UNIVERSITY OF ALBERTA

SELECT VEGETATIVE CHARACTERISTICS AND SOIL PHYSICAL PROPERTIES OF DIFFERENT AGED RUSSIAN WILDRYE PASTURES

BY

MARK WALTER DELL ©

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Mark Walter Dell
10101 - 90 Street
Morinville, Alberta
T8R 1B6

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- on Work

... "And I say that life is indeed darkness save when there is urge, and all urge is blind save when there is knowledge, and all knowledge is vain save when there is work,"...

- on Self-knowledge

... Say not, "I have found the truth," but rather, "I have found a truth "

Kahlil Gibran
The Prophet, 1923

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled SELECT VEGETATIVE CHARACTERISTICS AND SOIL PHYSICAL PROPERTIES OF DIFFERENT AGED RUSSIAN WILDRYE PASTURES submitted by MARK WALTER DELL in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in ENVIRONMENTAL AND CONSERVATION SCIENCES.

M. Anne Naeth
M.A. Naeth
Co-Supervisor

D.S. Chanasyk
Co-Supervisor

J.F. Dormaar

Ian Campbell

July 6, 1995

Abstract

The focus of this study was to quantify select plant characteristics and soil physical properties of three different aged (3, 13, 23 years) Russian wildrye pastures and to compare them with adjacent native range. Ground cover, plant species composition, root mass, seedbank, particle size analysis, bulk density, total soil carbon, aggregate size and stability, modulus of rupture and micro-topography were analyzed. Percent bare ground between rows of Russian wildrye increased from 50 to 80% while percent litter decreased with increasing age of the field. Percent bare ground in the native range was below 10%. Root mass was greatest in the surface 5 cm of native range but was similar to Russian wildrye below 5 cm. Species richness increased with increasing age of the fields from 6 to 12 to 26 species for the 3-, 13- and 23- year old fields but remained less than native range at 34 species. Percent sand in the 23- year field was 8% higher within the rows of vegetation than between rows for the surface 4 cm compared to increases of less than 2 and zero percent sand in the 13- and 3- year old fields. Bulk density between rows was higher than within rows. Micro-topography changed from level in the 3- year old field to increases in topography of up to 4 cm in the rows compared to between the rows for the 13- and 23- year old fields. Changes in texture and topography are likely a result soil of redistribution within the fields

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Chapter 1. Introduction

1.1 Background

The number of beef cattle on the Canadian prairies increased from 2.7 million head to 6.5 million head from 1951 to 1981 for an annual growth rate of three percent. With potential for this increase to continue, even at a slowed rate, further forage resources on the prairies will be needed (Smoliak and Wilson 1981). The introduction of agronomic forages has provided forage production over and above those production expectations on native range (Lawrence and Heinrichs 1977).

The primary area for cattle use is in the semi-arid regions of the prairie provinces where soils are classed as marginal to non-arable (Class 4 - 7) for agricultural purposes. Limitations to cultivation include moisture deficits, salts and topography. Most of the marginal to non-arable land is classed as mixed grass prairie (Coupland 1961). Large portions of this mixed grass prairie were broken early in the 1900s by settlers and later abandoned due to crop failures. Portions of this broken land were subsequently reseeded into introduced species, primarily crested wheatgrass (*Agropyron pectiniforme* R. and S.) (CWG) and Russian wildrye (*Elymus junceus* Fisch.) (RWR). RWR is fast becoming the most commonly seeded grass in the southern prairies (Looman 1982). Considerable research into forages and their effects in rotations to improve soil properties have been well documented. For example, the addition of perennial vegetation into rotations or as permanent cover improves soil aggregation, carbon content and soil fertility compared to cultivated crops (Lehane and Staple 1943, Harris et al. 1966, Clarke et al. 1967, Tisdall and Oades 1982).

1.2 History and Morphology of Russian Wildrye

Russian wildrye was introduced to Canada from Siberia by the University of Saskatchewan in the 1920s (Alberta Agriculture 1981). RWR is a non-rhizomatous, long-lived perennial bunch grass that may be identified by the basal leaf arrangement. Seed culms may reach heights of 90 cm and end in a dense spike 5 to 10 cm in length (Alberta Agriculture 1981, Moss

1992). Characteristic of *Elymus* genus is the presence of two or more spikelets at each node of the rachis with as many as three or four and rarely one. Each spikelet is two to six-flowered.

Ryegrass (*Lolium spp.*) should not be confused with the wildryes (*Elymus spp.*) as is sometimes indicated in the way RWR is written (Russian wild ryegrass vs. Russian wildrye or Russian wild rye) (Thaine 1954, Lawrence and Heinrichs 1968, Lawrence et al. 1991). Both are grasses found within the *Triticeae* tribe, however, ryegrasses may be annual or perennial with sessile, single spikelets per node (Moss 1992). RWR may also be confused with *Psathyrostachys juncea* ([Fisch.] Nevski) or trade name 'Tetracan' which is also a Russian wildrye but is a tetraploid form rather than a diploid form discussed here (Lawrence et al. 1990, 1991).

The growth form of RWR is unique to the mixed grass prairie region since several grass species in the mixed grass prairie are sod formers or rhizomatous western wheat grass (*Agropyron smithii* Rydb.), northern wheat grass (*Agropyron dasystachyum*, (Hook.) Scribn.), blue grama grass (*Bouteloua gracilis* H.B.K.), slender wheat grass (*Agropyron trachycaulum* (Link.) Malte) and RWR is a bunch grass (Looman 1982, Moss 1992).

1.3 Benefits and Limitations of Russian Wildrye

RWR is a long-lived, highly competitive, drought resistant and salt tolerant species (Lawrence and Heinrichs 1977). It is highly digestible with a long growing season, making it a valuable forage crop. Crude protein remains high in the plant throughout the year compared to CWG (Lawrence and Heinrichs 1977). In early leaf stage, crude protein is approximately three times as high as late fall when cured. Conversely, CWG has similar early leaf protein content, but by late fall its crude protein drops to less than half that of RWR (Lawrence and Heinrichs 1977). The growing season for RWR is much longer than either CWG or native range (NR), commencing most years in April and continuing to the end of October. Growth is greatest in May and June and then levels off in July through to October (Lawrence and Heinrichs 1977).

The widespread use of RWR did not occur until the 1940s and 50s due to the difficulty in establishing the stands. Seed yields were erratic, preventing the commercial sale of the plant

(Alberta Agriculture 1981). Variable seed depth is a major cause of failure in establishing pasture in semiarid range, with emergence of RWR decreasing with increasing depth of seeding (King 1987, King 1989, Lawrence et al. 1991). Decreases in emergence of RWR in greenhouse studies for seeding depths of 2 and 4 cm were 73.6 and 47.4%, respectively (Lawrence et al. 1991). In studies conducted by McGinnies (1974) on the effects of planting depth on seedling growth of RWR, the number of emerged RWR seedlings per metre of row sown at a depth of 1.3 cm and 2.5 cm was nearly double that of seed sown at a depth of 3.8 cm. The depth by species interaction accounted for approximately 95% of the variability in emergence (Lawrence et al. 1991).

1.4 Management of Russian Wildrye Pastures

1.4.1 Dry matter yields

Considerable research has been conducted on the influence of row spacing on dry matter yields and seed production of RWR. In long term studies by Lawrence and Heinrichs (1968), the greatest forage yields for fertilized and unfertilized treatments occurred for a row spacing of 60-cm. Average yields over 19 years of the study in the 60-cm row spacing were 158% higher than the 30-cm row spacing and 115% higher than the 120-cm row spacing. Similarly, Kilcher et al. (1976) found dry matter yields of RWR under fall grazing over a nine year period were greatest in row spacings of 60 cm to be 1.75 times greater than 20-cm spacings. Although yields were higher, only an additional 10 to 12 days of grazing were provided. The small increase in grazing period was attributed to the increased stemminess of RWR that occurred with increased row spacing (Kilcher et al. 1976).

Lorenz and Rogler (1959) observed significant increases in forage yields with increasing row spacing under irrigated conditions. Statistical significance, however, was only found in the first cuttings in most years. Early in the study, narrow row spacings (15 and 45 cm) produced the largest forage yields but as the 90-cm row spacing established itself, yields in subsequent years increased for the 90-cm row spacing (Lorenz and Rogler 1959). Thaine (1954) observed higher dry matter yields and protein content under a higher frequency of clipping than a single clipping.

1.4.2 Seed yields

Seed yields of RWR increased with increased row spacings and were more susceptible to periods of drought than forage yields (Lawrence and Heinrichs 1968). Yield data were collected in only 9 of 19 years of the study. Following a drought, seed production was equal to pre-drought levels (Lawrence and Heinrichs 1968).

Both forage and seed yields were highly correlated ($p = 0.05$) with spring and previous fall precipitation (Lawrence and Heinrichs 1968). Forage yields were most influenced by early precipitation (March through May) (Lawrence and Heinrichs 1968).

1.4.3 Growth habit in rows

Lawrence and Heinrichs (1968) found that row width or sward width increased over the 19 years of their study. Row width increased with row spacing, with growth being most vigorous at the peripheries of the sward. Row width increases were greatest from the 30- to 60-cm row spacing where row width increases from 18 to 33 cm were observed (Lawrence and Heinrichs 1968). Lorenz and Rogler (1964) found crown widths of RWR increased with increased row spacing and nitrogen application for 5- year- old stands. Seedlings were observed between the rows of vegetation but died out due to lack of moisture (Lorenz and Rogler 1964). Lawrence and Heinrichs (1968) observed that the highly competitive nature of RWR prevented the invasion of other species into the between-row position. Campbell (1963) observed the abundance of alfalfa decreased in relation to RWR and other grasses over a six-year study. Weed competition for widely spaced rows of RWR required chemical treatments for only the first two years after which weed species were suppressed. Bare ground between rows was observed but not quantified (Lorenz and Rogler 1964, Lawrence and Heinrichs 1968).

1.4.4 Root studies

Russian wildrye may root to a depth of 2 m (Lawrence and Lodge 1975). The majority of the RWR root mass is located in the top 30 cm of soil profile. In root studies carried out on RWR, root distribution was uniform over a row spacing of 22 cm; for 90-cm row spacings; the majority of roots were located directly below the row (Lorenz and Rogler 1964, Dormaar et al. 1995). Root distribution of RWR decreases with increasing distance from the row. Total dry matter yields per sample decreased from 12 g to approximately 4 g from the in-row (IR) to the between-row (halfway between rows of vegetation) (BR) position in a row spacing of 45 cm (Lorenz and Rogler 1964). Similarly, Dormaar et al. (1995) observed ash free weight of roots decreased from 550 to 235 g m^{-2} for IR and BR positions, respectively, in a 70-cm row spaced field. Applications of nitrogen increased root mass in all row spacings with applications of 112 kg ha^{-1} and 224 kg ha^{-1} but decreased root mass with N rates of 448 kg ha^{-1} (Lorenz and Rogler 1964). Thaine (1954) observed that clipping frequency of RWR increased the forage content and nutritive value of the forage, but decreased the root mass. A single spring clipping produced approximately 1700 kg ha^{-1} of forage and 3700 kg ha^{-1} of roots (0 to 45 cm depth), compared to 2100 kg ha^{-1} of forage and 2000 kg ha^{-1} of roots (0 to 45 cm depth) for a treatment clipped five times at three week intervals.

1.4.5 Grazing and live weight gain on Russian wildrye

RWR provides benefits in live weight gain over native range and CWG pastures. The increase in live weight gains of yearling steers per acre on continuously grazed RWR were six times greater than on native range over a six year study (Smoliak and Slen 1974). Protein content of cured RWR was approximately 6% compared to 3% for CWG (Lawrence and Heinrichs 1977). RWR and CWG effectively lengthen the grazing season (Smoliak and Slen 1974). Holt et al. (1986) reported grazing of RWR in the first crop year was detrimental to subsequent productivity. Gains of yearling steers were greater when grazing began on June 15 than on May 1 for RWR (90-cm spacing) sown the previous May. Delays of grazing until August, when the plants were headed out, reduced the live weight gain when compared to the June 15 commencement date. Campbell (1963) reported live weight gains were greater under RWR pastures with alfalfa intermixed than with grasses alone in southern Saskatchewan. RWR appeared to maintain the best stand when compared to CWG or intermediate wheatgrass (*Agropyron intermedium* [Host.] Beauv.). Kilcher et al. (1976) observed fall grazing time was increased on 60-cm row spacings compared to 20-row spacings by about 2 weeks. The association between dry matter yield and grazing time was not well defined. The small increase in grazing time compared to the abundant increase in forage from 20- to 60-cm spacings of RWR was attributed to stemminess of the 60-cm spaced RWR. Although individual plants were larger, an increasing amount of the plant was made up of seed culms which were not consumed by cattle until the leaves were gone (Kilcher et al. 1976).

1.5 Soil Conservation

Erosion is a two-step process, the first being detachment and the second, transportation. Erosion depends upon whether the agents of erosion, wind and water, can overcome the conditions that prevent soil from being eroded, such as good aggregation and vegetative cover (Hausenbuiller 1985). For a soil to be eroded by water, the land must be sloped and runoff occurring. Raindrop impact is a major component of the detachment process in water erosion. Wind erosion is less dependent on soil moisture and slope. The major detachment process of wind erosion is saltation of larger particles hitting aggregates and breaking them down into more erodible sizes (Hausenbuiller 1985).

Wind erosion is the major erosive force in more arid regions where winds are frequent and vegetation sparse. Wind erosion in the Great Plains regions of North America was minimal, though still a naturally occurring event, while land remained under native vegetation, but with cultivation and overgrazing, erosion due to wind was accelerated (Chepil and Woodruff 1963). The use of plant residues as cover to reduce wind and water erosion is well documented. The role of vegetation on wind erosion is to reduce the wind speed near the surface of the soil. Vegetation also provides a carbon source for the soil aggregating process (Harris et al. 1966).

The process of wind erosion sorts particles and aggregates (Chepil 1946). Chepil and Woodruff (1963) reported that those aggregates smaller than 0.84 mm in diameter are wind erodible. Further, equivalent diameter of particles (assuming a particle density of 2.65 Mg m^{-3}) that are erodible are approximately 0.5 mm (Chepil and Woodruff 1963). Lyles and Tatarko (1986) observed up to 6% increases in absolute sand content (0 - 10 cm depth) of cultivated fields in Kansas after 40 years. An overall decrease of 0.40% in total soil carbon was observed over 10 sites.

Soil structure is defined as the organization and arrangement of soil particles (Hillel 1982). Under favorable conditions individual particles arrange themselves into structural units called aggregates (Hillel 1982). Aggregation is a function of physical, chemical and biological processes. Soils with good structure are less susceptible to erosion if aggregates are larger than those identified by Chepil and they remain stable when acted upon by erosive forces. Micro-aggregates, those aggregates smaller than 0.250 mm, are formed predominantly by fine humic material and clay complexing (Oades 1984). Macro-aggregates, those greater than 0.250 mm, are also bound by humic substances and clay, but as aggregates become larger, the role of plant roots and associated mycorrhizae become more prominent (Tisdall and Oades 1979). The use of perennial forages in cereal rotation for improving soil aggregation has been well documented by Harris et al. (1966). Soils low in organic matter and clay are less stable than those higher in clay and organic matter. The loss of perennial vegetation has led to decreases in soil organic carbon and subsequent loss in aggregate stability. Adequate cover to reduce wind velocity as well as a source of carbon to maintain good aggregation is paramount in reducing soil erosion.

1.6 Research Focus

The use of RWR as a forage to lengthen the grazing season and increase livestock gain per unit area provides a unique opportunity to study soil and vegetation interaction under perennial row cropping. The seeding of perennial RWR into rows, and lack of revegetation between rows over long periods, increases the amount of bare ground present that is exposed to the erosive forces of wind and water. From the view point of sustainability and conservation of soil resources, such widely spaced perennial row cropping may jeopardize the soil/plant system established under native vegetation. To assess whether or not the RWR system is sustainable, quantification of properties and processes over time is needed.

Research objectives include the quantification of changes in vegetative characteristics and select soil physical properties of RWR fields over specific time periods. The quantification of ground cover parameters, specifically; bare ground, live vegetation and litter, will provide insight onto the amount of soil exposed to erosive forces of wind and water. The quantification of soil parameters may provide supporting evidence of erosion processes, if any, that may have occurred since seeding.

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Chapter 2. Select Vegetation Characteristics Of Three Different Aged Russian Wildrye Pastures In Southern Alberta.

2.1 Introduction

Approximately 18 million ha of rangeland and 2.5 million ha of pastures are utilized by the beef industry in the Canadian Prairie Provinces. Many hectares of native range (NR) have been plowed and converted to forages in an attempt to increase productivity on overgrazed rangelands, crested wheatgrass (*Agropyron pectiniforme* R. and S.) (CWG) and Russian wildrye (*Elymus junceus* Fisch.) (RWR) being the most popular in arid parts of the provinces. There are now over one million ha of CWG and 100,000 ha of RWR contributing to forage supplies for livestock production (Smoliak and Dormaar 1985). These two forages have been used extensively to complement native range in spring and fall, often doubling livestock gains per hectare by improving pasture carrying capacity (Smoliak and Slen 1974).

Research has been conducted on RWR in western Canada and the western United States on RWR dry matter yields as affected by row spacing, fertilization and intercropping with alfalfa (Kilcher and Heinrichs 1958, Lorenz and Rogler 1959, Campbell 1963, Lawrence and Heinrichs 1968, Kilcher et al. 1976), grazing trials and liveweight gains (Smoliak 1968, Smoliak and Slen 1974), and clipping frequencies on productivity (Thaine 1954). Further RWR research has been completed on seed yields (Lawrence 1963, Lawrence and Ashford 1964, Lawrence and Kilcher 1964), seed placement (McGinnies 1974, Lawrence et al. 1991) and viability and emergence (King 1987, King 1989). In a 9-year study, dry matter yield in 60-cm row spaced RWR was double that of 20-cm spaced RWR (Kilcher et al. 1976). Similarly, in a 15-year study, Lawrence and Heinrichs (1968) found dry matter yields of 60-cm row spaced RWR were significantly greater than those for 30-, 90- or 120-cm spaced rows. The competitive nature of these grasses and subsequent bare ground between the rows were observed by Lorenz and Rogler (1964) in a 3-year study and by Lawrence and Heinrichs (1968), but results were not quantified.

Research on the below ground component of RWR has been more limited (Thaine 1954, Lorenz and Rogler 1964, Bowman et al. 1984, Smoliak and Dormaar 1985, Dormaar et al. 1995).

Nearly 60% of RWR root mass was located in the top 30 cm of soil (Lorenz and Rogler 1964). Root mass increased on irrigated RWR plots from 7900 to 11200 kg ha^{-1} for 15- and 45- cm row spacing, respectively, and decreased with increasing distance from the row (Lorenz and Rogler 1964). Stevenson and White (1941) found over 85% of the root mass of CWG, brome grass (*Bromus inermis* Leyss.) and slender wheat grass (*Agropyron trachycaulum* Link.) was located in the top 30 cm of soil compared to 77% for grazed prairie. Total root weight in the surface 15 cm was greater in native range than under either CWG or RWR, allowing increased energy flow into the native system (Smoliak and Dormaar 1985). In 20- to 25-year old RWR and CWG monocultures, there was 7.6 times more root mass in NR in the 0 to 7.5 cm depth than either CWG or RWR but equivalent amounts from 7.5 to 40 cm (Dormaar et al. 1995).

The focus of early studies had been on increasing forage and seed production. Sustainability of the grassland system had not been considered fully. In early studies of CWG, soil erosion was reduced and grazing capacity increased compared to cultivated land (Lehane and Staple 1943). However, the presence of bare ground observed between widely spaced rows of RWR increases the risk of wind and water erosion by exposing the soil surface. The lower root mass of RWR compared to NR may compromise the plant/soil system that was established under NR. Studies to date have not assessed the temporal consequences of RWR monocultures on the soil/plant system.

It is hypothesized that breaking of NR and seeding with RWR will lead to decreased vegetative cover, reduced root mass and increased susceptibility of RWR fields to erosion. It is further hypothesized that the effects of treatment differences will occur with depth and over time since seeding.

2.2 Study Site

Five sites, three RWR and two NR, were selected in the Brown soil zone of Alberta (Appendix A-1). The fields were chosen based on proximity to each other, differences in age and similarity of soils. The NR fields were chosen to best represent the average range condition for the area as well as similarity in soil type to the RWR fields. The native vegetation is of the Mixed Prairie (*Stipa-Bouteloua-Agropyron*) Faciation as defined by Coupland (1961).

The three RWR fields are monocultures with row spacings of approximately 60 cm and were seeded in 1972, 1980 and 1989. RWR1989 and 1980, along with one NR field (NR1), are located approximately 3 km apart. RWR1972 and the second NR field (NR2) are located less than 100 m (a road right of way) apart. RWR1972 was located 40 km due north of RWR1989. Surface and soil properties are outlined in Table 2.1.

Site 1 (RWR1989) was located southeast of Wardlow (50° 50' Lat., 111° 30' W Long.). The field is 260 ha in size and is fenced from adjacent NR. The land was broken from NR and was farmed in the 1950s under a wheat/fallow rotation until 1989. Seeding to RWR was completed in 1989 with a seed drill at a rate of 1.4 kg ha^{-1} in a circular pattern at a 60-cm row spacing. The field was grazed in the autumns of 1990 and 1991 and grazed in the springs of 1992 and 1993. The soils are mapped as predominantly Brown Solods with inclusions of Solonetzic Brown Chernozems (Kjearsgaard and Pettapiece 1986).

Site 2 (RWR1980) was located adjacent to Site 1 but was fenced separately. The field is 130 ha in size and is grazed free choice (both RWR and NR are available to livestock for consumption, no fence separates RWR1980 from adjacent NR) with NR to the west. The land was broken from NR in the 1920s and abandoned shortly after. The field was then re-broken and cropped with cereals from 1976 to 1979. The field was seeded at a spacing of 60-cm in August 1980 with a similar seed rate as for Site 1. Seed catch was not complete so the field was partially reseeded in spring 1981. The north end of the field received a fertilizer treatment of 150 kg ha^{-1} of 34-0-0 at time of seeding. Soils at this site are similar to those at Site 1.

Site 3 (RWR1972) was located east of Pollockville (51° 10' Lat., 111° 30' W Long.). The field is 162 ha in size and was seeded in a circular pattern with 53 cm row spacings in spring 1972 with a double disc drill at a rate of 1.4 kg ha^{-1}. The field was grazed free choice (defined as above) with NR in May, June, September and October of each year. The field was broken previous to 1972 and cropped. Land management of this site is vague since the land was sold several times. Soils are mapped predominantly as Brown Solodized Solonetz with inclusions of Solonetzic Brown Chernozems (Kjearsgaard 1976).

Site 4 (NR1) was located west of Site 2 (50° 50' Lat., 111° 30' W Long.). The field is adjacent NR to Site 2 and was grazed free choice with Site 2 in June and then again in October. Soils are mapped as predominantly Brown Solods with inclusions of Brown Solodized Solonetz (Kjearsgaard and Pettapiece 1986). Range condition of NR has been extrapolated from data collected to provide a point with which to compare the RWR treatments. Range condition was rated as fair since more palatable species such as wheat grasses constituted a very small percent of ground cover while june grass (*Koeleria macrantha* Ledeb.) and little club moss (*Selaginella densa* Rydb.) are very high. June grass, though high in composition, contributes little to overall weight of forage (Pyle 1990). Bare ground was not considered when determining range condition (Wroe et al. 1981) but a sign of deterioration is reduction in plant litter (Pyle 1990) and increases in invader species (Wroe et al. 1981).

Site 5 (NR2) was located north of Site 3 (51° 10' Lat., 111° 30' W Long). The field is a fenced NR and grazing periods are unknown. Species composition was not quantified on this field, but a visual comparison with NR1 indicates a similar composition. Soils were similar to Site 4.

2.3 Methods and Materials

2.3.1 Experimental design and statistical analysis

The experimental design for all vegetation parameters is nested or hierarchical (Namboodiri et al. 1975; Searle 1987). Each RWR field and NR constitute a treatment. Three randomly selected replicates per field, each consisting of three random (five for ground cover and species composition) samples points were used. In-row (IR) and between-row (BR, halfway between rows) positions within the RWR fields were classed as subtreatments and were nested within the treatments (n=18) (Appendix A-2). Depth measurements, where made, were nested within the subtreatment. The linear model utilized was $Y = A + B(A) + C(B)$ where Y is the response or dependent variable, A is the primary factor (treatment), B is the secondary factor (subtreatment) nested within the primary factor and C is the tertiary factor (depth) nested within the secondary factor (Searle 1987). An interaction plot indicated no interactions between variables occurred. Root mass and total soil carbon (TC) data were log transformed and residuals of the fitted model were used to test for normal population distribution using the Kolmogorov-Smirnov test (SPSS 1983). Residuals for the fitted model for ground cover data met the normality assumption without transformation. Comparison of within and between treatment means for fixed depth increments (each depth increment analyzed separately) were analyzed using Fisher's least significant difference (LSD) (defined by $LSD = (MSE)^{1/2} * (1/n_i + 1/n_j)^{1/2} * (t_{\alpha/2, d.f.})$) only if analysis of variance was significant ($p < 0.05$).

2.3.2 Ground cover and plant species composition

Percentage ground cover (live vegetation, litter, bare ground, feces and stones) and plant species composition were determined using randomly located 0.1 m^2 (20 by 50 cm) quadrats. Species present in the field but not located within the frame were noted. Fifteen samples, five each from three replicates, were obtained from each of the IR and BR positions of each RWR field and from NR1 in August 1993. Cost and time limited the sampling of the NR2 field. Litter depth was determined by ruler measurement from top of the litter layer to the mineral soil for all RWR fields and NR1. Thirty random measurements of sward width for RWR fields were taken in August 1994 perpendicular to the row at the soil surface.

2.3.3 Roots

Root samples were collected from four depth intervals (0 - 5, 5 - 10, 10 - 20 and 20 - 30 cm) using a truck-mounted hydraulic corer with a 5-cm diameter core. Three samples (each consisting of four depths) each from three replicates, from within three subtreatments (IR, BR and MR, one half the distance between IR and BR) were collected from each field (n = 108) (Appendix A-2). Root masses of IR, BR and MR were hand washed by soaking the cores in tap water for a minimum of one hour then agitating by hand to loosen the soil from roots and to break down the aggregates. The sample was then placed on a 1-mm square mesh sieve and the soil washed through the sieve into a 4-L pail. The soil was retained for further sieving. The roots remaining on the 1-mm sieve were washed into a second 4-L pail and the soil particles larger than 1-mm were allowed to settle. The roots were then placed on a 0.125-mm sieve and washed. The remaining soil and roots were also washed through the 0.125-mm sieve with a minimum of two washings to obtain as many fine roots as possible (modified from Bohm 1979). The roots were washed from the screen and placed into an aluminum drying tin then oven-dried at 58 °C to constant weight and weighed.

2.3.4 Total soil carbon

In 1993 and 1994, TC samples were collected. Three samples, each consisting of two depths (0 - 5 and 5 - 10 cm), from each of three replicates within two subtreatments IR and BR (n = 36), were collected from each RWR field. Three samples (two depths each) from each of three replicates were collected from NR1 (n = 18). No samples were collected from NR2. Samples were air-dried then ground to 2 mm using a rotary grinder. Litter and plant crowns were removed prior to grinding. Any root material that had not passed the sieve was discarded. Carbon samples were then fine ground using a Siebtechnik Mill set at a 16 second grinding period. TC was determined by dry oxidation using a Leco Carbon Determinator Model CR-12.

2.3.5 Seedbank

In August 1994 three samples, from each of three replicates (n = 9) were collected from the surface 5 cm of soil from each RWR field BR position using a square spade. Field observations of seed were also made at the time of collection. Samples were air-dried and ground to pass a 4-mm sieve to minimize damage to the seed. A 200-ml sub-sample was taken from each sample, placed in an individual 10 by 10 cm tray and put in a greenhouse under a 16-hour photo period and 20 to 23 °C air temperature in a completely randomized design. Samples were watered every few days when the soil appeared to be drying out. A tally of grass and forb plants was completed for each tray after 31 days.

2.4 Results

2.4.1 Meteorological data

Precipitation and temperature data were from the Brooks weather station located about 30 km south of the research sites. Long-term (30 yr. average) annual precipitation is 341 mm with 64% falling between May 1 and September 30. Annual precipitation for 1993 and 1994 was 342 and 288 mm, respectively. Long-term mean annual temperature is 3.8 °C with July being the hottest month at 18.6 °C and January the coldest at -14.1 °C. Annual temperatures for 1993 and 1994 were both above normal at 4.6 and 5.2 °C, respectively (Dzikowski 1994). Prior to sample collection in 1993 (June), precipitation was about 20% above normal and temperature 2.6 °C below normal.

2.4.2 Ground cover and species composition

Live vegetation and litter were highest, and bare ground lowest, on NR accounting for 36, 52 and 10% of ground cover, respectively (Table 2.2). Live vegetation and bare ground increased while litter decreased with increasing age of RWR treatments. Differences in live vegetation, litter and bare ground over whole treatments (IR and BR combined) were similar ($p > 0.36$).

Live vegetation IR was greater than BR for all RWR treatments ($p = 0.000$). Live vegetation BR increased with age of RWR field from less than 1% in RWR1989 to 8% in RWR1972 but remained well below that on either IR or NR. Live vegetation IR was lower in RWR1989 than RWR1980 and was similar between RWR1980 and RWR1972 at less than 75% that of NR. Live vegetation on NR was greater than all RWR IR ($p = 0.000$). Sward width for RWR IR was variable with age but was greatest in RWR1980 at 20-cm followed by RWR1972 and RWR1989 with a width of 16 and 10 cm, respectively. RWR swards in RWR1980 and

RWR1972 were thinning in the centre of the sward and soil appeared to accumulate within the sward. Similar trends were not observed in RWR1989.

Standing and fallen litter combined was greater IR than BR for all RWR treatments. RWR1989 litter cover was similar IR and BR ($p > 0.400$), while BR litter on RWR1980 and 1972 had a marked decrease to approximately one-tenth that of IR ($p = 0.000$). Litter on NR was similar to RWR IR ($p > 0.050$). IR and BR litter depths were variable compared to NR, however, overall treatment means of RWR litter depth were less than that of NR. Standing litter decreased with increasing age of RWR. Standing litter accounts for 20, 8, 6 and 4% of total litter for RWR1989, 1980, 1972 IR, and NR, respectively. There was less than 1% standing litter in any given RWR BR treatment.

BR bare ground was greater than that for NR and IR RWR ($p = 0.000$). Bare ground increased with increasing age of RWR. Bare ground BR was lowest for RWR1989 (50% of ground cover, five times that of NR) and increased to over 80% for both RWR1980 and 1972 (eight times that of NR). Bare ground of RWR1989 and 1972 IR was higher than NR ($p = 0.030$) and similar to RWR1980 ($p = 0.110$).

Species richness was highest in NR with over 30 species identified (Table 2.3). NR was dominated by june grass, needle and thread grass (*Stipa comata* Trin. and Rupr.) and little club moss. Species richness was similar in RWR1972 but was dominated by RWR and june grass. Species richness was low in RWR1989 and RWR1980 with less than one half that of NR. RWR1989 and 1980 were dominated by RWR IR for RWR1989 and IR and BR for RWR1980. Annual forbs or short lived perennials were common BR. RWR1972 contained more native vegetation (annual and perennial) than the younger RWR sites.

2.4.3 Roots

Root mass to 30 cm was significantly different ($p = 0.024$, Table 2.4) among treatments, with smallest masses in RWR1989 (2.7 kg m^{-3}) and largest masses in RWR1980 (5.6 kg m^{-3}). Root masses of RWR1972 and NR were 10 and 5% less respectively, than that of RWR1980, and were not significantly different from RWR1980 ($p > 0.170$). Root mass decreased with depth and with increasing distance from the seeded row. Variability in RWR treatments was greatest in the surface 10 cm. Between treatment means of IR, MR and BR root mass of RWR treatments and NR were greatest in the surface 5 cm. Root mass was greater in NR ($p < 0.010$) than all subtreatments in all RWR sites except IR of RWR1980 and RWR1972. Root mass in NR was 3.4 times greater than RWR1989 BR. In the remaining depth increments, NR root mass was much reduced compared to that in the RWR treatments. In the 5 to 10 cm depth increment, root masses of NR were higher than those for all row positions of RWR1989 ($p = 0.320$, 0.030 and 0.040, respectively, for IR, MR and BR). In the 5 to 10 cm depth increment, root mass in NR was less than RWR1980 IR, MR and RWR1972 IR ($p < 0.020$) but similar to MR and BR ($p > 0.310$). Trends were similar in the remaining two depth increments.

IR root masses in the surface 5 cm were larger than those for the same depth increments in the MR or BR positions ($p < 0.020$) for all within treatment comparisons. MR root masses were greater than BR root masses in RWR1980 ($p = 0.020$), but were not as evident in RWR1972 ($p = 0.080$), and were not observed in RWR1989 ($p = 0.390$). In the 5 to 10 cm depth increment, similar trends were evident with RWR1980 and 1972 but there were no differences between row positions in RWR1989 beyond the surface 5 cm. In RWR1980, IR, MR and BR root masses were different in the 10 to 20-cm depth increment with IR 28% higher than MR and 86% higher than BR ($p < 0.007$). IR root mass was higher than MR and BR root masses in RWR1972, but only marginally ($p > 0.090$). In the 20 to 30 cm depth increments, differences in root mass IR compared to MR and BR were not as evident ($p > 0.100$).

2.4.4 Total soil carbon

Overall treatments means for TC (mass/mass basis) were not statistically significant ($p > 0.260$, Table 2.5). TC in NR1 and NR2 were 2.36 and 2.66%, respectively, for the 0 to 10 cm depth compared to less than 2.20% for the highest RWR treatment. TC in the NR was higher in the 0 to 5 cm depth increment than all other treatments ($p < 0.001$), except for RWR1980 IR ($p = 0.200$).

TC did not decrease with age of RWR field for IR positions in the 0 to 5 cm depth increment but did in the 5 to 10 cm increment. TC in the 0 to 5 cm depth increment was highest in RWR1980 at 2.8%, 22 and 33% higher than in RWR1989 IR and RWR1972 IR ($p < 0.020$), respectively. RWR1989 and RWR1972 IR had similar TC in the 0 to 5 cm depth increment ($p = 0.130$). In the 5 to 10 cm depth increment, RWR1989 IR TC was 2.1%, 1.1 times higher than RWR1980 IR ($p = 0.120$), whereas RWR1980 IR TC was approximately 1.2 times greater than that for RWR1972 IR ($p = 0.010$). Decreases in TC with age of RWR treatments were observed in the BR positions in both depth increments. TC BR decreased in both depth increments. Decreased TC with age was more pronounced in the 5 to 10 cm depth increment with decreases in TC greater than 25% between RWR1989 and RWR1980, and RWR1980 and RWR1972 ($p < 0.010$).

TC decreased with depth on all fields (Table 5), most rapidly under NR where decreases were about 1.25% absolute or 40% relative over both NR fields from the 0 - 5 cm to 5 - 10 cm depth increments. Reductions under RWR1980 and 1972 were approximately 20 to 30% less than surface values (0 to 5 cm depth), while reduction in TC in RWR 1989 were less than 10% that of surface values (0 to 5 cm depth).

2.4.5 Seedbank

The majority of seed emergence occurred mainly in the first 8 days for RWR1989 and RWR1980 (Table 2.6). The greatest number of seedlings were observed in RWR1989 (26 grass and 12 forbs) followed by RWR1972 (16 grass and 11 forbs) and RWR1980 (7 grass and 10 forbs). In one of nine RWR1989 trays no plants emerged while in two RWR1980 and RWR1972 trays no plants emerged.

RWR seed was observed in the BR position on the soil surface and in cracks and hoof depressions for all fields. Seedlings of RWR or any grass were not observed on the site in either July or August 1993 or August 1994. Old seed was observed and differentiated from current year seed by color (weathered seed was gray and current seed was light brown).

2.5 Discussion

Plant growth is a function of the environment a plant grows in and the stresses, such as grazing, imparted on it. The response of vegetation to grazing is a function of intensity, frequency and duration (Tainton 1981). As reported by Thaine (1954) and Crider (1955), the below ground component is indirectly affected by grazing above ground through loss in root mass and unfavorable changes in soil properties of decreased infiltration and increased bulk density (Naeth et al. 1990).

Root masses of RWR1980 and RWR1972 were similar to those reported by Dormaar et al. (1995), however, the root masses of RWR1989 and NR were not. RWR is slow to establish (Lawrence and Heinrichs 1977) which may be reflected in the much reduced root mass observed after only 3 years of growth. The use of root cores to determine root mass does not allow discrimination between live and dead root material. The older RWR fields had more time to contribute root material, now in varying stages of decomposition, to the soil. The apparent similarities in root mass of the two older RWR fields may indicate an equilibrium of root matter input to root decay. Less palatable species on NR indicate overgrazing and the presence of little club moss, an unpalatable, shallow-rooted forb, may influence the amount of root mass present. Coupland and Johnson (1965) found that little club moss produced a thick root mat that extended only to depths of 5 cm and roots were generally less than 0.2 mm in diameter. Smoliak et al. (1972) found the basal area of little club moss increased with increased grazing by sheep from light to heavy treatments (18.7 to 26.0%, respectively). The high presence of bare ground and litter would also replace the live vegetation present and subsequent root mass below ground. Smoliak et al. (1972) found increased root mass in the 0 to 15 cm depth increment due to increases in shallow rooted species. No quantification of bare ground was made, however, in their study.

TC values were similar to those reported by Dormaar et al. (1995), but correlation with root mass was not evident. Previous management of RWR fields may have affected this. RWR1980 was broken in the 1920s and shortly thereafter abandoned, leaving a permanent cover after several years until 1976. Carbon inputs were continuing during this period with little carbon removal by grazing. Conversely, RWR1989 was in a crop/fallow rotation since the 1950s which may have increased the rate of mineralization of carbon in the field and thereby reduced TC. Bowman et al. (1990) found total organic carbon decreased by 63% over 60 years of cultivation in the short grass prairie with about half the loss occurring in the first three years. The small variation that is evident between the IR and BR of RWR1989 in the top 10 cm of soil is likely to be a remnant of cultivation. The addition of perennial vegetation in the IR position increased in TC in the surface 5 cm. RWR roots were much coarser than those observed in the NR. During the initial grinding of the TC samples the large roots were not all pulverized and therefore did not pass the 2-mm sieve. Similarly, the dense root mat formed by little club moss remained in a mat and did not pulverize. Higher contents of carbon may be evident if all material within the sample had been included in the grinding. Though root mass is similar in RWR1980, RWR1972 and NR1, TC values differ. RWR roots may not decompose as quickly as those in NR, due to their larger size. The root mass observed under RWR1980 may also be a result of priming (initial flush of growth) by the initial addition of N fertilizer. Lorenz and Rogler (1964) observed increases in root mass with N additions. Wikeem et al. (1993) found increased forage production under a single N pulse to occur for at least three years compared to unfertilized treatments. The possibility of lower decomposition rates, improved fertility of RWR1980 and higher root masses may be evident although the carbon may not be available to microbes and aggregation processes.

Bare ground between rows of RWR has been documented but not quantified (Lorenz and Rogler 1964; Lawrence and Heinrichs 1968). The effect of increasing bare ground with age of RWR field is apparent in the BR position. Lawrence and Heinrichs (1968) observed in their long term study that weed control was required in the wider spaced rows in the first two years but thereafter RWR exerted sufficient competition to prevent the establishment of volunteer plants or weeds. A seedbank, dominated by grasses, was present on each RWR field but establishment of grasses or forbs BR was minimal. The precise factor or factors involved in failure to establish is unclear. Current year seed is viable, however, viability may be markedly reduced by severe fluctuations in temperature at the soil surface. Lorenz and Rogler (1964) suggested that RWR exerted extreme competition for water and nutrients near the soil surface. Reduced bare ground in RWR1989 was attributed to litter of other species that have since disappeared. Weed control was not undertaken in RWR1989. The effect of vegetation loss and subsequent litter loss resulted in the increased bare ground. The growth form of the RWR plant is dominated by a basal leaf arrangement and does not provide litter BR but litter collects IR. The only inputs would occur from the seed culms of the RWR plants which provide far less cover than the leaves. The decrease in bare ground in the IR position with increasing age of RWR fields was due in part to the increases in sward width that occur with age. Bare ground remains high in the IR positions in the older fields due in part to the morphology of the RWR plant. As the bunch grass matures, tillers form around the plant while the inner tillers die. With several dominant species in the mixed grass prairie being rhizomatous this effect is not evident.

The increase in live vegetation in RWR with time was attributed to increase in sward size with age. Similar observations were made by Lorenz and Rogler (1959). Productivity of RWR with wider spaced rows was lower in the early years but productivity under wider spaced rows surpassed that under narrow spaced rows once vegetation was established (Lorenz and Rogler 1959). The reduction in vigor of RWR swards in RWR1972 was not repeated in other RWR fields of similar age near the study area (Naeth unpublished) and may be attributed to variability in stands.

The erosion and long term sustainability of RWR stands may be questioned. Chepil and Woodruff (1963) identified the role of vegetation as a cover in reducing wind erosion. The high incidence of bare ground increases the risk of wind and water erosion by exposing soil. Further, reduced live vegetation and litter expose the soil to raindrop splash reducing infiltration as a result of crust formation.

2.6 Conclusions

Live vegetation, bare ground and litter cover were similar for all treatments, however, bare ground BR increased in RWR1980 and RWR1972 from RWR1989 compared to adjacent IR positions. Root mass in the surface 5 cm was greatest under NR but higher root mass was measured under RWR in the 5 to 10 cm depth. Root mass was similar among treatments below 10 cm. TC was higher under NR in the surface 5 cm than under RWR but similar at 5 to 10 cm. Root mass and TC were not highly correlated. Bare ground BR and live vegetation IR increased with age of the RWR treatment and remained well below and above NR, respectively. Litter IR was similar to NR over the RWR treatments but a 5 to 10 fold reduction in litter is evident BR for RWR1980 and RWR1972. Increased erosion within RWR fields compared to NR is not evident based on only vegetative measurements, however, increased erosion within RWR fields is expected with the increase in bare ground for RWR1980 and RWR1972.

Table 2.1. Near surface soil characteristics and select soil properties for three Russian wildrye and two native range fields.

Site	Depth	Parameters: Bulk Density (Mgm^{-3})	Particle Size Analysis: S	Si	C	Textural Class	Reaction[1]	Slope[2]	Row Orientation
NR	Surface							< 2%	—
	0 - 5 cm	1.01	42	49	9	Sil - L	None		
	5 to 10 cm	1.21	45	44	11	L	Audible		
RWR1989	Surface							< 2%	North/South
	0 - 5 cm	1.02	34	58	8	SiL	None		
	5 to 10 cm	1.21	31	57	12	SiL	Audible		
RWR1980	Surface							< 2%	East/West
	0 - 5 cm	1.13	32	55	13	SiL	None		
	5 to 10 cm	1.28	30	55	15	SiL	Audible		
RWR1972	Surface							< 2%	North/South East/West
	0 - 5 cm	1.12	52	38	10	L	None		
	5 to 10 cm	1.38	48	36	16	L	Audible		
NR2	Surface							< 2%	---
	0 - 5 cm	1.12	36	53	11	SiL	None		
	5 to 10 cm	1.28	33	54	13	SiL	Audible		

1 - Reaction of soil determined by 10% HCl; audible indicates effervescence barely heard close to the ear.
2 - Slope was determined over the site using a Suunto Clinometer.
RWR followed by year indicates the year field was seeded.

Table 2.2. Ground cover, litter depth and sward width of three different aged Russian wildrye and one native (NR1) range site.

		Ground Cover (%)					
Treatment		Live Vegetation	Litter	Bare Ground	Other[2]	Litter Depth (cm)	Sward Width (cm)
RWR1989	IR	14 (3)	51 (15)	22 (11)	13	0.8	10
	BR	< 1 (1)	41 (22)	50 (22)	8	0.8	
	Mean[1]	7 (7) a	46 (19) b	36 (22) c	11	0.8	
RWR1980	IR	21 (9)	60 (13)	16 (17)	3	1.3	20
	BR	1 (2)	6 (4)	89 (7)	4	0.3	
	Mean	11 (12) a	33 (30) b	52 (39) c	4	0.8	
RWR1972	IR	21 (7)	51 (15)	19 (14)	9	0.7	16
	BR	8 (3)	5 (4)	80 (8)	7	0.2	
	Mean	14 (9) a	28 (26) b	49 (33) c	9	0.4	
NR1	Mean	36 (10) a	52 (13) b	10 (11) c	2	0.9	-

Mean values followed by same letter for ground cover parameters are not significantly different ($p > 0.360$).
1 - Mean of IR and BR position combined.
2 - Other includes fecal material and rocks.
Numbers in parentheses indicate standard deviation
RWR followed by year indicates year field was seeded

Table 2.3. Percent plant species composition of three Russian wildrye (RWR1989, RWR1980, RWR1972) and one native range (NR1) site.

Species Present[1]	Treatment						
	RWR1989		RWR1980		RWR1972		NR
	IR	BR	IR	BR	IR	BR	
Grasses							
Agropyron pectiniforme					7		
Elymus junceus	99		99	58	44	8	
Hordeum jubatum		39					
Koeleria macrantha					28	52	36
Stipa comata							30
Forbs							
Artemesia frigida					7	15	9
Gueterizzia sarothrae						5	
Kochia scoparia		48					
Polygonum spp.				6			
Salsola kali		13		27			
Schedonnardus paniculatus						9	
Selaginella densa					5		13
Sphaeralcea coccinea				9			
Total species identified (field)	6		12		26		34

1 - Species listed were greater than 5 percent of total composition within the quadrat.

Other species found in trace amounts in the quadrat or identified in the field:

RWR1989 - *Agropyron pectiniforme, Polygonum* sp..

RWR1980 - *Hordeum jubatum, Amaranthus retroflexus, Anemone* sp., *Artemisia frigida, Atriplex* sp., *Descurainia sophia, Erigeron* sp., *Plantago* sp..

RWR1972 - *Agrostis* sp., *Bouteloua gracilis, Stipa comata, Stipa viridula, Antennaria* sp., *Grindelia squarrosa, Malvaceae, Melilotus alba, Monolepis nuttaliana, Polygonum* sp., *Potentilla norvegica, Ratibida columnifera, Solidago* sp., *Sphaeralcea coccinea, Taraxacum officinale, Tragopogon dubius, Rosa woodsii, Symphoricarpos alba, Symphoricarpos occidentalis, Carex* sp. and lichen.

NR - *Agropyron smithii, Agropyron spicatum, Agropyron trachycaulum, Bouteloua gracilis, Festuca hallii, Hordeum jubatum, Poa compressa, Stipa comata, Achillea millifolium, Allium* sp., *Antennaria* sp., *Artemesia ludoviciana, Corypantha vivipara, Cruciferae, Erigeron* sp., *Grindelia squarrosa, Happlopappus* sp., *Lappula squarrosa, Linum rigidum, Orthocarpus luteus, Oxytropis sericea, Phlox hoodii, Plantago* sp., *Ratibida columnifera, Schedonnardus paniculatus, Sphaeralcea coccinea, Tragopogon dubius, Vicia americana, Carex* sp. and lichen

RWR followed by year indicates year field was seeded

Table 2.4. Root mass, by row position and depth, of three different aged Russian wildrye and one native (NR1) range site.

		Depth Increment (cm) Root Mass (kg m^{-3})				
Treatment		0 - 5	5 - 10	10 - 20	20 - 30	Grand Mean
RWR1989	IR[1]	5.7 (2.0)[5]	4.2 (1.4)	1.6 (1.0)	1.4 (0.5)	
	MR[2]	3.9 (1.0)	3.4 (1.6)	1.3 (0.4)	0.9 (0.3)	
	BR[3]	3.9 (1.4)	3.4 (1.3)	1.4 (0.5)	1.2 (0.7)	
	Mean	4.5 (1.7)	3.7 (1.4)	1.4 (0.7)	1.2 (0.6)	2.7 (1.9) a
RWR1980	IR	16.3 (6.0)	11.0 (2.7)	3.8 (1.2)	3.1 (1.7)	
	MR	8.2 (1.3)	6.4 (1.4)	3.0 (0.9)	2.3 (0.4)	
	BR	5.7 (1.5)	4.2 (1.6)	2.0 (0.4)	1.9 (0.2)	
	Mean	9.8 (5.6)	7.2 (3.4)	2.9 (1.2)	2.3 (1.2)	5.6 (4.0) b
RWR1972	IR	12.6 (3.6)	9.0 (3.6)	3.1 (0.9)	2.2 (0.8)	
	MR	8.7 (4.1)	5.1 (2.5)	2.6 (1.3)	1.7 (0.9)	
	BR	6.5 (2.5)	4.8 (1.7)	2.5 (1.2)	2.4 (1.7)	
	Mean	9.1 (4.2)	6.3 (3.3)	2.7 (1.1)	2.1 (1.1)	5.0 (4.5) b
NR1[4]		11.8 (4.4)	5.7 (2.7)	2.1 (0.6)	1.7 (0.6)	
		13.2 (4.2)	4.5 (1.2)	2.0 (0.7)	1.8 (0.4)	
		14.6 (4.3)	4.1 (1.0)	1.8 (0.6)	1.6 (0.9)	
	Mean	13.3 (4.0)	4.8 (1.9)	2.0 (0.6)	1.7 (0.7)	5.3 (5.2) b

Mean followed by same letters are not significantly different ($p = 0.024$)

1 - In-row position; sample taken within seeded row.

2 - Mid-row position; sample taken 15 cm from IR for RWR1989, 1980 and NR; and 13.5 cm for RWR1972.

3 - Between-row position; sample taken 30 cm from IR for RWR1989, 1980 and NR; and 27 cm for RWR1972.

4 - NR root mass taken at a 15-cm spacing.

5 - Numbers in parentheses are standard deviations.

RWR followed by year indicates when field was seeded

Table 2.5. Total carbon content of in-row and between-row positions of three different aged Russian wildrye and two native range sites.

	Total Carbon (%)							
Depth	RWR1989		RWR1980		NR	RWR1972		NR2
(cm)	IR	BR	IR	BR		IR	BR	
0 to 5	2.31(0.3)a	2.13(0.3)a	2.76(0.3)c	2.08(0.2)c	2.97(0.4)	2.13(0.5)e	1.72(0.3)e	3.34(0.7)
5 to 10	2.13(0.2)b	2.07(0.3)b	1.93(0.2)d	1.67(0.2)d	1.76(0.2)	1.65(0.3)f	1.26(0.3)f	1.99(0.8)

NR2 - NR site adjacent to, and compared to, RWR1972.
a - values statistically significant at a p- value of 0.20, b - 0.36, c - 0.02, d - 0.09, e - 0.04, f - 0.08
RWR followed by year indicates when field was seeded.

Table 2.6. Total seed germination (based on 9 samples) of surface 5 cm for BR position for three different aged Russian wildrye sites.

Treatment	Growing Period							
	Day 8		Day 15		Day 22		Day 31	
	Grass	Forb	Grass	Forb	Grass	Forb	Grass	Forb
RWR1989	20	7	26	10	26	12	26	12
RWR1980	5	5	7	7	7	11	7	10
RWR1972	5	5	10	8	15	13	16	11

RWR followed by year indicates when field was seeded

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Chapter 3. Select Soil Physical Properties Of Three Different Aged Russian Wildrye Pastures In Southern Alberta

3.1 Introduction

Approximately 18 million ha of rangeland and 2.5 million ha of pastures are utilized by the beef industry in the Prairie Provinces of Canada. Many ha of native range (NR) have been plowed and converted to introduced forages in an attempt to increase productivity on overgrazed rangelands, crested wheatgrass (*Agropyron pectiniforme* R. and S.) (CWG) and Russian wildrye (*Elymus junceus* Fisch.) (RWR) being the most popular in arid parts of the province. There are now over one million ha of CWG and 100,000 ha of RWR contributing to forage supplies for livestock production (Smoliak and Dormaar 1985). These two forages have been used extensively to complement native range in spring and fall, often doubling livestock gains per ha by improving pasture carrying capacity (Smoliak and Slen 1974).

Perennial forages are considered important in improving soil structure and increasing nitrogen and organic carbon, all of which deteriorate under intensive row crop agriculture. Soil structure is improved by increasing aggregate stability through physical enmeshment by plant roots and enhanced production of polysaccharides that bind soil particles. Tisdall and Oades (1982) suggest that roots provide only temporary binding of larger soil aggregates over periods of up to a year or more. Aggregates are under a hierarchical grouping of smaller aggregates being bound up into larger ones. The role of mycorrhizae in this binding has also been recognized (Tisdall and Oades 1980, Molope 1987).

In earlier studies, it was implied that individual forage species may have a specific effect on the degree of soil structural change. From other studies, it was concluded that clay and organic matter contents may significantly affect the aggregate stabilizing impacts of forages. Grevers and de Jong (1990), for example, found no significant differences in bulk density, total porosity and air-filled porosity of a heavy clay soil under 10 grasses grown continuously for 11 years. However, Perfect et al. (1990) found highly significant rates of structural improvement of a silt loam soil seeded to forages. Thus the effects of forages on soil physical properties are not definitive.

Soil bulk density data under grazing of perennial forages and NR under different grazing intensities are contradictory. Van Havern (1983) found significant differences in bulk densities between light and heavy and moderate and heavy grazing intensities on fine textured soils. Increases of 13% between light and heavy grazing were observed in the top 2.5 cm of soil. Under coarse textured soils, no significant differences were observed. Similarly, Naeth et al. (1990) observed no significant differences in bulk density in the uppermost 10 cm of mixed grass prairie in southern Alberta but under foothills and parkland fescue significant differences were observed to 65 cm for foothills fescue and 0 to 7.5 and 35 to 55 cm for park land fescue, for the control compared to heavy grazing treatments. Rauzi and Hanson (1966) found significant increases in bulk densities from 1.17 to 1.29 Mg m^{-3} in the 0 to 70 cm depth on silty clay and silty clay loam soils from light to heavy grazing.

Semi-arid regions are prone to high risk of erosion by both wind and water due to relatively poor soil structure as a result of low organic matter and low clay content. After considerable research, Chepil and Woodruff (1963) reported that wind erodible fractions for soils are those aggregates below 0.84 mm in diameter. For single particles (assuming a particle density of 2.65 Mg m^{-3}) the equivalent diameter for wind erodiblility is approximately 0.5 mm (Chepil and Woodruff 1963). The fine fraction most susceptible to erosion is silt (Chepil 1946). Sand particles may be large enough to withstand wind while clay particles may form sufficiently large aggregates to resist erosion. Most research into erosional processes is relegated to cultivated fields. The presence of bare ground under perennial RWR and CWG has been observed (Lawrence and Heinrichs 1968) and quantified (Chapter 2). Bare ground of 30 to 50% has been observed on RWR fields (Chapter 2). Increasing exposed soil increases the risk of erosion. Erosional processes sort fractions with the coarser non-erodible fraction left behind and the silt, or more erodible fraction, removed along with clay and organic matter. Lyles and Tatarko (1986) found increases in sand content of cultivated fields in Kansas to increase by 6% over 40 years of cultivation for the 0 to 10 cm depth.

The role of soil crusts on seed emergence of seed has been documented (Carnes 1934, Frelich et al. 1973). Further research into erosion and crusting has also been reported (Hagen 1984, Potter 1990). Chepil (1958) found that crusts are susceptible to saltation that may lead to the breakdown of the crust. Further research into the reduction in infiltration and air movement through crusted soils is documented. Soils high in sodium (Na+) are more susceptible to crusting due to clay dispersion under wet conditions that will lead to puddling (Richards 1953). Potter (1990) observed that crusts formed on coarse textured soils had 30 times more loose material available for abrading crusts.

Micro-topography of cultivated fields has been quantified with use of relief meters and chains (Kuipers 1957, Saleh 1993). Saleh (1993), used a chain to quantify the changes in surface of cultivated a field. Changes in micro-topography under perennial vegetation has not been considered, however.

The role of perennial forages in improving soil physical properties is well documented for soils under cultivation, but not for pastures. The use of perennial forages in rows that do not fill in may have adverse effects on the fields, reducing the sustainability of the soil/plant system compared to adjacent native range (NR). The abundance of bare ground between the rows (BR) of RWR vegetation may increase the likelihood of increased bulk density compared to in row (IR) and NR.

It is hypothesized that breaking of NR and seeding with RWR will lead to changes in soil physical properties due to changes in vegetative cover and increased susceptibility of RWR fields to wind erosion. It is further hypothesized that treatment differences will occur with depth and over time since seeding. The study will provide insight into changes in soil physical properties over short-term and long-term grazing.

3.2 Study Site

Five sites, three RWR and two NR, were selected in the Brown soil zone of Alberta. The fields were chosen based on proximity to each other, differences in age and similarity of soils. The NR fields were chosen to best represent the average range condition for the area as well as similarity in soil type to the RWR fields. The native vegetation is of the Mixed Prairie (*Stipa-Bouteloua-Agropyron*) Faciation as defined by Coupland (1961).

The three RWR fields are monocultures with row spacings of approximately 60 cm and were seeded in 1972, 1980 and 1989. RWR1989 and 1980, along with one NR field (NR1), are located approximately 3 km apart. RWR1972 and the second NR field (NR2) are located less than 100 m (a road right of way) apart. RWR1972 was located 40 km immediately north of RWR1989. Surface and soil properties are outlined in Table 2.1.

Site 1 (RWR1989) was located southeast of Wardlow (50° 50' Lat., 111° 30' W Long.). The field is 260 ha in size and is fenced from adjacent NR. The land was broken from NR and was farmed in the 1950s under a wheat/fallow rotation until 1989. Seeding of RWR was completed in 1989 with a seed drill at a rate of 1.4 kg ha^{-1} in a circular pattern at a 60-cm row spacing. The field was grazed in the autumns of 1990 and 1991 and grazed in the springs of 1992 and 1993. The soils are mapped as predominantly Brown Solods with inclusions of Solonetzic Brown Chernozems (Kjearsgaard and Pettapiece 1986).

Site 2 (RWR1980) was located adjacent to Site 1 but was fenced separately. The field is 130 ha in size and is grazed free choice (both RWR and NR are available to livestock for consumption, no fence separates RWR1980 from adjacent NR) with NR to the west. The land was broken from NR in the 1920s and abandoned shortly after. The field was then re-broken and cropped with cereals from 1976 to 1979. The field was seeded at a spacing of 60-cm in August 1980 as outlined for Site 1. Seed catch was not complete so the field was partially reseeded in spring 1981. The north end of the field received a fertilizer treatment of 150 kg ha^{-1} of 34-0-0 at time of seeding. Soils at this site are similar to Site 1.

Site 3 (RWR1972) was located east of Pollockville (51° 10' Lat., 111° 30' W Long.). The field is 162 ha in size and was seeded in a circular pattern with 53 cm row spacings in spring 1972 with a double disc drill at a rate of 1.4 kg ha^{-1}. The field was grazed free choice (defined as above) with NR in May, June, September and October of each year. The field was broken previous to 1972 and cropped. Land management of this site is vague since the land was sold several times. Soils are mapped predominantly as Brown Solodized Solonetz with inclusions of Solonetzic Brown Chernozems (Kjearsgaard 1976).

Site 4 (NR1) was located west of Site 2 (50° 50' Lat., 111° 30' W Long.). The field is adjacent NR to Site 2 and was grazed free choice with Site 2 in June and then again in October. Soils are mapped as predominantly Brown Solods with inclusions of Brown Solodized Solonetz (Kjearsgaard and Pettapiece 1986). Range condition of NR has been extrapolated from data collected to provide a point with which to compare the RWR treatments. Range condition was rated as fair since more palatable species such as wheat grasses constituted a very small percent of ground cover while june grass (*Koeleria macrantha* Ledeb.) and little club moss (*Selaginella densa* Rydb.) are very high. June grass, though high in composition, contributes little to overall weight of forage (Pyle 1990). Bare ground was not considered when determining range condition (Wroe et al. 1981) but a sign of deterioration is reduction in plant litter (Pyle 1990) and increases in invader species (Wroe et al. 1981).

Site 5 (NR2) was located north of Site 3 (51° 10' Lat., 111° 30' W Long). The field is a fenced NR and grazing periods are unknown. Species composition was not quantified on this field, but a visual comparison with NR1 indicates a similar composition. Soils were similar to Site 4.

3.3 Methods and Materials

3.3.1 Experimental design and statistical analysis

The experimental design for soil parameters is nested or hierarchical (Namboodiri et al. 1975; Searle 1987). Each RWR field and NR constitute a treatment. Each field consisted of three randomly selected replicates, each replicate consisted of three randomly selected samples (n = 9)

(Appendix A-2). In-row (IR) and between-row (BR, halfway between rows of vegetation) positions within the RWR fields were classed as subtreatments and were nested within the treatments (n = 2 x 9 = 18). Depth measurements, where collected, were nested within the subtreatment. The linear model utilized is Y = A + B(A) + C(B) where Y is the response or dependent variable, A is the primary factor (treatment), B is the secondary factor (subtreatment) nested within the primary factor and C is the tertiary factor (depth) nested within the secondary factor (Searle 1987). An interaction plot indicated no interactions between variable. Residuals for the fitted models were used to test normality assumption using the Kolomogorov-Smirnov test ($SPSS^{X}$ 1983). Rill meter data were log transformed to meet the normality assumption while bulk density, percent sand, aggregate size and aggregate stability data met the normality assumption and were analyzed without transformation.

Comparison of within and between treatment means for fixed depth increments were analyzed using Fisher's least significant difference (LSD) (defined by if $LSD = (MSE)^{1/2} * (1/n_i + 1/n_j)^{1/2} * (t_{\alpha/2,d.f.})$) only if analysis of variance was significant.

3.3.2 Bulk density

Three bulk density samples, each consisting of eight depth increments (0-2, 2-4, 4-6, 6-8, 8-10, 10-12, 12-14, 14-16 cm) were collected from each replicate within each subtreatment in July 1993 for each of RWR1989, RWR1980, RWR1972 and NR1 (n = 144 per field for RWR and n = 72 for NR1), and only four depths (to 8 cm) for NR2 (n = 36) in August 1994 using the Uhland core method (Blake and Hartge 1986). A 7.5-cm diameter core was used in two steps (0-8 and 8-16 cm), each step consisting of four 2-cm sleeves. Depth of the sampling was maintained as close as possible to the diameter of the sample to minimize the effect of disturbed soil interfacing the cylinder wall (Blake and Hartge 1986). The Uhland core was gently pounded into the ground using a 3.6-kg hammer and wood was used for the cap to absorb vibration from the pounding. Samples were oven-dried at 105 °C for 24 h and weighed. Soil volume was determined by the formula $\pi r^2 * h$ where r is the radius and h the height of the core sleeve. Inside diameter and height of the eight core sleeves were measured with a precision calipers and averaged. Soil samples were retained for use in particle size analyses.

3.3.3 Particle size analysis

Particle size analysis (PSA) was determined by pipette method (McKeague 1978). Sample collection was obtained as described in section 3.3.2. Ten-gram samples were mixed with 10 mL sodium metaphosphate and 300 mL distilled water and allowed to sit undisturbed for 12 to 24 h to equilibrate water temperature with room temperature before being mixed for 5 min with a standard milkshake mixer. The samples were washed through a 53 µm (270 mesh) sieve with distilled water to collect the sand fraction. The solution containing silts and clays was collected in a 1-L cylinder and and allowed to sit undisturbed for 12 to 24 h to equilibrate to room temperature. The cylinder was then mixed with a plunger for 30 s and allowed to sit undisturbed for sedimentation. A 25-ml aliquot of sample was removed from the cylinder for clay determination. Sand and clay samples were oven dried at 105 °C for 24 h and the clay sample was corrected for metaphosphate mass. Silt content was determined by difference. Due to low organic matter contents (2 to 5%) and lack of soil reaction under HCl, samples were not pretreated for organic matter or carbonates.

Sand fractions were retained and their size distribution was determined using 1, 0.5, 0.25, 0.125 and 0.053 mm square mesh sieves. Samples were washed with tap water for several minutes and then placed in drying tins and oven dried at 105 °C for 24 h and weighed to determine distribution of sands.

3.3.4 Aggregate size and stability

Three aggregate size and stability samples were collected from each replicate, within each subtreatment from the surface 5 cm in each RWR field and NR1 in July 1993. Samples were carefully bagged, and placed in buckets to minimize disturbance. Aggregate size samples were air-dried and a subsample of approximately 600 g was taken and hand sieved after being passed through a 25-mm sieve to standardize samples. Pieces of sod and large roots not adhering to soil were removed. Hand sieving consisted of a 10-sieve nest (19, 16, 12.5, 8, 4, 2, 1, 0.5, 0.25, 0.125

mm) and a pan, being slid over a distance of 40 cm 25 times. Aggregates that passed through a sieve but remained attached to the sieve by roots were severed from the root and allowed to fall to the appropriate sieve. Sieves were then weighed. Oven dried correction for water was made on a second subsample of 20 g.

Aggregate stability was determined using a wet sieving technique modified from Yoder (1936). A six sieve nest (4, 2, 1, 0.5, 0.25 and 0.125 mm) was passed through a tank of tap water over a stroke distance of 10 cm at a rate of 30 strokes min^{-1}. Samples were air-dried and passed through an 8-mm sieve and a subsample of 30 to 35 g taken and placed on the 4-mm sieve. The sample was submerged for approximately 1 min prior to sieving. Samples were sieved for 10 min and then washed from the sieves into drying tins. Samples were oven dried at 105 °C for 24 h and then weighed. Samples were corrected for sands by placing them in 5 mL of metaphosphate solution and 95 mL distilled H_2O for 3 h then re-sieving samples through appropriate sieve size to remove sands. Retained sands were oven dried at 105 °C for 24 h and weighed. Mass of sand was then subtracted from aggregate mass to determine aggregate distribution.

3.3.5 Soil crusting

Soil crusting was measured on RWR BR only using a Modulus of Rupture (MOR) apparatus as outlined by Richards (1953). The BR position is the one most likely to crust. Three samples, each from three replicates (n = 9), were collected from each RWR field in August 1994 from the surface 5 cm using a square shovel. Samples were air-dried and ground to 2 mm. Six subsamples were taken from each sample. Briquettes were wetted with distilled H_2O for 1 h and then oven dried at 50 °C to constant weight (approximately 18 h).

3.3.6 Micro-topography

Soil micro-topography was quantified with a rill meter. The rill meter contained 140 pins 12.5 mm apart (1.75 m total distance). The rill meter was placed perpendicular to the seeded rows of RWR and randomly placed on NR and the pins lowered to the ground surface. The height of each pin above a datum was measured. Three rill meters samples were collected from each of three replicates for each of RWR1989, RWR1980 and RWR1972 (n = 9), and two samples from each of three replicates for NR1 (n = 6). To obtain a three dimensional view of topography, three separate sets of rill meter readings, each parallel to each other at 2-m intervals, were taken. The sum of squares deviation, using the mean elevation of a set of measurements, was used as the measure parameter for micro-topography. A low sum indicates relatively flat (smooth) micro-topography. Each pin was checked to ensure it was in contact with the soil surface and not obstructed by vegetation before the measurements were taken.

3.4 Results

3.4.1 Meteorological data

Precipitation and temperature data were from the Brooks weather station located about 30 km south of the research sites. Long-term (30 yr. average) mean annual precipitation is 341 mm with 64% falling between May 1 and September 30. Annual precipitation for 1993 and 1994 was 342 and 288 mm, respectively. Long-term mean annual temperature is 3.8 °C with July being the hottest month at 18.6 °C and January the coldest at -14.1 °C. Mean annual temperatures for 1993 and 1994 were both above normal at 4.6 and 5.2 °C, respectively (Dzikowski 1994). Prior to sample collection in 1993 (June), precipitation was about 20% above normal and temperature 2.6 ° C below normal.

3.4.2 Particle size analysis

Overall treatment means for sand content (0 - 8 cm) were significantly different ($p = 0.005$) (Table 3.1). RWR1989 and RWR1980 had similar sand contents at 34.2 and 32.0%, respectively ($p = 0.110$), however, NR1 had 8 and 10% more sand than either RWR1989 or RWR1980, respectively ($p < 0.010$). Textural class of the fine fraction for RWR1989, RWR1980 and NR1 are similarly classed as silt loam (SiL). Conversely, NR2 had 15% less sand than RWR1972 ($p = 0.002$) and soils were classed as loam (L) and silt loam (SiL), respectively.

Percent sand generally decreased with depth while clay content increased for all RWR IR and BR positions and NR2. Percent sand content of NR1 increased almost 7 % (absolute) between the 2 - 4 and 4 - 6 cm depth increment. Overall subtreatments means were larger IR than BR but values were not significantly different (p= 0.300).

Treatment means for sand for each depth increment for RWR1989 were similar between IR and BR and with depth (p > 0.130),with means not varying by more than 7% (absolute). Similarly, treatment means for each depth increment in RWR1980 were similar IR and BR (p > 0.190). Sand content did not vary by more than 4% (absolute) over the four depth increments. Values of both RWR1989 and RWR1980 were similar. Percent sand content of RWR1972 was higher IR than BR by 10 and 7% , respectively, for the 0 to 2 and 2 to 4 cm depth increment (p < 0.001). Below 4 cm, sand contents were similar (p > 0.360). In RWR1972, percent sand in the 0 to 2 cm depth increment was similar to that for the 2 to 4 cm depth increment for both the IR and BR positions of RWR1972 (p > 0.130), though sand content IR was higher than BR for the same depth increments. Percent sand content decreased markedly from 55 to 48% between the 2 to 4 cm depth increment and the 4 to 6 cm depth increment for RWR1972 IR. Below the 0 - 6 cm depth increment for RWR1972 IR, and the 0 - 4 cm for RWR1972 BR, sand contents were similar (p > 0.340)

Sand contents for all depth increments were higher in NR than RWR1989 IR and BR and RWR1980 IR and BR for all depth increments (p < 0.023). Conversely, sand content of NR2 was lower than RWR1972 IR or BR for all four depth increments (p < 0.001).

Overall size distributions of sand contents for all RWR treatments and NR1 were similar (Table 3.2) for the 0 - 2 cm depth increment. Very coarse sand accounts for less than 5% of the total sand fraction, while fine sand and very fine sand account for between 68 and 83% of the total sand fraction. The sand fraction for NR1 appeared the most evenly distributed.

3.4.3 Bulk density

Mean (0 - 16 cm) bulk density increased with age of the RWR treatments from 1.17 Mg m^{-3} to 1.22 Mg m^{-3} to 1.26 Mg m^{-3} for RWR1989, RWR1980 and RWR1972, respectively, compared to 1.18 Mg m^{-3} for NR1 (Table 3.3). Mean values for bulk density for overall treatment and subtreatments were not significantly different ($p > 0.403$) however.

Bulk density in all fields and subtreatments increased with depth from a low of 0.66 Mg m^{-3} for the 0 to 2 cm depth increment for NR to a high of 1.52 Mg m^{-3} for the 14 to 16 cm depth increment of RWR1972 BR. Bulk densities for IR subtreatments for each depth increment for all RWR fields were lower than those in adjacent BR subtreatments except for three cases.

For the 0 to 2 cm depth increment, NR1 had the lowest bulk density at 0.66 Mg m^{-3} compared to all RWR subtreatments while NR2 had the highest bulk density (1.03 Mg m^{-3}). All RWR IR positions had bulk densities less than 1.00 Mg m^{-3} for the 0 to 2 cm depth increment. The bulk densities of NR and RWR1989 were similar ($p = 0.201$) while the bulk density of NR1 remained less than than of RWR1989 BR, and RWR1980 IR and BR ($p < 0.001$). Bulk density of NR2 was similar to RWR1972 IR and BR ($p = 0.060$, and 0.410, respectively) in the 0 - 2 cm depth increment. For depths of 2 - 8 cm, bulk densities were not significantly different between NR1 and NR2 and RWR treatments except for 2 cases. Below 8 cm, bulk densities for NR and RWR IR and BR positions were similar.

Within treatment means for fixed depth increments of RWR were more variable in the surface 6 cm than for greater depths. RWR IR positions had consistently lower bulk densities than BR positions for all depths (0 to 16 cm). Bulk densities IR for RWR1989, RWR1972 and RWR1980 were 33, 15 and 9% less than those BR for RWR1989, RWR1972 and RWR1980, respectively ($p < 0.029$ for RWR1989 and RWR1972, and $p = 0.152$, for RWR1980) for the 0 - 2 cm depth increment. Similarly, in the 2 - 4 cm depth increment, bulk densities were 0.14, 0.10 and 0.30 Mg m^{-3} higher IR than BR for RWR1989, RWR1980 and RWR1972, respectively ($p < 0.027$ for RWR1989 and RWR1972 and $p = 0.072$ for RWR1980). In the 4 to 6 cm depth increment RWR1972 IR was lower than the BR position ($p = 0.000$) while IR and BR positions for

RWR1989 and RWR1980 were similar (p > 0.310). All remaining depth increments for IR and BR positions for RWR treatments had similar bulk densities (p > 0.100).

ıdividual depth increments for RWR1989 had lower bulk densities than RWR1980 and RWR1972 to 12 cm. No defined trend in bulk density exists for RWR1980 and RWR1972. Below the 4-6 cm depth increment bulk densities IR and BR for RWR treatments are similar (p > 0.100) except for two cases. Bulk density of the 8 - 10 cm depth increment are lower for all RWR IR and BR subtreatments than the immediate overlying and underlying layers.

3.4.4 Modulus of rupture

The average breaking force of soil from the BR positions of the RWR treatments was similar at 58, 62 and 59 mbars for RWR1989, RWR1980 and RWR1972 BR, respectively (data not shown). All samples were within 5 mbars breaking pressure of each other except for two briquettes in RWR1972 which were nearly double that of the others.

3.4.5 Aggregate size and stability

Aggregate size and aggregate stability distributions are outlined in Figures 3.1 and 3.2. The general aggregate size distribution was similar for all RWR and NR1 treatments with the greatest proportion of aggregates less than 0.50 mm and greater than 19 mm. NR1 has a greater proportion of aggregates less than 0.50 mm than all RWR IR and BR subtreatments, but a similar proportion of larg aggregates greater than 19 mm. Conversely, aggregate stability of NR1 was greater in the larger diameter (greater than 4 mm) aggregates compared to RWR IR and BR subtreatments. Aggregate stability trends are evident, with BR subtreatments for all RWR fields having a greater proportion of aggregates less than 0.125 mm compared to IR subtreatments and. IR subtreatments having a greater proportion of aggregates greater than 4.0 mm than BR subtreatments.

The mean weight diameter (MWD) was defined by Van Bavel (1949 as cited by Blake and Hartge 1986) : aggregates being assigned a weighting factor proportional to their size provides an indicator of aggregation of the soil. Based on aggregate size distributions above, NR1 had the lowest MWD of all treatments followed by RWR1989, RWR1980 and RWR1972, respectively (Table 3.4). MWD values increased 0.8, and 1.0 units from NR1, respectively, for RWR 1989, RWR1980 and RWR1972. Overall treatment and subtreatment means were not significantly different ($p > 0.220$).

MWDs for aggregate stability were less variable than those for aggregate size. No clear treatment trend is evident for overall treatment effect. MWD of NR1 is highest (3.0) with RWR1980 being the lowest (2.0). RWR1989 and RWR1972 were similar (2.4 and 2.5 respectively). Overall treatment effect was not significantly different ($p > 0.400$). MWDs for subtreatment effects of aggregate stability were significantly different ($p = 0.000$). MWD for all BR subtreatments were smaller than IR subtreatments as outlined in their distributions, however a clear trend was not evident. MWD values for RWR1989, RWR1980 and RWR1972 were similar (2.5, 2.5 and 2.6, respectively) and remained below NR MWD (3.0).

3.4.6 Micro-topography

Mean square values for treatments were significantly different ($p = 0.001$) (Table 3.5 and Figure 3.3a-d). Soil micro-topographical differences were greatest on RWR1980 and RWR1972, and approximately double the values for RWR1989 and NR1. Mean square values for RWR1989 and NR1 were similar ($p = 0.330$), while those for RWR1989 and NR1 were significantly less ($p = 0.000$) than that for either RWR1980 or RWR1972. Mean square value for RWR1972 was significantly less than that for RWR1980 ($p = 0.050$).

3.5 Discussion

The decrease in sand content and increase in clay content with depth would be expected under the solonetzic conditions present in each field. The soil forming process of eluviation/illuviation would move clay from overlying horizons and deposit it in the lower b horizon. NR, which had the marked increase in sand cont nt below the surface, provides evidence of the eluviated layer which would not be identifiable under the RWR fields which have undergone cultivation and near surface homogenization.

The presence of higher sand contents IR compared to BR for RWR1972 is not supported by previous wind erosion research. During wind erosion events, the wind sorts soil particles with a tendency for larger soil particles to remain in the eroded area and finer particles to be removed. Chepil and Woodruff (1963) reported that soil aggregates less than 0.84 mm in diameter were considered wind erodible and the most erodible material in this class was silt sized (0.1 mm diameter). The higher content of sand IR would suggest that an erosional process other than wind may be at work within the RWR fields. Parsons et al. (1992) reported soil accumulation under desert shrubs in Arizona from differential splash erosion. The shrub vegetation intercepted raindrops and protected the soil beneath it from raindrop impact. Conversely, the exposed soil around the shrubs was susceptible to raindrop impact and subsequently, a greater amount of soil was transported into the shrubs' protected area than out from under the shrubs. Coarse textured material (> 2 mm diameter), however, still dominated the unprotected soil and was a result of runoff due to slope which removed finer materials. The possible occurrence of differential splash erosion at our site is supported by our particle size data. The large exposed areas of soil BR are subject to intense short duration rainfall events that are common to the arid region of southern Alberta. Furthermore, the thinning of the RWR sward observed in RWR1980 and RWR1972 (Chapter 2) due to necrosis from the center out may provide a receptacle for the catchment of splashed particles.

Higher clay and silt contents BR for RWR1972 are not indicative of wind erosion results reported by other researchers.The presence of surface crusts, and the shelterbelt effect provided by the culms, would also reduce the potential risk of wind erosion. Conversely, the tunneling effect provided by the rows of vegetation, which may increase turbulence and subsequent wind erosion, would likely be minimized by the circular seeding pattern used on the fields we researched. The similarity in particle size analysis between IR and BR of RWR1989 and to some extent RWR1980 may indicate that sufficient time has not yet passed to manifest the textural changes that are observed in RWR1972. Increases in sand content in the surface of RWR1980 IR may suggest the process is underway but sufficient sorting has not yet occurred.

The presence of higher clay and silt contents BR than IR for RWR1972 may be a result of water erosion on a micro-scale. Overall slopes on all fields is less than 2% (Chapter 2) so minimal runoff would be expected BR of RWR fields given the moisture regime of the area. On a microscale, however, the micro-topographical differences between IR and BR observed in the rill meter data allow for finer particles to be eroded by water into the BR position while sands would be trapped by the vegetation. The relative elevational differences from IR to BR for RWR1972 is approximately equal to the depth of increased sand accumulation as indicated by Figure 3.3 and Table 3.1.

Large differences in sand content between RWR1972 and NR2 are likely due to a subsequent erosional process prior to RWR being seeded. RWR1972 and NR2 are separated by a secondary road right-of-way (approximately 30 m). The varying management history of RWR1972 prior to the seeding of RWR is unclear but, it was under cultivation for some time. The difference in sand content may be attributed to wind erosion while the field was under cultivation. The depth of change is at least 8 cm (within the cultivation zone). The southern part of Alberta is subject to wind and wind gusts regularly. Cultivation and wind erosion may have resulted in loss of silt, clays and organic matter prior to emergence of RWR. Differences in PSA between RWR1989, RWR1980 and NR1 is most likely due to natural variability over the distance between fields. NR1 is located west approximately 2 km of RWR1989 and RWR1980 and soils may change appreciably over that distance.

Bulk density magnitudes are similar to those published by Naeth et al. (1990) for the 0 to 7.5 cm depth for mixed grass prairie. The observed increases in bulk density under grazing occur only in the near surface (Van Havern 1983). Our results agree with this one, though changes in bulk density in the near surface cannot be attributed to grazing since no control was used. The increase in bulk density from IR to BR for RWR1989, RWR1980 and RWR1972 is not a clear trend with time. This lack of trend in increasing bulk density may be due to grazing of each field at different times of the year. Spring grazing on RWR1989 and RWR1972 might result in higher

BR bulk densities compared to those on RWR1980 which is grazed in June when the field would tend to be drier. The lack of animal unit data utilizing these fields also limits casual relationships.

Bulk density magnitudes would be expected given the solonetzic properties of the soils and semi-arid moisture regime of the area. The columnar structure of the subsoil, and its proximity to the surface (generally within 5 - 8 cm), results in high bulk density and macro structure that is not readily subject to compaction. As well, the semi-arid moisture regime and high moisture deficit during the growing season may indicate the absence of sufficient amounts of water to enhance soil compaction while it is being grazed.

The low bulk density values observed in the 8 - 10 cm depth increment are likely a result of the technique for collecting the samples. Although every precaution was taken to minimize disturbance to the samples, the pounding of the core into the soil in sample collection could loosen the underlying layer and result in reduced bulk densities. The use of a single large core in bulk density collection may mask this anomalous reading and lower bulk density values may be reported if a similar technique is used. Increases in bulk density values at a depth of approximately 12 cm may indicate the depth of cultivation that occurred in the RWR fields.

Bulk density values of mixed grass prairie soils in Alberta are limited. The high depth resolution of measurement provides insight into the high variability that bulk density can have even for shallow depths. Treatments with similar average bulk density to 16 cm have different values for the small measurement increments. Larger depth increments for bulk density samples may not provide the detail for observing treatment effects under grazing.

The large proportion of aggregates less than 1.0 mm in diameter for aggregate size distribution indicates a high proportion of material is wind erodible. The concern, however, may be unwarranted under perennial vegetation. Roots are likely dominating aggregate distributions given the very large MWD for aggregate size and aggregate stability. The varying root masses between RWR1989 and the other RWR and NR1 treatments (Chapter 2) do not appear to have an effect on aggregate size distribution. Most aggregate size and stability research is concentrated on cultivated fields where aggregates are more susceptible to erosion due to the exposed soil surface.

As well, aggregate size fractions that are similar to seed size are necessary for good soil/seed contact. These size fractions, however, are smaller and may fall within the erodible size range as described by Chepil (1958). The role of roots acting as a 'sticky string bag' (Oades 1993) is masked when fields are cultivated. The reduced stability in the BR position is likely due to reduced root mass (Chapter 2) for physical binding of soil particles and reduced carbohydrates. Dormaar et al. (1995) observed decreases in carbohydrates for all sizes of aggregates with the decrease being greatest in larger aggregates (1.0 to 12.5 mm diameter) for 20- to 25- yr old stands of RWR. Carbohydrate concentration NR was 20 to 35% higher than either IR or BR positions of RWR stands. Reduction in carbohydrates is associated with loss of soil structure.

Mean square values for quantifying micro-topographical differences was an effective technique. However, micro-topographical differences and the near sine wave landscape observed in RWR1980 and RWR1972 would not be identifiable with only mean square values (i.e. without graphical representation). The statistical differences between RWR1980 and RWR1972 may be explained by the greater sward width (Chapter 2) and wider row spacing observed in RWR1980 compared to RWR1972.

The crust strengths observed in the BR positions of the RWR fields were small, however, the methodology outlined by Richards (1953) produces values relative to the other RWR fields. The preparation of the samples for MOR does not mimic true crusting conditions for the area since wetting of samples is from underneath and is analogous to furrow irrigation (Richards 1953). Further, the soil is preground to 2 mm. The effect of raindrop impact on the soil surface and aggregate breakdown is not considered. Under the high sodium conditions that exist in solonetzic soil environments, the effect of crusting may be more profound than the data reported. Richards (1953) observed no bean seedling emergence from soil with an artificial SAR of 31 and a crust strength of 200 mbars. With a considerable smaller seed size for RWR, and the raindrop impact, emergence may be greatly affected.

3.6 Conclusions

Sand contents in RWR1972 IR to a 4-cm depth were higher than those BR, suggesting splash erosion as a mechanism for particle redistribution on the field. Increases in sand content of RWR1972 compared to adjacent NR likely indicates a previous sorting of the fine fraction by wind. Small increases in sand content were observed in RWR1980 IR compared to BR but increases were not significant. Bulk density was most variable in the near surface only, with RWR BR having higher bulk densities than IR. No clear trend differences between IR and BR for increasing age of RWR fields was present. Aggregate size distribution was highly variable and dominated by the physical presence of roots. Aggregate stability was greater IR than BR for RWR fields but remained less than NR1 for both positions. Micro-topographical differences in the two oldest RWR fields were observed where elevation was greatest IR. Soil loss on RWR fields due to wind or water erosion is likely minimal due to the level topography, the presence of a crust, and the vegetation acting as a shelterbelt. However, the marked increase in bare ground compared to NR will increase risk to erosion

Table 3.1. Percent sand, silt and clay and textural class of four depth increments for three Russian wildrye and two native range sites where n=9 for the 0 to 2 and 2 to 4 cm depths, and n=3 for the 4 to 6 and 6 to 8 cm depth increments.

		Treatment							
Depth		RWR1989		RWR1980		NR1	RWR1972		NR2
(cm)	Fraction[1]	IR	BR	IR	BR		IR	BR	
0 - 2	S	36.3	35.8	34.4	32.1	42.3	58.2	48.3	37.1
	C	6.5	6.4	10.9	12.7	7.2	5.9	10.7	9.1
	Si	57.2	57.8	54.7	55.2	50.5	35.9	41.0	53.8
Textural Class		SiL	SiL	SiL	SiL	SiL	SL	L	SiL
2 - 4	S	34.3	34.9	32.4	31.6	39.4	55.7	48.1	36.3
	C	8.4	9.0	13.1	15.1	9.2	7.8	11.1	12.1
	Si	57.3	56.1	54.5	53.3	51.4	36.5	40.8	51.6
Textural Class		SiL	SiL	SiL	SiL	SiL	SL	L	SiL
4 - 6	S	30.7	31.9	30.1	29.7	46.1	48.4	49.4	33.7
	C	11.2	11.7	15.2	15.0	10.0	13.8	15.2	11.3
	Si	58.1	56.4	54.7	55.3	43.9	37.8	35.4	55.0
Textural Class		SiL	SiL	SiL	SiL	L	L	L	SiL
6 - 8	S	29.8	31.8	30.9	30.2	45.9	47.0	48.5	33.5
	C	12.2	12.3	13.8	15.8	11.1	15.6	16.4	13.6
	Si	58.0	55.9	55.3	54.0	43.0	37.4	35.1	52.9
Textural Class		SiL	SiL	SiL	SiL	L	L	L	SiL
Mean	S	34.2 (4.4)		32.0 (3.1)		42.2 (5.2)	51.5 (6.8)		36.0 (6.4)

1 - Mean value is for the whole treatment, IR and BR combined.
( ) - Standard deviation
RWR followed by year indicates when field was seeded.

Table 3.2. Particle size distribution of the sand fraction for the 0 to 2 cm depth increment for three Russian wildrye and one native range site.

		Treatment (% Sand)						
Size		RWR1989		RWR1980		RWR1972		NR1
Class (um)	Classification	IR	BR	IR	BR	IR	BR	
53 - 125	very fine sand	54	56	56	50	36	42	39
126 - 250	fine sand	25	21	27	20	35	31	29
251 - 500	medium sand	16	18	13	13	21	18	22
501 - 1000	coarse sand	4	5	3	5	6	6	9
1001- 2000	very coarse sand	0	1	1	2	2	3	2

RWR followed by year indicates when fields were seeded.

Table 3.3. Soil bulk density (Mg m^{-3}) for three Russian wildrye and two native range sites.

Treatment		Depth Interval (cm)								
		0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	Mean
RWR1989	IR	0.73	1.02	1.15	1.20	1.04	1.17	1.36	1.43	1.14
	BR	1.01	1.16	1.18	1.25	1.05	1.18	1.33	1.41	1.20
	Mean	0.87	1.09	1.17	1.23	1.05	1.17	1.35	1.42	1.17a
RWR1980	IR	0.90	1.19	1.27	1.28	1.05	1.18	1.32	1.37	1.20
	BR	0.98	1.29	1.28	1.26	1.11	1.19	1.33	1.32	1.22
	Mean	0.94	1.24	1.28	1.27	1.08	1.19	1.33	1.35	1.21a
RWR1972	IR	0.91	1.03	1.18	1.36	1.03	1.27	1.37	1.41	1.19
	BR	1.04	1.33	1.38	1.45	1.17	1.35	1.41	1.52	1.33
	Mean	0.98	1.18	1.28	1.41	1.10	1.31	1.39	1.46	1.26a
NR1		0.66	1.24	1.26	1.20	1.03	1.27	1.40	1.39	1.18a
NR2		1.03	1.20	1.14	1.31	-	-	-	-	1.17

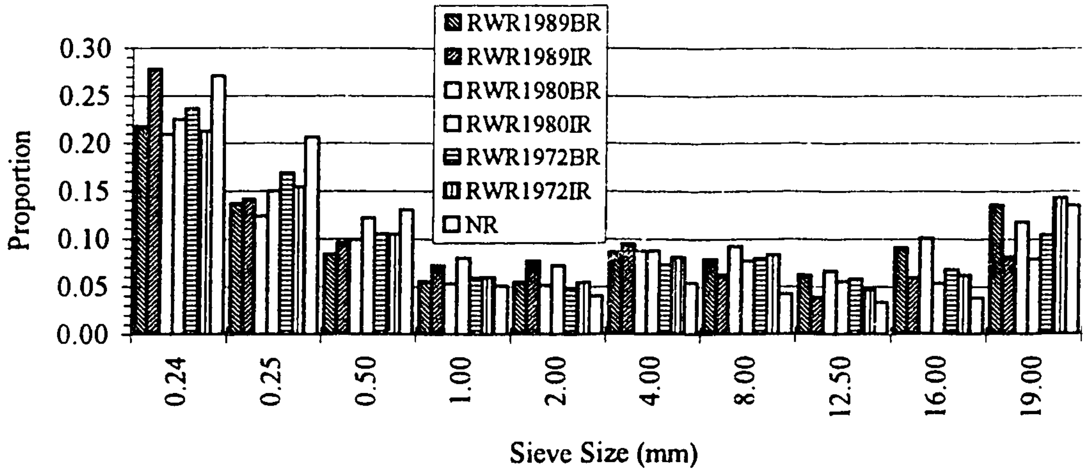

Figure 3.1. Dry aggregate distributior [illegible] different aged Russian wildrye (RWR) and one native range (NR1) field. All aggreg[illegible] passed through a 25 mm sieve to normalize. RWR followed by year indicates year field [illegible] indicates in-row and BR indicates between rows of vegetation. Row spacings for [illegible] cm for RWR1980, RWR 1980 and 53 cm for RWR1972.

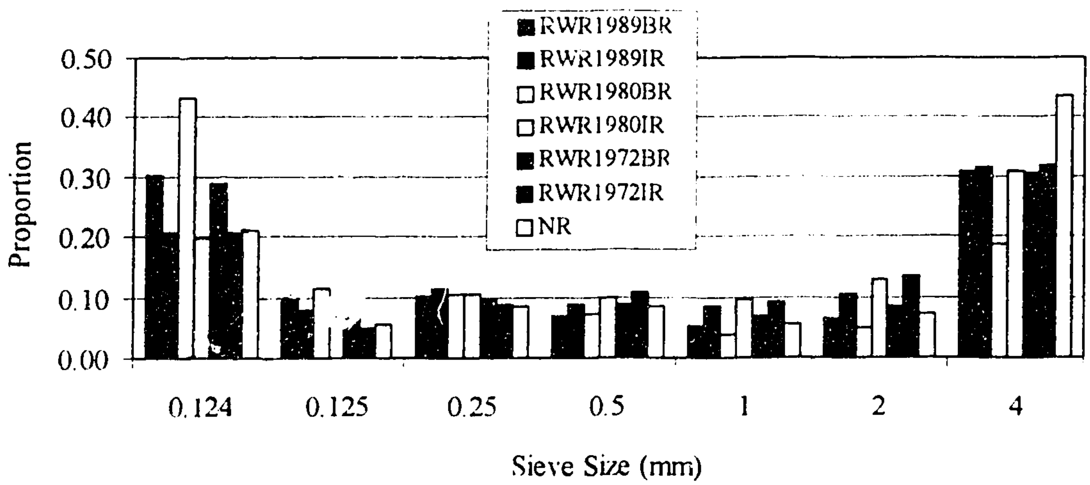

Figure 3.2. Wet aggregate distribution of three different aged Russian wildrye (RWR) and one native range (NR1) field. All aggregates initially passed through a 8 mm sieve to normalize. RWR followed by year indicates year field was seeded. IR indicates in-row and BR indicates between rows of vegetation. Row spacings for RWR were 60-cm for RWR1980, RWR 1980 and 53 cm for RWR1972.

Table 3.4. Mean weight diameter (MWD) for aggregate size and stability for three Russian wildrye and one native range field.

	Treatment						
	RWR1989		RWR1980		RWR1972		NR
Parameter	IR	BR	IR	BR	IR	BR	
Aggregate size	5.1(2.5)	7.1(3.5)	5.3(1.6)	7.1(2.5)	6.6(2.9)	6.0(3.3)	5.3(1.7)
Mean	6.1(3.1)		6.3(2.3)		6.3(3.0)		5.3(1.7)
Aggregate Stability	2.5(0.5)	2.3(0.8)	2.5(0.4)	1.5(0.5)	2.6(0.4)	2.3(0.5)	3.0(0.7)
Mean	2.4(0.7)		2.0(0.7)		2.5(0.4)		3.0(0.7)

( ) - standard deviation

RWR followed by year indicates when field was seeded.

Table 3.5. Mean sum of squares for soil micro-topography for three different aged Russian wildrye and one native range (NR1) field.

Treatment	Mean Sum of Squares	Cv (%)
RWR1989	21,650 (14,628)	67
RWR1980	57,543 (13,549)	22
RWR1972	47,610 (9,545)	20
NR1	19,996 (5,435)	20

( ) - standard error

RWR followed by year indicates when field was seeded

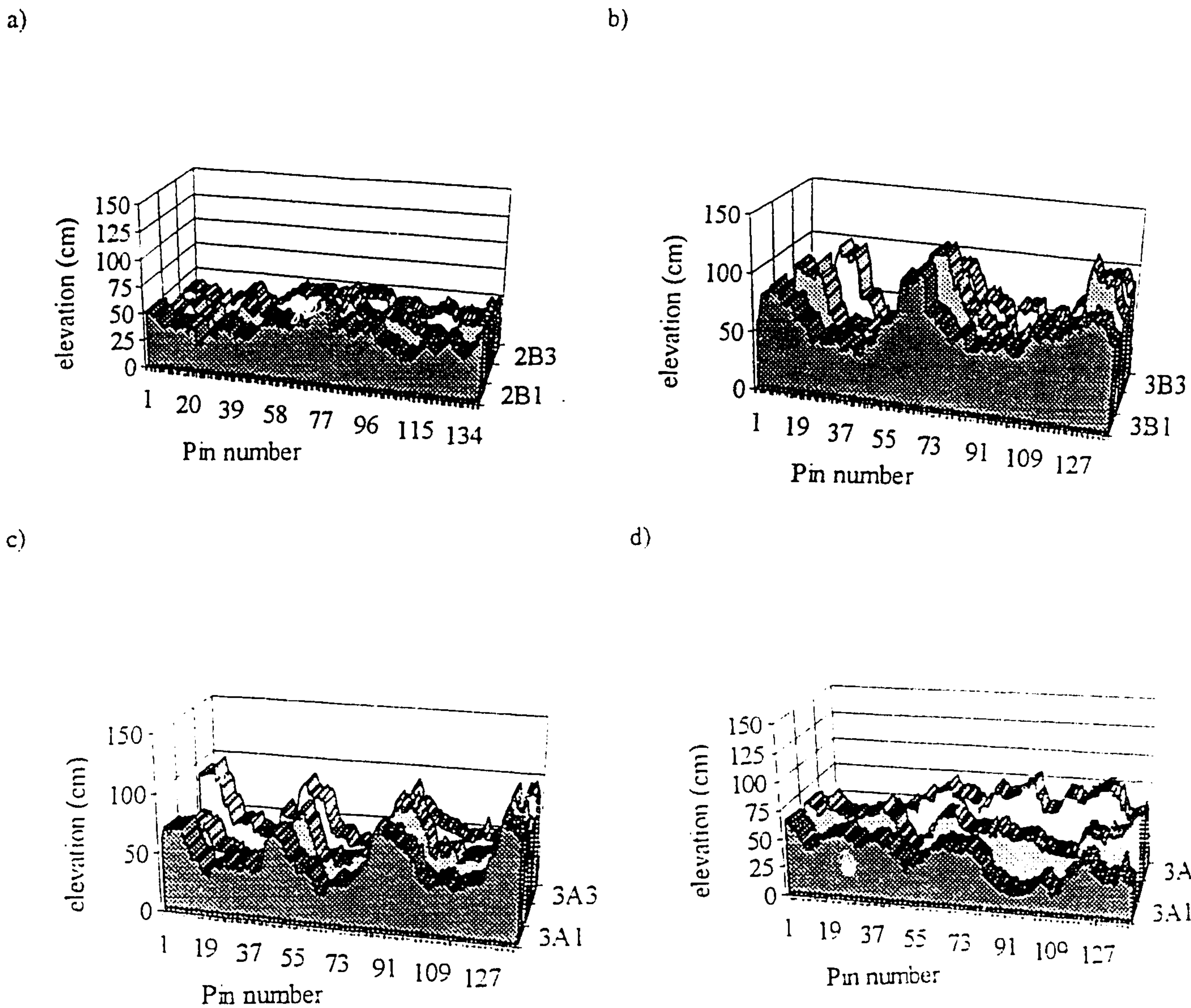

Figure 3.3. Representative three dimensional micro-topographical relief of three different aged Russian wildrye (RWR) and one native range (NR1) field. a) - RWR1989 (2B1, 2B2 and 2B3 are rill meter runs within one sample), b) - RWR1980 (3B1, 3B2 and 3B3 are rill meter runs within one sample. vegetation is located along peaks in topography), c) - RWR1972 (3A1, 3A2 and 3A3 are rill meter runs within one sample. vegetation is located along peaks in topography), d) - NR. (3A1, 3A2 and 3A3 are rill meter runs within one sample, vegetation is located throughout topography). RWR followed by year indicates year the RWR field was seeded.

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Chapter 4. Synthesis

With the introduction of RWR into North America in the 1920s, and increased commercial use starting in the 1950s, research on productivity has been extensive. The increases, relative to native range (NR), in productivity, nutrition, tolerances to drought and apparent competitiveness, makes RWR a valuable forage in the semi-arid region of the prairie provinces. In addition, with the recent ·itical decision to eliminate the Cro·· Ra· the potential for marginal land being taken out of cereal production and placed into perennial forage is apparent, leading to a probable increase in RWR hectrage.

The main focus of this research was to encompass an interdisciplinary approach to RWR pastures to assess whether the use of RWR under its current management is sustainable when compared to NR. Under 60-cm row spacings, RWR fields may have as high as 50% bare ground. The exsistence of 150 ha of exposed soil in a 300-ha field could present a very high risk of wind and water erosion. However, the shelterbelt effect provided by the RWR culms and the crust present on the soil surface would re·uce some of the potential for soil loss due to wind erosion. The increase in sand content in the surface 4 cm of the older RWR field indicates only a redistribution of soil and not loss due to water erosion.

If erosion is defined as the removal of soil material from the field in question, the use of RWR as a perennial forage for grazing purposes in southern Alberta would not appear to increase erosion of the system under the study conditions and the soil parameters studied. This lack of erosion may indicate the system is sustainabable. However, erosion is not the only parameter use to measure sustainability. The decrease in total carbon with increasing age of RWR fields is not clear since a control was not available on which to base the changes. The previous histories of the fields will influence the carbon status of the soil.

If only vegetative parameters are considered, the Russian wildrye pasture would not appear to be sustainable since species richness increases with the age of the RWR fields. Clearly, the RWR is not competitive enough to maintain a monoculture over extended periods of time.

Furthermore, identifying sustainability as either economical or ecological must be considered. From the extensive body of literature on productivity of RWR compared to NR, the benefits of RWR in producing greater amounts of forages and liveweight gains than equivalent area of NR even after periods of 20 yrs is evident. The RWR would appear to be sustainable economically. Conversely, the ecological sustainability of RWR is not clear. Under the study parameters used, the sustainability of the RWR fields is still in question. The system has undergone a change with the replacement of NR with RWR. Total carbon has decreased lowering aggregate stability from NR to RWR fields. The change is more apparent in the BR positions. The greatest concern would be the risk of soil loss that may occur given the right conditions. What those conditions are and in what combination may not be that easy to define. Extended drought may be the main force driving potential for severe soil loss. Extended drought will increase mortality of RWR. The near monoculture would not have the ability for other species to dominate the ground cover as is the case in NR. With continuing grazing pressure by livestock, the erosion-reducing crust may be eliminated providing a relatively poorly aggregated surface soil prone to blowing. On sloped fields, the increase in soil loss to water erosion from a intense rainfall would likely occur under a 60-cm row spacing.

Appendix

Acronyms

RWR - Russian wildrye (*Elymus junceus* Fisch.).

RWR1989 - Russian wildrye was seeded in 1989.

RWR1980 - As above.

RWR1972 - As above.

CWG - Crested wheatgrass - (*Agropyron pectiniforme* R.and S.)

NR - Native range - (native vegetation that has never been broken by plow or cultivation).

NR1 - First native range site that is adjacent to and compared with RWR1989 and RWR1980.

NR2 - Second native range site that is adjacent to and compared with RWR1972.

BR - Between-row (Halfway between rows of Russian wildrye. In the 60-cm row spaced fields studied, samples were collected 30 cm from the row of Russian wildrye).

IR - In-row (Sample site was directly within the Russian wildrye row).

MR - Mid-row (Sample site was halfway between in-row and between row sample sites).

TC - Total soil carbon (both organic and inorganic forms).

MOR - Modulus of rupture.

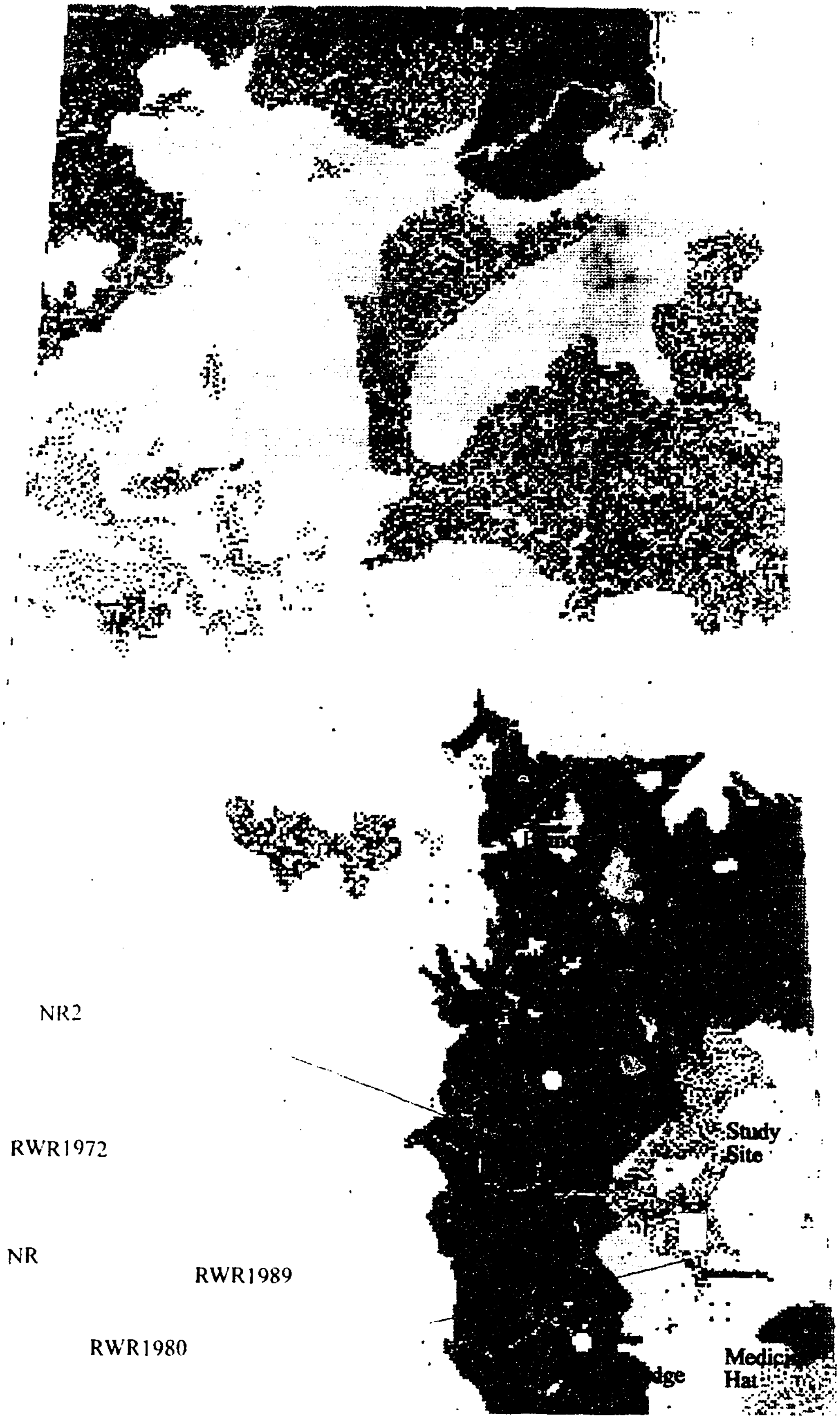

Figure 1. Site Location Map

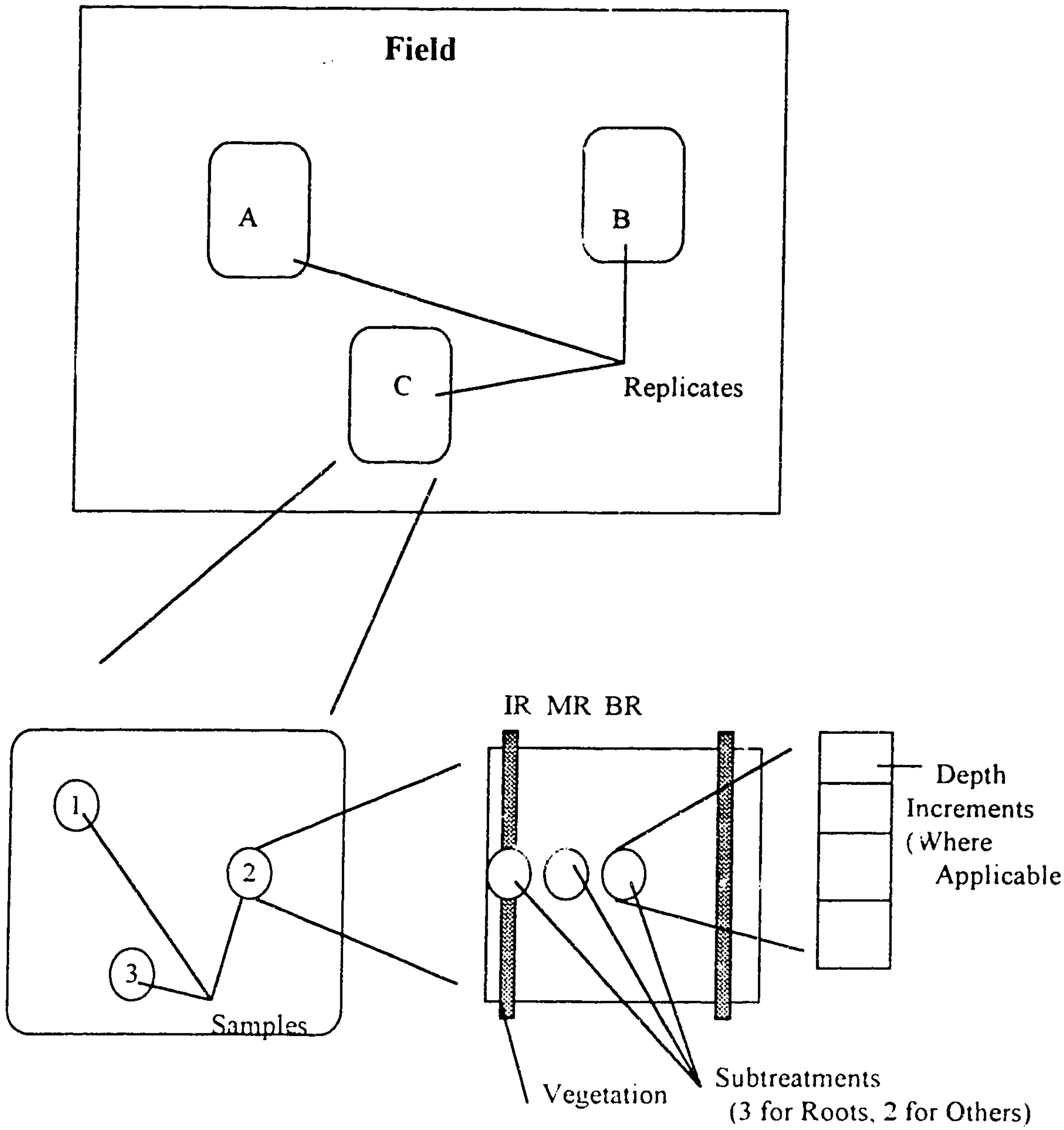

Figure A-2. Schematic diagram of sampling for three Russian wildrye and two native range fields (schematic is generic).