EFFECTS OF MILITARY TRAINING ON MIXED-GRASS PRAIRIE AT SHILO, MANITOBA, CANADA, AND UTILITY OF REMEDIAL SEEDING MEASURES

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Master of Science

by

John Michael McKernan

Department of Botany

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ABSTRACT

Stressed and control Areas were studied within the C.F.B. Shilo Military Reserve, 40 000 ha of Bouteloua-Stipa mixed-grass prairie on sandy loam soils 25 km east of Brandon, Manitoba. Since 1974, military manoeuvres using tanks and armoured personnel carriers have been conducted annually. Impacts include increased mean frequencies of Bouteloua gracilis (6-64%) and Carex spp. (20-77%), reduced mean species diversities (26-30%), and increased mean litter (182%) and mean bare ground (240%). Mean penetrometer soil strengths were 50% greater in stressed areas, but are considered insufficient to inhibit seedling emergence. Most soil chemistry variables show increased concentrations (Cu 88-934%, Zn 16-111%, Na 3-101%) in response to a military stress gradient. However elevated concentrations in most cases scarcely exceed levels associated with mineral deficiency in commercial crops.

To evaluate seeding as a rehabilitation measure for stressed areas, six seed mixtures of various combinations of Agropyron cristatum, A. intermedium, A. trachycaulum, Bromus inermis, Elymus junceus, Festuca rubra, Medicago sativa and Melilotus officinalis were sown on replicated plots in a formerly damaged area in a completely randomized experimental design. Individual and averaged seeded plot responses were compared to those of non-seeded control plots, as regards (1) contributions to regrowth of desirable native species, (2) suppressed growth of undesirable weed species, (3) increased species diversity, and (4) increased above-, and below-ground biomass.

According to these criteria, greater renovation was achieved by light harrowing of damaged areas and two years' protection from stress than by seeding with any of six mixtures of legumes and grasses.

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INTRODUCTION

This study describes the response of a mixed-grass *Bouteloua-Stipa** prairie in southwestern Manitoba to the stresses of sustained military training exercises, and evaluates various seeding treatments for restoration of damaged grasslands.

Since 1974, military manoeuvres using tanks and other tracked vehicles have been conducted annually at the 40 000 ha Canadian Forces Base at Shilo, Manitoba. A variety of training-related adverse effects have been alleged to result. Concerns about military training effects were predicated, in part, upon the absence of detailed information describing the vegetation and soils of the Military Reserve, and the attendant inability to allow time-series analyses for impact trends. In addition, because it was unclear whether military training effects could be approximated by cattle grazing, for which there was sufficient literature describing rangeland damage symptoms and recovery procedures, it was equally unclear whether grazing land rehabilitation methods were appropriate. Accordingly, this study was initiated in 1978 to investigate the type, extent and reversibility of training-related impacts on Ranges of C.F.B. Shilo. The data generated were designed to provide a baseline for future studies of impact, and to provide interim management information to the Range Control staff of C.F.B. Shilo.

The climate of the study area is continental with a mean annual temperature of 2.2°C. Annual precipitation is less than 50 cm, nearly half falling as rain in sudden summer squalls (Longley 1972). Post-glacial

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* Nomenclature follows Scoggan (1980).

aolian deposits underly the sandy loam soils in the area, which are well-drained, have low natural fertility and poorly-developed structure, and are subject to wind erosion after loss of the thin vegetation cover.

Training effects include defoliation, soil compaction, soil scouring and excavation, and alterations of soil chemistry (McKernan 1978). This study provided an opportunity to determine the extent to which areas displaying such effects could be restored. It was hypothesized that various mixtures of drought-adapted grasses and drought-tolerant legumes would germinate and grow well in the stressed areas, and would likely exhibit greater species frequencies than native species, and greater surface and subsurface biomass.

This thesis is divided into two chapters. In the first, the training effects are described, quantified and evaluated. The second evaluates the utility of seven seeding treatments for restoration of damaged areas. The relevant literature is reviewed in the appropriate chapters.

CHAPTER 1

MILITARY TRAINING IMPACTS ON VEGETATION AND SOILS

1.1 INTRODUCTION

Ecologists have long believed that prairie persists because ungulate grazing and environmental stresses inhibit the growth of invading shrubs and trees (Weaver 1954, Coupland 1979b, Lauenroth 1979). In agriculture, a consequence of this observation is the belief that controlled grazing can maintain the prairie resource and support animal husbandry simultaneously. Whether other kinds of defoliation stress can be maintained without evidence of impaired function in prairie flora or soils is a moot point.

In the plant science literature of the 1940's, the inherent resilience of prairies to a variety of pressures was not studied directly. Rather, inferences about stress tolerance were implicit in estimates of "grazing capacity" and responses to various environmental pressures (Sarvis 1941). Frolik and Sheperd (1940) described the native vegetation and computed grazing capacity for a "typical" area of the Nebraska Sandhill rangeland. Clarke and Heinrichs (1941) described reclamation of over-grazed prairie in Western Canada and classified native pasture in southern Alberta, Saskatchewan and Manitoba by carrying capacity of "grazing districts" (Clarke _et al_ 1942). They also described the relations between cattle growth and various regimes of grazing intensity, and studied forage yield in response to a variety of grazing and forage management practices (Clarke _et al_ 1943). More explicit concern about prairie resilience in the face of sustained stress came when Costello and Turner (1949) emphasized the need for careful management of the prairie ecosystem in Colorado. They prescribed stocking rates which optimized both cattle growth and prairie longevity. This theme was more frequently expressed as the science of range management developed (Smoliak and Peters 1952, Costello 1969).

A more truly ecological, less exploitation-oriented assessment of the effects of environmental stress on prairie took place when grazing and other pressures were described as a potentially positive force favorably influencing prairie composition and stability of prairie vegetation (Johnston 1961, Ehrenreich & Aikman 1963, Smoliak 1965, Weaver 1968). The varied tolerance of prairie plants to environmental stresses was described and both stimulatory and inhibitory effects of drought, desiccation, fire and grazing were discussed. The present range management literature maintains this ecological perspective on stress effects (Dodd & Laüenroth 1979) however the innate stability of stressed prairie ecosystems, mixed-grass prairie in particular, has received little attention.

The capacity of a prairie system to be resilient in the face of systematic and sustained pressure has remained relatively uncharacterized. Where measurement has been attempted, indices of stability did not truly reflect system dynamics (van Voris *et al* 1980). The time required for a stressed prairie to return to pre-stress conditions has been little studied (Holling 1973, van Voris *et al* 1980) and the "hysteresis" of recovering ecosystems has not been considered susceptible to study (Westman 1978). Quantitative recovery studies in damaged prairie are few, usually focussing on plant-animal interactions (Dettling *et al* 1980).

Short-grass prairie as classified by Clarke and others (1942) is also described by Coupland (1979a) as mixed-grass prairie. Unifying the classifications is the co-dominance of blue grama (*Bouteloua gracilis*) and needlegrass (Stipa spartea). The responses of both species to various environmental and agricultural pressures have been well characterized (Costello & Turner 1949, Ehrenreich & Aikman 1963, Smoliak 1965, Weaver 1968, Holderman & Goetz 1981).

However, the responses of mixed-grass prairie to consisten tracked vehicular and other military stresses have not been described. While portions of the Canadian prairie have been used extensively for military training for decades, no documentation of the attendant ecological effects on the flora and soils exists in the literature. Access by the author to a mixed-grass prairie in south-western Manitoba used for long-term military training provided an opportunity for such study. The ecological responses of this community to the concentrated, systematic and continuing stress imposed by tracked vehicle firing manoeuvres was studied for three years beginning in 1978.

This thesis describes the changes in prairie vegetation and soils as a function of military stress, and evaluates seeding as a rehabilitation measure.

LOCATION

The Canadian Forces Base Shilo Military Reserve (approximately 49° 45' N, 99° 30' W) occupies 39 500 ha of land adjacent to the Spruce Woods Provincial Forest 2ʳ km south-east of Brandon, Manitoba (Figure 1-1). Some 34 000 ha of the reserve have been used since 1910 for various military training purposes. Each summer since 1974, the Federal Republic of Germany has used large portions of the reserve for training manoeuvres with Leopard II tanks and Marder armoured personnel carriers (A.P.C.'s) (Photo 1-1).

Training areas named Aachen, Berlin, Cologne, Deilinghofen and Essen were established as Ranges in 1976. Since the onset of training thereafter,

Figure 1-1. C.F.B. Shilo Military Reserve.

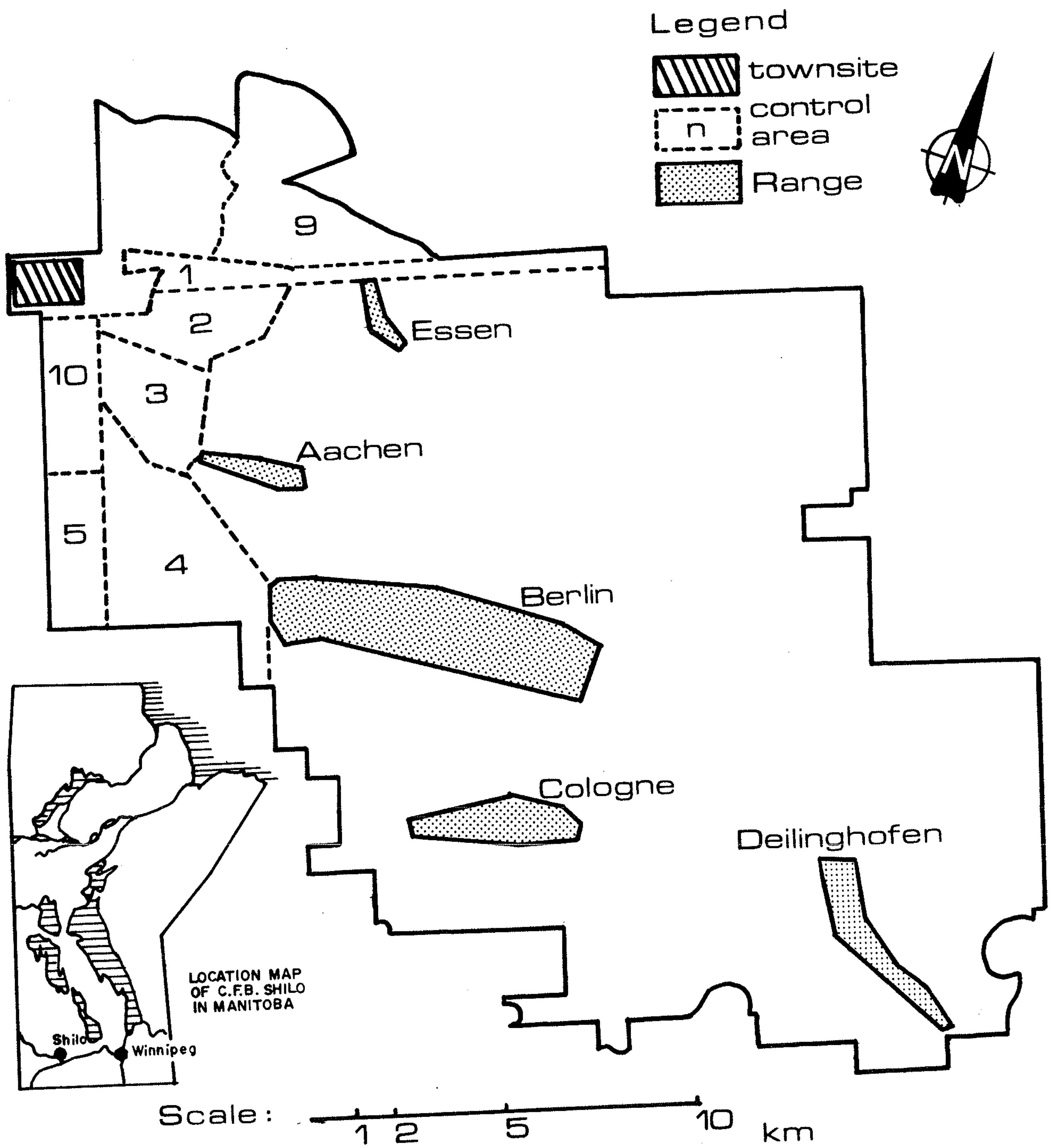
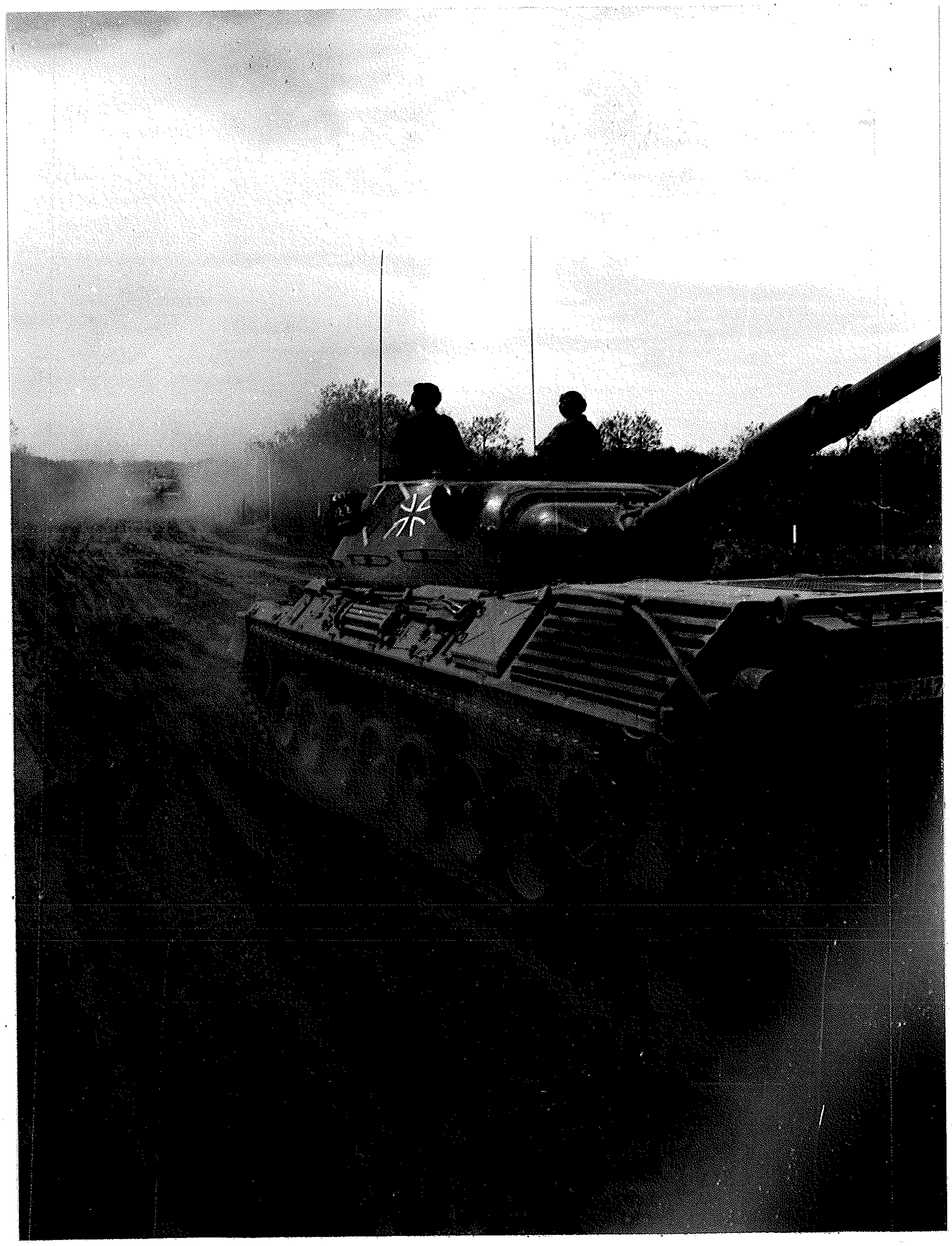

Legend
townsite
n
control area
Range
N
9
1
2
10
3
5
4
Essen
Aachen
Berlin
Cologne
Deilinghofen
LOCATION MAP OF C.F.B. SHILO IN MANITOBA
Shilo
Winnipeg
Scale:
1 2 5 10 km

Photo 1-1. Leopard II tanks of Federal Republic of Germany travelling to training Ranges at C.F.B. Shilo. July 1978.

Note confinement to linear corridors; note impact of concentrated traffic on vegetation cover and surface soil structure.



damage to the mixed-grass prairie vegetation on the reserve has been consistently observed, resulting in concern about the capacity of the area to sustain continued military use. A loss of cover, and subsequent wind erosion of the exposed sandy soils adversely affects training manoeuvres as the unvegetated soils are rapidly scoured, excavated and destabilized by tank and A.P.C. traffic. In addition, Range Essen and Range Berlin are located on soils classed as having very low "trafficability" (Stevens & Carriero 1973), using established criteria (Kjearsgaard 1973). This has prompted concern for the condition of range soils generally and on Ranges Essen and Berlin specifically. Accordingly, the study objective was to describe and quantify the damage to vegetation and soils on tank and A.P.C. training Ranges by comparison with adjacent (control) Areas.

1.1.1 Site Characteristics

Till overlies bedrock throughout the area, the bedrock being comprised of Cretaceous shales (Manitoba Department of Mines and Natural Resources 1970). Sand deposits above the till were deposited by the ancient Assiniboine River as it flowed into glacial Lake Agassiz. Prevailing winds piled these sands into a series of parabolic dunes now stabilized by vegetation except for several hundred hectares in the southeast corner of the reserve. These unvegetated dunes continue to advance in a southeast direction, at an annual rate of 15-20 cm (Ward 1980). Soils that developed on the deep (up to 60 m) deltaic sand included the loamy sands of the Stockton soil association, and the level or slightly undulating glacio-fluvial outwash supports soils of the Miniota association (Table 1-1). Both are well-drained and exhibit low natural fertility, have

Table 1-1. Chemical and Mechanical Analysis
Of Stockton and Miniota Soil Profiles

'A' HORIZON CHEMISTRY	STOCKTON FINE SANDY LOAM	STOCKTON LOAMY SAND	MINIOTA LOAMY COARSE SAND
pH	6.7	7.0	7.1
% Total Nitrogen	0.25	0.20	0.14
C/N Ratio	13.1	12.2	12.7
Available PO_4 (ppm)	5-25	5-25	5-12
Available Potash (ppm)	100-150	75-100	0-100
% Clay (0.002 mm)	12.0	8.5	n.d.
% Silt (0.05-0.002 mm)	19.3	5.6	n.d.
% Sand (1.0-0.05 mm)	68.7	85.9	n.d.

n.d. = no data.

Source: Ehrlich *et al* 1957.

weakly developed structures and are subject to wind erosion after loss of the thin vegetation cover. Recommended agricultural uses of these soils are limited to pasturing, if trash cover and windrows are utilized to prevent loss of fine surface organics by wind erosion (Ehrlich et al 1957).

The climate is continental, with hot dry summers and cold winters (Table 1-2). Annual precipitation is less than 50 cm, nearly half falling as rain in sudden squalls in May, June and July (Longley 1972).

Bird (1961) described the vegetation as in an almost "primaeval condition". The dominant prairie grasses are Bouteloua gracilis, Stipa spartea, Agropyron trachycaulum var. unilaterale, Andropogon scoparius, and Koeleria cristata. Growing in association are several species of Carex, typical prairie herbs such as Vicia americana, Cerastium arvense, Solidago missouriensis, Potentilla arguta, Anemone patens, Geum triflorum, Artemisia campestris, Erigeron strigosus, and the spike-moss Selaginella densa. In the "Aspen parkland" portions of the reserve, stands of Populus tremuloides, Symphoricarpos occidentalis and Eleagnus commutata occur, often in association with Juniperus horizontalis, Arctostaphylos uva-ursi, Prunus pumila and the lichens Cladonia arbuscula* and Cetraria islandica. There are also stands of Picea glauca, Quercus macrocarpa, and occasionally, Populus balsamifera. The presence of White Spruce (Picea glauca) is a botanical curiosity, constituting a relict stand left as the boreal forest retreated northward (Ritchie 1960, Shay 1976).

A species list of vascular plants observed on the Reserve is appended (Appendix I). Several have been recently classified as rare or endangered (White & Johnson 1980).

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* Nomenclature for lichens follows Hale 1969.

Table 1-2. Long Term(1) Meteorological Data

Agriculture Canada Research Station, Brandon, Manitoba

	MAX.		MIN.
Mean annual temperature (°C)		2.2	
Mean daily temperature (°C)			
January	-12.5		-22.7
April	9.6		- 2.9
July	26.9		12.2
October	12.0		- 1.2
Mean annual precipitation (cm)		47.7	
Mean annual snowfall (cm)		117.9	
Mean 5-month summer precipitation (cm)		32.3	
Total 1978 4-month summer precipitation (cm) Carberry, Manitoba		29.2	
Total 1979 4-month summer precipitation (cm) Carberry, Manitoba		14.5	
Total 1980 4-month summer precipitation (cm) Carberry, Manitoba		28.8	
Mean annual evapotranspiration (cm):			
Potential		54.2	
Actual		39.9	
Mean annual water supply deficit (cm)		14.3	
Mean length frost-free period (days)		107.0	
Mean annual number days where $T > 5.5^{o}C$ ($42^{o}F$)		168.0	

(1) 10-31 year mean values.

Sources: Longley 1972.
Environment Canada 1982.

1.1.2 The Military Stress

Designated Areas (numbered 1,2,3,4,5,9, and 10) (Figure 1-1) in the Reserve are sporadically used by Canadian Artillery units, causing localized (± 900 m^2) and slight transient damage. The species composition and condition of these Areas allows them, in the absence of pristine grasslands on the reserve, to be considered as controls to compare with the five Ranges- Aachen, Berlin, Cologne, Deilinghofen, and Essen. The Ranges are clearly circumscribed, varying in size from 80-100 ha, in contrast to Areas, which vary from 375-1 575 ha. All Areas and Ranges are flat, except for Essen, where there are small undulations.

Within Ranges, fixed marshalling areas (Photo 1-2) feed groups of tanks or A.P.C.'s towards a startline, along which they are distributed at non-fixed, arbitrary intervals. Moving in unison and parallel to each other down the Range (Photo 1-3), they fire a wide variety of medium and high-explosive, large and small calibre ordinance at fixed and pop-up targets of various sizes (0.4-3.6 m^2). Each wave of tracked vehicles assembles downrange after firing exercises and returns to the startline via designated dirt roads along the edge of each Range. Ranges are used for 18 days of each 21-day training period from mid-May to mid-October. Track width of the Leopard tank is 55 cm and that for the Marder A.P.C. is 45 cm. Ground pressures exerted by the vehicles are 1.55 kg cm^{-2} and 1.34 kg cm^{-2} respectively (Pers. comm., Capt. A. Robertson, 1978).

1.2 METHODS

1.2.1 Vegetation

Composition was estimated for the five Ranges and seven Areas in late May, mid-June, and mid-July 1979 and 1980 by recording the individual

Photo 1-2. Tank and/or A.P.C. marshalling area.

Photo 1-3. Leopard II tanks on training manoeuvres on Berlin Range. July 1978. Tanks fire 105 mm ordinance at fixed and pop-up targets approximately 1 000 m down-Range.

species at each of 100 intervals along a 33 m transect line and calculating frequency. Because of the great difficulty in discriminating between species in the vegetative state, the few sedges encountered (*Carex filifolia*, *C. pensylvanica*, *C. obtusata*, *C. stenophyla*) were pooled together and considered as a single species variable (*Carex* spp.). In July, cover was also assessed using a modified method common in ecological studies of grasslands. Cover was defined as the sum of the species widths of the downward projections of canopy-spread encountered along the transect tape. A minimum of 10 transects were sampled on each Range and in each Area, each year. Transects were located at random in variously stressed portions of each Range or Area, degree of stress being subjectively determined by visual consideration of vegetation type and condition, presence or absence of explosion craters, tracked vehicle damage to soil surfaces and fire. These locations were visually classified as "relatively undisturbed", as receiving "moderate" and "severe" disturbance, or as "explosion craters".

Voucher plant specimens are lodged in the University of Manitoba Department of Botany.

1.2.2 Soils

1.2.2.1 Chemistry

Seventy-two soil samples in 1978 and fifty-seven in 1979 were taken in September from Areas and locations on Ranges exhibiting the four degrees of disturbance. Samples from each location were subdivided into two strata (0-5 cm, 6-10 cm) and all sub-samples analyzed for pH, conductivity, NO_3, P, K, Cu, Zn, Fe, Mn, Ca, Mg, Na and organic matter. Sodium absorption ratios were subsequently calculated from concentrations of Na, Ca and Mg, using the formula (Anonymous 1979):

$$\text{S.A.R.} = \frac{\text{Na}}{\sqrt{\frac{\text{Ca} + \text{Mg}}{2}}}$$

Analyses were conducted by the Manitoba Provincial Soils Test Laboratory, using standard techniques and Technicon Autoanalyzer and atomic absorption apparatus (Anonymous 1979).

1.2.2.2 Compaction

Using a Penetrometer measuring device calibrated from 0.1-4.0 kg cm^{-2}, unconfined compressive strength of soils (Baver et al 1972) was assessed in 1979 for all Ranges and Areas 2, 3, and 4. These Areas were selected because of their proximity and similarity to the Ranges. In addition, soils of both of the trafficability classes (Kjearsgaard 1973) underlying Ranges (Low, Very Low) are present in these Areas. Compaction was inferred from the force required to penetrate the soil surface to a depth of 2 $\pm$ 0.1 cm. Penetration readings were recorded at the time of vegetation sampling for 50 intervals along each 33.3 m transect. For comparative purposes, readings were also taken at random along tank trails and roadways within two Ranges, and in several lawns and tilled gardens of homes in Shilo.

1.2.2.3 Moisture Tension

Ten irrometers (Irrometer Company of California) were installed at three locations in Area 10 in 1979 and 1980, and at seven locations adjacent to the startline of Range Berlin in 1979 and Range Aachen in 1980. These instruments measured soil moisture tension, an index of available soil water (Kramer 1969) at two depths (15 and 30 cm below grade). Moisture tension data were recorded almost daily at all locations.

1.3 DATA ANALYSIS

1.3.1 Vegetation

Range and Area floristic data were compared in order to identify groups of species and environmental variables found in both types of locations. In any data set (eg., Range mean percent frequency), twenty-one groups of 86 species and environmental variables were successively tested by the SAS (1979) General Linear Models MANOVA procedure to determine the percentage variation explained (Hotelling-Lawley trace F statistic approximation). Many groups contained species or environmental variables considered capable of indicating either vegetation health or impaired function. Others were comprised of variables chosen arbitrarily, their ecological roles being less clearly known. Groups were evaluated according to their ability to meet the criteria of small size (few variables preferred), high explanatory power (i.e., very low probability of exceeding the F test statistic), and low linear dependence among variables.

Two groups ("models") were selected for comparison. Achillea millefolium was not used as an indicator species, in spite of selection by MANOVA analysis, because any variation in the typically very low occurrence observed for this species produced disproportionately great distortion in the calculations of percentage increase or decrease in frequency. Mean frequency and mean cover values for all other model variables were calculated for each Range and Area in each year using the SAS MEANS procedure. DUNCAN'S Test was conducted for equality of variable means within Areas and Ranges. Mean frequency and cover values for each variable in each model were then averaged across Areas and Ranges, generating an aggregate mean value for each variable for Ranges and Areas each year.

1.3.2 Soils

1.3.2.1 Chemistry

To increase the sample size in each of the four stress categories, 1979 and 1980 data were pooled. Subsequently, data for each stratum were pooled after removal of extreme observations and averaged using the BMDP-2D procedure (Dixon & Brown 1977). The Hampel (center-weighted) mean values for each variable so derived were grouped in the four stress categories previously noted.

1.3.2.2 Compaction

Grouped raw data for Areas and Ranges were analyzed and mean compressive strength values for Areas and Ranges compared.

1.4 RESULTS

1.4.1 Vegetation

Statistical analyses identified two groups (models) of indicator species and/or environmental variables (eg., frequency of bare ground) that appeared most useful for comparing data for Ranges with those of control Areas. For analysis of 1979 and 1980 data, different models were selected containing different species/environmental variables (Table 1-3). MANOVA analyses indicated that the capability of each model to explain differences within Ranges and within control Areas was highly significant (Prob $> F = 0.0001$). With the exception of *Achillea millefolium*, the

Table 1-3. Indicator Species/Variables Selected for Comparison of Range and Control Area Vegetation

	1979
Model J	*Achillea millefolium* *Artemisia campestris* *Chrysopsis villosa* *Prunus pumila* *Stipa spartea* var. *curtiseta*

	1980
Model K	Mean number of species per 100 m transect length: *Artemisia frigida* *Bouteloua gracilis* *Carex* spp. (*C. filifolia*, *C. pensylvanica* var. *digyna*)

species and/or environmental variables included in these models were therefore considered 'indicators' capable of discrimination between Ranges and Areas. Mean July frequency data for all variables are in Table 1-4.

Vegetation on Ranges differed from that in control Areas both in 1979 and 1980 with respect to percent frequency of native grasses and forbs, the amount of bare ground or litter present, and the mean number of species encountered per 100 m transect length (Table 1-4). Cover data displayed a similar pattern, and accordingly, are not presented here.

Bare ground and litter were more frequently observed on Ranges in 1979. *Bouteloua gracilis*, the dominant grass, increased in frequency on Ranges by 6% in 1979 and 64% in 1980. *Stipa spartea*, a subdominant grass, increased in 1979 but declined in 1980. Sedges (*Carex* spp.) increased in both years, especially in 1979. Native species sensitive to grazing and other pressures (*Chrysopsis villosa*, *P. pumila*),and even those which invade disturbed areas (*Artemisia* spp.), declined in frequency. Almost all exhibited more pronounced reductions in 1980 than in 1979. Species diversity, as inferred from the average number of species encountered per transect, also declined in both years, most markedly in 1980.

1.4.2 Soils

1.4.2.1 Chemistry

Data for soil constituents in "relatively undisturbed" locations on the reserve were compared with mean concentrations in "moderately" and "severely" disturbed locations on Ranges. The concentrations of the majority of the variables increased along this stress gradient (Table 1-5). Excluding ratio variables (pH, SAR), ten of eleven variables increased in magnitude or concentration by an average of 51% in "moderately" stressed

Table 1-4. Percent Frequency of Native Prairie "Indicator" Species/Variables - Ranges vs. Control Areas

SPECIES	CONTROL AREAS AGGREGATE MEAN	RANGES AGGREGATE MEAN	PERCENTAGE CHANGE
		1979	
Bare ground	3.5	11.9	+240%
Number species/transect[1)]	16.7	12.4	- 26%
Litter	6.2	17.5	+182%
Artemisia campestris	2.7	0.8	- 70%
Artemisia frigida	5.7	2.1	- 63%
Bouteloua gracilis	14.0	14.8	+ 6%
Carex spp.	13.0	23.0	+ 77%
Chrysopsis villosa	1.7	0.6	- 65%
Prunus pumila	1.8	1.1	- 39%
Stipa spartea	4.9	5.7	+ 16%
		1980	
Bare ground	n.d.	n.d.	n.d.[2)]
Number species/transect[1)]	16.1	11.3	- 30%
Litter	n.d.	n.d.	n.d.[2)]
Artemisia campestris	1.5	0.2	- 87%
Artemisia frigida	6.2	1.8	- 71%
Bouteloua gracilis	12.9	21.2	+ 64%
Carex spp.	17.3	20.7	+ 20%
Chrysopsis villosa	2.1	0.3	- 86%
Prunus pumila	1.7	1.0	- 41%
Stipa spartea	6.0	4.7	- 22%

[1)] Values are absolute, not percentages.

[2)] n.d. = no data.

Table 1-5. Percent Change for Soil Chemistry Variables Along a Military Stres Gradient

(Averaged 1978 and 1979 Data, n=129)

	MEAN VALUE "UNDISTURBED"	PERCENT CHANGE OF MEAN "MODERATELY DISTURBED" VALUES FROM MEAN "UNDISTURBED"	PERCENT CHANGE OF MEAN "SEVERELY DISTURBED" VALUES FROM MEAN "UNDISTURBED"	PERCENT CHANGE OF MEAN "EXPLOSION" VALUES FROM MEAN "UNDISTURBED"
pH(1)	6.54	- 12.90	- 6.67	- 56.35
Conductivity (umhos/cm)	0.16	+ 81.25	+ 81.25	+ 37.50
P	5.75 ppm	+ 13.04	- 31.65	- 24.00
K	114.30 ppm	- 10.75	- 9.31	- 34.55
Ca	1330.11 ppm	+ 24.13	+ 37.06	- 13.01
Mg	116.38 ppm	+ 20.04	+ 41.24	- 14.06
Na	16.03 ppm	+ 20.02	+ 3.43	+101.37
Cu	0.49 ppm	+ 87.76	+138.78	+934.69
Zn	2.19 ppm	+110.96	+ 85.39	+ 15.98
Fe	13.38 ppm	+ 49.40	+ 29.67	+ 21.67
Mn	10.08 ppm	+ 52.18	+ 58.83	+ 2.58
Organic Matter	2.56%	+ 47.66	+ 44.53	- 23.05
Sodium Absorption Ratio (SAR)	0.59	+ 10.17	- 10.17	+118.64
Arithmetic Mean(2) Increase (%)		50.6	57.8	185.6
Arithmetic Mean(2) Decrease (%)		10.8	20.5	21.7

(1) Increases in pH were calculated as percent changes in hydronium ion concentration, where pH = $-\log (H_3O+)$.

(2) Excluding pH and SAR, which are ratios.

areas. Nine of eleven increased by an average of 58% in areas "severely" stressed. Six of eleven increased, several (eg., Cu) dramatically, by an average of 186% in explosion craters. Stress, especially explosions, increased hydronium ion concentrations.

In general, the majority of variables increased in magnitude in locations receiving "moderate" and "severe" military stress. Several elements increased very dramatically in explosion craters. Greatest increases in response to "moderate" levels of stress are displayed by Zn (111%), in "severe" stress by Cu (139%), and in explosion craters also by Cu (935%). The mean rate of increased response among variables increased consistently (from 51-186%) along the military stress gradient. Calcium, magnesium and manganese increased under "Severe" stress but decreased in explosion craters.

The relationship of these increased concentrations to threshold values for deficiency effects and normal upper limits in agricultural crops is presented in Table 1-6. Data are provided for agricultural crops because of the paucity of similar data for native mixed-grass species.

1.4.2.2 Compaction

On average, Range soils were 1.5 times more compacted than Area soils (Table 1-7a). When individual Range mean values are compared to the aggregate mean for control Areas (Table 1-7b), certain Ranges appear more compacted than others (eg., Ranges Aachen and Deilinghofen). One Range (Deilinghofen) displayed mean compression values (Table 1-7b) equal to or greater than those recorded for corridors of concentrated tank and A.P.C. traffic (Table 1-7c). The soil surface of Range Essen has been so scoured

Table 1-6. Relationship of Soil Chemistry Variables Along a Military Stress Gradient to Threshold Values

(Units are ug g^{-1} unless otherwise specified, n=129)

VARIABLE	RELATIVELY UNDISTURBED	MODERATELY DISTURBED	SEVERELY DISTURBED	EXPLOSION CRATERS	POSSIBLE THRESHOLD FOR DEFICIENCY EFFECTS IN CROPS (1)	NORMAL UPPER LIMIT (1)
pH	6.54	6.60	6.57	6.90	5.5	8.5
P	5.8	6.5	3.9	4.4	5.0	500
K	114.3	102.0	103.7	74.7	70	1000
Ca	1330.1	1651.0	1823.0	1157.1	400	30000
Mg	116.4	140.1	164.4	100.0	50	3000
Na	16.0	19.2	16.6	32.3	n.d.	300
Cu	0.5	0.9	1.2	5.1	0.3	100
Zn	2.2	4.6	4.1	2.5	0.3	100
Fe	13.4	20.0	17.4	16.3	4.5	400
Mn	10.1	15.3	16.0	10.3	1.0	400
Organic Matter (%)	2.6	3.8	3.7	2.0	1.0	10
Sodium Absorption Ratio	0.6	0.7	0.5	1.3	1.0	10

n.d. = no data.

(1) Sources: Chapman 1966
Agriculture Canada (no date)
Loewen-Rudgers (no date)

Table 1-7. Mean 1979 Soil Compression

(kg cm^{-2})

a.

CONTROL AREAS AGGREGATE MEAN	RANGES AGGREGATE MEAN	PERCENTAGE CHANGE
1.44	2.18	+ 51%

b.

CONTROL AREAS AGGREGATE MEAN	INDIVIDUAL RANGE MEAN		PERCENTAGE CHANGE
1.44	Aachen Range:	2.64	+ 83%
1.44	Berlin Range:	2.42	+ 68%
1.44	Cologne Range:	1.79	+ 24%
1.44	Deilinghofen Range:	3.11	+116%
1.44	Essen Range:	0.94	- 34%

c.

Tank trails on Range Aachen:	2.95
Tank trails on Range Berlin:	3.69
Return road to Aachen startline:	3.06

d.

Shilo lawns:	2.01
Shilo gardens:	0.93

by manouevres that soil structure has been significantly damaged. Mean penetrometer compressive strength for Essen (Table 1-7b) was virtually identical with that recorded for tilled gardens in the vicinity (Table 1-7d).

1.4.2.3 Moisture Tension

Soil moisture tension was more variable in 1980 than 1979 (Figure 1-2). While soil moisture availability declined and moisture tension increased progressively through the 1979 growing season, greater and more highly variable precipitation in 1980 (Table 1-2) caused more pronounced extremes in soil water availability early in the season, and low tensions thereafter.

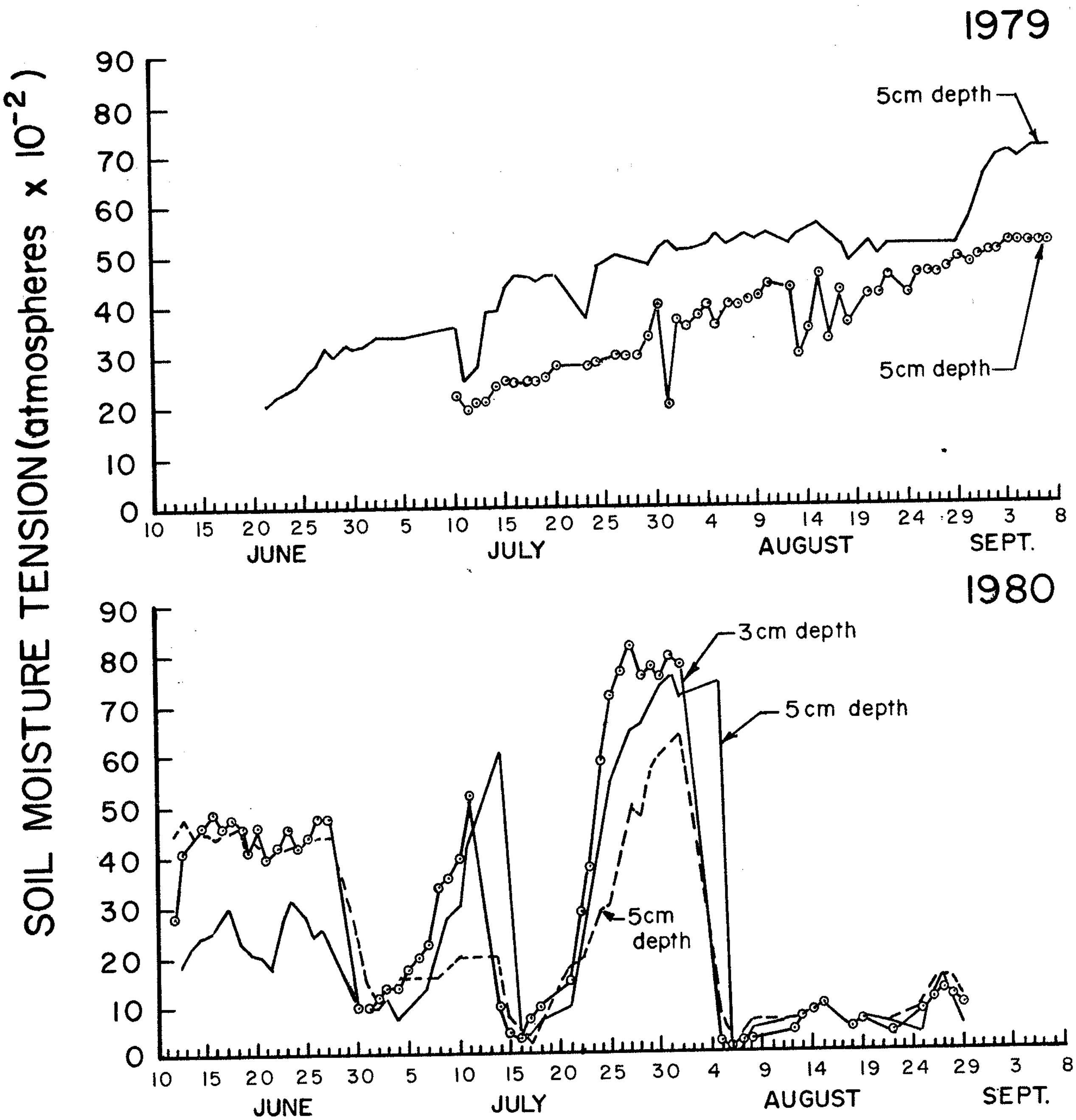
Assessment of soil moisture tension by means of the Irrometer instruments was problematic. Firstly, instruments required frequent application of vacuum (using a special hand pump) to purge the water column of air bubbles that developed in the gauges; the presence of air bubbles tended to make readings suspect. Secondly, the instruments varied in their individual responses to soil conditions within the same areas. Data presented in Figure 1-2 are from Irrometers displaying similarity of data trend; data from several other Irrometers could not be used, because gauge readings were frequently highly suspect (eg., high tension readings immediately after rainfall, low tension readings during periods of protracted dryness).

1.5 DISCUSSION

1.5.1 Vegetation

The two groups of species and/or environmental variables indicated as most statistically useful by MANOVA analysis to compare Range and

Figure 1-2. Seasonal Soil Moisture Tension.


1979
5cm depth
5cm depth
SOIL MOISTURE TENSION (atmospheres x 10^{-2})
0
10
20
30
40
50
60
70
80
90
10 15 20 25 30 5 10 15 20 25 30 4 9 14 19 24 29 3 8
JUNE
JULY
AUGUST
SEPT.
1980
3cm depth
5cm depth
5cm depth
10 15 20 25 30 5 10 15 20 25 30 4 9 14 19 24 29 3 8
JUNE
JULY
AUGUST
SEPT.

control Area vegetation are botanically meaningful.

Almost all variables can be used to evaluate the degree of defoliation stress to which the prairie vegetation is subjected. This arises from the characteristic nature of the stress tolerance responses of these species, and from consideration of their Raunkiaer life forms (Kershaw 1964). In this regard, high frequencies of Bouteloua gracilis, sedges (Carex pensylvanica var. digyna, C. filifolia), Artemisia frigida, and A. campestris can indicate high levels of grazing defoliation or trampling stress (and attendant increases in frequency of bare ground). Low frequencies of Achillea millefolium, Chrysopsis villosa, Prunus pumila, and Stipa spartea, and low numbers of species per transect can indicate these same or similar stresses (Campbell et al 1966, Budd & Best 1969). Low frequencies of the Artemisia species could also indicate defoliation stress, by virtue of the susceptibility of the chamaephytic growth form to tank traffic. This kind of susceptibility would also explain reduced frequencies of C. villosa and P. pumila. Because Achillea millefolium occurs with very low frequencies in the reserve, and because even slight changes in frequency appear disproportionately large when considered on a percentage basis, this species was not used for comparative purposes. All others used were therefore considered as ecologically indicative or explanatory, and are referred to hereafter in that sense, as "indicator" variables.

The MANOVA analysis, although time-consuming, allowed objective identification of useful analytical models. These two groups of variables besides having botanical (i.e., subjective, qualitative) meaning, were also found to be statistically (i.e., objective) valid tools for determination of military effects on vegetation.

In both years, the data indicate reduced performance of prairie vegetation on Ranges compared with control Areas. Most indicator species and variables on Ranges when compared with control Areas, showed a consistent pattern of increased frequency if stimulated by stress or reduced frequency if sensitive. Presumably this was the effect of military training. These data are corroborative of other research which indicated that vehicular traffic caused reductions in mean total cover values, the number of species present in a stressed area, density values, and altered species composition (Hosier & Eaton 1980, Liddle & Grieg-Smith 1975b). Bouteloua gracilis and Carex spp. (especially C. pensylvanica var. digyna) increased in frequency in both years. All are considered to be stimulated by grazing and other defoliating pressures (Moss 1952, Weaver 1968, Holderman & Goetz 1981), which may be approximated by military training manoeuvres.

The decreased competitive ability observed for other caespitose native grasses not in the comparative models used (eg., Festuca ovina) also results from vehicular defoliation. Decreased competitive ability appears related to the ability of tufted bunchgrass canopies to concentrate rainwater in the rooting zone beneath the tuft. Defoliation of these species precludes this optimizing response to rainfall (Ndawula-Senyiba et al 1971).

Defoliation pressures can stimulate productivity in prairie grasses, an effect not necessarily solely attributable to increased rates of organic matter turnover (Rice & Parenti 1978). Patches of prairie defoliated by tank and A.P.C. traffic may exhibit reduced surface albedo, with concomitant increases in diurnal outgoing longwave radiation, which varies largely as a function of soil surface temperature. Maximum surface temperature during mid-day sun periods is increased by defoliation (Johnston 1961, Jacques 1977, Rice & Parenti 1978), as are reductions in available soil moisture (Mishra 1979). Rapid reradiation of energy would occur at night, reducing night respiration, thereby enhancing net photosynthetic production (Kucera & Ehrenreich 1962, Daubenmire 1968). The warmer soils and increased light intensity at soil surfaces aid in initiating early growth, contributing to early creation of carbohydrate reserves (Annala & Kapustka 1982). Growth of *Bouteloua gracilis* and *Stipa spartea* is related to soil temperatures, regrowth of defoliated *B. gracilis* being especially dependent on high soil temperatures to initiate and sustain new biomass production (Clarke *et al* 1943, Chung & Trlica 1980). Allocation of ^{14}C in defoliated *B. gracilis* is greatest to production of new culms and leaves at high temperatures (34°C day, 16°C night) if soil moisture tensions are much less than -30 bars (Chung & Trlica 1980). While field crops effectively cease stomatal transpiration and growth as soil moisture tension declines below -15 bars, drought-tolerant grasses, especially C_4 species (eg., *Bouteloua gracilis*), transpire and grow at higher soil matric potentials (Brown 1977). *B. gracilis* can lose up to 98% of its free water and survive (Oppenheimer 1960) and *Calamagrostis canadensis* (native to Shilo) has displayed measurable growth at soil moisture tensions of -28 bars (Eddleman and Minlos 1972).

Consideration of soil moisture data (Figure 1-2) reveals lower moisture tensions in mid-July 1980 compared with the same period in 1979. This suggests that the greater increase in frequency of *B. gracilis* on Ranges in 1980 (64%), compared to 1979 (6%), may be attributed to a high temperature, moderate moisture tension (-15 bars) regrowth phenomenon (Chung & Trlica 1980).

The Kranz-type anatomy of C_4 plants (larger phloem cross-sectional areas, fewer cells between leaf vascular bundles, closer proximity of leaf cells to vascular tissue, and shorter interveinal distances as compared with C_3 plants) confers upon these species a greater water use efficiency than C_3 species (Waller & Lewis 1979). This competitive advantage is most effective in semi-arid environments, where high temperatures favor C_4 photosynthesis (Ps) preferentially, producing net Ps rates two- to three-fold greater than seen in C_3 plants (Waller & Lewis 1979). These characteristics, and the greater nitrogen use efficiency reported for C_4 plants (Brown 1978), make them capable of rapid regrowth in response to defoliation stress, even under apparently adverse conditions (high temperatures, low moisture and nitrogen).

The functional displacement in time of C_3 and C_4 productivities (Ode *et al* 1980) ensures that the factors stimulating greatest production in C_4 species at Shilo (eg., *B. gracilis*, *Andropogon scoparius*, *Calamovilfa longifolia*, *Panicum capillare*, *Setaria viridis*, etc.), occur later in the growing season, when grass regrowth is most needed in response to the prior exertion of military stress.

Mean *B. gracilis* frequency values of 20% and 40% have been suggested as indicative of "moderate" grazing and "overgrazing" conditions respectively (Smoliak *et al* 1976). Use of these criteria would suggest that, on average, all Ranges were "moderately" stressed in 1979 and 1980 (Table 1-4).

The ratio of *Bouteloua gracilis*: *Stipa spartea* (B/S) can also indicate the general condition of stressed prairie. In ranching, increases in the B/S ratio are thought to indicate increased grazing stress, while decreases signify lower levels of such stress (Clarke *et al* 1943). In southern Alberta and south-western Saskatchewan, Clarke and others (1943) observed a reduction of 30% in the B/S ratio in sandy loam and silt loam shortgrass pastures "lightly" grazed (16 ha/animal). Increases in the ratio of 5% were seen in pastures "moderately" grazed (12 ha/animal), and 10% in "heavily" grazed pastures (8 ha/animal).

Although the topography and soils at Shilo are roughly similar to those at Manyberries, Alberta, the B/S ratios derived by Clarke and others (1943) are not directly applicable to this study, due to large differences in mean annual precipitation between the two sites. Nonetheless, a reduction in the B/S ratio derived from the frequency data (Table 1-4) for 1979 can be interpreted as indicating lower stress than obtained in 1980, for which the ratio exhibits a 74% increase.

1.5.2 Soils

1.5.2.1 Chemistry

Range soil chemistry data show increasing concentrations or magnitude for 9 of 13 variables under "severe" training stress, and for 11 of 13 variables under "moderate" stress.

The changes in constituent concentrations or magnitude all appear related to military activity. High explosives are usually nitration products of organic compounds (U.S. Department of the Army 1956). Copper, iron and zinc are important constituents in shell casings, and stability additives in high explosives. Increased concentrations of these elements in training Areas (Table 1-6) are therefore not unexpected. Sodium and potassium are present as oxidizers in pyrotechnic ordinance (eg., flares, smoke screens). The high concentration of Na in craters (Table 1-6) is therefore not unexpected, although the low concentration of K is. Potassium is present at all stressed locations at concentrations approximating background levels (Table 1-1). Phosphorus is the major ingredient in White Phosphorus (W.P.) flares and smoke screens. When dispersed as small particles by explosion, it burns spontaneously on exposure to air and is widely dispersed in fallout. Zinc is the principal agent in smoke screen ordinance. Zinc concentrations are low in explosion craters, approaching background levels (Table 1-6). This finding is not surprising, because this ordinance is not recommended for terrain in which projectiles can be easily buried or smothered, and is typically used in a parachute-suspended shell. Combustion products are thus easily dispersed, accounting for the generally elevated concentrations in Areas "moderately" and "highly" stressed.

Magnesium ignites readily, burning with intense heat and light, causing its extensive use in pyrotechnic mixtures and incendiary ordinance. Used typically as an illuminating flare for night manoeuvres, the oxidized particles of combustion are disseminated as the flare floats to earth, producing the elevated concentrations seen in the "moderately" and "highly" stressed sample locations (Table 1-6). The relatively low concentration in explosion craters is attributed to its greater use in illuminating, rather than artillery, ordinance.

The heats of detonation of both low- and high-explosives ($\pm$ 3300°C) (Department of the U.S. Army 1956) are sufficient to vaporize many metals, eg., copper (B.P. 2576°C), iron (B.P. 2750°C), zinc (B.P. 907°C) (Weast 1975). This ensures slow accumulation of metal oxides and other elements (eg., B.P. sodium = 883°C)(Weast 1975) around and in explosion sites, and in locations "moderately" and "highly" stressed.

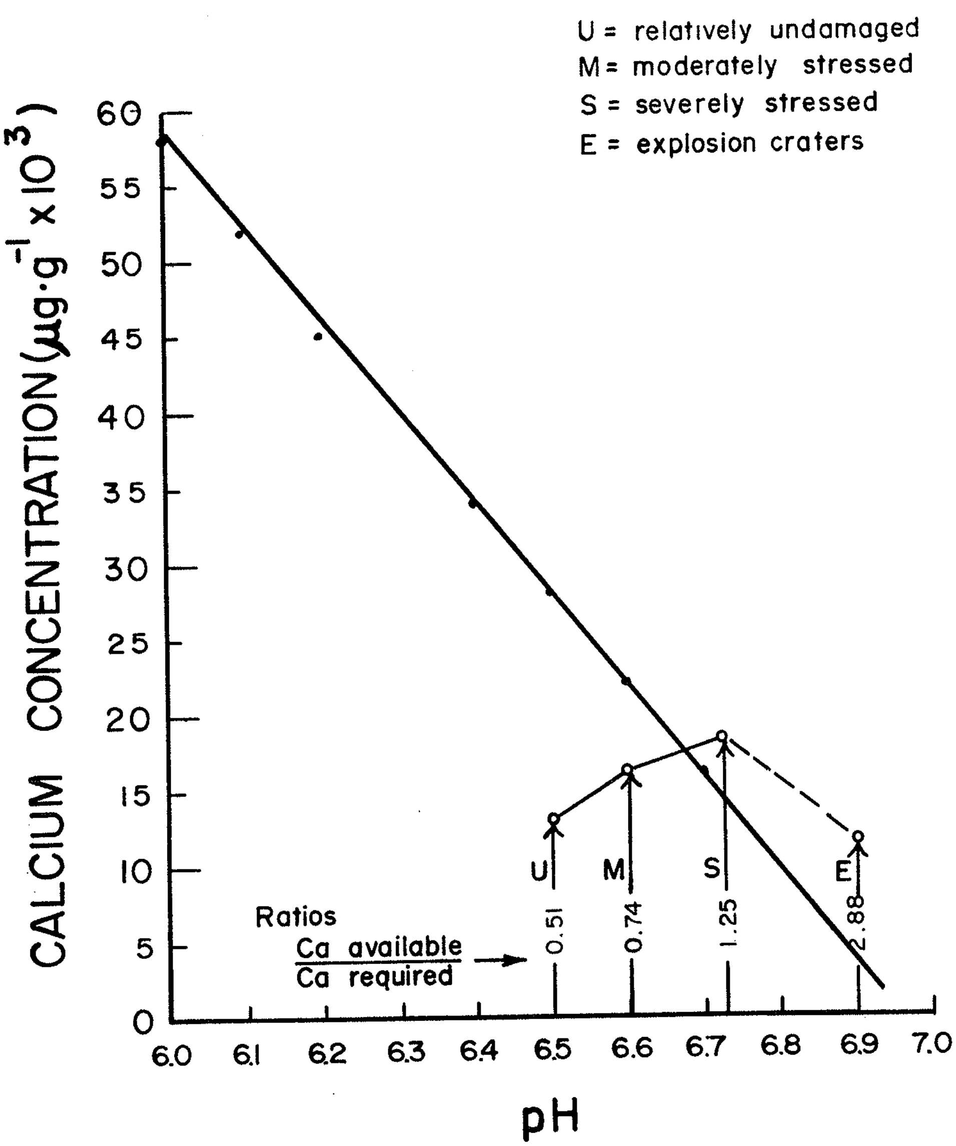
Many of these apparent increases in concentration may be beneficial to the nutrient-poor soils of the reserve. Sandy, slightly acidic soils are noted for their mineral deficiencies, especially for Zn, K, Mg, Cu, etc. (Chapman 1966, Loewen-Rudgers et al,no date). In addition, only in locations "severely" stressed and in explosion craters are Ca concentrations above the pH-related minimum requirements for agriculture. Calcium requirements decline with increasing pH. The ratio of Ca supply:Ca required varies with pH along the stress gradient, from 0.5 in "relatively undisturbed" locations, to 0.7 in "moderately" disturbed sites, to 1.25 in "severely" stressed locations. In craters, where pH is highest and calcium requirements therefore lowest, the ratio is greatest at 2.8 (Figure 1-3). Thus Ca supply exceeds theoretical need only in severely stressed locations, and is otherwise in sufficiently short supply that any military-related increase would be beneficial.

Because saturation by H+ on cation exchange sites provides little space for other cations, soil acidity is associated with infertility; displacement of H+ by Ca^{2+} and Mg^{2+} cations associated with increased soil fertility is also characterized by increased availability of these cations at higher pH values. As noted, such availability increases along the hypothesized stress gradient, and benefiting both plant growth (Chapman 1966) and soil flocculation and aggregation (Baver et al 1972). Conversely, increased Fe concentrations along the gradient are more than balanced by pH-related decreases in Fe availability (Bannister 1976). A similar pH-related relationship holds for Zn along the stress gradient.

Plants converting CO_2 to carbohydrates via the C_4, B-carboxylation pathway are numerous in warm arid environments, and frequently require more sodium than is present (Moore 1977). Native Shilo C_4 plants (eg., Andropogon scoparius and Bouteloua gracilis) would benefit by the increases in sodium in explosion craters and under apparently "moderate" levels of

Figure 1-3. Soil Acidity and Calcium Requirement on C.F.B. Shilo Training Ranges.

Source: Chapman 1966.



U = relatively undamaged
M = moderately stressed
S = severely stressed
E = explosion craters
CALCIUM CONCENTRATION (µg·g⁻¹ x 10³)
60
55
50
45
40
35
30
25
20
15
10
5
0
Ratios
Ca available
Ca required
U
M
S
E
0.51
0.74
1.25
2.88
6.0
6.1
6.2
6.3
6.4
6.5
6.6
6.7
6.8
6.9
7.0
pH

stress. This increase in sodium is not so great as to threaten soil structure, however, because of compensating increases in soil calcium and magnesium. The magnitude of the sodium absorption ratio, a measure of soil de-aggregation and potential impairment to structure, declines with increasing military stress. This suggests that another apparent effect of military stress may be beneficial to soil structure.

1.5.2.2 Compaction

Range soils are being compacted as a result of military training (Table 1-7a). Most Shilo Ranges appear substantially compacted by manoeuvres, when compared with control Areas, and one (Essen) displays considerable destruction of soil surface structure by scouring and excavation (Table 1-7b). These data verify the ranking of soils beneath this Range as having very low trafficability (Kjearsgaard 1973), and indicate that use of this Range should be reduced or reconsidered.

The compaction data are congruent with study results on the effects of tracked vehicle traversal trials on the silt-loam soils of C.F.B. Suffield, Alberta, where Beare (1972) observed mean increases of 11% in bulk density in stressed macro-plots. Jacques (1977) found a mean increase of 19% in disturbed training Range soils elsewhere on the Suffield Reserve. However, the magnitude of the Shilo compression values is, in general, relatively small. The highest mean compressive strength value recorded on a Range (3.11 kg cm^{-2}) is far less, for example, than the highest mean value (20 kg cm^{-2}) observed beneath off-road vehicle pathways in Carolina sand-dunes (Hosier & Eaton 1980).

Regarding effects of compression on vegetation, compaction can reduce the infiltration rate, as compression-related increases in soil bulk density (Kucera 1958) cause reductions in total pore space (Mishra 1979). Reductions in the infiltration rate can cause increases in the water content of surface soils (Liddle & Greig-Smith 1975a). In addition, soil compaction can reduce total root growth (Timm & Flocker 1966) and change the vertical distribution of root biomass in soil profiles (Taylor & Burnett 1964). Growth inhibition has been shown to be related more to soil strength than to other physical factors (eg., bulk density) (Taylor & Gardiner 1963).

A significant inverse relationship (r = -0.96) between soil strength as measured by penetrometer, and percentage of cotton taproots penetrating a soil column has been demonstrated for plants growing in a fine sandy loam under soil moisture tensions ranging from 0.11 - 0.65 atmospheres (Taylor & Gardiner 1963). A similar relationship has been shown for several Gramineae (*Panicum virgatum*, *Triticum aestivum*, *Secale cereale*, *Echinochloa crusgalli*, *Zea mays*, *Sorghum vulgare*) growing in the same soil in laboratory trials at 0.33 atmospheres soil tension (Taylor *et al* 1966). Gramineae seedling emergence in the latter study was precluded when penetrometer soil strengths exceeded 12.2 - 18.4 kg cm^{-2}. Emergence was slightly decreased as soil strengths approached the 6.1 - 9.2 kg cm^{-2} range. The range of soil moisture tensions under which this experiment was conducted (0.11 - 0.65 atmospheres) is virtually identical to the range of values observed (0.18 - 0.69 atmospheres) in 1979 and very similar to that observed (0.20 - 0.82) in 1980 for the fine loamy sand soils at C.F.B. Shilo (Figure 1-2).

While the Shilo soils are not identical to those for which seedling emergence data are reported (Taylor & Burnett 1964), they are sufficiently similar that general comparisons may be made.

The mean penetrometer soil strengths (Table 1-7) for control Areas (1.44 kg cm^{-2}) and Ranges ($0.94 - 3.11$ kg cm^{-2}) are much lower than the $6.1 - 9.2$ kg cm^{-2} threshold for inhibited seedling emergence observed for a fine sandy loam (Taylor *et al* 1966). In addition, these values are much less than the absolute soil strength limit to emergence (30.18 kg cm^{-2}) observed for the same soil by Taylor & Gardiner (1963).

If the regression equation ($Y = 104.6 - 3.53 X$) derived by Taylor & Gardiner (1963) could be applied against the soil strength data observed for Shilo soils, the maximum reduction that could be predicted for seedling emergence would be approximately 8.5% beneath tank trails on Berlin. Using this regression, the mean Range compressive strength value (2.18 kg cm^{-2}) would predict an emergence inhibition of only 2.5% (Figure 1-4). Thus the soil compression resulting from military training manouevres on Shilo Ranges is not likely to have affected gramineous seedling emergence, nor subsequent plant growth to a significant extent.

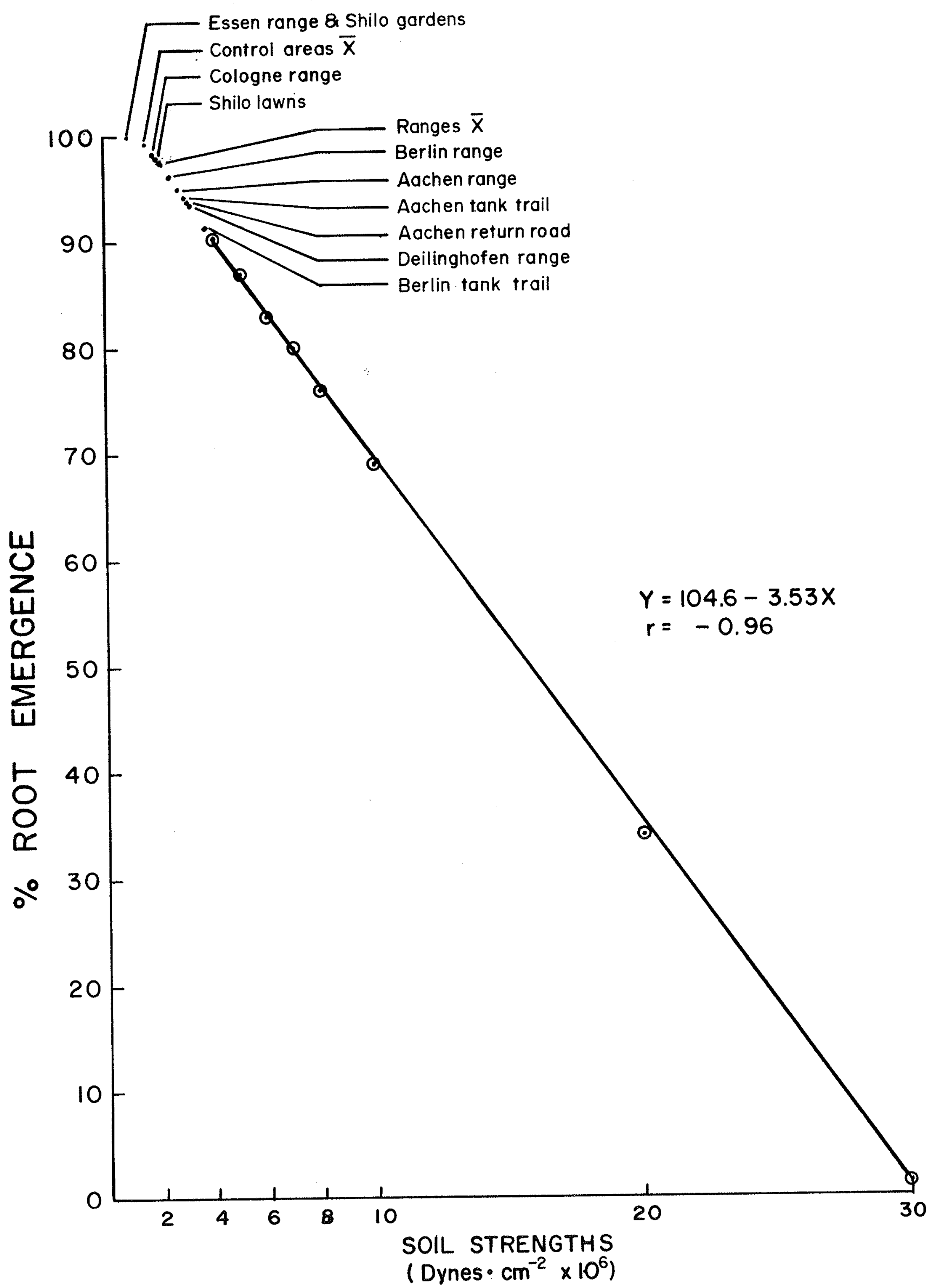
The relatively low magnitude of compression is likely related to the large surface areas of the rubber-padded tank and A.P.C. tracks, which reduce vehicular pressures (1.55 and 1.34 kg cm^{-2} respectively) to levels lower than those (3.16 and 2.11 kg cm^{-2}) reported by contrast, for Jersey cows or sheep (Vaugh 1931).

1.6 CONCLUSIONS

Consistent indications of adverse effects on native species composition are displayed by the mixed-grass training Ranges used for tracked vehicle firing manoeuvres. Species responding positively to grazing and other stresses are more frequent on Ranges than control Areas; *Artemisia frigida* is 64-71% more frequent on Ranges, *Bouteloua gracilis* is from

Figure 1-4. Predicted Seedling Emergence Inhibition by Soil Compaction.

Source: Taylor & Gardiner 1963.



Essen range & Shilo gardens
Control areas X̄
Cologne range
Shilo lawns
Ranges X̄
Berlin range
Aachen range
Aachen tank trail
Aachen return road
Deilinghofen range
Berlin tank trail
Y = 104.6 − 3.53X
r = −0.96
% ROOT EMERGENCE
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
20
30
SOIL STRENGTHS
(Dynes • cm^{-2} x 10^{6})

6-64% more frequent. Conversely, species which respond negatively to such stresses displayed reduced frequency on Ranges. Increased growth of B. gracilis appears related to the ability of C_4 grasses to display strong regrowth in response to defoliation pressures in circumstances of high temperature and low available moisture.

A potentially irreversible trend to soil enrichment, particularly by metals, is also observed on training Ranges. Enrichment generally increases with stress. Enrichment is, however, elevating concentrations which presently scarcely exceed levels associated with growth deficiencies in agricultural crops. In addition, increased concentrations of several elements is offset by reductions in availability as pH increases with stress.

Range soils are being compacted by training manoeuvres. However the capacity of sandy soils to be compressed is limited. In addition, increases in soil calcium, magnesium and organic matter may, along with compaction, be contributing to improvements in the structure of the sandy loam Range soils. Compaction appears to be of a magnitude insufficient to significantly inhibit seedling emergence of Gramineae.

Short-term effects on the soils of Ranges could therefore be construed as neutral or positive.

The use of Irrometers to assess soil moisture tension is judged to be unsatisfactory. The devices require overly frequent maintenance, and display differing sensitivities.

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CHAPTER 2

RECLAMATION MEASURES

2.1 INTRODUCTION

Damage to grasslands devoted to military training activities is frequently severe, although few quantitative impact data are reported in the literature. Qualitative descriptions of impact are more frequently encountered, many in relatively non-scientific journals (Anonymous 1976a, 1976b). The limited impact data available are typically generated by researchers under contract to the military (Jacques 1977, Beare 1972), whose reports are not widely disseminated nor subjected to critical review. Where literature deals with recovery of such damaged grassland systems, those few quantitative recovery studies available usually focus on plant-animal interactions (Dettling et al 1980).

Reclamation of damaged grasslands typically involves soil preparation, seeding with various combinations of native and introduced grasses and legumes, and subsequent protection, in varying degree, from the original stress. The design of a recovery program for grasslands stressed by military training is frequently based on inferences drawn from classical range reclamation studies, such as that of Clarke and Heinrichs (1941), who described reclamation of over-grazed prairie in Western Canada. The best known reclamation project based on military training damage is a 6-year project to revegetate the 19 000 ha Puckapunyal firing ranges in central Victoria, Australia begun in 1971. Nearly 16 000 ha were graded and seeded to legumes and grasses and an additional 850 ha to trees and shrubs in an attempt to restore the badly damaged facility (Anonymous 1976a, 1976b).

At the Shilo Military Reserve, experiments were initiated in 1978 to identify the most effective means of restoring damaged mixed-grass prairie training Ranges. Zero-tillage seeding treatments, using several combinations of drought-tolerant exotic grasses and legumes, was considered the most appropriate rehabilitation strategy to be evaluated. Of particular interest was the capacity for self-restoration of damaged areas, given suitable protection, as compared with the rehabilitation effected by seeding. Additionally, because the time required for a stressed prairie to return to pre-stress conditions has been little studied (van Voris et al 1980), determination of an appropriate "resting" period for all treatments was also of interest.

2.2 METHODS

To evaluate the response of damaged prairie to seeding reclamation procedures, six seed mixtures were prepared and sown in a heavily traversed area behind one of the training Ranges. Studies were undertaken to identify, in the face of competition from seeded species, the response of the native prairie vegetation in terms of:

1) Frequency of desirable native species;
2) Species diversity;
3) Root production;
4) Aboveground productivity.

2.2.1 Site Preparation

In the fall of 1978, training Ranges and adjacent areas were surveyed to find a suitable location for seeding trials. A flat, heavily traversed area adjacent to the tank marshalling area and behind the startline of a training Range was desired. The location had to have been subjected to great training-related stress. Degree of stress was visually determined by consideration of vegetation type and condition, presence or absence of explosion craters, and degree of tracked vehicle damage to soil surfaces (eg., scouring). An area behind the startline of Range Berlin (Photo 2-1) was found and used for the study.

Twenty-one plots, each having an area of 0.1 ha, were laid out to test the response of damaged grasslands to seven (zero-tillage) seeding treatments (Figure 2-1). Each treatment was replicated three times and assigned to the field plot position at random. Six mixtures of grass and legume seed were sown. The seventh treatment, a control, consisted of no seeding but replicate plots were harrowed in the same fashion as plots receiving seed. The plot distribution exemplifies the Completely Randomized statistical design leading to a one-way Analysis of Variance with fixed-effect treatments (Huntsberger & Billingsley 1977).

Species were included in a mixture on the basis of apparent appropriateness to the existing meteorological, pedologic and ecological conditions. They possessed several of the following characteristics:

1) Commercial availability of seed;
2) Aggressive colonization of bare ground;
3) Fibrous and/or rhizomatous root systems;
4) Drought tolerance;
5) Perennial growth habit;
6) High germination rate;
7) Long growing season;
8) Good growth on sandy soils;
9) Addition of atmospheric nitrogen to the soil;
10) Early, "cool season" growth.

Photo 2-1. Colour Infrared Photograph of Eastern Half of Range Berlin, Showing Seeding Plots (lower right-hand corner).

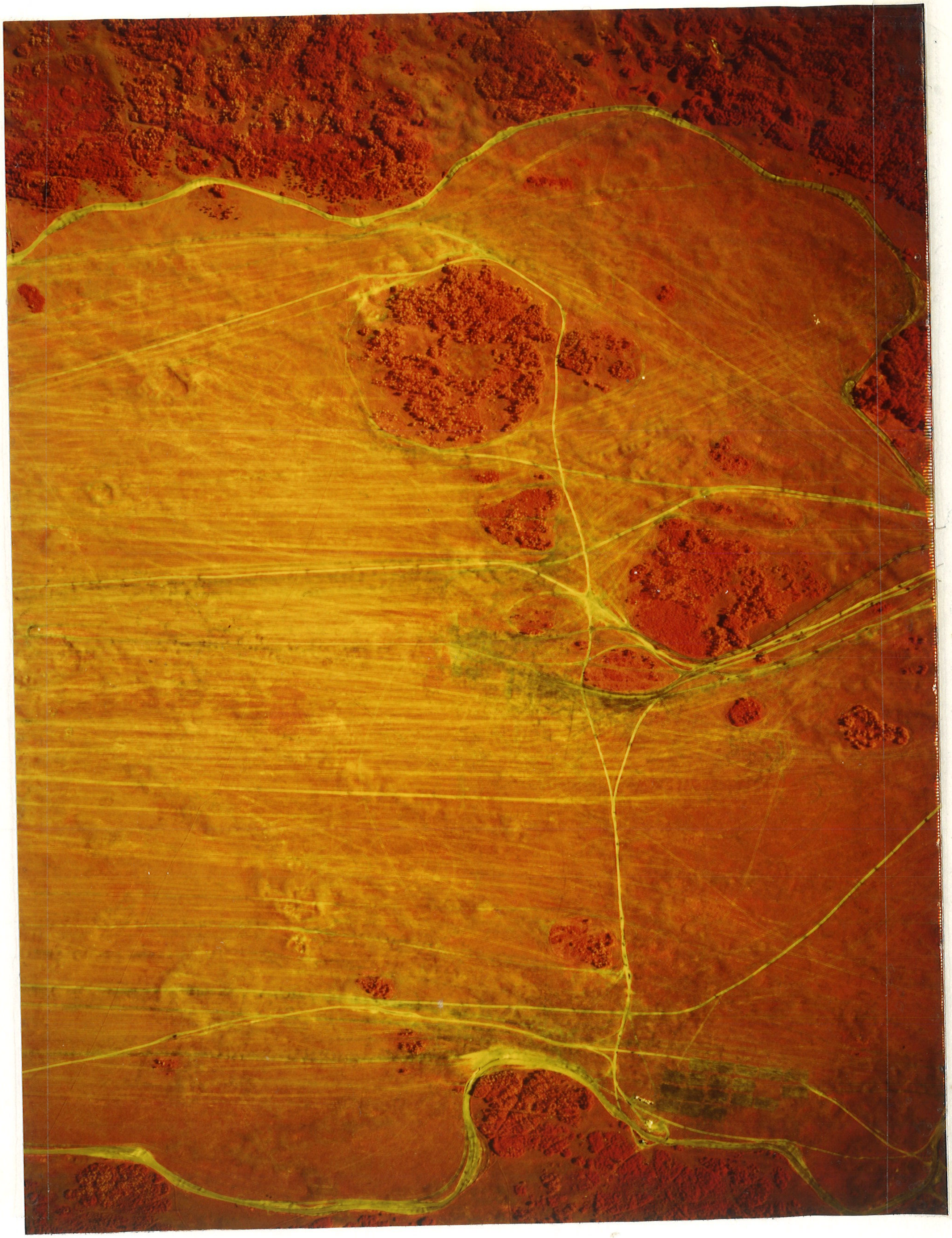
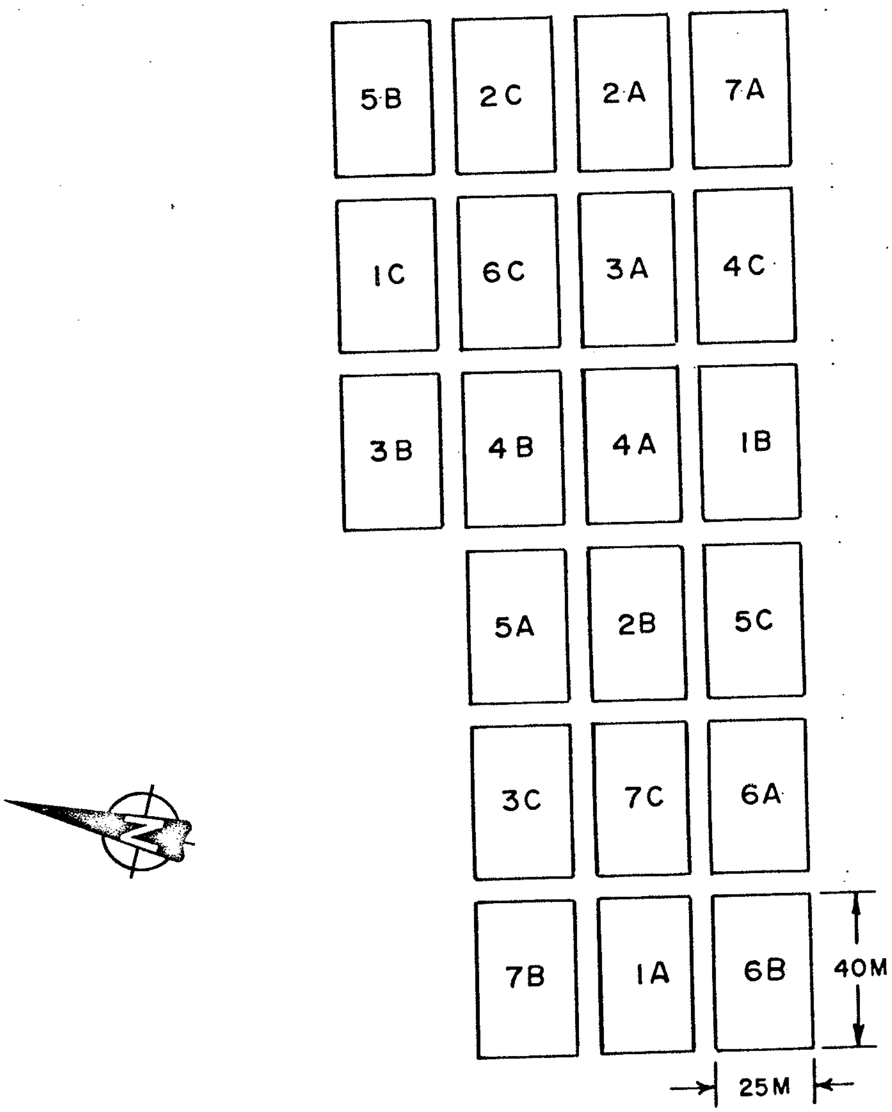


Figure 2-1. Site Configuration - Seeding Experiment.



Legend:

'A'	1st replication
'B'	2nd replication
'C'	3rd replication
'1'	Seed Mix One
'2'	Seed Mix Two
'3'	Seed-Mix Three
'4'	Seed Mix Four
'5'	Seed Mix Five
'6'	Seed Mix Six
'7'	Treatment Seven (no seed)

Agropyron cristatum, noted for its drought tolerance, early spring growth, dense fibrous root production and aggressive growth was sown in three mixtures. *A. cristatum* is the most commonly used perennial grass for range revegetation in the western United States (Holechek 1981) and Canada, and is considered to be grazing and defoliation tolerant (Caldwell *et al* 1981). *A. intermedium*, also drought-tolerant and showing high germination and an excellent soil-binding rhizomatous root system, was sown in two mixtures. *Elymus junceus* is a large, cool-season bunchgrass with extensive fibrous roots capable of soil penetration to depths of three meters. A long-lived perennial, *E. junceus* is exceptionally cold and drought tolerant, although germination and emergence are often slow (Smoliak & Johnston 1980). This grass was sown in four mixtures. Each of the legumes *Medicago sativa* and *Melilotus officinalis* was sown in three mixtures to provide nitrogen fixation and the fire resistance afforded by their long growing seasons.

Species included in a seed mixture were always present at the same seeding rate (Table 2-1). The species and rates used were recommended by the University of Manitoba Plant Science Department.

The control treatment provided for comparison of treatment performances, including the study of the effect of mere protection of damaged prairie.

2.2.2 Vegetation

Species composition was estimated as percent frequency in the manner previously described (Chapter 1) three times each summer in 1979 and 1980 on all plots. The three annual surveys were conducted in early June, late June and mid-July each year. Only mid-July data are reported herein, to describe vegetation responses at the height of the growing season. A

Table 2-1. Experimental Seed Mixtures

MIXTURE	CONSTITUENT SPECIES	SEEDING RATE (kg ha^{-1})
One	*Agropyron cristatum*	6.7
	A. intermedium	11.2
	A. trachycaulum	4.5
	Bromus inermis	9.0
	Elymus junceus	6.7
	Festuca rubra	5.6
	Medicago sativa	3.4
	Melilotus officinalis	6.7
		53.8
Two	*A. cristatum*	6.7
	B. inermis	9.0
	M. sativa	3.4
		19.1
Three	*E. junceus*	6.7
	F. rubra	5.6
	M. sativa	3.4
		15.7
Four	*A. cristatum*	6.7
	E. junceus	6.7
	M. sativa	3.4
		16.8
Five	*A. intermedium*	11.2
	A. trachycaulum	4.5
	M. officinalis	6.7
		22.4
Six	*A. intermedium*	11.2
	E. junceus	9.0
	M. officinalis	6.7
		26.9
Seven	No seeding. Harrowed like seeded plots	

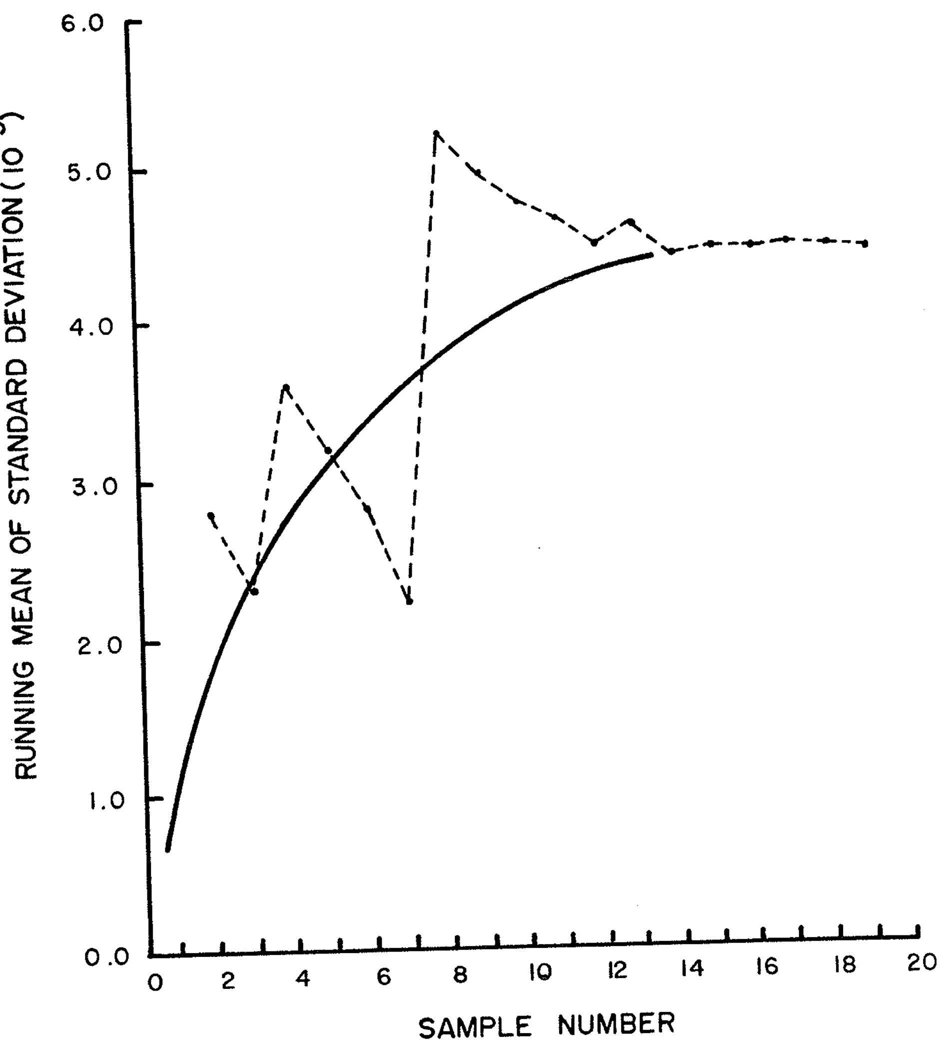
minimum of two transects per replicate plot was used during each survey each year.

2.2.3 Root Biomass

Using a manual corer designed for prairie soils (Bartos & Sims 1974), 65 cores of approximately 500 cm^3 volume each were taken from a single representative plot according to a pre-determined sequence of randomly located sample locations; these were used to identify the minimum number of samples needed to characterize a replicate plot. All cores were weighed immediately in the field with an Ohaus triple beam balance. After manual fragmentation of the core over a 2 mm mesh and sieving of the soils, roots were separated by hand and the fresh weights and fraction of sample mass recorded. Subsequently, the running mean of the standard deviations of the mean root fraction of all samples was plotted against sample number (Figure 2-2), to determine the number at which fitted curve deflection was greatest and standard variation was stabilized. Variation was found stabilized completely at sample sizes of 20.

Accordingly, twenty soil cores of approximately 500 cm^3 volume each were obtained from two of three replicate plots of each treatment in September of 1979, and from all replicate plots of each treatment in September 1980. Each year at the Botany Department laboratories, each core was sieved with a 2 mm mesh, separating soil and root fractions. Separation of roots from fine sand was done by flotation. The vast majority of the floating roots were visually judged to be living biomass; the bulk of the settled biomass was judged to be dead. Floating roots were decanted into Buchner suction funnels fitted with Whatman No. 1 Qualitative filter papers previously labelled. After application of vacuum, roots retained on filtration were

Figure 2-2. Running Mean of Standard Deviation of Root Proportion of Sample Versus Sample Number.



RUNNING MEAN OF STANDARD DEVIATION (10^{-3})
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
2
4
6
8
10
12
14
16
18
20
SAMPLE NUMBER

oven-dried to constant weight at 80°C in a forced-air drying oven. Subsequently, samples were cooled in a dessicator, separated into woody and non-woody fractions, and weighed on an Ainsworth precision balance.

2.2.4 Aboveground Biomass

In 1978, 1979 and 1980, while the majority of plot vegetation was flowering, biomass was harvested within two 0.25 m^2 quadrats located at the 10 m and 20 m intervals of two 30 m transect tapes intersecting diagonally on each plot. Plant material was stored in labelled, weighed paper bags and oven-dried at 80°C to constant weight in forced-air drying ovens.

2.3 DATA ANALYSES

2.3.1 Vegetation

A list was assembled of native species occurring on, and environmental variables characteristic of, all treatment replicate plots. The Statistical Analysis System (1979) General Linear Models (GLM) Analysis of Variance (ANOVA) analytical procedure was applied on 1979 and 1980 frequency and cover data to test for equality of means for species and variables across treatments. Subsequently, groups of species and environmental variables previously selected (Chapter 1) by the SAS GLM Multivariate ANOVA (MANOVA) procedure were used to evaluate the relative performance of seed mix treatments in 1979 and 1980, because the constituents in these groups were proven indicators of stress in prairie ecosystems (Weaver 1968).

In both years, mean percent frequency and cover values for these variables were calculated, and in 1980, tested for equality of treatment means by the SAS GLM DUNCANS procedure. To focus on the relative merits of seeding versus not seeding, mean frequency values for each variable were averaged across seeding treatments to produce aggregate means for all seeding treatments each year. Aggregate means for variables under seeded treatments were compared to mean values for the non-seeded control treatment plots.

2.3.2 Root Biomass

Data were grouped by fraction and seed mix treatment for each year and analyzed by the SAS GLM ANOVA procedure. The SAS DUNCANS procedure testing for equality of treatment means was also used in 1980.

2.3.3 Aboveground Biomass

Data were grouped by seed mix treatment for each year and analyzed using the SAS GLM ANOVA and MEANS procedures. The DUNCANS procedure was also used in 1980 to test for equality of treatment means.

2.4 RESULTS

2.4.1 Vegetation

All seeded species germinated and grew successfully on all test plots. The mean frequencies of seeded species in mixtures tended to increase from 1979 to 1980 (Table 2-2). In both years, the highest total frequency of seeded species was recorded for mix 2, the lowest for mix 5. Consistent declines in the frequency of all seeded *Melilotus officinalis* and *Festuca rubra* were observed in 1980.

To identify the relative performance of the non-seeding treatment, mean values for percent frequency and cover for this treatment were compared to aggregate means for the same variables averaged across all seeding treatments. The results of this comparison for 1979 and 1980

Table 2-2. Annual Frequency of Seeded Species on Test Plots

MIXTURE	CONSTITUENT SPECIES	FREQUENCY 1979	1980
One	*Agropyron cristatum*	5.1	8.3
	A. intermedium	10.2	9.5
	A. trachycaulum	0.2	0.3
	Bromus inermis	10.5	13.8
	Elymus junceus	0.5	0.7
	Festuca rubra	0.1	Ø
	Medicago sativa	9.0	12.0
	Melilotus officinalis	2.3	Ø
		37.9	44.6
Two	*A. cristatum*	9.0	14.7
	B. inermis	21.3	19.2
	M. sativa	8.3	13.2
		38.6	47.1
Three	*E. junceus*	3.2	11.3
	F. rubra	3.7	0.2
	M. sativa	12.0	19.2
		18.9	30.7
Four	*A. cristatum*	10.5	21.5
	E. junceus	0.5	3.7
	M. sativa	11.0	9.8
		22.0	35.0
Five	*A. intermedium*	7.5	16.8
	A. trachycaulum	0.7	1.5
	M. officinalis	8.8	0.2
		17.0	18.5
Six	*A. intermedium*	10.8	13.5
	E. junceus	3.8	8.3
	M. officinalis	12.9	0.2
		27.5	22.0

frequency data follow (Table 2-3). Cover data were similar and are not accordingly presented here.

These results are presented in terms of the importance of indicator species to prairie health. Plants considered "desirable" are drought-adapted native species capable of sod-formation (eg., Bouteloua gracilis). "Undesirable" species are invader species (eg., Artemisia frigida), whose frequency increases with defoliation stress. Increased frequency of the latter also tends to indicate a reduced native species diversity and higher incidence of bare ground.

Generally speaking, in both 1979 and 1980, mean frequencies of desirable native species (eg., Stipa spartea) were higher on control plots than the aggregate mean values for seeded plots. In addition, species diversity (as inferred from the mean number of species encountered per 100 m transect length) was also higher on control plots than the aggregate mean value for seeded plots.

In terms of undesirable species, Artemisia frigida increased from 2.9% in 1979 to 4.5% in 1980 in frequency on control plots. By comparison, an aggregate mean increase, 0.7%-3.4%, was observed for seeded plots. The increase under the control treatment (55%) was much less dramatic than that (386%) recorded for seeding treatments. Similarly, A. campestris declined in mean frequency, 1.4%-0.7%, under the control treatment, whereas aggregate mean frequency increased, 0.6%-0.9%, on seeded plots during the same period (Table 2-3).

In terms of individual seed mix treatment responses compared to those of the control (Table 2-4), and as regards desirable "indicator" species, Bouteloua gracilis had the highest frequency on control plots in both 1979 and 1980 (Table 2-3). Its 1980 mean frequency on control plots was higher

Table 2-3. Mean Annual Percent Frequency of "Indicator" Variables on Test Plots

YEAR	VARIABLE	AGGREGATE MEAN OF SIX SEED MIX TREATMENTS %	MEAN CONTROL TREATMENT %	RELATIVE PERFORMANCE OF CONTROL
1980	Number of species/ transect: *	22.5	27.0	+ 20%
	Artemisia campestris	0.9	0.7	- 27%
	Armemisia frigida	3.4	4.5	+ 32%
	Bouteloua gracilis	8.5	25.8	+204%
	Carex spp.	11.4	21.7	+ 90%
	Chrysopsis villosa	2.2	3.8	+ 73%
	Stipa spartea	2.5	6.5	+160%
1979	Number of species/ transect: *	13.5	16.3	+ 21%
	Artemisia campestris	0.6	1.4	+133%
	Artemisia frigida	0.7	2.9	+314%
	Bouteloua gracilis	4.9	16.1	+229%
	Carex spp.	6.7	12.7	+ 90%
	Chrysopsis villosa	2.3	2.2	- 4%
	Stipa spartea	1.4	4.0	+186%

* Values are absolute, not percentages.

Table 2-4. Mean Annual Percent Frequency of "Indicator" Species/Variables Under Seeding Treatments

YEAR	VARIABLE	SEED MIXTURE 1	2	3	4	5	6	CONTROL
1980	Number species/ transect: *	24.5	19.8	24.3	23.2	21.8	21.7	27.0
	A. campestris	0.5	0.7	1.0	1.0	1.7	0.5	0.7
	A. frigida	2.5	1.5	4.5	3.8	4.5	3.5	4.5
	Bouteloua gracilis	7.7	8.5	7.0	3.7	6.7	17.5	25.8
	Carex spp.	5.7	9.3	14.1	11.5	13.5	14.0	21.7
	Chrysopsis villosa	2.7	1.5	2.5	1.7	2.3	2.3	3.8
	Stipa spartea	2.0	1.8	3.8	3.2	2.7	1.7	6.5
1979	Number species/ transect: *	10.3	10.3	18.2	15.2	13.7	13.5	16.3
	A. campestris	0.2	0.0	1.2	0.4	1.1	0.8	1.4
	A. frigida	0.0	0.3	1.1	0.9	1.0	0.8	2.9
	Bouteloua gracilis	0.8	3.6	5.8	0.8	5.8	12.3	16.1
	Carex spp.	3.8	2.3	9.8	8.3	10.6	5.5	12.7
	Chrysopsis villosa	1.6	1.8	3.5	1.9	1.5	3.4	2.2
	Stipa spartea	0.3	0.6	2.5	2.3	1.8	1.0	4.0

* Values are absolute, not percentages.

(26% vs 16%) than that for 1979.

In both 1979 and 1980, Stipa spartea was more frequent on control than seeded plots of any treatment (Table 2-4). Mean frequency on control plots, like that of B. gracilis, increased from 4.0%-6.5% for the period.

Like B. gracilis and S. spartea, the Carex spp. variable was highest in mean frequency on control rather than any seeded plots in both 1979 and 1980, and also displayed higher frequency on control plots in 1980 than in 1979.

In 1979, species diversity (inferred from mean number of species/transect) was exceeded on control plots only by mixture 3, but was higher on control plots than any seeding treatment plots in 1980. Like all of the preceding desirable variables, 1980 mean diversity value on control plots was higher than in 1979.

The desirable Chrysopsis villosa was less frequent on control plots in 1979 than plots seeded to mixtures 3 and 6. However in 1980, increased mean frequency (from 2.2%-3.8%) on control plots was sufficient that the mean value exceeded that for any seeding treatment.

Regarding the performances of individual seeding treatments exclusive of the control, mix 3 gave the most consistently desirably results of the six treatments. Relative to the others, this treatment produced:

1) The highest frequency of the desirable Carex spp. in 1980;
2) The highest frequency of the desirable Stipa spartea in both 1979 and 1980;
3) The highest frequency of the desirable Chrysopsis villosa in 1980;
4) The highest mean number of species/transect in 1979;
5) The second highest mean number of species/transect in 1980;
6) The second highest frequency of the desirable Bouteloua

gracilis in 1979;

7) The second highest frequency of the desirable *Carex* spp. in 1979.

Best supression of *Artemisia* spp. was observed on plots seeded to mixtures 1 and 2, especially in 1979. Best enhancement of the dominant *B. gracilis* was recorded on plots of mix 6.

Table 2-5 compares the mean percent frequencies of "indicator" variables on the control treatment plots to the aggregate mean for the same variables in Areas 1, 2, 3, 4, 5, and 9 on the Reserve. These Areas were used as "controls" in an earlier comparative study (Chapter 1) of species composition on training Ranges (Figure 1-1). (Strictly speaking, these control Areas are not classical experimental controls, in which fixed treatment effects are completely absent, but constituted the best available approximation of that condition. There are, in fact, no locations within the Shilo Reserve where military training effects are completely absent.)

Comparison of frequencies for "indicator" variables on control plots to frequencies in control Areas (Table 2-5) reveals dissimilarity between equivalently unstressed, non-treated locations within the Reserve. Species diversity (inferred from mean number of species/transect) was 3% lower on control plots than in Areas in 1979 but was 67% greater on plots than in Areas a year later (Table 2-5).

In both 1979 and 1980, the undesirable *Artemisia campestris* was approximately half as frequent on control plots as in Areas. Absolute frequencies declined by about 50% in both plots and Areas from 1979 to 1980. *A. frigida* was also half as frequent on control plots as in Areas in 1979, but in 1980 was only 28% less frequent on plots, having increased in mean

Table 2-5. Percent Frequency of "Indicator" Variables on (No-Seeding) "Control" Treatment Plots and Control Areas

YEAR	VARIABLE	AGGREGATE MEAN CONTROL AREAS	AGGREGATE MEAN OF "CONTROL" TREATMENTS ON PLOTS	PERCENT CHANGE IN FREQUENCY
1980	Number species/ transect: *	16.1	27.0	+ 67%
	Artemisia campestris	1.5	0.7	- 54%
	Artemisia frigida	6.2	4.5	- 28%
	Bouteloua gracilis	12.9	25.8	+100%
	Carex spp.	17.3	21.7	+ 25%
	Chrysopsis villosa	2.1	3.8	+ 80%
	Stipa spartea	6.0	6.5	+ 8%
	Ratio B/S	2.15	3.97	+ 85%
1979	Number species/ transect: *	16.7	16.3	- 3%
	Artemisia campestris	2.7	1.4	- 49%
	Artemisia frigida	5.7	2.9	- 50%
	Bouteloua gracilis	14.0	16.1	+ 15%
	Carex spp.	13.0	12.7	- 3%
	Chrysopsis villosa	1.7	2.2	+ 29%
	Stipa spartea	4.9	4.0	- 19%
	Ratio B/S	2.86	4.03	+ 41%

* Values are absolute, not percentages.

frequency proportionately more from 1979 to 1980 on plots (from 2.9%-4.5%) than in Areas (from 5.7%-6.2%).

The desirable Bouteloua gracilis was 15% more frequent on control plots in 1979 but was 100% more frequent in 1980. Carex spp. displayed almost the same frequency on plots as in Areas in 1979, but increased strongly on plots in 1980 being 25% more frequent there than in Areas. Chrysopsis villosa increased both on control plots and in Areas from 1979 to 1980, but the greatest increase was on plots. The margin over frequency in Areas increased from 29-80% for that period. While approximately 19% less frequent on control plots in 1979, Stipa spartea was 8% more frequent than in Areas in 1980, the increase on plots being proportionately greater than in Areas.

The ratio of B. gracilis : S. spartea, an index of response to grazing and defoliation stress in animal husbandry (Clarke et al 1943) was 41% higher in 1979 on control plots than in Areas, and 85% higher in 1980.

2.4.2 Root Biomass

Greatest mean root production was observed for the non-seeded control plots when compared with the aggregate mean for all seeding treatments (Table 2-6). In 1980, the control displayed 40% greater non-woody root biomass than the aggregate mean for the six seeding treatments. Total root biomass was 33% greater. In 1979, the control produced 35% more non-woody biomass than the aggregate mean value for seeding treatments, and total production was 56% greater.

Total root biomass on control plots declined 18% from 1979 to 1980 (i.e., from 2.79-2.28 g 500 cm^{-3}), compared with a decline of 4% for averaged seeding treatments (which declined from 1.79-1.71 g 500 cm^{-3}).

Table 2-6. Mean Annual Root Biomass on Test Plots

(g 500 cm^{-3})

YEAR	SAMPLE	AGGREGATE MEAN OF SIX SEED MIX TREATMENTS	MEAN CONTROL TREATMENT	RELATIVE PERFORMANCE OF CONTROL
1980	Non-woody fraction	1.39	1.95	+ 40%
	Total sample	1.71	2.28	+ 33%
1979	Non-woody fraction	1.56	2.10	+ 35%
	Total sample	1.79	2.79	+ 56%

However, non-woody biomass declined at similar rates on both control and seeded plots.

Regarding the performance of individual seed mixtures, greatest mean non-woody root biomass was produced by vegetation on the non-seeded control plots, in both 1979 and 1980 (Table 2-7). There was a general production decrease for all seven treatments from 1979, the first year following seeding, to 1980. The DUNCAN's test indicated significantly ($P < .05$) greater production by the control treatment in 1979 than all other treatments, with mix 2 producing significantly less than all others. In 1980, mix 2 production increased dramatically. This increase is attributed to sampling all three replicate plots of all treatments in 1980, compared with 2 of 3 replicate plots of treatments in 1979. The replicate plot of mix 2 not sampled in 1979 but sampled in 1980 was characterized by a large area colonized by _Euphorbia esula_. Root biomass of _E. esula_ was encountered in 1980 mix 2 samples, skewing mean treatment production values because of its relatively great mass.

Greatest total root biomass was produced by the control treatment in 1979 (Figure 2-3); the margin of superiority over production by all other treatments was statistically significant ($P < .05$). In 1980, mix 2 and the control produced significantly more total roots than all other treatments but mix 5 (Table 2-8). The difference between mix 2 and the control was statistically insignificant. Treatment 5 lay between the high and low yielding treatments.

2.4.3 Aboveground Biomass

Table 2-9 indicates the mean biomass of the control treatment exceeded the aggregate mean production of the six seeding treatments each year from

Table 2-7. DUNCAN's Multiple Range Test for Seed Mix Non-Woody Root Production

Alpha Level = .05 DF = 14

YEAR	GROUPING (1)			MEAN	N	SEED MIX
1979		A		2.095750	40	Control
	B	A		1.851750	40	3
	B	A	C	1.658108	37	1
	B		C	1.534250	40	6
	B		C	1.458000	40	5
	B		C	1.454000	40	4
			C	1.380500	40	2

Alpha Level = .05 DF = 21

YEAR	GROUPING (1)			MEAN	N	SEED MIX
1980		A		1.948500	60	Control
		A		1.852333	60	2
	B	A		1.701333	60	5
	B		C	1.330508	59	3
			C	1.242000	60	1
			C	1.124500	60	6
			C	1.090833	60	4

(1) Means with the same letter are not significantly different.

Figure 2-3. Total Root Biomass of Seed Mixtures.

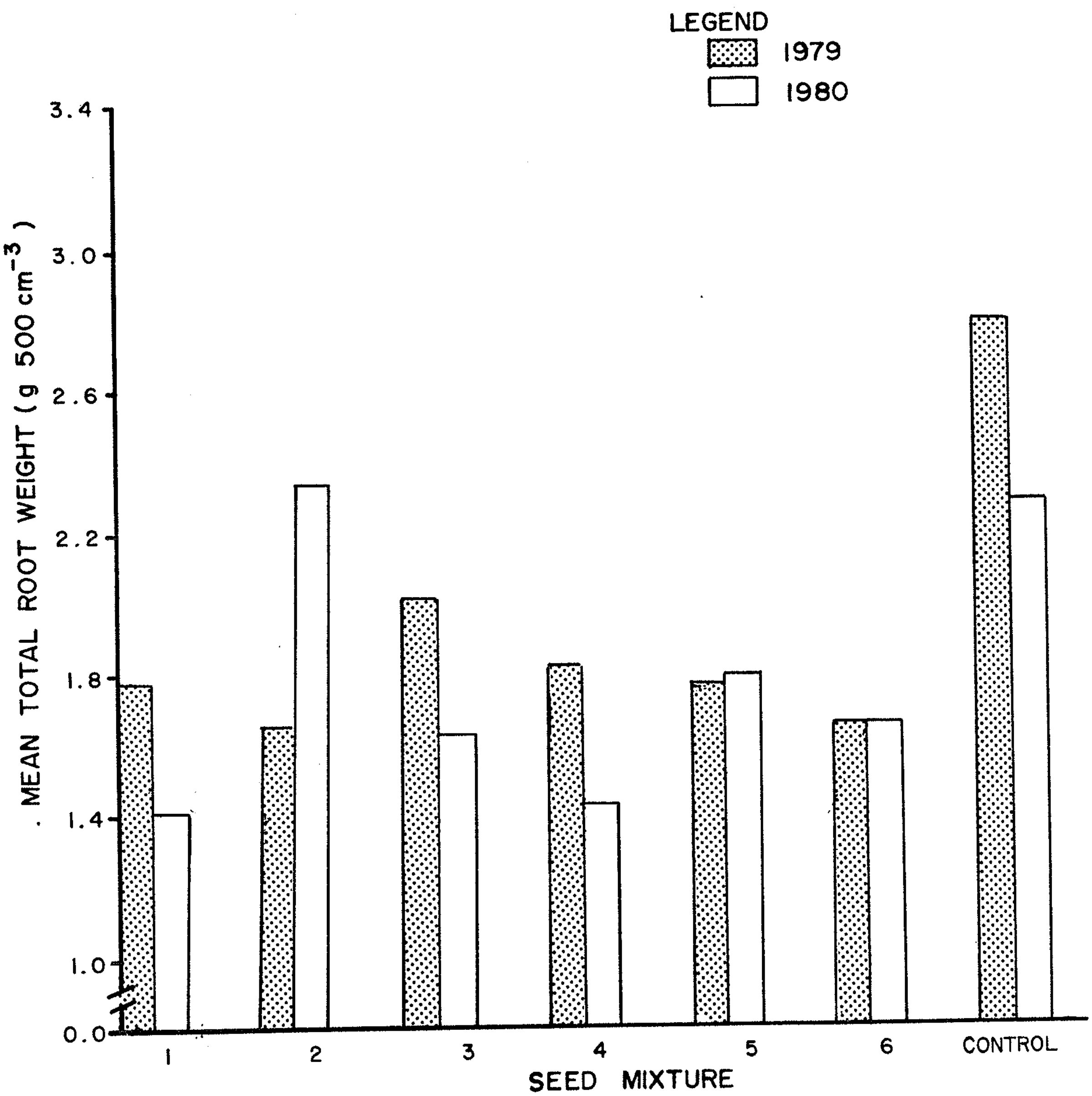

LEGEND
1979
1980
MEAN TOTAL ROOT WEIGHT (g 500 cm-3)
3.4
3.0
2.6
2.2
1.8
1.4
1.0
0.0
1
2
3
4
5
6
CONTROL
SEED MIXTURE

Table 2-8. DUNCAN's Multiple Range Test for Seed Mix Total Root Production

Alpha Level = .05 DF = 14

YEAR	GROUPING[1]		MEAN	N	SEED MIX
1979		A	2.793500	40	Control
	B		2.042750	40	3
	B		1.822500	40	4
	B		1.781822	37	1
	B		1.769250	40	5
	B		1.650256	39	6
	B		1.649250	40	2

Alpha Level = .05 DF = 21

YEAR	GROUPING[1]		MEAN	N	SEED MIX
1980		A	2.339500	60	2
		A	2.281500	60	Control
	B	A	1.797667	60	5
	B		1.644667	60	6
	B		1.628644	59	3
	B		1.433000	60	4
	B		1.409500	60	1

[1] Means with the same letter are not significantly different.

Table 2-9. Mean Annual Aboveground Biomass on Test Plots

($g\ m^{-2}$)

YEAR	AGGREGATE MEAN OF SIX SEED MIX TREATMENTS	MEAN CONTROL TREATMENT	RELATIVE PERFORMANCE OF CONTROL
1978	77.7	119.2	+ 53%
1979	282.7	444.6	+ 57%
1980	75.3	85.6	+ 14%

1978 to 1980. The absolute value of production on control plots for the period 1978-1980 peaked in 1979, the first year after initiation of the experiment (Table 2-10). Production by all treatments was dramatically less in 1980 than in 1979, and approximated production levels observed in 1978.

In terms of individual performances, mix 5 produced only very slightly more biomass than the control treatment in 1978 and in 1980 mixtures 1 and 6 produced significantly more biomass than the control (Table 2-10). In the intervening year, production by the control was greater than that of any other treatment. DUNCAN's Multiple Range Test analyses conducted on 1980 data indicated that production of mixtures 1 and 2 is significantly different (P .05), but is not significantly different from that of the intermediate treatments (mixtures 6, 3, control 4 and 5) (Table 2-11). Control plot mean production in 1980 was virtually identical to that for mix 3.

2.5 DISCUSSION

2.5.1 Vegetation

All seeded species except Festuca rubra and Melilotus officinalis increased in frequency from 1979 to 1980 on test plots. The most successful of the seeded species was Agropyron cristatum while the least successful was A. trachycaulum. The former was always above 5% frequency wherever seeded (mixtures 1, 2 and 4) while the latter was never above 2% frequency where seeded (mixtures 5 and 1).

The increased frequency of seeded species corresponds to an increase in growing season precipitation from 1979 to 1980 (Table 1-2) and generally lower mid- to late-summer soil moisture tensions in 1980 than in

Table 2-10. Mean Annual Aboveground Biomass

Experimental Seed Mixtures Versus Control Treatment

($g\ m^{-2}$)

YEAR	SEED MIXTURE 1	2	3	4	5	6	CONTROL
1978	61.2	78.4	59.6	61.2	121.2	80.8	119.2
1979	310.5	275.0	259.0	307.5	283.5	255.9	444.6
1980	103.0	43.3	86.3	77.7	51.0	90.2	85.6

Table 2-11. DUNCAN's Multiple Range Test for 1980 Seed Mix Aboveground Biomass Production

($g\ m^{-2}$)

Alpha Level = .05   DF = 42

GROUPING[1]		MEAN	N	SEED MIX
	A	103.03556	9	1
B	A	90.13422	9	6
B	A	86.26667	9	3
B	A	85.64888	9	Control
B	A	77.71111	9	4
B	A	51.00444	9	5
B		43.33333	9	2

1979 (Figure 1-2).

In terms of seeding versus not seeding as rehabilitation strategies, the non-seeding control treatment consistently gave higher mean frequencies of desirable species, higher species diversity, and lower frequencies of undesirable species when compared with the averaged response of seeding treatments (Table 2-2). The data support the suggestion that, on average, regrowth of native grasses and other species is more pronounced on control than seeded plots. Undesirable species, particularly plants noted for their ability to invade disturbed ground (Weaver 1968) either increased less dramatically (eg., Artemisia frigida) or declined (eg., A. campestris) under the control treatment.

A lag time of at least one year in the recovery of A. frigida following termination of severe defoliation has been noted (Menke 1973). This delayed response may explain the reduced rate of increase noted for A. frigida on the control plots in the second year after initiation of the experiment.

Of the individual seeding treatments, mix 3 gave the best combination of high frequencies of desirable species, low frequencies of undesirable species, and high (inferred) species diversity. This result may be explained by the relatively poor colonization of plot surface by constituent species of mix 3 (Table 2-2), resulting in the seeding treatment most akin to the superior non-seeding control treatment.

Festuca rubra typically requires substantial moisture for adequate growth, often occurring only where annual precipitation is of the order of 1 100 mm (Coupland 1979). Mean annual precipitation for nearby Brandon, Manitoba is 477 mm; total four-month summer precipitation for Carberry, Manitoba (closer than Brandon) for 1979 and 1980 was 145 mm and 288 mm, respectively (Table 1-2). Growth of F. rubra was therefore likely inhibited in 1979 and 1980, especially the former year, by low precipitation.

This hypothesis is borne out by data indicating that mean frequency for F. rubra at the height of the growing season, in 1979 for example, was only 3.8% on mix 3 plots (Table 2-5). While much more drought tolerant than F. rubra, the other constituent grass of mix 3, Elymus junceus, is difficult to establish and may require 3-5 years from seeding for adequate stand establishment (Smoliak & Johnston 1980). Evidence of poor establishment of E. junceus was demonstrated by a mean percent frequency in mix 3 in 1979, the first year after seeding, of only 3.2%. Low frequency was also recorded that year for mixtures 4 and 6, in which it was also a constituent, with mean values in 1979, for example, of 0.5% and 3.8% respectively.

The poor surface colonization of plots seeded to mix 3 is apparent from a comparison of the total percent frequency of seeded species on plots of each seed mixture. To illustrate, in 1979 the total frequency of seeded species in plots of mix 1 was 37.6%; a similar value was recorded for plots seeded to mix 2. Total frequency of seeded species on plots sown with mix 6 was 27.5%. By comparison, replicate plots seeded with mix 3 averaged only 18.7% total frequency of seeded species. Of this total value, more than half (11.8%) was attributable to the legume, Medicago sativa, a value comparable to that observed on plots seeded to other mixtures in which it was a constituent species and to values recorded for the other legume, Melilotus officinalis used in other mixtures (eg., 12.9% in mix 6).

These data therefore suggest that mix 3 constituents were poor colonizers of previously disturbed areas. In turn, poor colonization of disturbed soils by introduced species allowed indigenous species to regrow with less competition for moisture, light and nutrients than in those plots seeded to mixtures whose constituent species displayed more aggressive germination and growth.

The Festuca rubra component of mix 3 is likely an inappropriate grass for such restorative seeding in so arid an environment.

These data also support the suggestion that while some seed mixtures were capable of aggressive colonization of disturbed areas, indigenous species on non-seeded control plots appear capable, if protected from previous stresses, of sufficient regrowth in two years that species composition may be considered restored to levels indicative of unstressed conditions. Of particular importance is the ability of native C_4 grasses (eg., Bouteloua gracilis) to respond strongly to the cessation of defoliation stress, especially under conditions of high temperature and low soil moisture (Chung & Trlica 1980) encountered later in the growing season (Ode et al 1980). They possess a competitive advantage in regrowth compared with C_3 species (eg., Stipa spartea), arising from Kranz anatomy and other characteristics (Chapter 1). Recommendations for protection from stress in newly seeded grassland revegetation projects may be for as little as two years' duration (Anderson 1982), but are typically longer. Some estimates place arid grassland recovery rates after cattle grazing at between 20 and 40 years (McLean & Tisdale 1972). In this study, impacts on species composition associated with military training appeared reversible, given only two years' protected rest after light harrowing.

The implication that native flora (especially C_4 grasses) possess superior capacity for regeneration of damaged prairie is not unexpected. However this suggestion is at variance with recommendations that such exotic grasses as *Agropyron cristatum* and *Elymus junceus* are most appropriate for increasing the carrying capacity of the diminishing rangeland resource (Smoliak & Johnston 1980, Holechek 1981). Seeding with such species has been suggested as suitable for prairie or range "reclamation" (Knowles & Buglass 1971, Hubbard 1974), especially with regard to making "more productive" those lands classed as having lower agriculture potential by the Canada Land Inventory (Lawrence & Heinrichs 1977, Coupland 1980). Such recommendations are frequently based on allegedly greater forage yields of such exotics (by comparison with native species), high drought and frost resistance, and earlier initiation of growth. *A. cristatum* is frequently recommended (McLean & Bawtree 1971) because of its early season accumulation of carbohydrate reserves (Hyder & Sneva 1959), and preferential allocation of carbohydrates to rapid reestablishment of photosynthetic canopy after defoliation stress. In addition, *A. cristatum* has demonstrated a remarkable response to defoliation pressure, in producing new blades of higher photosynthetic capacity than unclipped blades of the same plant (Caldwell *et al* 1981). Recently, however, the alleged productive advantage of such exotics has been challenged, and related more to the tillage effect of increased soil nutrient availability than to the change from native to exotic species (Coupland 1980). The pronounced recovery effected by the native flora, even in the face of competition from apparently highly suitable exotic species introduced by seeding, indicates a superior "fit" of native species with environmental influences, emphasizing the effectiveness of managing stressed ecosystems for self-restoration.

The ratio of *Bouteloua gracilis* to *Stipa spartea*, an index of grazing stress (Clarke *et al* 1943) which may approximate responses to defoliation caused by tank traffic, was approximately 41% higher on control plots of the seeding experiment than in various control Areas in 1979. The margin roughly doubled (to 85%) the following year. The increase in this ratio derives from a decline in the B/S ratio in control Areas of 25% (from 2.86 to 2.15) for the period 1979-1980, but a corresponding decline on the control plots of only 3% (from 4.03-3.97) for the same period (Table 2-5). Less B. gracilis and more S. spartea in control Areas in 1980 than in 1979 account for these trends.

This suggests that less training stress might have been occurring in these Areas in 1980 than in 1979. Because these Areas were the "controls" in a previous study of the botanical and pedologic condition of training Ranges (Chapter 1), this interpretation suggests that the results of the previous study may be open to differences in interpretation. The previous study may therefore have understated the degree of damage observed on the Ranges in 1979.

The absolute value in B. gracilis frequency on control plots in 1980 was 25.8% (Table 2-4). A frequency of 20% has been suggested as indicative of "moderately grazed" mixed-grass prairie by Agriculture Canada (Smoliak et al 1976). The frequency of Bouteloua on plots in 1980 indicates that the stress exerted prior to the experiment may be considered "moderate".

2.5.2 Root Biomass

The mean annual root production on control treatment plots consistently exceeded the averaged production of seed mixtures (Table 2-6). Total summer rainfall in Carberry during the growing seasons of 1979 and 1980 was 145 mm and 288 mm respectively (Table 1-2). For the period 1979 to 1980, when rainfall increased by 199%, mean non-woody root production on control plots declined 7% while the mean for all seeding treatments declined 11%. In terms of total root production, control plots showed an 18% decline for the period, while the mean for all seeding treatments declined 4%. All individual seed mixtures except 2 and 5 displayed decreased root production for the same period.

These data are consistent with the suggestion that root production of native and most exotic species is inversely related to precipitation. This interpretation is congruent with experiments on short-term regrowth of defoliated B. gracilis, wherein greatest translocation of labile ^{14}C to root production occurred under greatest soil moisture deficit; i.e., when stressed to -30 bars (Chung & Trlica 1980). Analysis of these data allows the inference that the additional burden of military stress on the prairie training Ranges is insufficient to alter historic patterns of metabolic plant responses to moisture stress, and is apparently not "additive" to moderate levels of moisture deficit.

2.5.3 Aboveground Biomass

Mean production on control plots consistently exceeded the averaged response of all seed mixtures tested but was significantly more productive than all other seed mixtures in 1979 (Table 2-9). From 1978 to 1979, when rainfall at Carberry decreased by 50%, biomass on control plots increased by 373% and the mean production across seeding treatments increased 364%. From 1979 to 1980, when rainfall increased 199%, production on control plots declined 81%, and the averaged production of all seed mixtures declined 73%.

On this basis, biomass production on both seeded and non-seeded plots appeared inversely related to rainfall. This suggestion is apparently incongruent with Chung & Trlica's short-term regrowth experiments conducted on *B. gracilis*, the dominant species of the Shilo prairie, wherein reduced soil moisture tensions (arising from increased precipitation) prompted maximum biomass production in recently defoliated (less than 4 weeks) plants. The apparent discrepancy is explained by the longer post-stress recovery period observed at Shilo (2 years vs. 4 weeks), and the dramatically lower soil tensions recorded at Shilo than those used in their experiments.

The range of production values (256-445 g m^{-2}) observed across seeding and control treatments in 1980, the second year of the experiment is congruent with production data for *Bouteloua gracilis*-dominated faciations in an ungrazed, non-tilled mixed prairie in western North Dakota (47° 45'N, 102° 30'W), underlain by Dark Brown grassland soils (Redmann 1975). Our data slightly exceed those reported (240-302 g m^{-2}) for an adjacent (46° 54'N, 102° 49'W) protected mixed-grass *Stipa comata* - *Agropyron smithii* - *Bouteloua gracilis* prairie on a loamy fine sand (Lauenroth & Whitman 1977). Our results might be interpreted to suggest that two years' protection from stress may be adequate for something approaching a complete recovery from stress.

2.6 CONCLUSIONS

Light harrowing and complete protection from stress is an effective strategy for management of mixed-grass prairie damaged by military training. Compared with seeding with six mixtures of grasses and legumes, this treatment consistently produced:

1) More species per 100 m transect (implied higher species diversity) than the six seeding treatments;

2) Higher mean frequencies for more desirable native species than any seeding treatment;

3) Higher mean root production than any seeding treatment;

4) Higher mean aboveground production than most seeding treatments.

Festuca rubra and Melilotus officinalis appeared to possess particularly little utility for reclamation of damaged mixed-grass prairie in an arid environment.

As mean root production on both seeded plots and the non-seeded control plots declined when precipitation increased, mean root production during the 1979-1980 test period appeared inversely related to moisture supply. Mean aboveground biomass production appeared similarly related. Biomass production data may be interpreted to suggest that two years' protection of damaged Shilo prairie training Ranges may approximate a complete recovery from stress.

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CHAPTER 3

CONCLUSIONS

A two-year study was initiated in late 1978 at Canadian Forces Base Shilo to evaluate effects of military training on local soils and vegetation. The utility of seeding as a method to rehabilitate areas displaying training effects was also evaluated. Mixed grass Ranges at C.F.B. Shilo used for tracked vehicle training manoeuvres display consistent indications of adverse effects on native species composition. Species responding positively to defoliation and traffic stresses were more frequent on Ranges than control Areas; Artemisia frigida was 64-71% more frequent on Ranges. The C_4 grass Bouteloua gracilis was from 6-64% more frequent. Increased frequency in this grass is attributed to its competitive advantage over native C_3 grasses (eg., Stipa spartea) in regrowth responses to cessation of defoliation stress, under conditions of high temperature and low soil moisture. Conversely, species which respond negatively to such stresses (eg., Prunus pumila) displayed reduced frequency on Ranges.

A potentially irreversible trend to soil enrichment, particularly by metals (copper, zinc, iron, magnesium) was also observed on training Ranges. Increases in sodium were sufficient to benefit sodium-dependent C_4 species but insufficient to threaten soil structure, being offset by relatively greater increases in calcium and magnesium across a hypothetical stress gradient. Enrichment generally increased with stress along this gradient. Enrichment was, however, elevating concentrations which scarcely exceeded levels associated with growth deficiencies in agricultural crops. Short-term effects on Ranges soil chemistry could therefore be construed as positive.

Range soils were being compacted by training manoeuvres. However, the capacity of sandy soils to be compressed is limited, and compaction (along with increased soil calcium, magnesium and organic matter) may be contributing to improvements in the structure of the sandy loam Range soils. Compaction was of a magnitude apparently insufficient to inhibit seedling emergence in Gramineae.

To elevate the utility of seeding in restoration of damaged Areas, seeding trials were carried out on an appropriate site behind the start-line of a training Range. Seven seeding treatments, including a non-seeding control treatment, were randomly assigned to twenty-one experimental plots exemplifying a completely randomized statistical design.

Light harrowing and two years of protection from stress was found to be an effective strategy for management of mixed-grass prairie damaged by military training. Compared to the results of six seeding treatments (using various mixtures of grasses and legumes) this no-seeding treatment consistently produced:

1) More species per 100 m transect (implied higher species diversity) than the six seeding treatments;
2) Higher mean frequencies for more desirable native species than any seeding treatment;
3) Higher mean root production than any seeding treatment;
4) Higher mean aboveground production than most seeding treatments.

As mean root production on both seeded plots and the non-seeded control plots declined when precipitation increased, mean root production during the 1979-1980 test period appeared inversely related to moisture supply. Mean aboveground biomass production displayed a similar pattern.

Biomass and floristic data suggest that two years' protection of damaged Shilo prairie training Ranges may approximate a complete recovery from stress.

Execution of this study has resulted in:

1) Detailed description of the vegetation of C.F.B. Shilo;
2) Description of year-to-year variation in species composition;
3) Generation of useful soil chemistry data;
4) Creation of baseline data regarding vegetation and soils for future monitoring and impact assessment studies;
5) Determination of initial Range management strategies for Department of National Defence, based on the concept of management of stressed areas for self-restoration.

APPENDIX I

VASCULAR PLANTS

C.F.B. Shilo Military Reserve

(Arranged Alphabetically)

Nomenclature follows Scoggan (1980)

APPENDIX I

Vascular Plants

C.F.B. Shilo Military Reserve

Achillea millefolium L.

Agoseris glauca (Pursh) Raf.

Agropyron cristatum (L.) Gaertn.

Agropyron intermedium (Host) Beauv.

Agropyron subsecundum (Link) Hitchc.

Agropyron trachycaulum var. *unilaterale*

Agrostis scabra Willd.

Allium textile Nels. & Macbr.

Amaranthus graecizans L.

Amelanchier alnifolia Nutt.

Andropogon gerardi Vitman

Andropogon hallii Hack.

Andropogon scoparius Michx.

Anemone canadensis L.

Anemone cylindrica A. Gray

Anemone patens L. var. *wolfgangiana* (Bess.) Koch

Antennaria parviflora Nutt.

Aquilegia canadensis L.

Arabis holboellii Hornem. var. *collinsii* (Fern.) Rollins

Arctostaphylos uva-ursi (L.) Spreng.

Artemisia campestris L.

Artemisia caudata Michx.

Artemisia frigida Willd.

Artemisia ludoviciana var. *gnaphalodes* Nutt.

Asclepias syriaca L.

Aster falcatus Lindl.

Aster laevis L.

Aster pansus (Blake) Cronquist

Astragalus caryocarpus Ker.

Atriplex patula L.

Avena hookeri Scribn.

Bouteloua curtipendula (Michx.) Torr.

Bouteloua gracilis (H.B.K.) Lag.

Bromus inermis Leyss.

Calamovilfa longifolia (Hook.) Scribn.

Camelina microcarpa Andrz.

Campanula rotundifolia L.

Capsella bursa-pastoris (L.) Medic.

Carex filifolia Nutt.

Carex obtusata Lilj.

Carex pensylvanica Lam. var. *digyna* Bock.

Carex stenophylla Wahlenb. var. *enervis*

Cerastium arvense L.

Chamaerhodos erecta (L.) Bunge

Chenopodium album L.

Chrysopsis villosa (Pursh) Nutt.

Comandra pallida A. DC.

Convolvulus sepium L.

Corispermum hyssopifolium L.

Crepis tectorum L.

Cycloloma atriplicifolium (Spreng.) Coulter

Descurainia pinnata (Walt.) Britt. var. brachycarpa (Richards.) Fern.

Draba nemoralis L. var. lejocarpa Lindbl.

Echinacea angustifolia DC.

Eleagnus commutata Bernh.

Elymus canadensis L.

Elymus junceus Fisch.

Epilobium angustifolium L.

Eragrostis megastachya (Koel.) Link

Erigeron asper Nutt.

Erigeron canadensis L.

Erigeron strigosus Muhl.

Erysimum asperum (Nutt.) DC.

Erysimum inconspicuum (S. Wats.) MacM.

Euphorbia esula L.

Euphorbia geyeri Engelm.

Euphorbia serpyllifolia Pers.

Festuca ovina L. var. saxmontana

Fragaria glauca (S. Wats.) Rydb.

Gaillardia aristata Pursh

Galium boreale L.

Geum triflorum Pursh

Gypsophila paniculata L.

Helianthus laetiflorus Pers. var. subrhomboideus (Rydb.) Fern.

Helictotrichon hookeri (Scribn.) Henrard

Heuchera richardsonii R.Br.

Hordeum jubatum L.

Houstonia longifolia Gaertn.

Juniperus horizontalis Moench.

Koeleria cristata (L.) Pers.

Lactuca pulchella (Pursh) DC.

Lappula echinata Gilib.

Lathyrus ochroleucus Hook.

Lepidium densiflorum Shrad.

Lesquerella arenosa (Richards) Rydb.

Liatris punctata Hook.

Lilium philadelphicum L. var. andinum (Nutt.) Ker

Linum _rigidum_ Pursh

Lithospermum _angustifolium_ Michx.

Lithospermum _canescens_ (Michx.) Lehm.

Lygodesmia _juncea_ (Pursh) D. Don

Medicago _sativa_ L.

Melilotus _alba_ Desr.

Melilotus _officinalis_ (L.) Lam.

Monarda _fistulosa_ L.

Oenothera _biennis_ L.

Oenothera _nuttalli_ Sweet

Oenothera _serrulata_ Nutt.

Opuntia _polycantha_ Haw.

Orthocarpus _luteus_ Nutt.

Oxytropis _lambertii_ Pursh

Panicum _capillare_ L.

Penstemon _albidus_ Nutt.

Penstemon _gracilis_ Nutt.

Petalostemon _candidum_ (Willd.) Michx.

Petalostemon _purpureum_ (Vent.) Rydb.

Picea _glauca_ (Moench) Voss

Plantago _major_ L.

Polygonum _achoreum_ Blake

Polygonum _convolvulus_ L.

<u>Poa pratensis</u> L.

<u>Populus tremuloides</u> Michx.

<u>Portulaca oleracea</u> L.

<u>Potentilla anserina</u> L.

<u>Potentilla arguta</u> Pursh

<u>Potentilla concinna</u> Richards

<u>Potentilla pensylvanica</u> L.

<u>Prunus pumila</u> L.

<u>Prunus virginiana</u> L.

<u>Psoralea esculenta</u> Pursh

<u>Quercus macrocarpa</u> Michx.

<u>Ranunculus rhomboideus</u> Goldie

<u>Ratibia columnifera</u> (Nutt.) Woot. & Standl.

<u>Rhus radicans</u> L. var. <u>rydbergii</u> (Small) Rehder

<u>Rosa arkansana</u> Porter

<u>Rudbeckia serotina</u> Nutt.

<u>Salsola kali</u> L. var. <u>tenuifolia</u> Tansch

<u>Selaginella densa</u> Rydb.

<u>Senecio canus</u> Hook.

<u>Setaria viridis</u> (L.) Beauv.

<u>Silene noctiflora</u> L.

Sisymbrium altissimum L.

Sisyrinchium montanum Greene

Smilacina stellata (L.) Desf.

Solidago missouriensis Nutt.

Solidago rigida L.

Sonchus arvensis L.

Sporobolus cryptandrus (Torr.) Gray

Stipa comata Trin. & Rupr.

Stipa spartea Trin. var. *curtiseta* Hitchc.

Symphoricarpos occidentalis Hook.

Thlapsi arvense L.

Tragopogon dubius Scop.

Vicia americana Muhl.

Viola pedatifida G. Don

Viola rugulosa Greene