Agropyron riparium	-	-	13	2.1	-	-	-	-
Agropyron smithii	44	4.1	35	1.7	37	+	28	1.8
Agropyron trachycaulum	-	-	15	1.4	1	+	-	-
Agropyron trichophorum	7	2.6	18	1.4	-	-	-	-
Allium textile	1	+	-	-	-	-	-	-
Androsace septentrionalis	-	-	1	+	-	-	1	+
Artemisia frigida	-	-	2	0.5	23	0.5	23	3.5
Astragalus species	-	-	-	-	2	+	5	0.4
Atriplex species	2	+	4	0.1	-	-	4	0.1
Bouteloua gracilis	-	-	-	-	2	0.3	1	0.5
Chenopodium species	-	-	2	0.5	2	+	-	-
Descurainia sophia	78	4.5	81	1.4	1	+	-	-
Distichlis stricta	-	-	-	-	-	-	1	0.5
Elymus species	10	2.5	6	2.5	12	0.5	23	2.8
Gramineae species	-	-	-	-	11	0.2	1	0.2
Grindelia squarrosa	-	-	3	0.3	9	0.1	17	2.8
Gutierrezia sarothrae	-	-	-	-	2	0.3	1	3.5
Hordeum jubatum	1	0.5	-	-	6	2.2	5	1.7
Koeleria macrantha	2	8.0	-	-	3	0.2	-	-
Lappula species	38	0.4	20	0.7	-	-	-	-
Lepidium densiflorum	15	0.3	2	0.3	8	+	1	+
Lithospermum ruderale	-	-	-	-	2	+	-	-
Medicago species	20	2.1	18	0.5	7	0.1	12	0.9
Mellilotus officinalis	2	2.0	-	-	-	-	-	-
Monolepis nuttalliana	7	0.4	1	+	7	0.1	4	0.1
Onobrychis viciifolia	2	0.5	4	0.5	1	+	7	+
Phlox hoodii	-	-	1	0.5	4	0.1	1	0.5
Plantago species	4	4.7	1	+	18	0.1	2	+
Poa species	4	2.0	-	-	1	+	10	1.2
Polygonum arenastrum	75	2.4	15	0.5	64	0.3	47	0.6
Potentilla species	-	-	-	-	-	-	1	+
Ratibida columnifera	-	-	1	+	-	-	[illegible]	-
Salsola kali	-	-	-	-	-	-	[illegible]	+
Sphaeralcea coccinea	30	2.4	54	1.2	5	0.1	13	0.1
Stipa species	8	1.1	6	0.4	7	0.5	13	0.5
Symphoricarpus occidentalis	-	-	-	-	-	-	1	0.5
Taraxacum officinale	1	0.5	-	-	3	+	2	+
Veronica peregrine	-	-	-	-	-	-	1	+
Vicia species	9	0.5	24	1.4	6	+	15	0.2

Table 5. Mean frequency(%) and basal area(%) of species in the 1981 trench transect (n=100, June, 1983).

	Late season grazed				Early season grazed			
	Site 1		Site 4		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA
Agropyron pectiniforme	14	6.0	27	1.7	17	3.8	20	3.3
Agropyron repens	7	2.4	7	1.3	-	-	8	0.2
Agropyron riparium	-	-	-	-	1	+	-	-
Agropyron smithii	19	4.0	33	2.4	23	1.1	33	2.0
Agropyron trachycaulum	-	-	16	2.8	-	-	2	3.5
Agropyron trichophorum	2	4.3	11	2.7	-	-	7	2.6
Artemisia frigida	-	-	-	-	1	+	-	-
Astragalus species	-	-	2	0.5	-	-	1	0.5
Atriplex species	2	8.5	4	0.3	-	-	4	0.3
Bouteloua gracilis	1	6.7	-	-	-	-	-	-
Chenopodium species	5	+	-	-	5	6.0	-	-
Descurainia sophia	86	2.3	39	0.5	-	-	-	-
Elymus species	25	6.6	16	3.1	23	2.0	35	3.1
Gramineae species	-	-	-	-	8	0.5	-	-
Grindelia squarrosa	-	-	-	-	2	0.3	2	0.3
Gutierrezia sarothrae	-	-	-	-	-	-	2	+
Hordeum jubatum	1	8.0	-	-	1	+	1	3.5
Koeleria macrantha	-	-	-	-	1	+	-	-
Lappula species	16	0.2	14	0.3	-	-	-	-
Lepidium densiflorum	-	-	-	-	1	+	-	-
Lolium perenne	3	0.2	-	-	-	-	1	3.5
Medicago species	6	3.0	20	0.7	5	0.1	2	0.6
Monolepis nuttalliana	32	2.8	4	0.4	5	0.1	7	0.6
Onobrychis viciifolia	3	1.3	2	0.3	4	0.1	8	0.4
Polygonum arenastrum	55	2.0	14	1.5	35	0.6	27	0.5
Potentilla species	-	-	-	-	-	-	1	+
Salsola kali	-	-	-	-	-	-	1	0.6
Sphaeralcea coccinea	1	0.5	2	0.3	-	-	-	-
Stipa species	1	3.5	1	0.5	1	+	5	0.3
Vicia americana	-	-	12	1.3	2	+	-	-

Table 6. Mean frequency(%) and basal area(%) of species in the stockpile transect (n=100, June, 1983).

	Late season grazed				Early season grazed			
	Site 1		Site 4		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	-	-	1	0.5	2	4.0	5	1.4
Agropyron pectiniforme	16	1.7	38	1.2	32	2.5	32	0.7
Agropyron elongatum	1	3.5	-	-	1	+	-	-
Agropyron intermedium	-	-	3	1.2	-	-	-	-
Agropyron repens	2	3.5	-	-	-	-	5	2.3
Agropyron riparium	-	-	3	0.5	-	-	-	-
Agropyron smithii	47	1.9	61	1.4	34	1.0	60	0.6
Agropyron species	-	-	-	-	4	+	-	-
Agropyron trachycaulum	2	2.0	5	2.0	2	0.3	-	-
Agropyron trichophorum	-	-	2	0.3	-	-	-	-
Androsace septentrionalis	-	-	-	-	1	+	-	-
Antennaria parvifolia	1	+	-	-	-	-	1	0.5
Artemisia cana	-	-	-	-	-	-	3	12.8
Artemisia frigida	4	2.1	1	3.5	14	1.4	9	5.1
Astragalus species	-	-	-	-	-	-	13	+
Atriplex species	7	0.3	13	0.1	-	-	5	+
Bouteloua gracilis	5	2.8	2	0.3	4	0.1	3	1.2
Cerastium arvense	2	0.5	-	-	-	-	2	5.6
Chenopodium species	9	0.1	2	+	10	0.1	3	+
Descurainia sophia	93	3.1	65	1.5	3	1.2	1	+
Distichlis stricta	-	-	-	-	-	-	2	0.3
Elymus species	6	3.8	4	5.8	20	1.3	14	1.6
Erigeron asper	-	-	1	8.0	-	-	-	-
Gaura coccinea	-	-	-	-	-	-	3	27.0
Grindelia squarrosa	4	0.3	-	-	3	1.3	8	0.4
Gutierrezia sarothrae	-	-	-	-	1	+	4	9.5
Hordeum jubatum	3	1.5	-	-	6	5.2	1	0.5
Koeleria macrantha	9	2.1	6	3.9	19	1.0	19	1.5
Lappula species	41	0.4	35	0.7	-	-	-	-
Lepidium densiflorum	20	0.3	10	0.7	6	0.7	3	0.2
Linum species	1	+	-	-	-	-	-	-
Lithospermum ruderale	-	-	-	-	1	0.5	1	+
Lolium perenne	-	-	-	-	15	0.7	-	-
Medicago species	10	2.0	17	0.3	12	0.0	7	0.1
Monolepis nuttalliana	43	0.9	8	0.1	7	0.6	9	0.1
Opuntia polyacantha	-	-	-	-	2	+	-	-
Onobrychis viciifolia	1	+	-	-	4	2.6	1	0.6
Oxytropis sericea	-	-	-	-	1	0.5	-	-
Phlox hoodii	-	-	1	3.5	3	2.5	10	0.9
Plantago species	-	-	-	-	10	1.3	2	+
Poa species	6	0.9	-	-	2	+	3	+
Polygonum arenastrum	88	0.8	28	0.8	61	0.5	40	0.3
Ratibida columnifera	-	-	-	-	-	-	2	0.3
Scheddonardis paniculatus	-	-	-	-	2	+	-	-
Sphaeralcea coccinea	32	0.8	39	0.8	16	0.4	23	0.3
Stipa species	10	1.5	14	2.3	28	0.6	25	1.3
Taraxacum officinale	-	-	-	-	-	-	5	0.8
Vicia americana	13	+	18	0.9	1	+	16	0.9

Table 7 Mean frequency(%) and basal area(%) of species in the 1957 trench transect (n=100, June, 1983).

	Late season grazed				Early season grazed			
	Site 1		Site 4		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	15	1.3	9	5.1	19	1.6	29	6.7
Agropyron pectiniforme	1	0.5	1	3.5	-	-	1	0.5
Agropyron repens	2	3.5	1	0.8	8	2.1	5	4.4
Agropyron smithii	16	0.6	19	2.2	8	2.5	5	+
Androsace septentrionalis	-	-	-	-	-	-	-	-
Antennaria parvifolia	2	2.0	4	13.8	3	3.5	3	14.7
Arnica species	1	+	-	-	-	-	-	-
Artemisia cana	3	1.6	8	8.9	6	5.1	8	17.9
Artemisia frigida	53	3.6	43	2.7	84	1.6	74	9.3
Astragalus species	23	0.2	6	2.8	-	-	22	0.1
Bouteloua gracilis	34	+	38	2.6	1	+	5	0.2
Carex species	-	-	-	-	1	+	1	+
Cerastium arvense	8	3.9	7	+	2	0.3	7	1.1
Chenopodium species	-	-	1	+	-	-	1	+
Descurainia sophia	-	-	1	0.5	3	0.2	-	-
Erigeron asper	3	1.3	7	0.7	3	+	-	-
Erysimum inconspicuum	5	+	1	+	-	-	3	+
Gaura coccinea	24	4.5	20	0.6	-	-	3	2.7
Grindelia squarrosa	3	0.2	7	1.8	10	0.1	17	2.5
Gutierrezia sarothrae	42	2.6	53	2.8	39	2.4	67	5.9
Hordeum jubatum	-	-	-	-	4	1.1	-	-
Koeleria macrantha	95	3.9	85	1.7	84	6.9	95	3.2
Lappula species	-	-	1	0.5	-	-	-	-
Lepidium densiflorum	1	+	4	0.1	-	-	-	-
Linum species	5	+	4	+	-	-	-	-
Mellilotus officinalis	1	0.5	-	-	-	-	-	-
Opuntia polyacantha	-	-	-	-	4	6.4	-	-
Onobrychis viciifolia	-	-	-	-	1	+	-	-
Oxytropis species	4	1.3	-	-	-	-	1	3.5
Phlox hoodii	1	3.5	7	10.6	4	1.1	4	2.8
Plantago species	10	+	1	0.1	1	1.1	30	3.6
Poa species	7	+	1	0.1	8	1.3	55	0.5
Polygonum arenastrum	1	+	4	0.1	2	+	3	0.2
Ratibida columnifera	9	1.1	3	4.0	1	+	7	0.6
Rosa acicularis	-	-	-	-	-	-	4	7.5
Sphaeralcea coccinea	31	1.1	28	0.6	24	0.1	36	1.2
Stipa species	40	2.7	32	2.6	37	1.4	40	5.0
Symphoricarpus occidentalis	-	-	-	-	1	3.5	-	-
Taraxacum officinale	11	6.2	8	11.3	24	1.3	20	2.8
Tragopogon dubius	8	0.3	6	1.5	-	-	5	0.2
Vicia americana	25	0.6	49	0.8	20	0.3	43	0.8

Table 8. Mean frequency(%) and basal area(%) of species between the 1957 and 1983 trenches (n=100; June, 1983).

	Late season grazed				Early season grazed			
	Site 1		Site 4		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	28	0.8	5	2.5	27	2.1	28	2.5
Agropyron pectiniforme	1	0.5	-	-	-	-	-	-
Agropyron repens	5	2.3	-	-	-	-	10	0.4
Agropyron smithii	58	1.3	13	0.3	15	1.8	1	+
Allium textile	-	-	-	-	1	+	1	+
Antennaria parvifolia	9	8.4	7	10.5	3	2.8	5	7.6
Arnica species	-	-	-	-	1	+	-	-
Artemisia cana	8	2.5	8	17.2	3	6.5	5	18.5
Artemisia frigida	58	2.5	73	4.3	53	2.2	70	3.3
Astragalus species	18	0.3	8	+	6	0.3	25	0.3
Bouteloua gracilis	3	+	31	0.9	1	+	13	0.4
Campanula rotundifolia	1	0.5	-	-	-	-	-	-
Carex species	3	0.3	8	+	3	1.5	6	0.1
Cerastium arvense	2	0.6	2	18.0	20	2.4	4	5.4
Coryphantha vivipara	-	-	1	0.5	-	-	-	-
Descurainia sophia	1	+	1	+	1	+	-	-
Erigeron asper	8	0.6	9	0.8	8	+	-	-
Erysimum inconspicuum	-	-	1	+	-	-	3	+
Gaillardia aristata	-	-	1	0.5	-	-	-	-
Gaura coccinea	1	3.5	8	3.3	2	+	2	0.3
Geum triflorum	-	-	-	-	1	+	-	-
Grindelia squarrosa	15	0.4	7	0.2	27	1.6	15	1.0
Gutierrezia sarothrae	46	1.8	38	2.9	46	2.0	65	2.8
Helianthus villosa	8	1.6	-	-	-	-	-	-
Hordeum jubatum	-	-	-	-	4	1.3	-	-
Koeleria macrantha	98	8.8	88	2.3	97	6.4	86	3.1
Lappula species	-	-	1	+	-	-	-	-
Lepidium densiflorum	-	-	-	-	1	0.5	-	-
Linum species	5	0.9	4	0.3	1	0.9	1	+
Medicago species	-	-	-	-	-	-	1	+
Opuntia polyacantha	-	-	-	-	-	-	1	3.5
Oxytropis sericea	1	+	-	-	-	-	1	0.5
Phlox hoodii	1	+	14	2.7	1	3.5	9	1.3
Plantago species	23	0.2	6	0.1	11	+	5	+
Poa species	8	5.0	3	0.2	33	2.4	43	0.9
Polygonum arenastrum	-	-	-	-	2	+	-	-
Potentilla species	-	-	-	-	2	0.3	-	-
Ratibida columnifera	3	1.2	1	0.5	20	0.6	8	0.1
Rosa acicularis	-	-	-	-	-	-	3	1.3
Sphaeralcea coccinea	20	0.8	38	1.1	22	0.1	31	0.3
Stipa species	29	7.7	47	4.8	17	1.0	33	1.8
Symphoricarpus occidentalis	-	-	-	-	-	-	1	0.5
Taraxacum officinale	16	1.2	7	3.1	54	3.0	18	1.1
Tragopogon dubius	7	0.5	3	0.2	-	-	4	0.4
Vicia americana	28	1.5	19	0.5	12	0.7	11	0.9

Table 9. Mean frequency(%) and basal area(%) of species in the undisturbed prairie (n=12; June and September, 1982)

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	8.3	+	+	+	+	+	8.3	+	+	+	+	+
Agropyron pectiniforme	41.7	2.1	+	+	+	+	+	+	+	+	+	+
Agropyron smithii	41.7	0.1	+	+	+	+	+	+	+	+	+	+
Agropyron species	8.3	+	+	+	+	+	+	+	+	+	+	+
Antennaria parvifolia	8.3	+	25.0	2.3	8.3	0.5	+	0.1	16.7	0.5	8.3	0.5
Artemisia cana	+	+	8.3	3.5	+	+	+	+	8.3	5.7	+	+
Artemisia frigida	75.0	1.8	100.0	2.2	100.0	3.0	83.3	5.5	100.0	+	100.0	3.3
Astragalus species	41.7	0.1	+	+	33.3	+	41.7	+	+	+	16.7	+
Bouteloua gracilis	75.0	1.4	100.0	0.7	100.0	2.5	100.0	5.0	100.0	5.4	100.0	3.3
Campanula rotundifolia	8.3	+	+	+	+	+	+	+	+	+	+	+
Carex species	+	+	+	+	58.3	+	+	+	33.3	+	58.3	+
Cerastium arvense	+	+	8.3	+	+	+	+	+	+	+	+	+
Chenopodium species	41.7	+	8.3	+	8.3	+	33.3	0.1	+	+	+	+
Erigeron asper	8.3	+	+	+	+	+	+	+	+	+	+	+
Erysimum inconspicuum	+	+	+	+	+	+	+	+	8.3	+	+	+
Gaura coccinea	8.3	+	+	+	+	+	+	+	+	+	+	+
Grindelia squarrosa	8.3	+	16.7	2.0	16.7	+	8.3	+	16.7	0.3	25.0	+
Gutierrezia sarothrae	+	+	41.7	+	16.7	+	+	+	33.3	+	25.0	+
Koeleria macrantha	100.0	5.8	100.0	9.0	100.0	3.3	8.3	+	+	+	8.3	+
Lappula species	8.3	+	+	+	+	+	+	+	+	+	+	+
Lepidium densiflorum	8.3	+	+	+	+	+	+	+	+	+	+	+
Opuntia polyacantha	+	+	33.3	1.1	8.3	18.0	+	+	25.0	0.2	8.3	18.0
Parmelia chlorochroa	58.3	+	100.0	2.2	100.0	+	50.0	0.6	75.0	0.3	100.0	1.8
Phlox hoodii	41.7	0.9	41.7	1.0	5 +	0.4	+	+	+	+	41.7	1.0
Plantago species	66.7	0.4	+	+	+	+	41.7	0.7	8.3	+	+	+
Polygonum arenastrum	8.3	+	+	+	+	+	+	+	+	+	+	+
Potentilla species	+	+	+	+	16.7	+	+	+	+	+	8.3	+
Salsola kali	+	+	+	+	+	+	+	+	8.3	+	+	+
Selaginella densa	100.0	49.3	100.0	55.5	100.0	78.3	100.0	41.3	100.0	68.2	100.0	83.2
Sphaeralcea coccinea	75.0	0.9	33.3	+	75.0	0.1	58.3	+	50.0	+	50.0	+
Stipa species	83.3	1.5	+	+	66.7	+	83.3	2.9	+	+	16.7	+
Taraxacum officinalis	+	+	8.3	+	+	+	+	+	8.3	+	+	+

Table 10. Mean frequency(%) and basal area(%) of species in the semi-disturbed prairie (n=12, June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Agropyron pectiniforme	8.3	3.5	8.3	+	8.3	0.5	8.3	3.5	+	+	25.0	+
Agropyron smithii	+	+	+	+	33.3	+	+	+	+	+	16.7	+
Antennaria parvifolia	8.3	+	25.0	0.2	+	+	+	+	25.0	0.2	+	+
Artemisia cana	+	+	16.7	4.0	+	+	+	+	16.7	4.0	+	+
Artemisia frigida	91.7	1.8	91.7	4.2	100.0	2.5	91.7	3.5	91.7	3.5	100.0	4.0
Astragalus species	16.7	+	16.7	+	16.7	+	+	+	8.3	+	16.7	0.3
Bouteloua gracilis	100.0	0.9	100.0	1.6	100.0	0.5	83.3	2.8	100.0	7.3	100.0	3.7
Carex species	+	+	+	+	75.0	+	+	+	+	+	+	+
Chenopodium species	33.3	+	8.3	+	25.0	+	+	+	+	+	+	+
Gaura coccinea	+	+	+	+	+	+	+	+	8.3	+	+	+
Grindelia squarrosa	16.7	+	41.7	0.7	8.3	+	8.3	+	41.7	0.7	33.3	0.8
Gutierrezia sarothrae	16.7	+	66.7	0.4	16.7	+	+	+	41.7	0.2	8.3	+
Koeleria macrantha	100.0	4.0	100.0	2.3	91.7	5.5	33.3	+	+	+	8.3	+
Lappula species	8.3	+	+	+	+	+	+	+	+	+	+	+
Medicago species	+	+	+	+	16.7	+	+	+	+	+	+	+
Opuntia polyacantha	16.7	10.8	25.0	+	+	+	16.7	23.0	16.7	1.8	+	+
Parmelia chlorochroa	83.3	0.4	100.0	0.9	100.0	+	100.0	+	100.0	1.6	100.0	0.1
Phlox hoodii	5 +	1.9	50.0	1.3	33.3	1.1	+	+	+	+	+	+
Plantago species	91.7	0.1	+	+	16.7	+	16.7	+	8.3	+	8.3	+
Polygonum arenastrum	8.3	+	+	+	+	+	+	+	+	+	+	+
Potentilla species	8.3	+	+	+	+	+	+	+	+	+	+	+
Selaginella densa	100.0	71.7	100.0	77.8	100.0	58.3	100.0	65.4	100.0	65.6	100.0	70.8
Sphaeralcea coccinea	100.0	+	75.0	+	83.3	+	91.7	+	83.3	+	75.0	0.6
Stipa species	100.0	1.7	+	+	75.0	0.8	58.3	1.1	+	+	25.0	0.3

Table 11. Mean frequency(%) and basal area(%) of species in the work area (n=12; June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	+	+	+	+	8.3	+	+	+	+	+	8.3	+
Agropyron pectiniforme	83.3	0.4	100.0	+	75.0	0.2	+	+	75.0	+	91.7	0.4
Agropyron smithii	25.0	+	+	+	33.3	+	+	+	+	+	50.0	0.1
Agropyron species	8.3	+	+	+	+	+	+	+	58.3	+	+	+
Amaranthus species	33.3	+	8.3	+	+	+	16.7	+	25.0	0.2	+	+
Artemisia cana	+	+	16.7	+	+	+	+	+	+	+	+	+
Artemisia frigida	8.3	+	+	+	5.+	0.1	16.7	+	83.3	+	75.0	1.7
Astragalus species	66.7	+	8.3	+	41.7	0.1	25.0	+	16.7	+	50.0	+
Atriplex species	16.7	+	+	+	+	+	+	+	+	+	+	+
Bouteloua gracilis	+	+	+	+	16.7	+	+	+	+	+	41.7	+
Cerastium arvense	+	+	+	+	+	+	+	+	8.3	+	+	+
Chenopodium species	91.7	1.8	91.7	+	75.0	+	+	+	8.3	3.7	66.7	+
Descurainia sophia	66.7	2.8	33.3	+	+	+	+	+	+	+	+	+
Elymus junceus	+	+	16.7	+	+	+	+	+	+	+	+	+
Erysimum inconspicuum	25.0	+	+	+	+	+	+	+	+	+	+	+
Gaillardia aristata	+	+	8.3	+	+	+	+	+	+	+	+	+
Gramineae species	+	+	+	+	+	+	91.7	2.5	16.7	+	16.7	+
Grindelia squarrosa	25.0	+	16.7	+	75.0	+	+	+	25.0	+	66.7	+
Gutierrezia sarothrae	+	+	8.3	+	8.3	+	+	+	8.3	+	+	+
Hordeum jubatum	+	+	+	+	25.0	+	+	+	+	+	+	0.2
Koeleria macrantha	8.3	+	33.3	+	8.3	+	+	+	+	+	+	+
Lappula species	91.6	5.6	+	+	+	+	+	+	+	+	+	+
Lepidium densiflorum	50.0	+	16.7	+	8.3	+	+	+	25.0	+	8.3	+
Medicago species	8.3	+	33.3	+	41.7	+	+	+	25.0	+	58.3	+
Mononlepis nuttalliana	33.3	+	50.0	+	66.7	+	+	+	58.3	0.6	33.3	+
Phlox hoodii	+	+	+	+	58.3	0.9	+	+	+	+	25.0	+
Plantago species	33.3	0.9	8.3	+	50.0	+	8.3	3.5	58.3	+	50.0	+
Polygonum arenastrum	75.0	0.8	66.7	+	66.7	+	16.7	+	75.0	0.3	75.0	0.5
Ratibida columnifera	25.0	+	+	+	+	+	+	+	+	+	+	+
Salsola kali	+	+	+	+	+	+	+	+	8.3	+	+	+
Schedonnardis paniculatis	+	+	+	+	8.3	+	+	+	+	+	+	+
Seteria viridis	+	+	8.3	+	+	+	+	+	+	+	+	+
Solanum triflorum	+	+	+	+	+	+	+	+	+	+	16.7	+
Sphaeralcea coccinea	75.0	+	16.7	+	33.3	+	50.0	+	50.0	+	66.7	0.1
Stipa species	+	+	+	+	+	+	+	+	58.3	+	33.3	+
Taraxacum officinalis	+	+	+	+	8.3	+	+	+	+	+	+	+
Thlaspi arvense	+	+	8.3	+	8.3	+	+	+	+	+	8.3	+

Table 12. Mean frequency(%) and basal area(%) of species in the pipe lay area (n=12, June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	8.3	+	+	+	+	+	+	+	+	+	8.3	+
Agropyron pectiniforme	100.0	2.6	100.0	+	91.7	+	25.0	+	41.7	+	100.0	+
Agropyron species	+	+	+	+	+	+	+	+	91.7	+	83.3	+
Amaranthus species	16.7	+	8.3	+	+	+	16.7	+	25.0	+	+	+
Artemisia frigida	8.3	+	33.3	+	8.3	+	+	+	91.7	0.2	33.3	+
Astragalus species	41.7	+	58.3	+	16.7	+	33.3	+	41.7	+	58.3	+
Aster ericoides	+	+	25.0	1.2	+	+	+	+	+	+	+	+
Atriplex species	8.3	+	8.3	+	+	+	+	+	8.3	+	+	+
Bouteloua gracilis	8.3	+	+	+	+	+	8.3	+	91.7	+	+	+
Carex species	+	+	+	+	+	+	+	+	16.7	+	+	+
Chenopodium species	66.7	+	83.3	+	8.3	+	+	+	58.3	0.1	16.7	+
Descurainia sophia	50.0	0.6	+	+	+	+	+	+	+	+	+	+
Erigeron asper	8.3	+	+	+	+	+	+	+	+	+	+	+
Erysimum inconspicuum	+	+	8.3	+	+	+	+	+	8.3	+	+	+
Gaura coccinea	+	+	25.0	+	+	+	+	+	+	+	+	+
Grindelia squarrosa	8.3	+	33.3	+	33.3	+	+	+	25.0	+	25.0	+
Gutierrezia sarothrae	+	+	+	+	8.3	+	+	+	+	+	+	+
Hordeum jubatum	+	+	16.7	+	+	+	+	+	8.3	+	16.7	+
Koeleria macrantha	+	+	58.3	+	+	+	+	+	+	+	+	+
Lappula species	75.0	0.8	+	+	+	+	+	+	+	+	+	+
Lepidium densiflorum	41.7	+	8.3	+	+	+	+	+	16.7	+	8.3	+
Medicago species	58.3	+	33.3	+	33.3	+	16.7	+	16.7	+	50.0	+
Mellilotus officinalis	+	+	+	+	8.3	+	+	+	+	+	8.3	+
Mononlepis nuttalliana	33.3	+	50.0	+	+	+	+	+	50.0	0.2	8.3	+
Opuntia polyacantha	+	+	+	+	+	+	+	+	+	+	8.3	+
Oxytropis sericea	+	+	8.3	+	+	+	+	+	+	+	+	+
Phlox hoodii	+	+	+	+	25.0	+	+	+	+	+	+	+
Plantago species	41.7	+	+	+	16.7	+	+	+	58.3	+	+	+
Polygonum arenastrum	91.7	0.6	75.0	0.1	33.3	+	41.7	+	66.7	0.6	25.0	+
Ratibida columnifera	33.3	+	+	+	+	+	+	+	+	+	+	+
Selaginella densa	+	+	8.3	+	+	+	+	+	+	+	+	+
Seteria viridis	+	+	8.3	+	+	+	+	+	+	+	+	+
Sphaeralcea coccinea	58.3	+	16.7	+	+	+	58.3	+	41.7	+	41.7	+
Stipa species	+	+	16.7	+	+	+	+	+	33.3	+	+	+
Taraxacum officinalis	+	+	+	+	+	+	+	+	8.3	+	+	+

Table 13. Mean frequency(%) and basal area(%) of species in the 1981 trench transect (n=12; June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	+	+	+	+	16.7	+	+	+	+	+	+	+
Agropyron pectiniforme	83.3	+	41.7	+	100.0	+	25.0	+	91.7	+	100.0	+
Agropyron species	+	+	+	+	8.3	+	+	+	83.3	+	66.7	+
Agropyron trichophorum	+	+	+	+	+	+	+	+	+	+	8.3	+
Amaranthus species	+	+	+	+	+	+	25.0	+	8.3	+	+	+
Artemisia cana	+	+	+	+	+	+	+	+	+	+	8.3	+
Artemisia frigida	+	+	+	+	8.3	+	+	+	+	+	8.3	+
Astragalus species	+	+	+	+	83.3	+	16.7	+	8.3	+	41.7	+
Bouteloua gracilis	+	+	+	+	8.3	+	+	+	8.3	+	+	+
Chenopodium species	41.7	+	8.3	+	+	+	+	+	8.3	+	16.7	+
Gaura coccinea	+	+	+	+	8.3	0.5	+	+	+	+	+	+
Gramineae species	16.7	+	+	+	8.3	+	83.3	+	+	+	25.0	+
Grindelia squarrosa	+	+	+	+	8.3	+	+	+	8.3	+	16.7	+
Gutierrezia sarothrae	+	+	+	+	8.3	+	+	+	+	+	+	+
Hordeum jubatum	8.3	+	+	+	+	+	+	+	+	+	25.0	+
Lappula species	16.7	+	+	+	+	+	+	+	+	+	+	+
Medicago species	83.3	+	8.3	+	25.0	+	83.3	+	16.7	+	16.7	+
Mononlepis nuttalliana	41.7	+	+	+	8.3	+	+	+	+	+	8.3	+
Opuntia polyacantha	+	+	+	+	+	+	+	+	16.7	+	+	+
Plantago species	+	+	+	+	+	+	+	+	8.3	+	8.3	+
Polygonum arenastrum	66.7	+	33.3	+	25.0	+	33.3	+	41.7	+	16.7	+
Sphaeralcea coccinea	+	+	+	+	41.7	+	+	+	8.3	+	+	+
Stipa species	+	+	+	+	+	+	+	+	16.7	+	+	+
Taraxacum officinalis	+	+	+	+	33.3	+	+	+	+	+	+	+

Table 14. Mean frequency(%) and basal area(%) of species in the stockpile transect (n=12, June and September, 1982)

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	+	+	8.3	+	41.7	0.2	+	+	8.3	3.5	8.3	+
Agropyron pectiniforme	100.0	1.0	66.7	+	50.0	0.1	25.0	1.2	50.0	+	91.7	0.6
Agropyron smithii	+	+	+	+	16.7	+	+	+	+	+	+	+
Agropyron species	+	+	25.0	+	+	+	16.7	+	58.3	+	8.3	+
Amaranthus species	8.3	+	+	+	+	+	8.3	+	8.3	+	+	+
Antennaria parvifolia	+	+	+	+	8.3	+	+	+	+	+	+	+
Artemisia cana	+	+	+	+	8.3	+	+	+	+	+	+	+
Artemisia frigida	+	+	33.3	+	91.7	0.4	8.3	+	16.7	+	33.3	0.1
Astragalus species	+	+	8.3	+	41.7	+	16.7	2.3	25.0	+	66.7	+
Aster ericoides	+	+	+	+	+	+	+	+	16.7	0.3	+	+
Atriplex species	8.3	+	+	+	+	+	+	+	+	+	+	+
Bouteloua gracilis	+	+	33.3	1.1	33.3	0.3	66.7	+	41.7	0.8	41.7	0.7
Cerastium arvense	+	+	41.7	+	+	+	+	+	+	+	+	+
Chenopodium species	58.3	+	8.3	+	+	+	16.7	+	+	+	+	+
Descurainia sophia	33.3	+	+	+	+	+	+	+	+	+	+	+
Erigeron asper	+	+	+	+	8.3	+	+	+	+	+	+	+
Gaura coccinea	+	+	8.3	+	+	+	8.3	+	+	+	+	+
Gramineae species	91.7	+	+	+	+	+	+	+	16.7	+	+	+
Grindelia squarrosa	+	+	8.3	+	+	+	+	+	8.3	+	8.3	+
Gutierrezia sarothrae	8.3	+	8.3	+	83.3	2.0	+	+	+	+	+	+
Hordeum jubatum	+	+	+	+	8.3	+	+	+	+	+	16.7	+
Koeleria macrantha	8.3	+	16.7	0.3	100.0	3.0	+	+	+	+	+	+
Lappula species	8.3	+	+	+	+	+	+	+	+	+	+	+
Lepidium densiflorum	+	+	8.3	+	8.3	+	+	+	8.3	+	+	+
Medicago species	83.3	+	66.7	+	+	+	8.3	+	16.7	+	25.0	+
Mononlepis nuttalliana	58.3	+	+	+	+	+	+	+	+	+	8.3	+
Opuntia polyacantha	+	+	+	+	+	+	+	+	8.3	+	+	+
Plantago species	+	+	+	+	8.3	+	+	+	8.3	+	+	+
Polygonum arenastrum	16.7	+	33.3	+	16.7	+	16.7	+	25.0	+	33.3	1.6
Rosa acicularis	+	+	+	+	8.3	0.5	+	+	+	+	+	+
Sphaeralcea coccinea	75.0	+	41.7	+	58.3	+	66.7	0.2	41.7	+	58.3	0.6
Stipa species	8.3	+	+	+	+	+	+	+	+	+	+	+
Taraxacum officinalis	+	+	8.3	+	58.3	+	+	+	8.3	+	16.7	+

Table 15. Mean frequency(%) and basal area(%) of species in the 1957 trench transect (n=12; June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	16.7	+	33.3	2.1	66.7	3.4	16.7	0.3	25.0	2.8	41.7	0.8
Agropyron pectiniforme	75.0	8.3	+	+	41.7	0.8	33.3	0.3	+	+	+	+
Agropyron smithii	25.0	+	+	+	25.0	+	+	+	+	+	16.7	+
Andresace septentrionalis	+	+	8.3	0.8	+	+	+	+	+	+	+	+
Antennaria parvifolia	16.7	1.8	33.3	+	25.0	+	25.0	+	16.7	+	8.3	3.5
Artemisia cana	+	+	33.3	5.0	33.3	1.8	+	+	33.3	21.8	25.0	0.2
Artemisia frigida	58.3	0.1	100.0	0.8	91.7	2.8	83.3	0.6	91.7	2.8	100.0	0.7
Astragalus species	50.0	+	33.3	+	50.0	+	33.3	+	+	+	16.7	0.3
Aster ericoides	+	+	+	+	+	+	+	+	8.3	0.5	+	+
Bouteloua gracilis	+	+	100.0	5.8	+	+	100.0	4.3	100.0	11.8	100.0	0.8
Chenopodium species	+	+	+	+	+	+	8.3	+	+	+	+	+
Coryphantha vivipara	+	+	8.3	+	+	+	+	+	8.3	+	+	+
Erigeron asper	16.7	+	+	+	+	+	+	+	+	+	8.3	+
Gaura coccinea	41.7	+	16.7	0.3	+	+	33.3	0.1	+	+	+	+
Gramineae species	+	+	+	+	+	+	83.3	2.2	+	+	+	+
Grindelia squarrosa	25.0	+	16.7	0.3	33.3	+	16.7	+	8.3	+	33.3	+
Gutierrezia sarothrae	66.7	3.3	91.7	0.1	100.0	2.3	58.3	1.1	83.3	1.2	100.0	1.5
Hordeum jubatum	8.3	0.5	8.3	+	8.3	+	+	+	16.7	+	8.3	+
Koeleria macrantha	100.0	5.0	100.0	3.0	10 +	5.8	8.3	5.0	+	+	8.3	+
Opuntia polyacantha	+	+	25.0	8.3	+	+	+	+	33.3	24.1	+	+
Oxytropis sericea	8.3	+	+	+	+	+	+	+	+	+	+	+
Parmelia chlorochroa	+	+	+	+	+	+	+	+	8.3	+	+	+
Plantago purshii	+	+	8.3	+	+	+	+	+	+	+	+	+
Polygonum arenastrum	+	+	25.0	+	+	+	+	+	+	+	+	+
Ratibida columnifera	8.3	+	8.3	8.0	8.3	+	25.0	+	+	+	+	+
Rosa acicularis	8.3	+	+	+	+	+	8.3	+	+	+	8.3	+
Sphaeralcea coccinea	58.3	+	58.3	0.1	50.0	+	+	+	33.3	0.4	50.0	0.7
Stipa species	41.7	+	8.3	3.5	+	+	58.3	1.5	16.7	0.5	+	+
Taraxacum officinalis	33.3	+	83.3	0.1	10 +	5.8	8.3	+	25.0	2.5	16.7	1.8

Table 16. Mean frequency(%) and basal area(%) of species between the 1957-1963 trench transect (n=12, June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	50.0	+	50.0	+	16.7	+	16.7	+	41.7	1.4	8 +	2.8
Agropyron pectiniforme	+	+	+	+	41.7	0.8	+	3.2	+	+	+	+
Agropyron species	58.3	0.1	25.0	+	+	+	58.3	+	+	+	+	+
Antennaria parvifolia	50.0	0.1	8.3	+	16.7	1.8	25.0	1.2	16.7	+	41.7	1.5
Artemisia cana	+	+	16.7	+	50.0	12.1	+	+	8.3	+	50.0	6.8
Artemisia frigida	58.3	+	75.0	0.5	100.0	2.8	66.7	1.3	66.7	1.1	100.0	2.6
Astragalus species	41.7	+	33.3	0.1	50.0	+	+	+	+	+	16.7	+
Bouteloua gracilis	83.3	1.3	100.0	2.6	+	+	100.0	4.6	100.0	7.7	100.0	2.4
Cerastium arvense	+	+	16.7	+	+	+	+	+	+	+	+	+
Chenopodium species	8.3	+	+	+	+	+	+	+	+	+	+	+
Erigeron asper	33.3	+	+	+	+	+	+	+	+	+	8.3	+
Gaura coccinea	25.0	+	8.3	+	16.7	+	33.3	+	+	+	+	+
Gramineae species	8.3	+	+	+	+	+	83.3	2.8	+	+	+	+
Grindelia squarrosa	41.7	+	83.3	1.5	25.0	+	25.0	+	83.3	+	25.0	0.2
Gutierrezia sarothrae	66.7	0.5	100.0	8.5	91.7	3.4	66.7	0.9	100.0	5.3	100.0	1.4
Hordeum jubatum	25.0	0.3	33.3	+	8.3	+	+	+	+	+	16.7	1.8
Koeleria macrantha	100.0	16.3	100.0	0.9	100.0	4.1	25.0	+	+	+	+	+
Onagraceae species	+	+	+	+	8.3	+	+	+	+	+	+	+
Opuntia polyacantha	+	+	8.3	+	+	+	+	+	8.3	+	+	+
Plantago species	58.3	+	+	+	+	+	8.3	0.5	+	+	+	+
Polygonum arenastrum	8.3	+	16.7	+	8.3	+	+	+	+	+	+	+
Potentilla species	+	+	25.0	+	+	+	+	+	16.7	+	+	+
Ratibida columnifera	+	+	16.7	+	+	+	+	+	16.7	+	8.3	+
Rosa acicularis	+	+	+	+	25.0	5.0	+	+	+	+	16.7	1.8
Sphaeralcea coccinea	41.7	0.1	41.7	+	16.7	+	50.0	0.2	25.0	+	58.3	+
Stipa species	91.7	3.1	+	+	16.7	+	50.0	0.1	+	+	+	+
Taraxacum officinalis	33.3	+	10 +	0.9	41.7	2.1	+	+	33.3	1.0	16.7	3.5
Thermopsis rhombifolia	+	+	+	+	8.3	+	+	+	+	+	+	+
Vicia americana	41.7	0.7	+	+	+	+	25.0	+	+	+	+	+

Table 17 Mean frequency(%) and basal area(%) of species in the 1983 trench transect (n=12, June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	33.3	2.0	41.7	0.8	50.0	2.0	16.7	0.3	50.0	0.3	25.0	+
Agropyron pectiniforme	8.3	0.5	8.3	0.5	33.3	0.8	91.7	2.5	+	+	+	+
Agropyron smithii	+	+	66.7	0.2	+	+	+	+	+	+	+	+
Agropyron species	83.3	2.1	+	+	+	+	8.3	+	8.3	+	+	+
Antennaria parvifolia	8.3	3.5	41.7	0.8	33.3	1.8	8.3	0.5	+	+	8.3	0.5
Artemisia cana	16.7	0.3	+	+	41.7	1.7	16.7	1.8	16.7	8.3	41.7	18.0
Artemisia frigida	83.3	0.8	91.7	0.3	66.7	2.1	50.0	0.7	+	4.8	83.3	2.3
Astragalus species	75.0	0.4	+	+	41.7	+	+	+	8.3	+	41.7	+
Bouteloua gracilis	58.3	0.1	25.0	+	+	+	91.7	1.3	83.3	3.0	83.3	2.4
Cerastium arvense	+	+	+	+	+	+	+	+	8.3	8.0	+	+
Chenopodium species	+	+	8.3	+	+	+	+	+	+	+	+	+
Erigeron asper	+	+	8.3	+	+	+	8.3	+	+	+	16.7	+
Gaura coccinea	25.0	+	16.7	+	8.3	+	+	+	8.3	+	+	+
Gramineae species	+	+	+	+	+	+	100.0	13.0	+	+	+	+
Grindelia squarrosa	66.7	+	66.7	+	50.0	0.1	16.7	+	41.7	+	50.0	+
Gutierrezia sarothrae	75.0	0.4	50.0	0.2	91.7	2.8	83.3	0.4	83.3	1.8	91.7	2.0
Hordeum jubatum	8.3	0.5	41.7	1.7	25.0	0.3	+	+	16.7	4.0	8.3	0.5
Koeleria macrantha	100.0	10.5	41.7	1.7	100.0	7.8	+	+	25.0	+	16.7	+
Lappula species	+	+	8.3	+	+	+	+	+	+	+	+	+
Oxytropis sericea	+	+	+	+	8.3	+	+	+	+	+	+	+
Plantago species	8.3	+	16.7	+	+	+	+	+	+	+	+	+
Polygonum arenastrum	8.3	+	50.0	0.8	8.3	+	+	+	8.3	+	+	+
Potentilla species	+	+	+	+	8.3	+	+	+	+	+	+	+
Ratibida columnifera	41.7	+	25.0	0.2	25.0	+	41.7	0.2	33.3	2.0	+	+
Rosa acicularis	+	+	+	+	25.0	1.2	+	+	+	+	25.0	14.0
Salsola kali	8.3	+	+	+	+	+	+	+	+	+	+	+
Sphaeralcea coccinea	50.0	0.7	8.3	+	41.7	+	16.7	+	16.7	+	25.0	+
Stipa species	91.7	3.2	16.7	2.0	33.3	2.8	41.7	+	41.7	3.3	16.7	+
Symphoricarpus occidentalis	+	+	+	+	+	+	+	+	16.7	0.3	8.3	+
Taraxacum officinalis	58.3	0.5	66.7	0.1	58.3	0.6	8.3	+	41.7	+	16.7	+
Tragopogon dubius	8.3	+	8.3	+	+	+	+	+	+	+	+	+

Table 18 Mean frequency(%) and basal area(%) of species between the 1983 and 1988 trench transect (n=12, June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	33.3	0.1	41.7	+	8.3	+	8.3	+	41.7	0.8	66.7	2.4
Agoseris glauca	+	+	8.3	+	+	+	+	+	+	+	+	+
Agropyron pectiniforme	58.3	5.5	+	+	8.3	+	75.0	0.8	+	+	+	+
Agropyron smithii	+	+	25.0	+	+	+	+	+	+	+	+	+
Agropyron species	58.3	1.6	+	+	+	+	8.3	+	+	+	+	+
Antennaria parvifolia	25.0	1.2	+	+	+	+	25.0	0.2	25.0	1.3	25.0	3.5
Artemisia cana	+	+	25.0	1.2	8.3	8.0	+	+	8.3	3.5	8.3	8.0
Artemisia frigida	83.3	+	83.3	0.2	91.7	5.5	75.0	0.4	83.3	2.5	91.7	6.5
Astragalus species	33.3	1.8	33.3	+	8.3	+	+	+	+	+	16.7	+
Bouteloua gracilis	83.3	+	41.7	0.1	+	+	75.0	0.9	83.3	11.8	91.7	4.8
Carex species	+	+	+	+	+	+	+	+	8.3	+	+	+
Cerastium arvense	16.7	+	+	0.5	+	+	+	+	+	+	+	+
Chenopodium species	+	+	+	+	+	+	8.3	+	+	+	+	+
Coryphantha vivipara	+	+	+	+	+	+	+	+	8.3	+	+	+
Erigeron asper	+	+	+	+	8.3	+	+	+	8.3	+	+	+
Erysimum inconspicuum	16.7	+	+	+	+	+	+	+	+	+	+	+
Gaura coccinea	16.7	1.8	+	+	+	+	8.3	+	8.3	+	+	+
Gramineae species	100.0	15.2	+	+	+	+	+	+	+	+	+	+
Grindelia squarrosa	33.3	+	25.0	+	50.0	0.1	25.0	+	58.3	0.1	58.3	1.0
Gutierrezia sarothrae	8.3	+	91.7	0.5	75.0	3.8	8.3	+	66.7	0.5	83.3	1.0
Hordeum jubatum	+	+	41.7	5.7	+	+	+	+	+	+	41.7	+
Koeleria macrantha	100.0	33.0	91.7	1.8	91.7	1.2	8.3	+	+	+	25.0	1.3
Lappula species	25.0	+	+	+	+	+	+	+	+	+	+	+
Opuntia polyacantha	8.3	+	+	+	+	+	+	+	+	+	+	+
Parmelia chlorochroa	16.7	+	+	+	+	+	+	+	+	+	+	+
Plantago species	66.7	0.4	8.3	+	16.7	+	25.0	+	16.7	+	+	+
Polygonum arenastrum	25.0	+	16.7	+	33.3	1.8	+	+	66.7	3.7	+	+
Ratibida columnifera	16.7	+	25.0	+	+	+	+	+	8.3	+	8.3	3.5
Rosa acicularis	+	+	8.3	+	+	+	+	+	+	+	+	+
Sphaeralcea coccinea	25.0	+	25.0	+	75.0	+	8.3	+	8.3	+	41.7	+
Stipa species	91.7	0.5	41.7	1.4	83.3	2.8	25.0	1.2	50.0	2.1	16.7	+
Symphoricarpus occidentalis	+	+	16.7	+	+	+	+	+	+	+	+	+
Taraxacum officinalis	58.3	+	91.7	0.6	33.3	1.0	8.3	+	16.7	1.8	33.3	0.8
Tragopogon dubius	+	+	+	+	8.3	+	+	+	+	+	8.3	+

Table 19. Mean frequency(%) and basal area(%) of species in the 1958 trench transect (n=12; June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	+	+	8.3	+	33.3	1.0	+	+	8.3	4.0	16.7	1.8
Agropyron pectiniforme	100.0	23.8	25.0	+	58.3	0.3	100.0	14.0	+	+	16.7	1.8
Agropyron species	58.3	0.1	8.3	+	+	+	+	+	+	+	+	+
Antennaria parvifolia	8.3	0.5	+	+	+	+	8.3	0.5	+	+	+	+
Artemisia cana	+	+	8.3	16.0	16.7	4.0	+	+	8.3	16.0	8.3	16.0
Artemisia frigida	33.3	0.9	10 +	1.9	10 +	4.5	33.3	+	75.0	5.7	91.7	8.3
Astragalus species	50.0	0.1	8.3	+	8.3	+	+	+	8.3	+	16.7	+
Bouteloua gracilis	+	+	+	+	+	+	16.7	1.8	66.7	6.2	50.0	0.2
Chenopodium species	8.3	+	8.3	+	+	+	+	+	+	+	+	+
Erigeron asper	+	+	+	+	+	+	+	+	8.3	+	+	+
Erysimum inconspicuum	8.3	+	8.3	+	+	+	+	+	+	+	+	+
Festuca species	+	+	+	+	+	+	+	+	8.3	+	+	+
Gramineae species	+	+	+	+	+	+	50.0	1.3	+	+	+	+
Grindelia squarrosa	58.3	+	33.3	+	91.7	0.4	50.0	0.1	50.0	0.7	41.7	+
Gutierrezia sarothrae	25.0	+	58.3	0.6	91.7	2.6	33.3	+	75.0	1.3	83.3	2.9
Hordeum jubatum	+	+	33.3	0.4	83.3	2.6	+	+	58.3	4.2	41.7	0.8
Koeleria macrantha	66.7	2.4	83.3	0.6	75.0	0.8	8.3	3.5	+	+	+	+
Lappula species	16.7	+	8.3	+	+	+	+	+	+	+	+	+
Plantago species	+	+	8.3	+	+	+	+	+	16.7	+	+	+
Polygonum arenastrum	50.0	0.2	83.3	0.5	+	+	+	+	58.3	3.4	25.0	1.3
Ratibida columnifera	+	+	8.3	+	+	+	+	+	8.3	+	+	+
Sphaeralcea coccinea	66.7	0.6	+	+	25.0	+	25.0	+	+	+	50.0	1.2
Stipa species	41.7	1.4	83.3	3.4	83.3	1.9	8.3	3.5	8.3	3.5	50.0	2.5
Taraxacum officinalis	41.7	0.1	66.7	0.6	75.0	0.9	+	+	25.0	2.3	8.3	+
Tragopogon dubius	25.0	+	8.3	+	+	+	+	+	+	+	+	+

Table 20 Mean frequency(%) and basal area(%) of species between the 1958 and 1972 trench transect (n=12, June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	+	+	41.7	2.3	8.3	+	+	+	41.7	3.7	16.7	1.8
Agoseris glauca	+	+	+	+	+	+	+	+	+	+	+	+
Agropyron pectiniforme	100.0	20.5	8.3	3.5	16.7	+	100.0	10.8	+	+	25.0	+
Agropyron species	+	+	+	+	+	+	+	+	8.3	+	+	+
Artemisia cana	+	+	+	+	16.7	0.3	+	+	+	+	16.7	9.0
Artemisia frigida	16.7	0.3	91.7	3.0	100.0	3.0	8.3	+	100.0	4.3	91.7	5.3
Astragalus species	8.3	+	+	+	+	+	+	+	+	+	16.7	+
Bouteloua gracilis	+	+	+	+	+	+	+	+	91.7	1.2	83.3	+
Chenopodium species	+	+	16.7	+	+	+	+	+	+	+	+	+
Gaura coccinea	+	+	8.3	+	+	+	+	+	+	+	+	+
Gramineae species	91.7	7.7	+	+	+	+	+	+	+	+	+	+
Grindelia squarrosa	5 +	+	66.7	0.5	75.0	+	33.3	1.8	58.3	1.2	75.0	3.1
Gutierrezia sarothrae	8.3	+	41.7	1.7	10 +	4.1	8.3	+	75.0	1.2	91.7	2.8
Hordeum jubatum	+	+	58.3	3.7	75.0	0.4	+	+	75.0	5.0	91.7	2.1
Koeleria macrantha	16.7	3.5	83.3	0.7	91.7	0.3	+	+	+	+	+	+
Phlox hoodii	+	+	+	+	16.7	0.3	+	+	+	+	+	+
Polygonum arenastrum	83.3	0.4	58.3	8.3	+	+	+	+	66.7	4.4	8.3	+
Ratibida columnifera	+	+	8.3	+	8.3	+	+	+	+	+	+	+
Sphaeralcea coccinea	8.3	+	+	+	+	+	8.3	+	+	+	16.7	+
Stipa species	+	+	66.7	1.8	58.3	0.6	+	+	8.3	+	25.0	1.2
Taraxacum officinalis	8.3	+	66.7	0.8	33.3	+	+	+	25.0	+	16.7	2.0
Tragopogon dubius	8.3	+	8.3	+	8.3	+	+	+	8.3	+	8.3	+

Table 21. Mean frequency(%) and basal area(%) of species in the 1972 trench transect (n=12; June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	+	+	33.3	+	+	+	+	+	8.3	+	8.3	+
Agropyron pectiniforme	100.0	7.0	8.3	+	66.7	+	100.0	13.1	8.3	0.5	66.7	0.4
Agropyron species	+	+	8.3	+	+	+	+	+	8.3	+	+	+
Androsace septentrionalis	+	+	8.3	+	+	+	+	+	+	+	+	+
Artemisia cana	+	+	16.7	18.0	+	+	+	+	25.0	16.7	8.3	+
Artemisia frigida	8.3	+	91.7	1.1	50.0	0.1	8.3	+	83.3	3.8	100.0	4.4
Astragalus species	41.7	+	+	+	66.7	+	8.3	+	+	+	+	+
Bouteloua gracilis	+	+	16.7	+	+	+	8.3	+	5 +	1.2	66.7	0.4
Chenopodium species	8.3	+	+	+	8.3	+	+	+	+	+	+	+
Erigeron asper	8.3	+	8.3	+	+	+	+	+	+	+	+	+
Gaura coccinea	+	+	+	+	8.3	+	+	+	+	+	+	+
Gramineae species	16.7	5.8	+	+	+	+	+	+	+	+	+	+
Grindelia squarrosa	91.7	+	83.3	0.8	25.0	+	58.3	+	91.7	2.0	58.3	0.6
Gutierrezia sarothrae	8.3	+	91.7	2.8	+	+	+	+	66.7	7.8	91.7	4.3
Hordeum jubatum	+	+	91.7	3.2	25.0	+	+	+	91.7	5.0	75.0	2.5
Koeleria macrantha	25.0	0.2	41.7	1.0	+	+	+	+	+	+	+	+
Lactuca species	+	+	8.3	+	+	+	+	+	8.3	+	+	+
Medicago species	+	+	+	+	16.7	+	+	+	+	+	+	+
Mononlepis nuttalliana	+	+	+	+	16.7	+	+	+	+	+	+	+
Phlox hoodii	+	+	+	+	25.0	3.8	+	+	+	+	16.7	+
Plantago species	8.3	+	16.7	+	+	+	+	+	8.3	+	8.3	+
Polygonum arenastrum	16.7	+	16.7	2.0	8.3	+	+	+	16.7	3.5	+	+
Ratibida columnifera	16.7	+	33.3	1.8	+	+	16.7	+	25.0	5.0	8.3	8.0
Salsola kali	+	+	8.3	+	+	+	+	+	+	+	+	+
Setaria viridis	+	+	8.3	+	+	+	+	+	+	+	+	+
Sphaeralcea coccinea	+	+	+	+	16.7	+	+	+	+	+	+	+
Stipa species	+	+	5 +	0.9	+	+	+	+	8.3	+	+	+
Taraxacum officinalis	8.3	+	83.3	1.0	+	+	+	+	58.3	1.6	8.3	3.5
Thlaspi arvense	+	+	+	+	+	+	+	+	+	+	+	+
Tragopogon dubius	8.3	+	16.7	+	+	+	+	+	+	+	+	+
Vicia americana	+	+	+	+	25.0	+	+	+	+	+	8.3	+

Table 22. Mean frequency(%) and basal area(%) of species between the 1972 trench transect, and the roadway (n=12; June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	+	+	16.7	0.3	25.0	+	+	+	8.3	3.5	16.7	+
Agropyron pectiniforme	100.0	13.5	+	+	33.3	0.1	100.0	12.3	33.3	0.3	50.0	0.7
Agropyron smithii	16.7	2.0	+	+	+	+	+	+	8.3	+	+	+
Agropyron species	33.3	+	+	+	+	+	+	+	+	+	+	+
Androsace septentrionalis	+	+	+	+	+	+	+	+	8.3	+	+	+
Antennaria nitida	16.7	1.5	16.7	3.5	+	+	16.7	2.0	16.7	3.5	8.3	+
Artemisia frigida	50.0	+	100.0	5.1	91.7	9.5	25.0	1.3	100.0	7.7	100.0	15.0
Astragalus species	16.7	+	8.3	+	+	+	+	+	+	+	25.0	+
Bouteloua gracilis	+	+	+	+	+	+	+	+	91.7	3.5	83.3	0.5
Cerastium arvense	+	+	+	+	8.3	+	+	+	+	+	+	+
Chenopodium species	25.0	+	8.3	+	+	+	+	+	8.3	+	+	+
Erigeron asper	16.7	+	8.3	+	+	+	+	+	+	+	+	+
Grindelia squarrosa	33.3	+	66.7	0.1	58.3	+	41.7	0.8	91.7	1.0	58.3	0.1
Gutierrezia sarothrae	8.3	+	16.7	+	66.7	2.5	+	+	41.7	+	66.7	1.0
Hordeum jubatum	+	+	66.7	2.2	75.0	0.5	+	+	66.7	2.2	50.0	0.2
Koeleria macrantha	75.0	1.2	66.7	2.0	83.3	1.9	8.3	+	+	+	+	+
Lappula species	+	+	8.3	+	+	+	+	+	+	+	+	+
Parmelia chlorechroa	+	+	8.3	+	+	+	+	+	+	+	+	+
Phlox hoodii	+	+	+	+	25.0	+	+	+	+	+	+	+
Plantago species	8.3	+	25.0	+	41.7	+	+	+	25.0	+	33.3	+
Poa species	+	+	8.3	+	+	+	+	+	+	+	+	+
Polygonum arenastrum	33.3	+	75.0	0.5	25.0	1.3	+	+	25.0	1.2	16.7	+
Ratibida columnifera	8.3	+	8.3	+	+	+	8.3	+	8.3	+	+	+
Sphaeralcea coccinea	75.0	+	50.0	+	25.0	+	33.3	0.4	41.7	+	41.7	+
Stipa species	+	+	58.3	0.1	33.3	1.9	+	+	+	+	+	+
Taraxacum officinalis	16.7	+	58.3	1.1	+	+	+	+	8.3	+	+	+
Tragopogon dubius	8.3	+	+	+	+	+	+	+	+	+	+	+

Table 23. Mean frequency(%) and basal area(%) of species in the roadway transect (n=12; June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Agropyron pectiniforme	100.0	36.3	+	+	50.0	+	100.0	21.8	+	+	50.0	3.1
Agropyron smithii	8.3	+	+	+	+	+	+	+	+	+	+	+
Agropyron species	16.7	4.3	+	+	+	+	+	+	+	+	+	+
Amaranthus species	+	+	16.7	+	+	+	+	+	8.3	+	+	+
Artemisia frigida	50.0	0.1	25.0	+	50.0	1.3	41.7	3.6	8.3	0.5	50.0	3.7
Astragalus species	+	+	+	+	8.3	+	+	+	+	+	8.3	+
Bouteloua gracilis	16.7	+	+	+	+	+	+	+	+	+	16.7	+
Cerastium arvense	+	+	+	+	+	+	+	+	25.0	+	+	+
Chenopodium species	41.7	+	33.3	+	+	+	+	+	+	+	+	+
Gramineae species	+	+	+	+	+	+	16.7	+	+	+	+	+
Grindelia squarrosa	+	+	41.7	0.1	41.7	+	+	+	50.0	+	41.7	+
Gutierrezia sarothrae	+	+	+	+	25.0	+	+	+	+	+	50.0	0.6
Hordeum jubatum	+	+	8.3	+	8.3	+	+	+	50.0	+	41.7	1.5
Koeleria macrantha	16.7	+	8.3	+	33.3	0.1	+	+	+	+	+	+
Opuntia polyacantha	8.3	+	+	+	+	+	+	+	+	+	+	+
Polygonum arenastrum	33.3	+	66.7	0.6	25.0	5.5	+	+	83.3	1.1	33.3	2.9
Sphaeralcea coccinea	25.0	+	25.0	0.2	8.3	+	25.0	+	+	+	16.7	+
Stipa species	+	+	41.7	+	66.7	+	+	+	+	+	16.7	+
Taraxacum officinalis	+	+	33.3	1.0	16.7	+	+	+	+	+	+	+

Table 24. Mean frequency(%) and basal area(%) of species in the undisturbed prairie (n=12; June and September, 1982).

	June						September					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	F	BA	F	BA	F	BA	F	BA	F	BA	F	BA
Achillea millifolium	8.3	+	+	+	8.3	+	8.3	+	+	+	8.3	+
Agropyron pectiniforme	83.3	12.0	+	+	+	+	8.3	+	+	+	+	+
Agropyron smithii	8.3	+	+	+	+	+	+	+	+	+	+	+
Agropyron species	66.7	1.5	16.7	0.3	+	+	+	+	16.7	+	+	+
Antennaria parvifolia	+	+	16.7	1.8	+	0.2	+	+	8.3	3.5	25.0	5.8
Artemisia cana	+	+	+	+	16.7	+	+	+	+	+	+	+
Artemisia frigida	66.7	0.4	91.7	2.4	10 +	6.8	66.7	2.9	75.0	4.5	91.7	5.5
Astragalus species	+	+	8.3	+	+	+	+	+	+	+	+	+
Bouteloua gracilis	10 +	1.8	83.3	3.1	83.3	2.2	100.0	28.5	100.0	7.3	100.0	3.1
Carex species	8.3	+	+	+	25.0	+	+	+	+	+	+	+
Chenopodium species	83.3	+	+	+	+	+	8.3	+	+	+	+	+
Descurainia sophia	8.3	+	+	+	+	+	+	+	+	+	+	+
Erigeron asper	8.3	+	+	+	+	+	+	+	+	+	+	+
Erysimum inconspicuum	8.3	+	+	+	+	+	+	+	+	+	+	+
Gaura coccinea	8.3	+	+	+	+	+	8.3	+	+	+	+	+
Gramineae species	+	+	+	+	+	+	91.7	3.6	+	+	+	+
Grindelia squarrosa	8.3	+	25.0	0.2	+	+	+	+	+	+	+	+
Gutierrezia sarothrae	8.3	+	5 +	0.1	16.7	+	8.3	+	58.3	0.2	8.3	+
Hordeum jubatum	+	+	+	+	8.3	+	+	+	+	+	8.3	3.5
Koeleria cristata	100.0	10.1	100.0	3.6	75.0	3.3	8.3	+	8.3	0.5	8.3	3.5
Lappula species	16.7	+	+	+	+	+	+	+	+	+	+	+
Opuntia polyacantha	8.3	+	33.3	5.5	16.7	28.0	+	+	33.3	14.4	16.7	28.0
Parmelia chlorochroa	8.3	+	100.0	1.8	91.7	+	8.3	+	83.3	0.4	75.0	0.8
Phlox hoodii	+	+	58.3	1.2	58.3	1.1	+	+	+	+	25.0	+
Plantago species	33.3	+	+	+	+	+	+	+	+	+	+	+
Polygonum arenastrum	58.3	+	+	+	8.3	+	+	+	+	+	+	+
Potentilla species	+	+	8.3	+	+	+	+	+	+	+	+	+
Selaginella densa	25.0	5.0	100.0	44.0	100.0	53.3	25.0	21.3	100.0	51.3	91.7	54.1
Sphaeralcea coccinea	75.0	+	33.3	+	5 +	+	8.3	+	16.7	0.3	41.7	+
Stipa species	83.3	1.1	83.3	1.8	41.7	+	8.3	+	+	+	+	+
Taraxacum officinalis	8.3	+	+	+	+	+	+	+	+	+	+	+
Thlaspi arvense	8.3	+	+	+	+	+	+	+	+	+	+	+