CONTENT AND DISTRIBUTION OF ORGANIC MATTER IN NATURAL AND MANAGED ECOSYSTEMS IN THE MIXED PRAIRIE GRASSLAND REGION IN SASKATCHEWAN

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by

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UNIVERSITY OF SASKATCHEWAN

College of Graduate Studies

and Research

Saskatoon

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ABSTRACT

Weight of organic matter aboveground and underground in ungrazed natural grassland in sand-, loam- and clay-textured soil and the effects of grazing and cultivation in modifying the weight and distribution of organic matter in loam-textured soil were studied near Saskatoon, Saskatchewan. Mean weight of organic matter in ungrazed sand, loam and clay sites was, respectively, 213, 358 and 262 g/m^2 canopy; 274, 299 and 263 g/m^2 mulch; and to a depth of 35 cm, 1 004, 1 480 and 1 218 g/m^2 underground plant parts; and 14.2, 24.5 and 28.3 kg/m^2 soil organic matter. The proportion of total system organic matter aboveground and underground as plant parts was respectively, 3.1 and 6.4 percent in sand soil, 2.4 and 5.6 percent in loam soil and 1.7 and 4.1 percent in clay soil, the remaining proportion in each case being soil organic matter. Heavy grazing in loam soil transformed a *Festuca*, *Agropyron*, *Stipa* community to a *Stipa*, *Agropyron*, *Festuca* community, and reduced organic weight of the canopy from 258 to 82 g/m^2, mulch from 299 to 186 g/m^2 and soil organic matter in the upper 15 cm by 16.7 percent in comparison to ungrazed natural grassland. Weight of underground plant parts was not affected by grazing. Replacement of the dominant grasses with shallow-rooted species such as *Koeleria cristata*, *Carex* spp., *Bouteloua gracilis* and *Phlox hoodii* apparently maintained underground biomass. Aboveground biomass accounted for 1.1 percent and underground biomass accounted for 6.2 percent of the total system organic matter in grazed sites. Cultivation of loam soil for a period averaging 21 years reduced soil organic matter weight by 26 percent in the plough layer. The decline in soil organic matter content in grazed and cropped land is attributed to a reduction in the amount of plant material returned to the soil under grazing and cropping and the increased rate of decomposition as a result of tillage. The significance of the reduction in organic matter content is discussed.

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1. INTRODUCTION

Organic matter in the soil and plant material on the soil surface are vital components in the grassland ecosystem. As mulch, on the soil surface, this material can modify the immediate environment and directly influence soil microorganisms, seed germination, seedling emergence and plant growth. In soil, organic matter in the form of humus is an important storehouse of nutrients maintaining soil fertility and plant growth.

Many studies have dealt with the dynamics of biomass production and decomposition in natural grasslands. However, information on the amounts and distribution of organic matter in natural and managed grassland ecosystems is limited, particularly in Canada.

Much of the grassland has been broken and is used for crop production while the remainder is grazed on a regular basis by livestock. Disruption of the ecosystem by tillage and removal of organic matter through grazing and cropping raises concern over the maintenance of the productive capacity in grassland ecosystems.

The objective of this study was to collect quantitative data on organic contents of plant biomass aboveground and in the soil as underground plant parts and humus in natural grassland in Saskatchewan and to determine the effect of texture of soil, grazing and cultivation in modifying the distribution and amount of organic matter in the various subsystems. Field sampling was done during the growing season in 1974.

2. REVIEW OF LITERATURE

Organic matter content in grassland ecosystems has been studied by many researchers over the years. One of the early concerns dealt with the content of organic matter in soil and how this was influenced by such factors as temperature, moisture, texture, cultivation and, somewhat later in time, by grazing. More recently studies have been made on productivity and dynamics of aboveground and underground biomass in various grassland systems. The information published on organic matter contents in grassland often deals with only a part of the ecosystem, while this study treats the whole system.

In the review, which follows, organic matter in the ecosystem has been partitioned into aboveground and underground material. Aboveground material is further subdivided into canopy and mulch and the underground material is divided into underground plant parts and soil organic matter. The effects of texture of soil, grazing and cultivation on the content and distribution of organic matter in each compartment are reviewed.

2.1 ABOVEGROUND PLANT MATERIAL

The plant material found above the soil surface has been subdivided and described in several different ways. Dyksterhuis and Schmutz (1947) divided this material into four classes: (1) green herbage: consisting of all green and live plant material and dead tips of growing grasses; (2) cured herbage: consisting of standing, dried plant materials little affected by weathering; (3) fresh mulch: consisting of the upper primary layer of bulky, coarse, fresh, bright, undecayed plant residuum lying on the surface of the soil; and (4) humic mulch: consisting of largely decayed, disintegrated and fragmented organic residuum of fresh mulch. Tomanek (1948) cited in Abouguendia (1973) used the term "litter" to refer to the compact layer next to the soil surface. Odum (1960) used the term "litter" to refer to all dead plant material above the soil surface. More recently the IBP introduced a set of terminology to categorize all the aboveground plant material. The term "litter" was to include all the material lying on the surface of the soil, and "canopy" included the standing shoots, dead and alive, as well as detached shoot material held by the standing shoots (Medwecka-Kornaś 1971). The IBP terminology was used in this study to categorize the aboveground plant material with one modification. The term "mulch" was used instead of "litter" for all the material lying on the surface of the soil.

The biomass of standing dead shoots at any one time is a function of the quantity of green shoots that have been available for previous transfer to the dead shoot compartment, and the recent rate of transfer from standing dead to the mulch compartment (Coupland 1973). The principal input to "litter" or "mulch" is from standing dead, although considerable material goes directly from green herbage to mulch (Tomanek 1969).

A great deal has been written on the effects of "mulch" or "litter" in the grassland ecosystem on the environment and organisms that inhabit the environment. Tomanek (1969) presented a valuable review of the studies dealing with this matter. Mulch conserves soil moisture through increased infiltration rates, decreased runoff and decreased evaporation. It tends to stabilize soil moisture and soil temperatures which improves conditions for germination, and often the presence of mulch alters the botanical composition. All of these effects influence the amount of green herbage produced, which eventually replenishes the mulch.

Texture of soil affects the amount of dead plant material aboveground. Redmann (1975) established that standing dead averaged 295 g/m^2 in fine-textured soil, 227 g/m^2 in medium-textured soil, and 209 g/m^2 in coarse-textured soil in mixed prairie in North Dakota over a two-year period. Mulch on these sites averaged 689 g/m^2 on fine-textured soil and 794 g/m^2 on medium-textured soil. Cosby (1964) found a mulch biomass of 426 g/m^2 on convex slopes and 1 087 g/m^2 on concave slopes on a soil catena in ungrazed mixed prairie in North Dakota. Zeller (1963) showed that the amount of mulch varied from 225 g/m^2 on a solonetz clay to 673 g/m^2 on a silt-loam soil, in natural grassland in North Dakota. Rauzi _et al_. (1968) found the amount of mulch averaged 111 g/m^2 on clayey soils, 125 g/m^2 on sandy soils, 158 g/m^2 on sand soil and 186 g/m^2 on silty soil in range sites in six Great Plains states.

Cattle grazing has a considerable influence on the amount of aboveground biomass, since cattle remove portions of green shoot and standing dead material. Johnston (1960) found weight of green herbage in ungrazed and lightly grazed fescue grassland in Alberta was 250 and 245 g/m^2, respectively, while fresh mulch declined from 435 to 320 g/m^2 and humic mulch from 800 to 540 g/m^2, respectively. Under very heavy grazing as compared to light grazing, Johnston (1962), on a similar site, established that canopy weight declined from 210 to 62 g/m^2 and mulch from 915 to 388 g/m^2. In a later study Johnston et al. (1971) found mulch almost disappeared under heavy grazing. Zeller (1963) demonstrated that grazing reduced fresh mulch from 202 to 85 g/m^2 and humic mulch from 440 to 240 g/m^2 in a number of prairies in North Dakota. Whitman (1971) reported that grazing reduced standing dead from 324 to 31 g/m^2 and mulch from 625 to 150 g/m^2 in mixed prairie in North Dakota. Rhoades et al. (1964) found an ungrazed site on an Oklahoma sand range had accumulated 3.5 times as much mulch as a heavily grazed site. Coupland et al. (1960) reported that a climax mixed prairie in Saskatchewan also had three times as much mulch than an adjacent grazed area.

Organic matter accumulation is the net result of deposition minus decomposition. Decomposition of plant materials is a microbial process in which the plant tissues are utilized for the growth and development of the degrading organisms. Plant materials vary in their availability. Hemicelluloses and celluloses are readily decomposed, while lignin is relatively unavailable and appears to accumulate as decomposition proceeds (Norman 1933).

Kononova (1966) stated that hydrothermal conditions, i.e. temperature and moisture, and chemical composition of the plant material being decomposed are important factors determining the rate of humification. The activity of microbes increases with increasing temperature, given adequate moisture, from 0 to 35°C; further increases in temperature have a suppressing effect. The greatest flush in intensity of these processes with increasing temperature can be expected within the low temperatures. Fungi, actinomycetes and some bacteria begin to grow at a moisture level corresponding to maximum hygroscopic moisture. The optimum moisture level for the majority of soil microorganisms is 60 to 80 percent of maximum water holding capacity (Kononova 1966).

A number of workers have examined the effects of temperature and moisture on decomposition of plant material. Jenny *et al.* (1949) determined that mulch decomposition was high at high temperature and high moisture and low at low temperatures. Koelling and Kucera (1965) examined three prairies, one in northeast Iowa, one in central Missouri and one in southwest Missouri. Mean average annual temperature was 7.3°C lower and average annual precipitation was 30 percent lower at the Iowa site compared to the Missouri sites. Mulch accumulation was found to be inversely related to productivity, with slower decomposition and lower productivity in the north. Coleman (1973) found weight losses of mulch on the surface and 5 cm beneath the surface to be negatively correlated with soil temperature and positively correlated with soil moisture. Coupland (1973) reported that watering significantly reduced the amount of mulch on a range site in Saskatchewan.

Floristic composition has been shown to affect decomposition of plant material. Abouguendia (1973) reported that *Bouteloua gracilis* exhibited higher rates of decomposition during the early stages of decay than either *Stipa comata* or *Agropyron smithii*. Wiegert and Evans (1964) found that rates of decomposition of dead material varied with species of plant during the first two months but not thereafter. These differences are likely attributed to differences in chemical composition of plant materials. Peevy and Norman (1948), working on the decomposition of different plant materials, found that the chemical composition of plant materials had a direct influence on the quantity and the properties of the decomposed residue. Material high in lignin was much less decomposed than material low in lignin, even after 28 months of exposure. Koelling and Kucera (1965) found that over a two-year period there was a 60 percent loss in the dry weight of foliage mulch of *Andropogon* species, compared to a 40 percent reduction for flower stalks during the same period.

2.2 UNDERGROUND PLANT MATERIAL

Contributions of plant roots to the grassland ecosystem include the absorption of water, initiation of nutrient cycling, the provision of supporting structures for photosynthetic material aboveground and the addition of organic matter to the soil.

Vertical distribution of roots depends on fertility, physical properties of the soil and nature of the plant itself (Weaver *et al*. 1935). Coupland and Johnson (1965) examined the root distribution of a number of prairie species in Saskatchewan. In semi-arid regions *Stipa comata* rooted more deeply while *Agropyron smithii*, *A. dasystachyum* and *Festuca scabrella* were more shallowly rooted. Weaver (1958) indicated that rooting depth corresponded to the most frequent depth of penetration of soil water under the ambient rainfall regime.

Herbage removal, by grazing, has generally been shown to be somewhat detrimental to root growth. Stoddart *et al*. (1975) state that since grazing reduces the photosynthetic area, food manufacture is reduced, there is a reduction in material available to roots and consequently root biomass decreases. Coupland *et al*. (1960) found a reduction of quantity of roots of *Bouteloua gracilis* in the 0-5 cm layer of soil but no effects at greater depths and no evidence that overgrazing reduced the quantity of roots in the other dominant species in mixed prairie in Saskatchewan. Bartos and Sims (1974) showed total weight to a depth of 80 cm was not affected by light, moderate or heavy grazing of short grass prairie, although ungrazed and moderately grazed areas had more root material in the upper 10 cm than light and heavily grazed areas. Lorenz and Rogler (1967) sampling to a depth of 120 cm also found no difference in root weight between light and heavily grazed prairie in North Dakota.

Other studies have shown that grazing increased underground plant biomass. Smoliak *et al*. (1972) determined that weight of underground plant parts to depths of 15 and 60 cm increased significantly as pressure increased, did not differ significant in the 15-45 cm depth, but decreased in the 45-60 cm depth in mixed prairie in Alberta grazed by sheep. Johnston (1960) found light grazing compared to no grazing increased root biomass to a depth of 140 cm on fescue grassland in Alberta. Whitman (1971) reported that the mean annual weight of underground plant parts to a depth of 100 cm, in a year of above normal precipitation, was 1 640 g/m^2 in ungrazed prairie and 2 520 g/m^2 in grazed prairie in North Dakota. Annual production was 1 100 g/m^2 in ungrazed and 1 272 g/m^2 in the grazed prairie. Pearson (1965) estimated the average annual increment of underground plant parts in desert grassland in western Idaho and also found that grazing increased production, by at least 12 percent, compared to that in ungrazed grassland.

Soil organic matter is a diverse mixture that includes the soil biomass, partially degraded plant, animal and microbial components, and the true soil humic constituents. Many of these components are intimately associated with the sesquioxide clay fractions and are fairly resistant to further degradation. The recognizable plant and microbial components constitute 15 to 25 percent of the total soil organic carbon in the A horizon of cultivated soils and a larger proportion in natural grassland and forest ecosystems (Paul 1970).

Organic matter represents a small portion of the weight in mineral topsoil. Its influence on soil properties and consequently on plant growth, however, is considerable. Organic matter is a major source of phosphorus, sulphur and nitrogen and through effects on physical properties it tends to increase the water holding capacity of a soil and the proportion of water that is available for plant growth. It is also the main energy source for microorganisms without which biochemical activity would likely come to a standstill (Buckman and Brady 1962).

The organic matter content of a soil is regulated by the rate of addition of organic residue, primarily plant roots and mulch, to a soil and the rate at which this residue is decomposed. Decomposition of soil organic matter is primarily a microbiological process and therefore the factors which affect the degradation of organic matter aboveground are similar to those operative underground. Shively and Weaver (1939) reported that organic content of soil decreased with decreasing precipitation from 7.1 to 2.7 percent in true and mixed prairie in silt loam soil between Lincoln, Nebraska, in the east and Colorado Springs, Colorado, in the west. The annual precipitation declined from 828 mm in the east to 455 mm in the west, while mean annual temperature increased from 9°C to 11°C. Jenny (1930) concluded that within regions of similar temperature, organic matter content of the Great Plains grassland soil increases logarithmically with increasing factors of humidity. Within regions of similar moisture conditions, organic content of grassland soil decreases from north to south. Jenny (1930) also determined that for each fall of 10°C in annual temperature the average organic matter content of the soil increases "two to three times", providing the precipitation to evaporation ratio is kept constant. Further, he concluded that moisture is more important than vegetation, topography or parent material in determining the organic matter content of soil. Senstius (1958) cited in Porter (1969) concluded that activity of microorganisms decreases more rapidly than do photosynthetic processes of higher plants, as temperatures are lowered and therefore under aerobic conditions, organic matter increases with decreasing temperatures.

Texture, other factors being equal, also influences the content of organic matter in soil. Russel and McRuer (1927) found organic matter contents of 5.2, 2.8 and 2.5 percent, respectively, in the upper 15 cm of silt-loam, loam and sandy-loam soils in virgin grassland in Nebraska. Buckmann and Brady (1962) reported organic matter content of 1.5, 1.3 and 0.8 percent, respectively, in cultivated clay, clay-loam and sand-textured soil in North Carolina.

The reported effect of grazing on content of soil organic matter is variable. Lodge (1954) determined that organic matter content in the upper 10 cm soil layer declined as a result of grazing in two cases (from 7.9 to 4.6 percent and from 6.0 to 4.9 percent), remained unchanged in one set of plots and increased (from 4.8 to 5.4 percent) in another set of plots in mixed prairie in Saskatchewan. None of these differences were considered to be significant, however. Johnston _et al_. (1971) found long-term grazing of fescue grassland in Alberta also had no significant effect although organic matter levels decreased under moderate to very heavy grazing pressure. Substantial reductions in percentage soil organic matter content, ranging from 35 to 65 percent in soil layers to a depth of 60 cm were reported by Beebe and Hoffman (1968) following 22 to 25 years of heavy grazing in silt-loam soil in southeastern South Dakota. Kucera (1958), sampling to a depth of 15 cm, showed consistent reductions in organic matter content in the upper 10 cm of soil in tall grass prairie in Missouri. Values in successive 2.5 cm layers were 11.9, 8.5, 6.8, 6.2, 5.5 and 5.1 percent in the ungrazed prairie and 9.9, 8.1, 6.2, 5.6, 5.6 and 5.3 percent in the adjacent grazed prairie. In India, Sant (1966) determined that the content of organic matter decreased as the intensity of grazing increased. Organic content of soil at 5, 15 and 25 cm depths was 3.4, 2.1 and 1.6 percent, respectively, in protected grassland, 1.99, 1.15 and 0.94 percent, respectively, in moderately grazed areas and 0.89, 0.62 and 0.47 percent, respectively, in overgrazed areas. In contrast, Smoliak et al. (1972) determined light and moderate grazing by sheep resulted in a slight increase in organic matter content (from 1.9 to 2.0 percent) in the top 15 cm of soil, and that heavy grazing significantly increased organic matter content (from 1.9 to 2.4 percent) in mixed prairie in southeastern Alberta.

Cultivation of grassland soil has resulted in a substantial reduction in soil organic matter content. Mitchell et al. (1944) reported a decline under cultivation of 9 to 43 percent of the original content of organic matter. Similar reductions were reported by Brown et al. (1942), Doughty (1948), Jenny (1930), Martel (1972) and Newton et al. (1945) over 15 to 40 years of cultivation. These researchers and others (Jenny 1933, Jenkinson 1977) found that the reduction of organic matter was rapid when the prairie was first brought under cultivation and that the rate of loss declined with the period of cultivation.

Jenkinson (1977) established that growing grass in a cultivated soil for a period of ten years considerably reduced the rate of organic matter loss. Newton et al. (1945), working in the Canadian prairies, reported that seeding cropland to grass and alfalfa for three to four years and the addition of manure once in a seven to nine-year rotation also reduced the losses of organic matter as compared to that under grain and fallow rotations. In one instance the organic matter content was restored to the original level after 29 years under such a rotation.

Bulk density of a soil is another parameter which may be used to assess the effect of grazing and cultivation on grassland soils. Soils that are loose and porous have lower weights per unit volume than those that are more compact. Organic matter content encourages granulation, particularly in fine-textured soil, which in turn increases pore space and aeration of soil (Buckman and Brady 1962). McCarty and Mazurak (1976) found that after 25 years bulk density in the top 7.5 cm of soil increased from 1.02 in protected plots to 1.14 in deferred and rotationally grazed plots and to 1.22 in continuously grazed plots in loam soil in Nebraska. Skovlin et al. (1976), after eight years of light to heavy grazing in loam soil in ponderosa pine - bunchgrass range, and Smoliak et al. (1972), in mixed prairie in southeastern Alberta after 19 years of light to heavy grazing, found no change in soil bulk density. Buckman and Brady (1962) reported that cultivation for a period of over 50 years increased bulk density from an average of 1.0 to 1.6 in three loam soils in the eastern United

States. The increase in bulk density may be related to the reduction in the size of soil aggregates reported by Jenny (1933) in cultivated soils. Large (sand-sized) granules decreased by 28 percent and fine (clay-sized) granules increased by 39 percent following 60 years of continuous cultivation in prairie soils in the United States.

The review of literature pertinent to this study shows that little information is available on the content and distribution of organic matter in the mixed grass prairie region of Saskatchewan. The present study provides quantitative data on the amounts of organic matter aboveground and underground in undisturbed natural grassland and determines the effects of texture of soil, grazing and cultivation on these parameters in mixed grass prairie in Saskatchewan.

3. DESCRIPTION OF STUDY AREA

3.1 LOCATION

The study area was located in a region of Saskatchewan extending from Saskatoon southwest 320 km to Maple Creek. Study sites were situated near these two locations and at an intermediate point near Kyle (see Fig. 1).

3.2 SOILS

Soils in the study sites are developed on parent materials of glacial origin consisting of undifferentiated boulder clay of medium texture, lacustrine materials of fine texture and glacio-fluvial deposits of coarse texture. Sites in the Saskatoon area are in the dark brown soil zone and sites near Kyle and Maple Creek are in the brown soil zone, the former near its northern edge (Mitchell *et al*. 1944). Sites near Saskatoon are in fine-, medium- and coarse-textured soils and those near Kyle and Maple Creek are in medium-textured soils.

3.3 NATURAL VEGETATION

The study area is located within the Mixed-Prairie Grassland Association of North America (Coupland 1961) and in the transition to Fescue Prairie (Coupland and Brayshaw 1953).

Grasses and sedges dominate the natural vegetation. The most important grass species are *Stipa spartea* var. *curtiseta* and *Agropyron dasystachyum*, although *Stipa comata* and *Agropyron smithii*

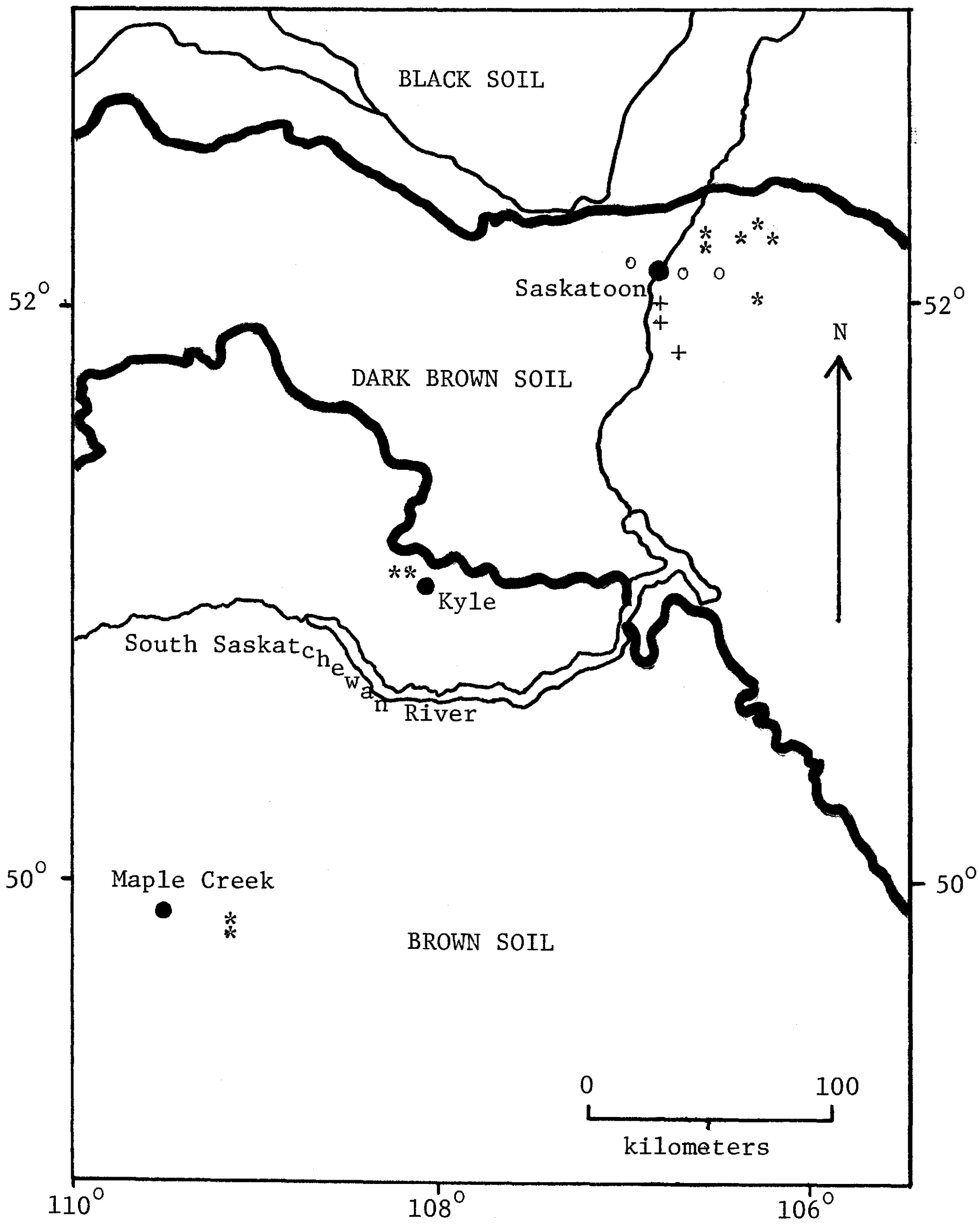

Fig. 1. Map of southwestern Saskatchewan showing location of sites. Sites were located in sand- (+), loam- (*) and clay- (o) textured soils.

are also abundant. Together these four species contribute three-quarters of the forage yield. *Stipa comata* is favoured in competition with *S. spartea* var. *curtiseta* in warmer and drier conditions, while the latter has an advantage in cooler and moister situations. In sand *S. comata* always has an advantage over *S. spartea* var. *curtiseta* because of its greater drought tolerance. *Agropyron smithii* tends to be more abundant than *A. dasystachyum* in the warmer, sandier soils and where the soil has been disturbed, while the latter abounds in the cooler, fine-textured soils. In rolling, dark brown soils *Festuca scabrella* becomes dominant on the lower slopes and margins of sloughs (Coupland 1950, 1961). *Bouteloua gracilis* contributes from 1 to 10 percent of the forage yield and is favoured by warm, dry slopes of medium-textured soil. *Carex stenophylla* var. *enervis* is considered ecologically as a short-grass, in the same category as *Bouteloua gracilis*. Its abundance expressed in terms of basal area approaches 30 percent in some instances. Other grasses and sedges, in approximate order of their importance, are: *Koeleria cristata*, *Carex filifolia*, *Calamagrostis montanensis*, *Muhlenbergia cuspidata*, *Poa canbyi* and *Carex pensylvanica* var. *digyma*.

Principal forbs are *Artemisia frigida* and *Phlox hoodii*. Shrubs are not abundant, but are located in areas where variation in topography or soil texture increase depth of moisture penetration. In such situations *Symphoricarpos occidentalis*, *Rosa* spp. and *Elaeagnus commutata* are the most common species (Coupland 1950).

3.4 CLIMATE

The climate of the study area is characterized by great annual extremes in temperature and by comparatively low annual precipitation. Low precipitation, high summer temperatures, and dry winds frequently make soil moisture the limiting factor in plant growth. According to Thornthwaite's 1948 classification, climate of southwestern Saskatchewan is semi-arid (with the exception of the Cypress Hills) and that of Saskatoon is semi-arid to dry sub-humid (Sanderson 1948).

Long-term temperature and precipitation data are presented in Table 1 for three stations in the study area. The records show that Maple Creek has the largest number of frost-free days, is warmer (both on an annual basis and during the growing season) and receives less precipitation during the growing season than areas to the north. In the central region, mean daily maximum temperatures are higher and precipitation is lower than in the north. Average evaporation from May to September is 77 cm in the brown soil zone (Kyle and Maple Creek) and 62 cm in the dark brown soil zone (Saskatoon) (Agriculture Canada 1974).

Increasing moisture and decreasing temperatures, evaporation and number of frost-free days to the northeast indicate more efficient use of moisture associated with a gradual change from semi-arid conditions in the southwest region of the study area to dry sub-humid in the north.

Table 1. A comparison of long-term temperature and precipitation at three stations in the study area[1].

Station	Saskatoon	Beechy[2]	Maple Creek
Mean daily temperature (°C)			
Annual	1.6	2.6	4.9
May - September	14.8	14.8	15.7
April	3.3	4.0	5.3
July	18.9	18.9	19.8
Mean daily maximum temperatures (°C)			
Annual	7.7	9.4	11.8
May - September	21.8	22.6	23.2
Mean number of frost-free days[3]	159	160	178
Precipitation (mm)			
Annual	353	340	294
May - September	223	222	213
Percent of total during May - September	62.9	65.3	72.4

1 Data from Atmospheric Environment Canadian Normals, Vol. 1 - Precipitation, and Vol. 2 - Temperature. 1941-1970. Environment Canada 1973. All data based on records taken over a period of 20 years or more.

2 Beechy is located 45 km southeast of the Kyle study site.

3 A day without frost is defined as a day on which the daily minimum temperature recorded remains above 0°C.

3.5 HISTORY OF SETTLEMENT

The history of settlement in Saskatchewan is of importance to this study because it is related to the impact that man's activities of grazing domisticated animals and cultivating land has had on the organic matter contents in ecosystems.

Settlement of Saskatchewan began late in the 19th century (McConnel and Turner 1969). A federal government scheme in 1881 brought the first settlers to the region and several communities were established, the most important being at present Saskatoon and Yorkton. It was not until the 1890's that the province began to experience a great influx of settlers. By 1901 the population was 91 000. Settlement in the province was limited largely to the areas in the southeast and an area between Saskatoon and Prince Alberta, bounded on the east and west by the South and North Saskatchewan rivers, respectively. Rapid settlement continued in the first three decades of this century and by 1931 the population had increased to 922 000 (Fig. 2) and settlement had spread over the entire province south of 54°N. The population declined in the next two decades to 832 000, increased again to 925 000 by 1961 and changed little in the ensuing 15 years.

The total area of occupied farmland increased rapidly with the rising population. "Improved" land, i.e. land in crop, summer fallow and seeded pasture, increased at an average annual rate of 1.1 million acres during the first three decades of this century. This resulted in an increase in "improved" land from 1 million acreas in 1901 to 32.7 million acres in 1931 (Fig. 3).

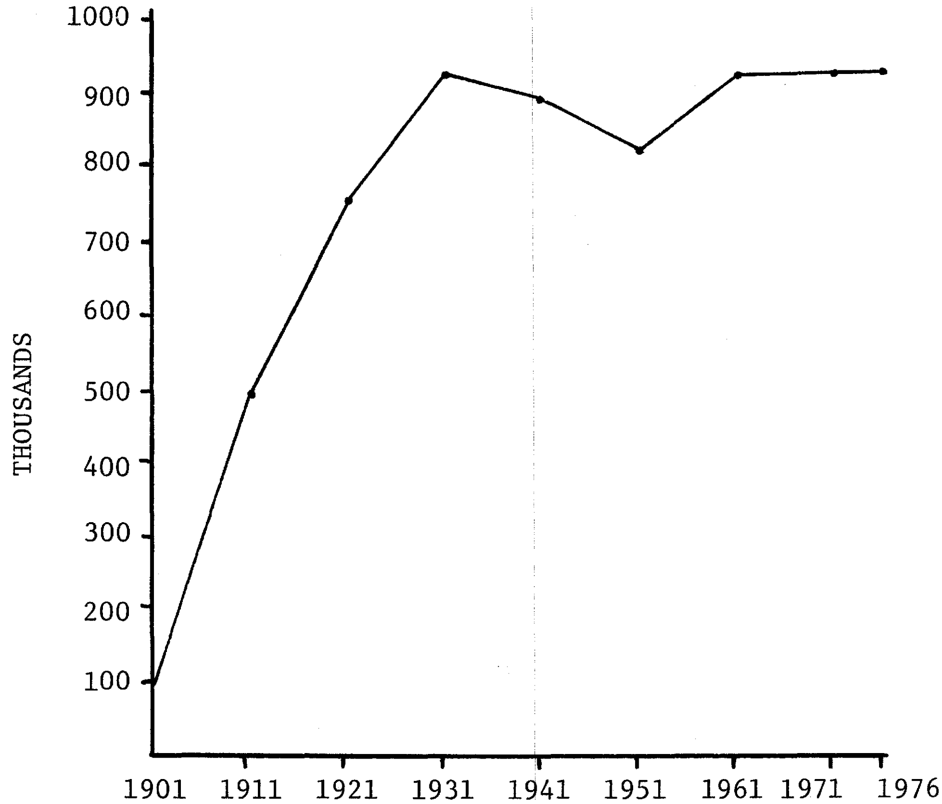

Fig. 2. Changes in human population in Saskatchewan since rapid settlement began (data from Statistics Canada).

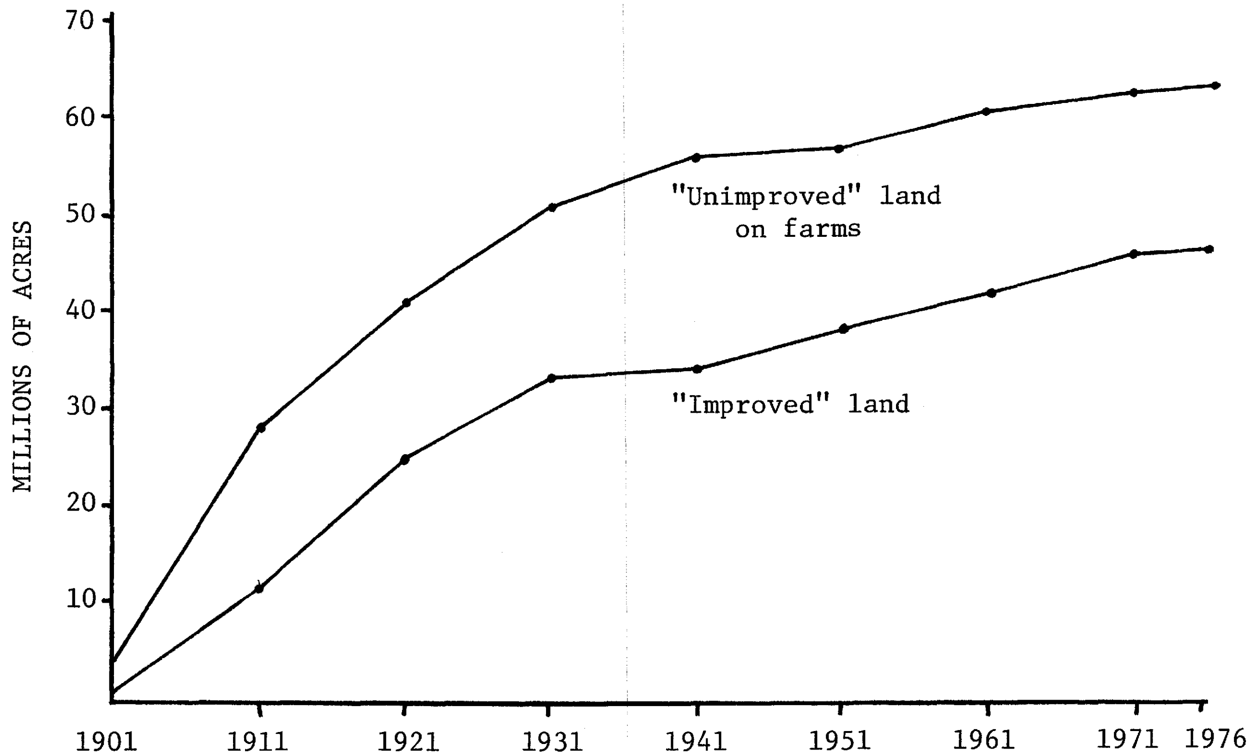

Fig. 3. Increases in the area of "improved" land (cropland, summer-fallow and seeded pasture) and in the total area of occupied farmland in Saskatchewan (data from Statistics Canada).

Subsequently, the average rate of increase of "improved" land declined to 0.3 million acres per year in the next four-and-a-half decades, so that the total of "improved" land was 46.1 million acres in 1976. Total area in farms was 51.4 million acres in 1931 and 63.7 million acres by 1976.

Cattle ranching began in the Maple Creek and Cypress Hills regions in the 1870's (Johnston 1970, McConnel and Turner 1969). By the 1890's the rapid expansion of ranching was halted by the competition for land from farmers. The populations of domesticated animals, however, continued to rise. Fig. 4 shows the livestock populations converted to animal units (Coupland 1978). The number of units indicate that grazing pressure increased very rapidly between 1901 and 1921, reaching a maximum of 1.9 million. Replacement of the horse as the major source of draft power resulted in a decline in animal units to 1.1 million by 1951. Subsequently, with the increase in "other cattle", i.e. beef cattle, the grazing pressure has again increased rapidly to 2.0 million in 1976.

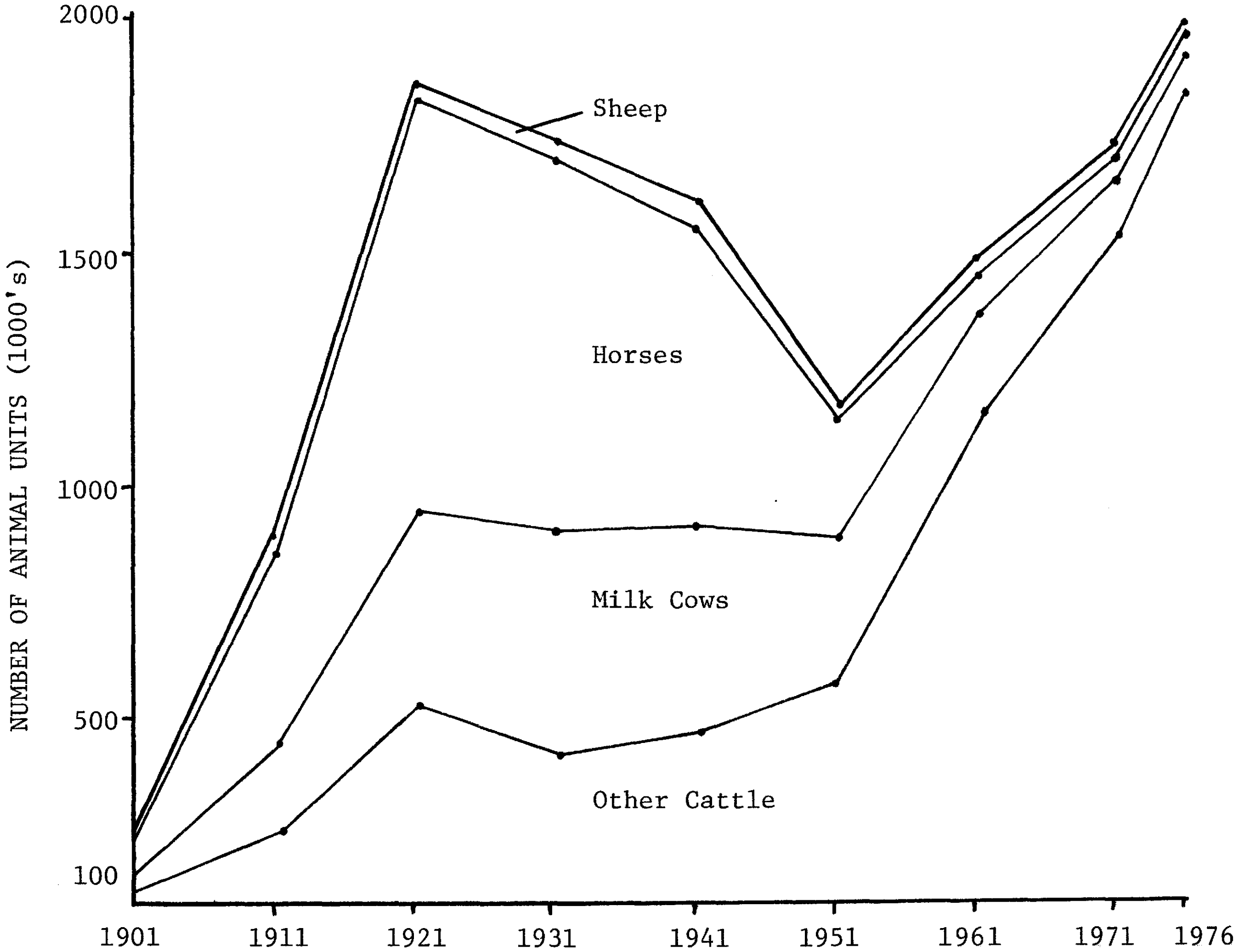

Fig. 4. Changes in the grazing load in Saskatchewan since the period of rapid agricultural settlement began. Each animal unit is the equivalent of 1 milk cow or 1.25 horses (of all ages) or 1.67 "other cattle" (of all ages) or 6.67 sheep (of all ages) at the time census data are taken in June (data from Statistics Canada).

4. METHODS

4.1 SELECTION OF STUDY SITES

Ungrazed natural grassland near Saskatoon, Kyle and Maple Creek was selected for study. Sites were located in undeveloped road allowances bounded on both sides by a well-maintained fence or in head lands protected from grazing. To qualify as "ungrazed", no appreciable physical evidence of grazing, such as livestock droppings or clipped tops was permitted. The site may have been grazed in the past and some likely were grazed, judging by differences in species composition from that expected in climax grassland of the region. A heavy mulch layer was generally a good indication that the site had been protected, from grazing or fire, for a considerable length of time.

Sites near Saskatoon were situated in sand-, loam- and clay-textured soil and those near Kyle and Maple Creek, to the southwest, were in loam soil. Selection of sites with the appropriate texture of soil was accomplished with the aid of Saskatchewan soil maps (Mitchell _et al_. 1944) and handtexturing. Loam-textured soil was of the Weyburn Association in the Saskatoon region and of the Haverhill Association in the southwest. Soils of these two associations are similar in origin and general characteristics, both having developed on undifferentiated glacial till deposits (Mitchell _et al_. 1944). Site locations are shown in Fig. 1; a legal description of each site is given in Appendix A. The soil associations in which the plots were located are characterized according to texture and parent material in Appendix B.

Each of the locations selected for study in loam soil, in the Saskatoon region, consisted of a grazed and a cultivated site in addition to the ungrazed site. The paired grazed and ungrazed sites were generally situated adjacent to one another, separated only by a fenceline. Cultivated sites were located in the vicinity of the paired uncultivated sites. In the course of selecting natural grassland sites it was observed that deposits of drifted soil, common on the eastern side of cultivated fields altered the floristic composition and in some cases completely buried the mulch layer. To minimize the effect of windblown soil, care was taken to ensure that grassland sites were situated upwind, on the western side of cultivated fields. A necessary assumption, when comparing ungrazed with grazed and cultivated sites, was that the grazed and cultivated sites were similar to the nearby ungrazed sites prior to being put to their present use. This assumption was strengthened by selecting sites to be compared with similar topography. Since the paired sites were not always immediately adjacent, statistical comparisons of ungrazed versus grazed and ungrazed versus cultivated were made using the students t test for unpaired data.

An attempt to document the length of time that each of the managed land systems had been under the direct influence of man met with limited success. Grazing history could not be determined with any dgree of confidence by interview of the landowner. Therefore, floristic composition and condition of the soil surface were the methods used to estimate range use and range condition.

The number of years each site had been cultivated was determined by interview. In some cases an estimate was obtained and, in others, the exact year of breaking was known.

Table 2 presents a summary of the sampling program conducted. The effects of soil texture, grazing and cultivation were investigated only in the Saskatoon region. The original intention was to use ungrazed loam sites in southwestern Saskatchewan to make interzonal comparisons of the content of organic matter in these different systems. Difficulty was experienced in locating ungrazed sites with zonal characteristics. Those available had vegetation similar to the sites near Saskatoon. While the sites in the southwest do not have use in showing zonal differences, they are included to increase the size of the sample. Field sampling started in the northern region in late May and was completed on July 30, 1974.

4.2 FLORISTIC COMPOSITION AND RANGE EVALUATION

The floristic composition of the plant cover was determined in order to characterize the plant cover in the uncultivated sites, estimate soil moisture relations in the ungrazed sites and estimate range condition in the grazed sites. Composition was determined by estimating, visually, the proportion that each species contributed to the weight of the total green shoot biomass. Separate estimations were made for the most common grasses except for *Stipa comata* and *S. spartea* var. *curtiseta* and *Agropyron dasystachyum* and *A. smithii* which were grouped as

Table 2. Summary of the sampling program conducted.

Location	Soil texture	Grassland use	No. of sites sampled
Saskatoon region	loam	ungrazed	6
		grazed	6
		cultivated	6
	clay	ungrazed	3
	sand	ungrazed	3
Southwest region			
Kyle	loam	ungrazed	2
Maple Creek	loam	ungrazed	2

Stipa spp. and Agropyron spp. This was done because these species were often not in flower and the similarity of vegetative characteristics in each pair of species presented difficulty in evaluating, visually, the relative proportions of each. Forbs, shrubs and other grasses were combined in one category as were Carex species. Estimates were made within 10 one-quarter square meter quadrats located systematically at a 10 m spacing in each grassland site.

The characteristic distribution of Festuca scabrella and Agropyron spp. was used to estimate soil moisture relations in the ungrazed sites. This procedure is based on a knowledge that F. scabrella is most common on moist, well developed soils while Agropyron spp. occupy relatively drier habitats (Coupland 1961, Moss and Campbell 1947). Sites were arranged along the independent axis according to the declining proportion of F. scabrella and then of Agropyron spp. in the canopy. The biomass of various organic matter compartments was represented on the dependent axis and the distribution of the sites observed.

Use of species composition as an index to range condition as developed by Dyksterhuis (1949) involves ecological analysis of the climax and succession leading to and away from the climax. This must be done for each soil type and physiographic unit. Plants generally are ranked as climax (natural) or invading. Climax species are further classed as those increasing under heavy grazing (generally the less palatable ones) and those decreasing under grazing (generally the more palatable ones).

By comparing the expected percentage of the shoot biomass contributed by each species with the actual composition it is possible to determine percentage of present floral composition that could be called climax. This is made up of the biomass of decreasers and that portion of the increasers not in excess of climax percentage.

Dyksterhuis (1949) used relative coverage of the total foliage contributed by each species as a measure of composition while in this study, the proportion of shoot weight contributed by each species was used. The use of relative coverage was found to be practical for rapid survey; however, Dyksterhuis (1949) suggests that relative forage production contributed by each species might prove to be a more satisfactory measure. Use of the green shoot biomass in this study rather than the total shoot biomass as a basis of estimating composition may have favoured the cool season grasses (*Festuca*, *Agropyron* and *Stipa* spp.) over the warm season grass (*Bouteloua gracilis*) in those sites sampled early in the growing season, i.e. the sites in the Saskatoon region.

Because the ecological analysis of climax is site specific, it was considered appropriate in this study to utilize the plant cover on the adjacent ungrazed sites as the original site vegetation. Ranking of the plants as to whether they were climax or invading was according to Wroe *et al*. (1972). On the basis of the total percentage original vegetation present, the range was classified to be in excellent (76 to 100 original percentage present), good (51 to 75 percentage), fair (26 to 50 percentage) or poor condition (0 to 25 percentage), the same scale used by Dyksterhuis (1949).

In addition to the species composition method of condition analysis, an ocular appraisal was made in which the present utilization of the primary forage plants was observed. Evidence of surface soil removal either through wind or water action was also appraised (Stoddart _et_ _al_. 1975).

4.3 SAMPLING PLANT BIOMASS

Plant biomass was sampled, both aboveground and underground. The field and laboratory methods adopted for each are described.

4.3.1 Aboveground Biomass

4.3.1.1 Field Methods

After the species composition was estimated the aboveground plant biomass was removed in three compartments. The standing dead shoots in each quadrat were removed by hand in a manner similar to that employed by Dyksterhuis and Schmutz (1947) in the removal of fresh mulch. Fingers extended in a fork-like manner were raised from the surface of the mulch extracting material which was detached from its base but still held within the canopy. It was noted, particularly in dense canopies, that a few attached, partially green shoots were also removed in this manner; however, relative to the total amount of standing dead or green-shoot biomass, this amount was considered insignificant. The remaining standing material was cut off just above the mulch layer using a battery-powered clipper. This material consisted primarily of green shoots of which some were partially dead; however, no attempt was made to separate this material. Green and dead shoots were placed in separate paper bags for transport to the laboratory. Next, the dead plant material on the surface of the soil, i.e. the mulch, was removed. A hand brush with stiff, plastic bristles was used to sweep the mulch into a paper bag. Care was taken during this procedure not to include stem bases or shallow rhizomes.

A sufficient number of samples was taken to keep the standard error of mulch weight to within 10 percent of the mean weight of mulch for a site. This calculation was based on the following formula using data obtained in a trial sampling program conducted the previous year in sand- to clay-textured soil.

$N = \frac{tS}{D\bar{x}}$; where N = number of clippings required

t = from statistic tables (value for continuous sample)

S = standard error of trial plots

D = desired accuracy expressed as a decimal

$\bar{x}$ = calculated mean.

4.3.1.2 Laboratory Methods

The standing green and dead plant material was oven-dried at 80°C for at least 12 hours and then weighed. Organic matter content of representative subsamples of this material from each site was determined by loss on ignition. A detailed description of this procedure is given later in this section.

Mulch sweepings were separated into several distinct size categories using a method devised by Coupland (1973). This was done to allow a more detailed study of the effect of different soil textures and grazing on the physical characteristics of mulch than that allowed by total weight. Unground samples were sorted to size by passing them through a bank of sieves mounted on a sieve shaker (Endecott Test Sieve - Model 1, Mark II). Air-dried material was loaded into the uppermost (coarsest) sieve, and after five minutes of shaking was separated into four compartments (Fig. 5), each of a distinct size:

Coarse - remaining above a #12 sieve (1.68 mm opening)

Medium - remaining above a #20 sieve (0.420 mm opening)

Fine - remaining above a #80 sieve (0.177 opening)

Very fine - passing through a #80 sieve.

The period of sieving was sufficiently long to permit all the fine plant material to pass through the sieves, but not so long that it resulted in breaking up the mulch fragments (Coupland 1973). The uppermost three sieves caught all of the relatively undecomposed mulch. The very fine material which passed through the third sieve contained well-decomposed plant material and large proportions of soil. Some soil was present even in the coarsest material so it was necessary to treat each subsample as a mixture. In order to determine the proportions of the mixture in each of the top two sieves that was comprised of mulch and of soil, it was necessary to determine the organic content (loss on

Fig. 5. Appearance of the four sizes of mixtures of mulch and soil. From left to right: 1. coarse (not passing the No. 12 sieve); 2. medium (held by the No. 20 sieve); 3. fine (held by the No. 80 sieve); 4. very fine (passing the No. 80 sieve).

ignition) of each of these components. This was done by sorting out 3 to 4 g of material recognizable as plant material from each of the two uppermost sieves. Since it was very difficult to extract soil from the mix in the uppermost sieve, soil organic values, as determined for the first 2 cm of soil beneath the mulch layer, were used to represent organic content of soil in the mix (the method used to determine organic matter content of soil is described in Section 4.4.2). Loss on ignition values were determined for plant components of the coarse- and medium-sized subsamples and for the mixture in both subsamples (after the material had been ground). Subsequent calculations were applied to all four subsamples, so organic matter values for soil, mulch and the mixture were needed for the fine and very fine levels as well. These were determined by ashing the (unsorted) mixture in each of the fine and very fine subsamples, while the value for soil was used as determined from the 0-2 cm soil layer and of plant material as in the medium-sized subsample. Occasionally the organic matter content determined for the soil was greater than that of the very fine material, in which case the latter value was used as a soil organic matter value for all four subsamples. Duplicate subsamples were always run in loss on ignition measurements; these were not accepted if they differed by more than 3 percent. The values were sufficiently different (soil 14 to 17 percent; mulch 75 to 85 percent) that reasonable estimates were possible of the proportion of mulch and soil in each sieve subsample by use of the following equations:

$$a + b = c$$

$$xa + yb = zc$$

where: a = weight of mulch

b = weight of soil

c = weight of mixture

x = percent loss on ignition of mulch portion

y = percent loss on ignition of soil portion

z = percent loss on ignition of mixture.

These equations were substituted and expanded to solve for a and b, the only two unknowns, so that:

$$a = \frac{c\,(z - y)}{x - y}$$

and

$$b = c - \frac{c\,(z - y)}{x - y} .$$

Organic content for plant material was determined gravimetrically, by loss of weight on ignition. Two samples of ground material of 2 g each were placed in crucibles, oven-dried at 80°C for at least 12 hours and, after cooling in a desiccator, weighed. Ashing consisted of burning the sample in a crucible on an electric hot plate for 2 hours until the sample became black, and then placing it in a muffle furnace at 600°C for 4 hours. After cooling in a desiccator the samples were reweighed and the loss in weight was considered to be the weight of organic matter. The weight of organic matter in each aboveground compartment was expressed in g/m^2.

4.3.2 Underground Plant Parts

4.3.2.1 Field Methods

Underground plant parts were sampled after the mulch had been removed. One soil core, 6.8 cm in diameter and 35 cm in depth, was taken within each of five (alternate) quadrat locations (plots) using a hydraulic, truck-mounted corer. The soil column was pushed from the tube onto a 45°-angled cutting board and sectioned (with a sharp paring knife) into 0-6 cm, 6-15 cm, 15-25 cm and 25-35 cm segments. The segments (samples) were placed in plastic bags and upon returning to the laboratory, frozen until processed.

Samples were taken to a depth of 35 cm in order to include the majority of the root biomass. Other studies in which samples were taken to greater depths indicate the proportion of the root material sampled in this study. Coupland (1974) sampled to 150 cm, the maximum depth of rooting in ungrazed mixed prairie at Matador, Saskatchewan, and found 65 percent of underground plant parts in the upper 35 cm layer. Abouguendia (1973), sampling to a depth of 100 cm, found 77 percent of the root material in the upper 30 cm in ungrazed mixed prairie in western North Dakota. Whitman (1971), working in grazed prairie in the same site as the previous researcher and also sampling to a depth of 100 cm, found 80 percent of the underground biomass in the upper 30 cm. On the basis of these studies and assuming root penetration to 150 cm, it is estimated that in grazed sites roughly 70 to 75 percent of the underground plant parts will have been accounted for within the upper 35 cm, while in ungrazed sites a slightly lower percentage would have been sampled within this layer. The chosen depth intervals were such that the zone with the highest root content (the 0-15 cm layer) was divided into smaller samples than the layers below, allowing for a more critical analysis of root distribution.

Size of core to be used was considered. One large core, with a cross-sectional area of 36.32 cm^2, was taken at each sampling station rather than a composite of three cores with a small cross-sectional area (10.17 cm^2). Examination of the weights of all root samples taken to a depth of 30 cm (at 10 cm increments) in the Matador study during 1968 and 1969 showed that the standard error of root weights, expressed as a percentage of the mean root weight, was lower for the single (large) core sample (5.2 percent) than for the composite sample (8.3 percent) (Coupland 1974). Further, the root weight data showed that at an intensity of five samples per depth increment, the standard error of root weights at each site ranged from 7.4 percent at 20-30 cm to 8.3 percent at 10-20 cm, within the desired 10 percent level of accuracy.

4.3.2.2 Laboratory Methods

Separation of underground plant parts from soil was accomplished using a method described by Coupland (1974). Stem bases and any plant debris were removed from the surface of the uppermost core segment (the 0-6 cm segment). The cores were placed in individual containers and soaked for at least 12 hours in a solution of Calgon to disperse the soil. The core was next transferred to No. 12 sieve (1.64 mm opening), stacked above a No. 35 sieve (0.50 mm opening) and both were attached to a mechanical washer which agitated the sieves vertically in a plastic pail containing a solution of bleach (Javex at 657 cc/10 l of water). The level of the solution and the speed of agitation was adjusted to prevent soil from washing over the edge of the containing sieves. Washing continued until the soil disappeared from the sieves (15 to 60 minutes). The sieves were then removed from the washer and individually inverted over a clean pail and sprayed with a jet of water to separate the plant material from the sieves. The dirty water was poured from the plastic pail through a No. 60 sieve (0.25 mm opening) to recapture the fine plant material which had passed through the No. 35 sieve. The plant material from the coarse sieves was also recaptured in the No. 60 sieve and the sieve (containing the plant material) was dried in an oven for 30 minutes at 80°C to facilitate the removal of plant material from it, which was subsequently accomplished with the aid of a spatula and brush. The plant material, so obtained, was oven-dried for 24 hours at 80°C to obtain oven-dry weight. To reduce error caused by adhering soil particles, data on underground plant material was expressed on an ash-free basis. Duplicate 2 to 3 g subsamples of root material from each depth class of one site in each soil textural class in each region were ignited and loss in weight values were used to calculate organic content of roots in the other related sites. Procedures to determine loss of weight on ignition were the same as those described previously for mulch samples. Weight of underground plant parts was expressed in g/m^2, ash-free basis.

4.4 SOIL ORGANIC MATTER AND BULK DENSITY SAMPLING

4.4.1 Field Methods

Samples for the determination of soil organic matter and soil bulk density were taken in the same five plots used to sample underground plant parts. Two small diameter cores (5.4 cm diameter) were taken to a depth of 6 cm and one large core (7 cm diameter) was taken to a depth of 35 cm at each of these plots. The small diameter cores were divided into three samples (0-2, 2-4, 4-6 cm) and the two samples from the same depth were bulked. The upper 6 cm of the large diameter core was discarded and the remainder of the core subdivided into three samples corresponding to the 6-15, 15-25 and 25-35 cm depth intervals. The division of the upper 6 cm layer into three samples was done to permit a more detailed study of the change in organic matter content in the zone where the content is greatest. The small diameter cores were taken with a constant volume sampler with a removable inner cylinder. The cylinder consisted of three metal rings, each one being 2 cm in height and 5.4 cm in diameter. Soil was forced into the rings when the sampler was pushed into the ground. The 6 cm column of soil contained by the rings was removed from the sample chamber and sectioned into three equal-sized samples using the edge of each ring as a guide. The sample of soil within each of the rings was removed and the sample chamber reassembled for the next set of samples. The large cores were placed into a 45° angled cutting board and carefully sectioned at the proper intervals with a sharp paring knife. Each sample was placed into a separate, previously labelled paper bag for transport back to the laboratory.

4.4.2 Laboratory Methods

Each soil sample was used to determine both soil bulk density and soil organic matter content. Bulk density was determined by dividing the weight of each sample, oven-dried at $105^{\circ}C$ to constant weight (for at least 36 hours), by the volume of that sample, calculated from the measurements of the sampler. Following this, the soil sample was crushed to pass through a 2 mm sieve, removing large roots, stem bases and extraneous material such as small rocks. The soil and small roots, which passed through the sieve, were finely ground in a Wiley mill. Each soil sample was tested, with a drop of dilute HCl, to determine whether it was calcareous. If the results were positive (indicated by effervescence) the sample was pretreated with an excess of H_2SO_3 (5 ml per 2 g soil) and allowed to stand overnight in an evacuated desiccator containing both drierite agent and NaOH pellets (Shaw 1959). Finally duplicate 2 to 3 g subsamples were oven-dried at $105^{\circ}C$ to constant weight and ignited on an electric muffle furnace at $450^{\circ}C$ for two hours (Wilde and Voigt 1955). Weight loss between 105 and $450^{\circ}C$ was considered to be equal to the amount of organic matter in the sample. Having determined the weight-volume relationship of the soils, weight of organic matter in g/m^2 was calculated for the various soil layers.

High loss on ignition values, particularly in clay soil, indicated that this method may be over-estimating organic content of the soil. This may be the result of the loss of some structural water from the hydrated alumino-silicates. The temperature under which loss of this water is avoided appears variable as the temperature for determination of organic matter by this method ranges from $325^{\circ}C$ (Ball 1964) to $450^{\circ}C$ (Wilde and Voigt 1955). Since water of hydration is related to clay content and since depth of sampling is limited to the upper 35 cm, where soil organic matter levels are relatively high, the error in estimating soil organic matter by ignition loss due to the possible loss of hydrated water is expected to be relatively small, particularly in sand and loam soil where clay contents are relatively low. In clay soil or in layers in any profile where the clay content is relatively high, error could be considerable. Therefore, in comparisons between clay-, loam- and sand-textured soils the organic matter content will be relatively higher in the clay-textured soil than in the loam- or sand-textured soil due to the method of analysis. As texture of soil in the paired ungrazed-grazed and ungrazed-cultivated sites is similar, it is not expected that comparisons of soil organic matter between these paired sites should be affected by differences in hydrated water content in the soil.

4.5 DECOMPOSITION OF PLANT SHOOTS

Studies have shown that floristic composition may affect the rate of decomposition of plant material. To determine whether floristic composition may influence weight of mulch on a site, through differential rates of decomposition, the rate of decomposition of the three dominant grass species found in the study sites was studied under greenhouse conditions using the litter bag technique described by Weigert and Evans (1964).

Dead standing shoot material of Stipa spartea var. curtiseta, Agropyron dasystachyum and Festuca scabrella was collected in a clay-textured site near Saskatoon. All material was collected in mid-October after the first killing frost. The harvested material included a mixture of recent dead material (shoots that were green at the time of freezing) and shoots that were previously dead. Pure samples of each species were prepared and consisted of the same proportion of blades and stalks in each case. One hundred grams (air dry) of this mixture was placed in 20 x 26 cm nylon mesh bags with 1 mm openings. Fifteen litter bags were prepared for each species. A representative sample of plant material from each species was retained for ashing to determine organic matter content of the plant material prior to incubation. After weighing, each litter bag with its contents was placed into a paper bag to avoid loss of plant material during transport to the greenhouse. The prepared litter bags were placed at random on the surface of a loam soil. Four-inch spikes, one at each corner, were used to position the litter bag and ensure good contact with the soil surface. The box of soil (3 m x 1.5 m in size) on which the litter bags were placed was enclosed with clear plastic sheeting to maintain high humidity. Periodically the samples were uniformly moistened. Temperature in the greenhouse was maintained near $20^{o}C$; however, on sunny days temperatures rose above this.

Nine litter bags, three from each species, were withdrawn after 2, 4, 7, 12 and 25 weeks of incubation to determine the amount of organic matter lost within each of these time intervals. On removal of the litter bag, care was taken to brush off all soil material clinging to the mesh. Each litter bag with sample was then placed in an individual paper bag (to avoid loss of plant material during handling), oven-dried at $80^{o}C$ to constant weight and weighed. Weight of the plant material remaining after incubation was calculated by subtracting the weight of the litter bag, after sample removal, from the combined weight of the bag plus sample. Finally the material remaining in each litter bag was ground and loss on ignition determined for duplicate 2 to 3 g subsamples. This procedure largely removed the influence of soil contamination of the plant material from subsequent calculations and permitted the weight loss calculations to be made on the basis of organic matter content of the material.

5. EVALUATION OF SITE CONDITIONS

Floristic composition, as judged from estimated contributions to the canopy biomass, was used to characterize the plant community in each site. In the paired ungrazed and grazed sites these estimates were also utilized to evaluate range conditions. Soil bulk density was also employed as a site evaluation criterion in the managed systems.

5.1 SPECIES COMPOSITION

The mean percentage species composition in each site is shown in Table 3. The principal species in ungrazed sites in the Saskatoon and southwestern regions were *Agropyron* spp., *Stipa* spp. and *Festuca scabrella*. The presence of *Festuca* in the sites near Maple Creek indicates that, although the sites were located 5 to 10 km north of the fescue grassland in the Cypress Hills (Coupland and Brayshaw 1953), local site conditions favoured *Festuca* in an area generally dominated by *Agropyron*, *Bouteloua* and *Stipa*.

Grazing transformed the grassland in the loam sites in the Saskatoon region from a *Festuca*, *Agropyron*, *Stipa* community to a *Stipa*, *Agropyron*, *Festuca* community. The percentage composition of *Agropyron* spp. and *Festuca* declined from a mean of 35 and 42 percent, respectively, in the ungrazed sites, to a mean of 20 and 6 percent, respectively, in the grazed sites. *Stipa* spp. responded to grazing by increasing percentage composition from

Table 3. Mean percentage species composition in sites near Saskatoon, Kyle and Maple Creek. Sites 1 to 3 are in sand soil, sites 4 to 6 are in clay soil and sites 7 to 16 are in loam soil. Each value is the mean of the species composition in ten 0.25 m^2 quadrats.

	Saskatoon region																		Southwest region			
																			Kyle		Maple Creek	
	Ungrazed sites												Grazed sites						Ungrazed sites			
Species	1	2	3	4	5	6	7	8	9	10	11	12	7	8	9	10	11	12	13	14	15	16
Stipa spp.	91	42	60		37	29		7		31	35	3	20	12	32	45	12	32	9	45		53
Agropyron spp.	9	50	23	28	43	50	7	82	20	52	34	17	10	32	20	15	25	17	89	52	7	43
Festuca scabrella				67	12	13	89	8	74		10	70			6		14	13			89	2
Koeleria cristata													30	3	4	6	5	4				
Bouteloua gracilis		1	1													5						
Helictotrichon hookeri											8						8					
Carex spp.		4	14	1	4	5	2	2	3	9	10	8	25	40	16	9	20	11				
Forbs, shrubs and other grasses		3	2	4	4	3	2	1	3	8	3	2	15	13	22	20	16	23	2	3	4	2

13 to 26 percent. Associated with the change in dominance of grasses was an increase in the abundance of *Carex* spp. and forbs due to grazing (Table 3). The estimated proportion contributed to the biomass by each of these groups of species increased from means of 6 and 3 percent to 20 and 18 percent, respectively, in response to grazing.

Reductions in *Agropyron* spp. and *Festuca scabrella* in response to grazing have been reported in other studies on Canadian rangeland (Coupland *et al.* 1960, Johnston 1962, Johnston *et al.* 1971, Moss and Campbell 1947). Mid-grasses, such as these, are palatable and readily consumed by livestock in preference to short-grasses such as *Koeleria cristata* and *Bouteloua gracilis*. In Site 11 the percentage composition of *Festuca* was found to be higher in the grazed area when compared to the ungrazed counterpart. A similar situation occurred in Site 7 with *Agropyron* spp. This may be explained by a short deferment of grazing or a reduction in grazing intensity allowing the widely-spaced *Festuca* or *Agropyron* spp., in the depleted range, to exhibit more vigor in the grazed than in the ungrazed area (Dyksterhuis 1949). The increase in *Stipa* spp. resulting from grazing is a response to more xerophytic conditions resulting from grazing (Moss and Campbell 1947).

5.2 RANGE EVALUATION

The species composition data provided a basis for calculating the condition of the grassland that was grazed. Assessment was based on the percentage of the original vegetation present in the grazed sites determined from that found in the ungrazed counterpart. Calculations and assessment of range condition are shown in Table 4. *Festuca scabrella* and *Agropyron* spp. were characterized as decreasers and the other species in the study sites were considered to be increasers according to the classifications by Wroe *et al*. (1972) for rangeland with similar soil texture and annual precipitation to that in this study. This characterization proved valid in most cases. However, as indicated in Section 5.1 above, *Festuca* and *Agropyron* spp. each increased in one site as a result of grazing. Also, the estimated composition of *Agropyron* spp. did not change as a result of grazing in Sites 9 and 12. Site 7 was in poor condition, retaining only 11 percent of the original composition; Sites 8, 9 and 12 were in fair condition, retaining from 32 to 43 percent of the original composition; and Sites 10 and 11 were in good condition with 63 and 68 percent, respectively, of the original composition remaining.

Visual assessment of the proportion of forage utilized in the current year and of the surface soil conditions, observed early in the growing season (June), indicated that the sites were being heavily grazed. The primary forage plants had been grazed at least once and in some sites they had been grazed repeatedly.

Table 4. Range condition in grazed sites in loam soil near Saskatoon assessed on the basis of the estimated proportion of the forage contributed by species in the ungrazed sites found in the grazed sites.

Site	Species	Estimated composition (percent)	Original or ungrazed portion (percent)	Range* condition
7	_Stipa_ spp.	20	7	
	Agropyron spp.	10		
	Koeleria cristata	30		
	Carex spp.	25	2	
	Forbs and shrubs	15	2	
		100	11	Poor
8	_Stipa_ spp.	12	7	
	Agropyron spp.	32	32	
	Koeleria cristata	3		
	Carex spp.	40	2	
	Forbs and shrubs	13	1	
		100	42	Fair
9	_Stipa_ spp.	32		
	Agropyron spp.	20	20	
	Festuca scabrella	6	6	
	Koeleria cristata	4		
	Carex spp.	16	3	
	Forbs	22	3	
		100	32	Fair
10	_Stipa_ spp.	45	31	
	Agropyron spp.	15	15	
	Koeleria cristata	6		
	Bouteloua gracilis	5		
	Carex spp.	9	9	
	Forbs and shrubs	20	8	
		100	63	Good
11	_Stipa_ spp.	12	12	
	Agropyron spp.	25	25	
	Festuca scabrella	14	10	
	Koeleria cristata	5		
	Helictotrichon hookeri	8	8	
	Carex spp.	20	10	
	Forbs and shrubs	16	3	
		100	68	Good
12	_Stipa_ spp.	32	3	
	Agropyron spp.	17	17	
	Festuca scabrella	13	13	
	Koeleria cristata	4		
	Carex spp.	11	8	
	Forbs and shrubs	23	2	
		100	43	Fair
		MEAN	43	Fair

* Excellent (76 to 100), Good (51 to 75), Fair (26 to 50), Poor (0 to 25).

Sites 7 to 10 appeared to have been grazed the heaviest. Primary forage plants were almost completely used and low-value plants were carrying the grazing load. Trampling damage was evident and soil movement was more or less noticeable in all grazed sites.

5.3 SOIL BULK DENSITY

Soil bulk density was measured in order to calculate weight of organic matter in the various soil systems under study. Soil bulk density can also be a criterion for site evaluation because of compaction that results from grazing or tillage.

5.3.1 Effect of Grazing

Bulk density of soil increased significantly ($P < 0.01$) in the top 6 cm as a result of grazing (Table 5). The increase, averaging 23 percent, was greatest in the 2-4 cm layer. Below 6 cm, to a depth of 35 cm, bulk density of the soil in grazed areas was not significantly greater, although values in the 6-15 cm layer were higher in the grazed than in the ungrazed.

Soil moisture conditions appear to be more important than factors such as length of time and intensity at which a site has been grazed in determining the impact of grazing on bulk density of soil. The increases in bulk density (12 to 20 percent) referred to by McCarty and Mazurak (1976) in the review of literature, following 25 years of light to heavy grazing, were recorded in loam soil in Nebraska. The studies referred to by Skovlin et al. (1976), in ponderosa pine - bunchgrass range in the Pacific Northwest zone of the United States and by Smoliak et al. (1972),

Table 5. Mean bulk density in loam soil (g/cc) at various profile depths in ungrazed and grazed natural grassland and in adjacent cultivated areas near Saskatoon. Values are the mean of six sites.

Depth (cm)	Ungrazed	Grazed	Cultivated
0-2	0.71^{a*}	$0.89^{b.05}$	
2-4	0.79^{a}	$1.04^{b.01}$	
4-6	0.97^{a}	$1.11^{b.01}$	
0-6	0.82^{a}	$1.01^{b.01}$	1.01^{b}
6-15	1.17^{a}	1.21^{a}	1.21^{a}
15-25	1.32^{a}	1.30^{a}	1.29^{a}
25-35	1.33^{a}	1.35^{a}	1.37^{a}

* Means in the same horizontal line with different superscripts are significantly different at the level of significance indicated (unpaired student's t test).

in southeastern Alberta, were also undertaken in loam soil. However, generally drier soil moisture conditions in these regions compared to those in the study by McCarty and Mazurak (1976) and in the present study likely is a major reason that bulk density remained unchanged despite 8 to 18 years of light to heavy grazing.

5.3.2 Effect of Cultivation

Cultivation significantly ($P < 0.01$) increased the bulk density of soil within the upper 6 cm of the plough layer (the 0-15 cm layer) and had little effect below the tilled layer (Table 5). Mean values in the 0-6 and 6-15 cm layers were 1.01 and 1.21 in cultivated sites, and 0.82 and 1.17 in ungrazed sites, representing increases in bulk density of 23 and 3.4 percent, respectively. Mean values in grazed sites were not different from those in cultivated sites.

The increase in bulk density in cultivated soil compared to undisturbed soil reflects changes in the physical structure of the soil usually associated with a decrease in organic matter content (Buckman and Brady 1962). A reduction in the size of the soil aggregates in soils under cultivation, noted by Jenny (1933) and referred to in the review of literature, reduces the pore space (Buckman and Brady 1962) and increases the degree of compaction in the soil.

6. PLANT BIOMASS

In this chapter the contribution of relatively undecomposed plant biomass (including both aboveground and underground parts) to organic matter in the grassland ecosystem is discussed in relation to the effects of soil texture and grazing. All weights are reported as oven-dry, ash-free, unless otherwise specified.

6.1 ABOVEGROUND BIOMASS

Aboveground biomass includes the standing crop of the canopy (green shoots and standing dead) and mulch. Total aboveground biomass, in ungrazed sites, varied considerably among sites. Values near Saskatoon (Sites 1 to 12) ranged from 450 to 800 g/m^2 and in the southwest region (Sites 13 to 16) the range was 740 to 890 g/m^2 (Fig. 6).

6.1.1 Effect of Soil Texture

Data from ungrazed natural grassland sites provided an opportunity to compare sand-, loam- and clay-textured soil. The influence of soil texture on total aboveground biomass is discussed followed by the effects on component compartments.

a) Total Aboveground Biomass

The distribution of the ungrazed sites ordered according to total aboveground biomass and soil moisture relations estimated by floristic composition of vegetation is shown in

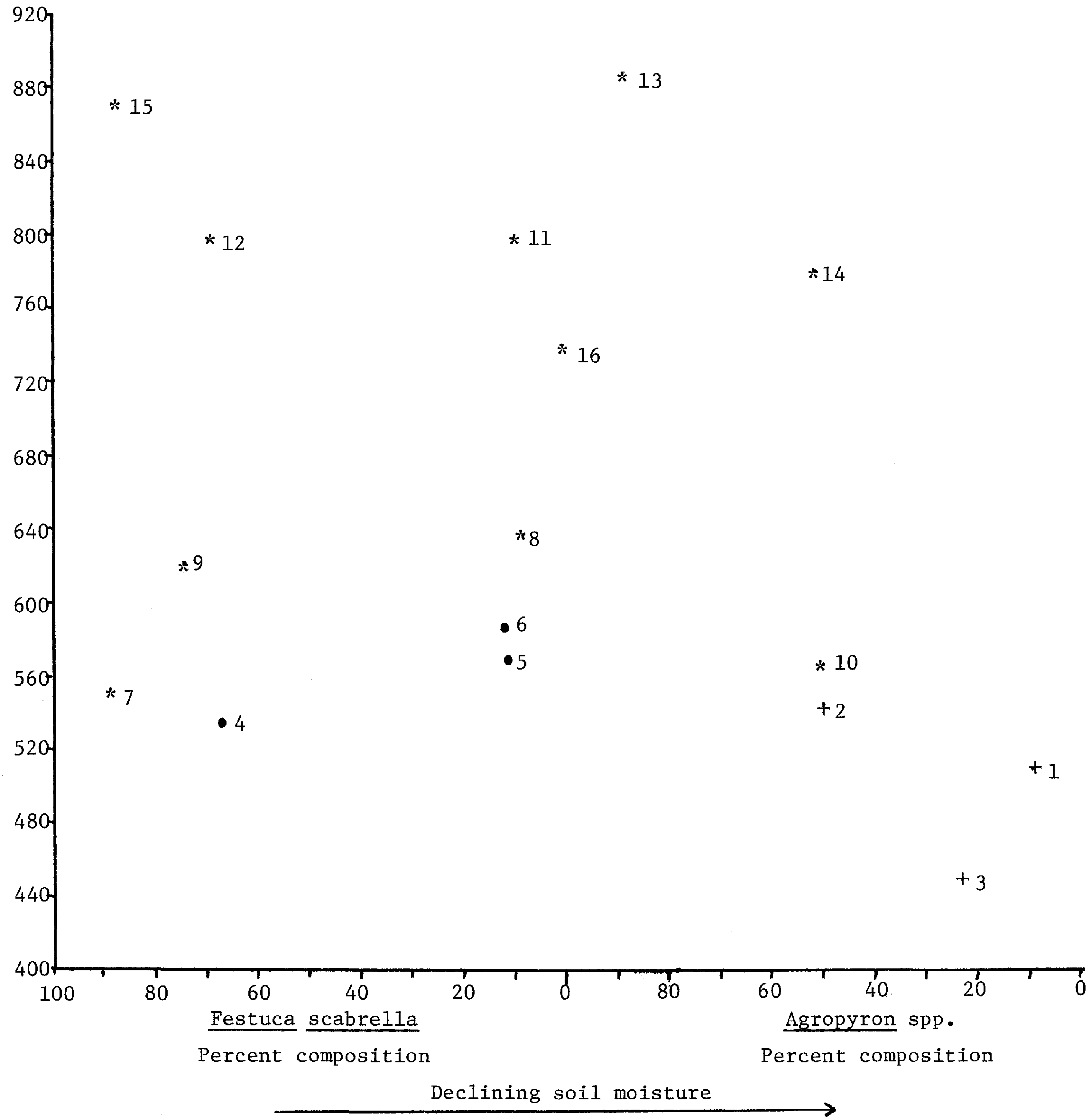

Fig. 6. Distribution of ungrazed sites according to total above-ground biomass and soil moisture approximated by floristic composition of vegetation. The symbols designate soil texture (+ - sand, * - loam, and • - clay). Site number is shown with each symbol.

Fig. 6. Sand sites are grouped in the lower right, indicating low soil moisture and low aboveground biomass. Clay sites are found near the centre of the moisture gradient with only marginally higher biomass than sand. Loam sites are widely distributed along the independent axis and generally to the right of the clay sites, indicating high weights of aboveground plant material and moisture conditions ranging from that similar in sand soil to as good or better than that in clay soil.

Mean weight of aboveground biomass in loam, clay and sand sites near Saskatoon was, respectively, 657, 525 and 488 g/m^2 (Table 6). The weight difference between the loam and sand sites was significant ($P < 0.05$). In loam soil in the southwest region, a mean weight of 821 g/m^2 was recorded for this plant material. These values are similar to those reported in intensive studies at Matador, Saskatchewan, and considerably lower than those reported at Dickinson, North Dakota. Coupland (1973) found mean seasonal values of aboveground biomass, over a four-year period, ranged from 615 to 756 g/m^2 (including ash) in mixed prairie in clay soil in Saskatchewan. Abouguendia (1973) found that mean seasonal values, over a three-year period, ranged from 1 115 to 1 143 g/m^2 (including ash) in mixed prairie in loam soil in North Dakota.

Care must be taken in interpreting aboveground biomass data as sites were sampled at different times of the year and studies have shown that the standing crop in the component compartments

Table 6. Mean weight of aboveground biomass in ungrazed natural grassland sites located in the Saskatoon and southwest regions. Sites were situated in sand, loam and clay soil near Saskatoon and in loam soil in the southwest. Weights are g/m^2, ash-free basis*.

	Saskatoon region			Southwest region
	sand	clay	loam	loam
Number of sites	3	3	6	4
a) Canopy+				
Green shoots	44	122	204	242
Standing dead	170	140	154	154
Total	214^{a}	262^{ab}	358^{b}	396
b) Mulch	274^{a}	263^{a}	299^{a}	425
c) Total aboveground	488^{a}	525^{ab}	657^{b}	821

* Means in the Saskatoon region in horizontal rows followed by the same letter are not different at the 5 percent level of significance (unpaired student's t test). Significance tests were not run on green shoot and standing dead biomass due to the influence of sampling time and seasonal changes in standing crop in these compartments as explained in the test.

\+ Aboveground biomass was sampled during late May and June in the Saskatoon region and during July in the southwest region.

changes during the year. The sites near Saskatoon were sampled in late May and June and the sites in the southwest, near Kyle and Maple Creek, were sampled in July. Coupland (1973), working in mixed prairie near Matador, Saskatchewan, found that green-shoot biomass increased rapidly from mid-April to early June, reaching a peak in different years in late June to early August. A similar pattern was exhibited by mixed prairie in western North Dakota studied by Redmann (1975). The seasonal trend in standing dead biomass is to decrease during spring and summer and to increase again in fall (Coupland 1973, Abouguendia 1973, Redmann 1975). The decrease in the standing dead material during the growing season is accounted for by leaching, decomposition, herbivorous consumption and transfer to the mulch compartment. The trend for the total shoot biomass is a function of the rate of addition of green shoots and the rate of loss from the canopy to mulch. The trend at the Matador study site (Coupland 1973) was for an increase from spring to fall but sometimes the total shoot biomass declined in August or later. Over a five-year period the mean maximum canopy weight (including ash) was 560 g/m^2 and the mean minimum was 408 g/m^2.

Seasonal changes in the mulch biomass reflect the net results of inputs to, minus outputs from, mulch. Observations by Coupland (1973) suggest that the rate of degradation of litter is sufficiently rapid to mask seasonal trends resulting from additions to mulch from the canopy. Abouguendia (1973) found that in two of three years, mulch in mixed prairie in western North Dakota declined during May and increased gradually thereafter. The decrease early in the season corresponded to a period of high soil moisture and moderate temperature. There was, however, no trend indicating that mulch accumulated under protection from grazing.

The above discussion suggests that seasonal differences in time of sampling, on a comparative basis, may have resulted in higher standing-dead and lower green-shoot biomass in the Saskatoon sites and higher green-shoot biomass and lower standing-dead biomass in the southwest sites. Total canopy weights would be most comparable, although during the time that sampling was conducted these weights would be expected to favour the southern sites as increases in green-shoot biomass would likely outweigh decreases in standing-dead biomass. As mulch biomass remains fairly constant throughout the season, weights reported here are not expected to be significantly influenced by time of sampling.

b) Canopy

The biomass in the canopy consists of green-shoot and standing-dead material. In ungrazed sites, in the Saskatoon region, mean weight in loam sites was 358 g/m^2, significantly higher than the weight in clay (262 g/m^2) or sand sites (214 g/m^2) (Table 6). Loam sites in the southwest had a mean canopy weight of 396 g/m^2, slightly higher than in comparable sites near Saskatoon. Although total canopy weight, in the Saskatoon region, was lowest in the sand sites, due to the low green-shoot biomass, standing-dead biomass was highest in the sand sites (170 g/m^2), followed by loam sites (154 g/m^2) and clay sites (140 g/m^2).

The lower canopy biomass on sand reported here agrees with the findings of two studies in North Dakota. Cosby (1964) found canopy biomass was lowest on the convex slopes and ridges, and highest in concave slopes on a common soil catena in loam-textured soil. Weights on sand, as noted in the literature review, were lower than on loam at any point on the soil catena. Redmann (1975) recorded the highest standing dead biomass on fine-textured soil and the lowest on coarse-textured soil.

The estimates of standing-dead biomass obtained in this study are compared with those of other grassland systems in Table 7. Mean literature values (including ash) range from 165 g/m^2 in North Dakota to 906 g/m^2 in Kansas. Weights in the present study, by individual sites, range from 70 to 270 g/m^2 (including ash).

c) Mulch

Mulch biomass in the Saskatoon region did not vary significantly between the three soil textures (Table 6). Mean total weight, however, was highest in the loam sites (299 g/m^2), followed by sand (274 g/m^2) and clay (263 g/m^2). Loam sites in the southwest had 425 g/m^2. The weight of mulch in each size category was similar within the three soil textures with the exception of the coarse grade in which the loam sites had significantly greater amounts ($P < 0.05$) than the clay sites (84 g/m^2 versus 65 g/m^2)(Table 8). Sand sites averaged 73 g/m^2 in the coarse grade. The percentage of the total mulch weight in each mulch grade was similar in the different soil textures. The

Table 7. Biomass of standing dead shoots (g/m^2, including ash) for some mixed prairie and fescue grassland systems in North America.

Reference	Location	Type of grassland	Weight of standing dead (g/m^2)
Present study	Saskatchewan	mixed prairie	70 - 270
Coupland (1973)	Saskatchewan	mixed prairie	308 - 527
Abouguendia (1973)	North Dakota	mixed prairie	266 - 323
Redmann (1975)	North Dakota	mixed prairie	165 - 366
Bartos (1968)	Kansas	mixed prairie	906
Johnston (1960)	Alberta	fescue prairie	435

Table 8. Mean weight and percentage of the total mulch weight in each mulch grade in ungrazed natural grassland sites with soils of various textures in the Saskatoon region. Weights are g/m^2, ash-free basis*.

	Sand		Loam		Clay	
Mulch grade	Weight	Percent	Weight	Percent	Weight	Percent
Coarse	73^{ab}	26.6	84^{a}	28.1	65^{b}	24.7
Medium	98^{a}	35.8	109^{a}	36.5	99^{a}	37.6
Fine	93^{a}	33.9	97^{a}	32.4	91^{a}	34.6
Very fine	10^{a}	3.7	9^{a}	3.0	8^{a}	3.1
Total	274	100.0	299	100.0	263	100.0

* Means in horizontal rows followed by the same letter are not different at the 5 percent level of significance (unpaired student's t test).

average organic content of mulch in loam, clay and sand sites was, respectively, 79.5, 77.0 and 76.1 percent.

Other researchers reported similar results on the effects of soil texture on mulch biomass. Zeller (1963) in North Dakota and Rauzi et al. (1968) in six Great Plains states recorded the highest mulch biomass on silt-loam and silty sites and lowest amounts on clay and clay-loam sites. Cosby (1964), sampling on a common soil catena of loam-texture in North Dakota, found mulch weights were lowest at the top of the slope and highest at the bottom of the slope.

Amounts of mulch reported in some grassland studies are compared with those obtained in the present study in Table 9. Weights in the present study, by individual sites, range from 223 to 460 g/m^2. Mean literature values range from 207 to 1 014 g/m^2 (including ash). The wide range of variation shown in these data and in the data for standing-dead biomass (Table 7) is attributed to differences in species composition, geographical location, soils, climate, weather and date and method of collecting data (Tomanek 1969).

The differences in weight of total aboveground biomass in sites of different texture, in the Saskatoon region, are related primarily to differences in green shoots; little difference was found in weight of dead biomass (standing dead and mulch). Mean weights, of dead biomass, in sand-, loam- and clay-textured soil were 444, 453 and 403 g/m^2, respectively (Table 6). Higher fertility inherent in finer-textured soils (loam and clay) likely account for the greater green-shoot biomass in these soils compared

Table 9. Mulch biomass (g/m^2, including ash) in some mixed prairie and fescue grassland systems in North America.

Reference	Location	Type of grassland	Weight of mulch (g/m^2)
Present study	Saskatchewan	mixed prairie	223 - 460*
Coupland (1973)	Saskatchewan	mixed prairie	207 - 299
Dix (1960)	North Dakota	mixed prairie	508 - 749
Redmann (1975)	North Dakota	mixed prairie	467 - 1 000
Abouguendia (1973)	North Dakota	mixed prairie	625 - 667*
Zeller (1963)	North Dakota	mixed prairie	225 - 672
Hopkins (1955)	Kansas	mixed prairie	256 - 1 014
Johnston (1960)	Alberta	fescue prairie	916

* Weights do not include ash.

to coarse, sand-textured soil. However, a higher rate of decomposition in finer-textured than in coarse-textured soils, due to more favourable moisture conditions at the soil surface, likely leads to the disproportionately higher dead biomass, compared to green shoots noted in sand soil compared to the finer-textured soils. The lower organic matter content of mulch in sand sites, compared to loam and clay sites, would appear to indicate a longer residence time of mulch in sand sites, further substantiating the above.

The better moisture conditions at the surface in the finer-textured soils also appears to favour transfer of standing dead from the canopy to mulch. Green-shoot biomass was lowest in sand, while standing-dead biomass in sand was higher than in loam or clay sites.

6.1.2 Effect of Grazing

Grazing affects aboveground biomass through removal of portions of the canopy and reducing the amount of plant material available for transfer to mulch.

a) Total Aboveground Biomass

The reduction in total aboveground biomass, as a result of grazing, is illustrated in Fig. 7. The graphical presentation indicates the effect of grazing by the placement of the paired sites in relation to the diagonal. The grouping of the sites below the diagonal indicates that total aboveground biomass was reduced and the (horizontal) distance that each site is from the diagonal represents the magnitude of this reduction. In Site 10

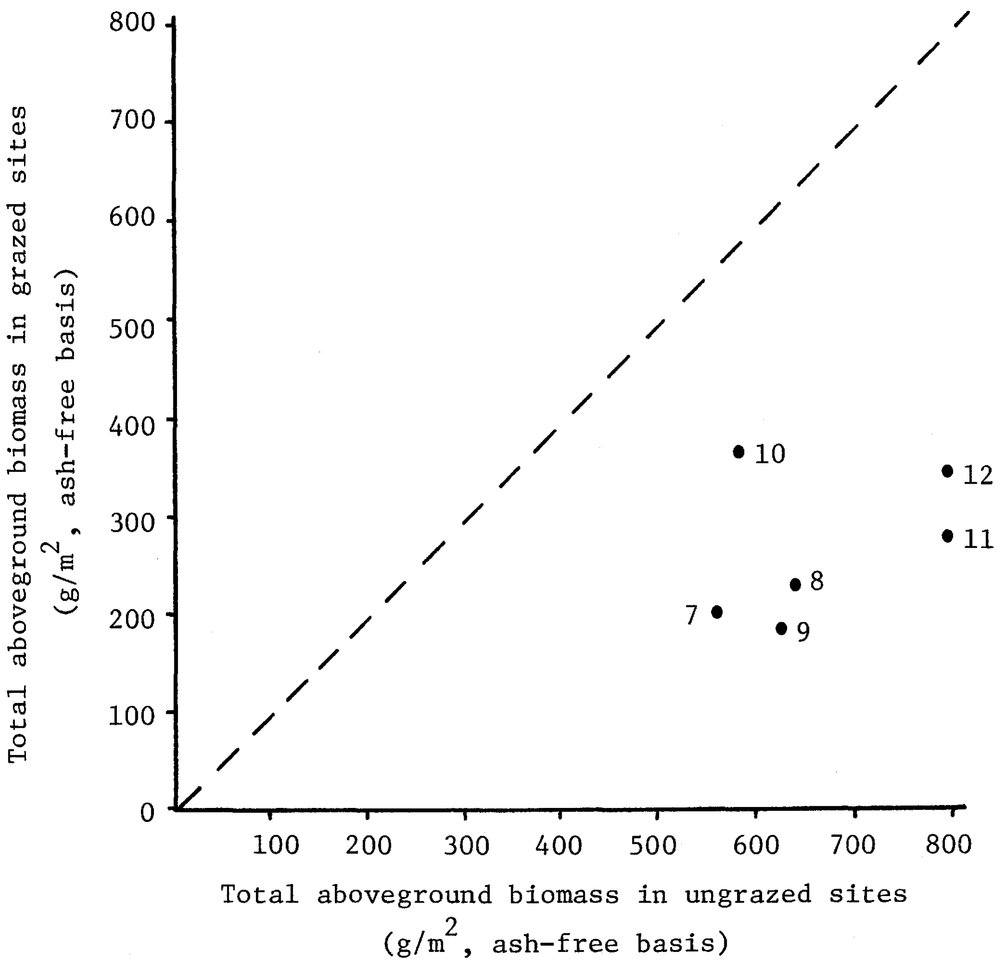

Fig. 7. Total aboveground biomass in paired ungrazed and grazed sites in loam soil near Saskatoon. The numbers in the figure designate site number.

aboveground biomass was reduced by about 200 g/m^2 and in the other sites, the average reduction was 433 g/m^2.

Mean weight of total aboveground biomass in ungrazed sites was 657 g/m^2 and in grazed sites it was 268 g/m^2, representing a reduction of 60 percent as a result of grazing. This is similar to the findings of Whitman (1971), who reported a reduction of 70 percent in total aboveground biomass as a result of grazing mixed prairie in North Dakota.

b) Canopy

The canopy in grazed sites consisted entirely of green shoots, heavy grazing having removed all the standing dead plant material as well as a considerable portion of the green shoots. Mean values for the grazed and ungrazed sites were, respectively, 82 and 358 g/m^2 (Table 10). This reduction due to grazing (approximately one-quarter) is similar to that found by Johnston (1962) in fescue prairie in Alberta, while Whitman (1971) found an even greater reduction (down to one-tenth) in mixed prairie in North Dakota.

c) Mulch

Mulch biomass was significantly less in grazed sites. Mean total mulch weight was reduced from 299 to 186 g/m^2, or by approximately one-third as a result of grazing (Table 10).

The results of a number of other studies show reductions in mulch, as a result of grazing, as great, or greater than those reported here. Johnston (1960) found that light grazing reduced

Table 10. Mean canopy and mulch weights in grazed and ungrazed natural grassland sites in loam soil near Saskatoon. Weights are g/m^2, ash-free basis and represent the mean for six sites.

	Ungrazed	Grazed
a) Canopy*		
Green shoots	204	82
Standing dead	154	0
Total	358	82
b) Mulch	299	186
c) Total aboveground	657	268

* Aboveground biomass was harvested during late June.

mulch biomass by one-third in fescue prairie in Alberta. With heavy grazing, mulch on this site declined by two-thirds (Johnston 1962) and in another study (Johnston _et al._ 1971) it almost disappeared. Whitman (1971) found one-quarter as much mulch in grazed as in ungrazed mixed prairie in North Dakota. Rhoades _et al._ (1964) in Oklahoma sand range; Lewis _et al._ (1956), cited in Tomanek (1969), in heavily grazed range in western South Dakota; and Coupland _et al._ (1960) in mixed prairie near Saskatoon found roughly three times as much mulch in ungrazed as in adjacent grazed areas.

In addition to reducing mulch biomass, grazing affected mulch characteristics. The proportion of the fine and very fine mulch particles increased from 35.4 to 39.8 percent as a result of grazing (Table 11). The average organic content of the mulch in the grazed sites was 10 percent higher (79.5 versus 89.5 percent) compared to the ungrazed. These differences could be explained by the trampling of grazing animals which would increase the rate of transfer of canopy biomass, material with a relatively high organic matter content, to the mulch layer and break up the mulch material. Zeller (1963) also found a higher proportion of fine mulch material in grazed compared to ungrazed areas and postulated that trampling was responsible for this difference.

6.1.3 Mulch Decomposition Under Controlled Conditions

The data from the rate of decomposition study conducted in the greenhouse using the litter bag technique are summarized in Table 12 and Fig. 8. The rate of weight loss was most rapid

Table 11. Mean weight and percentage of the total mulch weight in each mulch grade in ungrazed and grazed natural grassland sites in loam soil near Saskatoon. Weights are g/m^2, ash-free basis and represent the mean for six sites.

	Ungrazed		Grazed	
Mulch grade	weight	percent	weight	percent
1	84	28.1	54	29.0
2	109	36.5	58	31.2
3	97	32.4	67	36.0
4	9	3.0	7	3.8
Total	299	100.0	186	100.0

Table 12. A comparison of the rate of decomposition of dead shoot material of three grass species under greenhouse conditions. Plant material was in litter bags on a warm, moist soil surface. Values are percentage (± S.E.) of the original organic matter weight lost at various times over a 25-week period*.

Species	Time (weeks)				
	2	4	7	12	25
Agropyron dasystachyum	16.6 ± 1.9^{a}	27.6 ± 3.3^{ab}	37.0 ± 6.3^{ab}	43.1 ± 2.9^{a}	71.9 ± 1.4^{a}
Festuca scabrella	15.0 ± 1.2^{a}	25.9 ± 0.6^{b}	35.0 ± 1.9^{b}	43.9 ± 1.1^{a}	60.4 ± 2.1^{b}
Stipa spartea var. *curtiseta*	14.1 ± 0.9^{a}	20.3 ± 1.3^{a}	26.6 ± 3.2^{a}	38.7 ± 2.5^{a}	57.2 ± 1.8^{b}

* Values in vertical rows followed by the same letter are not different at the 5 percent level of significance (paired student's *t* test).

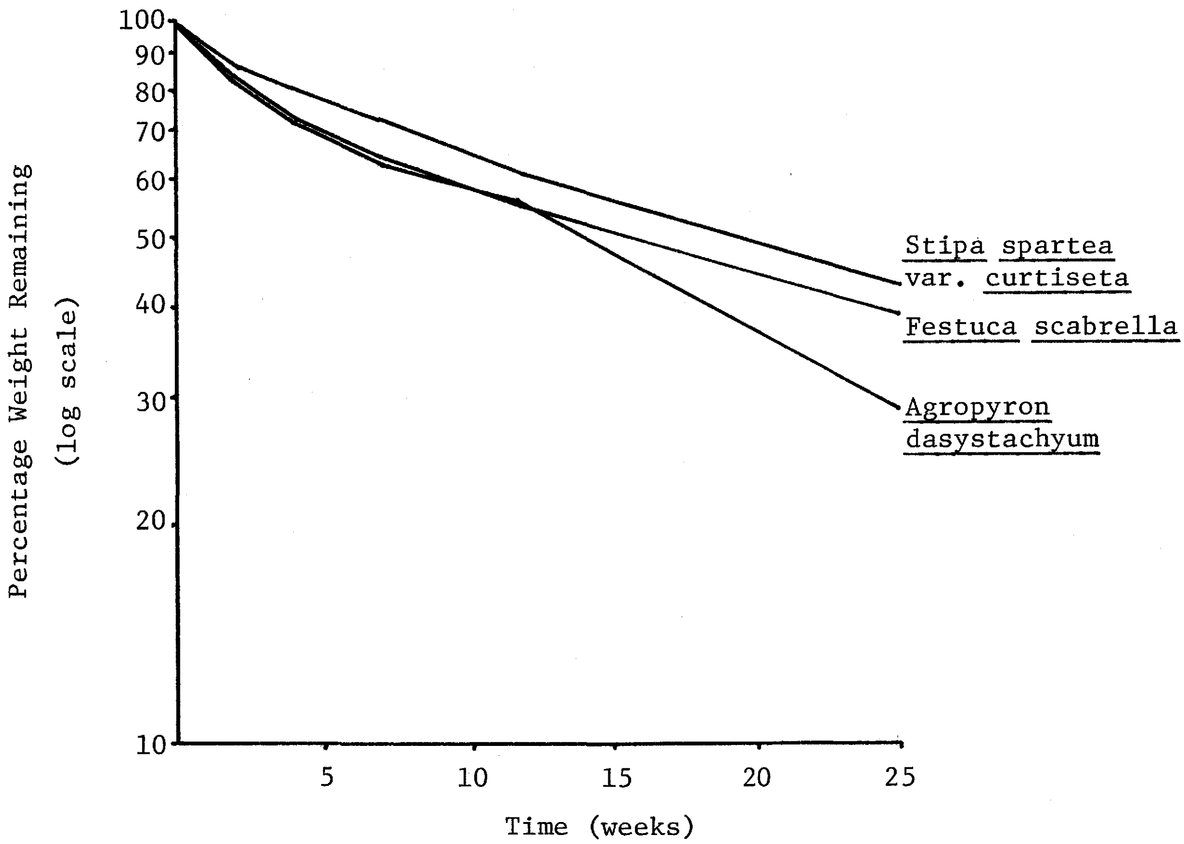

Fig. 8. A comparison of the rate of decomposition of dead shoot material of three native grass species under greenhouse conditions. Plant material was in litter bags on the soil surface. Plotted values represent the percentage initial organic matter remaining at various times over a 25-week period.

in the early stages and declined with time, particularly after the 12 week mark. The linear trend on the semilog scale (Fig. 8) suggests an exponential decrease in the fraction of weight remaining (Witkamp and Olson 1963). Weight losses in Stipa spartea var. curtiseta were consistently the lowest of the three species. Festuca scabrella lost significantly more organic matter than S. spartea var. curtiseta after four weeks ($P < 0.01$) and after 7 weeks ($P < 0.05$). At 12 weeks no significant differences were noted between any of the species. At 25 weeks, Agropyron dasystachyum had lost 72 percent of the original organic matter, significantly more ($P < 0.05$) than either S. spartea var. curtiseta (57.2 percent) or F. scabrella (60.4 percent). The slope of the curves for each species (Fig. 8) correspond to that of a line representing 13, 16 and 19 weeks, respectively, for half of the shoot material of A. dasystachyum, F. scabrella and S. spartea var. curtiseta to decompose under greenhouse conditions (Shields and Paul 1973).

Studies cited by various reviewers (Abouguendia 1973, Wiegert and Evans 1964, Peevy and Norman 1948, Koelling and Kucera 1965) also indicate that floristic composition may affect rate of decomposition particularly in the early stages and that chemical composition of plant material is responsible for the different decomposition rates. The various constituents of plant material vary in availability to microorganisms and accordingly, the extent of decomposition depends upon the composition of the material in question. The hemicelluloses and cellulose are readily available while lignin is almost unavailable and appears to accumulate as decomposition proceeds (Tomanek 1969).

The variation among species in the rate of decomposition in this study is probably related to the availability of the various chemical constituents. In view of these differences, it would have been interesting to have had lignin contents.

6.2 UNDERGROUND PLANT PARTS

The range in biomass of underground plant parts in ungrazed sites is shown in Fig. 9. Ash-free weight, to a depth of 35 cm, ranged from 875 to 1 975 g/m^2 in sites near Saskatoon (Sites 1 to 12) and from 1 160 to 1 745 g/m^2 in the southwest region near Kyle and Maple Creek (Sites 13 to 16).

The amount of underground biomass in the uppermost 35 cm of soil appears to decline with declining supply of soil moisture, approximated by the declining percentage composition of _Festuca_ and then _Agropyron_ spp. The average weight of underground plant parts in sites with _Festuca_ was 1 442 g/m^2 compared to 1 166 g/m^2 in sites with _Agropyron_ spp.

Care must be taken in comparing data from different locations since the sampling was done at different times of the year and there is evidence that biomass changes with season. Abouguendia (1973) reported a peak in standing crop of underground biomass within the 0-30 cm layer of soil occurring between June 15 and July 9 in the 1970 season and a slight drop in standing crop during the same period the following year. Coupland (1974) reports a similar variation in standing crop during the same monthly time frame over a period of three years. Variation in the conditions

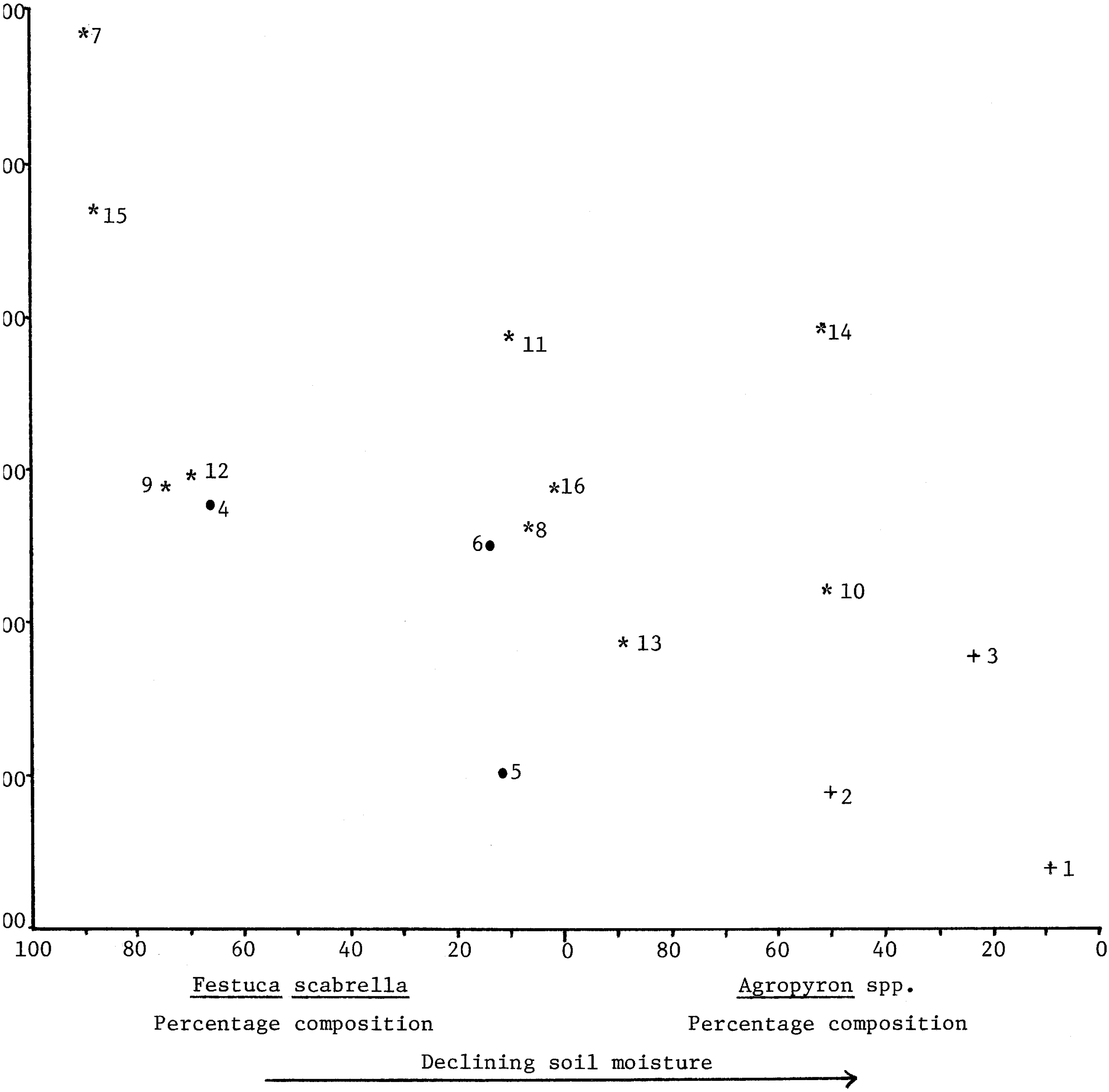

Fig. 9. Distribution of ungrazed sites according to weight of underground plant parts, to a depth of 35 cm, and soil moisture approximated by floristic composition of vegetation. The symbols designate soil texture (+ - sand, * - loam, and • - clay). Site number is shown with each symbol.

for plant growth likely account for these seasonal differences. Under conditions of favourable growth, root biomass would be expected to increase in June, when plant growth is generally rapid. Under unfavourable conditions, standing crop of underground parts would be expected to decrease. If a peak in underground plant production occurred during 1974, the year of sampling, it would likely have occurred in the time during which the sites near Saskatoon were sampled, resulting in the weights of underground materials being disproportionately high in these sites compared to those in the southwest.

6.2.1 Effect of Soil Texture

The relationship between biomass of underground plant parts and soil texture in ungrazed sites is illustrated in Fig. 9. Weight, to a depth of 35 cm, ranged from 875 to 1 150 g/m^2 in sand sites, 1 010 to 1 290 g/m^2 in clay sites, and 1 160 to 1 975 g/m^2 in loam sites.

The data in Table 13 suggest that the weight of underground plant parts is greater in the loam and clay soil than in the sand soil and that the plant material is distributed nearer to the surface in the finer-textured soils. Mean weight, in sites near Saskatoon, was 1 482 g/m^2 in loam sites, 1 218 g/m^2 in clay sites and 1 004 g/m^2 in sand sites, the weight in the loam being significantly greater ($P < 0.05$) than that in the sand. Mean weight in the loam sites in the southwest region was not different from that in the loam sites near Saskatoon. Within each of the various soil layers, weight of plant parts in the loam soil near

Table 13. Mean weight of underground plant parts in various soil layers to a depth of 35 cm and the percentage of the total weight in each layer in ungrazed natural grassland sites in the Saskatoon and southwest regions. Sites were located in sand, loam and clay soils near Saskatoon and in loam soil in the southwest. Weights are g/m^2, ash-free basis*.

	Saskatoon region						Southwest region	
	Sand		Clay		Loam		Loam	
Depth (cm)	Weight	Percent	Weight	Percent	Weight	Percent	Weight	Percent
No. of sites sampled	3		3		6		4	
0-6	509^{a}	50.7	672^{b}	55.2	784^{b}	52.9	811	55.2
6-15	224^{a}	22.3	259^{ab}	21.3	363^{b}	24.5	299	20.4
15-25	147^{a}	14.6	172^{a}	14.1	198^{a}	13.4	207	14.1
25-35	124^{a}	12.4	115^{a}	9.4	137^{a}	9.2	152	10.3
Total	$1\ 004^{a}$	100.0	$1\ 218^{ab}$	100.0	$1\ 482^{b}$	100.0	1 469	100.0

* Mean weights in the Saskatoon region in horizontal rows followed by the same letter are not different at the 5 percent level of significance (unpaired student's t test).

Saskatoon was consistently greater than that in either clay or sand soil and significantly greater ($P < 0.05$) than that in the sand soil in the upper 15 cm of the profile. In the clay soil, values were consistently greater than those in the sand with the exception of the 25-35 cm layer, and significantly greater ($P < 0.05$) than the sand in the upper 6 cm layer.

Differences in weight of underground plant parts appear to be related to species of plant as well as soil texture. *Stipa* spp., dominant in sand sites, are most extensively rooted in level, stabilized sand, as that found in the study sites, reaching depths of 110 cm. In soils of medium texture, in mesic situations, depth of rooting is reduced. *Agropyron dasystachyum*, *A. smithii* and *Festuca scabrella*, species dominant on the clay and loam sites, root most extensively in deep, rich (clay) soils and at shallower depths in soils of medium (loam) and coarse (sand) texture (Coupland and Johnson 1965). Hence the lower underground plant biomass recorded in sand in the present study appears to be related, in part, to the comparatively deeper root distribution of *Stipa* spp. in these soils. The higher underground plant biomass in loam soil over that in clay soil appears to be related to the response of *Agropyron* spp. and *F. scabrella* to deeper rooting in clay soil and shallower rooting in loam soil. *Stipa* spp. also present in these sites would be expected to root nearer the surface in these soils, further explaining the higher concentrations of roots near the surface in the finer-textured soils.

6.2.2 Effect of Grazing

Underground biomass to a depth of 35 cm was similar in grazed and ungrazed sites, averaging 1 471 and 1 482 g/m^2, respectively (Table 14). On an individual site basis, weights were greater in the grazed counterpart of Sites 8, 9 and 12, while in Sites 7, 10 and 11 the reverse was the case (Fig. 10). The percentage of the original vegetation remaining was highest in Sites 10 and 11 and lowest in Site 7.

Differences in weights of underground plant parts within comparative layers in ungrazed and grazed sites were not significant, although there was a tendency, in the grazed sites, towards a greater weight of plant parts in the upper 6 cm of soil and a lower weight below compared to the ungrazed sites.

The results of this study are in agreement with certain other studies. Coupland *et al.* (1960), examining the effects of grazing in the mixed prairie near Saskatoon, showed a reduction in quantity of roots of *Bouteloua gracilis* in the 0-5 cm layer, no effects at greater depths, and no evidence that overgrazing reduced the quantity of roots in the other dominant species. Lorenz and Rogler (1967) found no difference in root weight to a depth of 120 cm between lightly and heavily grazed mixed prairie in North Dakota. Bartos and Sims (1974), working in short grass prairie near Fort Collins, Colorado, found that total weight of underground plant biomass, to a depth of 80 cm, was not affected by light, moderate or heavy grazing, although in general, more root material was found in the upper 10 cm in the ungrazed and

Table 14. A comparison of the mean weight of underground plant parts to a depth of 35 cm, and the percentage of the total weight in each of the various soil layers in ungrazed and grazed natural grassland sites in loam soil near Saskatoon. Weights are g/m^2, ash-free basis, and are the mean of six sites.

	Ungrazed sites		Grazed sites	
Depth (cm)	Weight	Percent	Weight	Percent
0-6	784	52.9	854	58.1
6-15	363	24.5	319	21.7
15-25	198	13.4	169	11.5
25-35	137	9.2	129	8.7
Total	1 482	100.0	1 471	100.0

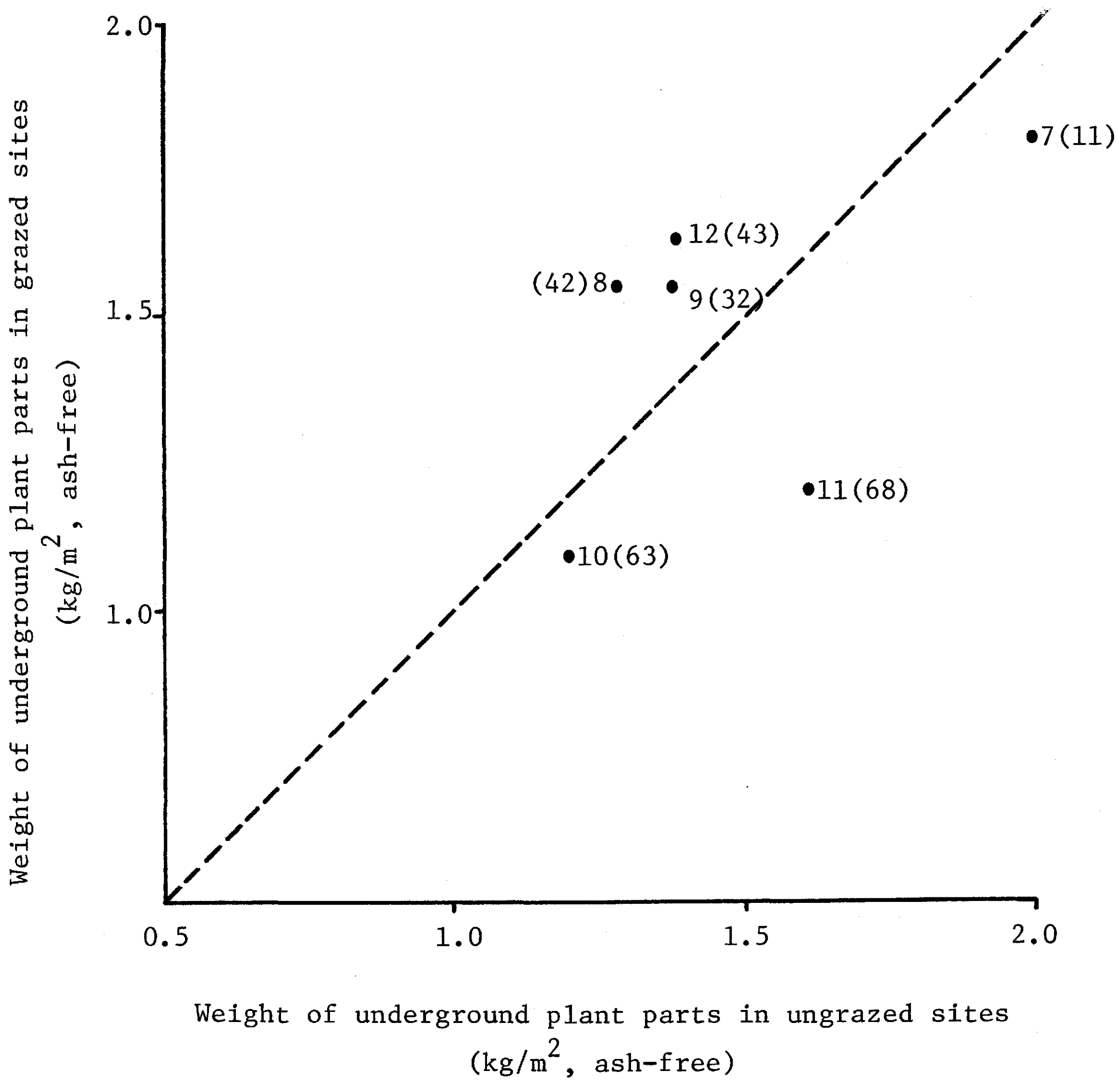

Fig. 10. Weight of underground plant parts (ash-free basis) in kg/m^2, to a depth of 35 cm, in ungrazed and grazed sites in loam soil near Saskatoon. Site number and the percentage of the original plant cover remaining in the grazed sites (in brackets) are indicated.

moderately grazed treatments than in the lightly grazed and heavily grazed treatments.

Results of some studies are inconsistent with those reported here. Smoliak _et al_. (1972) found that heavy grazing by sheep increased weight of underground plant biomass significantly in the 0-60 cm layer in mixed prairie in southeastern Alberta. Johnston (1960) reported that light grazing in fescue grassland of southwestern Alberta stimulated root growth down to depths of 140 cm, total weight of root material nearly doubling within this depth when compared to ungrazed range. Whitman (1971) recorded 53 percent greater weight of underground plant parts, to a depth of 100 cm, in a grazed compared to an ungrazed treatment in mixed prairie in North Dakota.

The increased weight of underground plant material in these studies reflected a change in the vegetation cover. In the study by Smoliak _et al_. (1972) deeper-rooted _Stipa comata_ and _Agropyron smithii_ were replaced by shallow-rooted _Selaginella densa_ and _Bouteloua gracilis_. The addition of feces and urine is also mentioned as a possible stimulant to root growth. Manure increases the content of mobile forms of humic acids in the composition of humus. Root production is vigorous in the presence of water-soluble humus substances (Smoliak _et al_. 1972). Johnston (1960) attributed the increase in root biomass, in part, to an increase in percentage basal area found under light grazing and in part to the reduction in shading and consequent increase in the near surface soil temperature. Mulch was heavier and taller-growing species dominated under no grazing.

From the above discussion it would appear that the underground biomass in this study was maintained under grazing by the replacement of the dominant grasses with the more xerophytic, shallow-rooted species such as _Koeleria cristata_, _Carex_ spp., _Bouteloua gracilis_ and _Phlox hoodii_.

7. SOIL ORGANIC MATTER

The organic content of a soil is regulated by the balance between the rate at which organic residue, primarily plant roots and mulch, is returned to the soil and the rate at which it is decomposed. Soil organic matter contents discussed below, unless otherwise indicated, include organic content of underground plant parts as well as that of buried straw in cultivated sites.

The range in weight of soil organic content in ungrazed sites, to a depth of 35 cm, less weight of underground plant parts, is shown in Fig. 11. Weights ranged from 12.6 to 30.4 kg/m^2 in sites near Saskatoon (Sites 1 to 12) and from 21.1 to 25.3 kg/m^2 in sites in the southwest region (Sites 13 to 16).

7.1 EFFECT OF SOIL TEXTURE

The distribution of ungrazed sites in Fig. 11 shows a strong influence of soil texture. Sand sites are grouped at the "dry" end of the moisture scale (approximated by the declining percentage composition of *Festuca* and *Agropyron* spp.) with the lowest soil organic matter content. Loam sites are widely distributed over the moisture gradient; however, they occupy a narrow band on the organic matter scale intermediate between sand and clay. Clay sites with the highest organic matter content are fairly well grouped near the moister end of the moisture scale.

Data in Table 15 indicate that organic matter content of soil in ungrazed sites was significantly affected by texture of soil. In sites near Saskatoon, values in sand ranged from 5.6 percent in

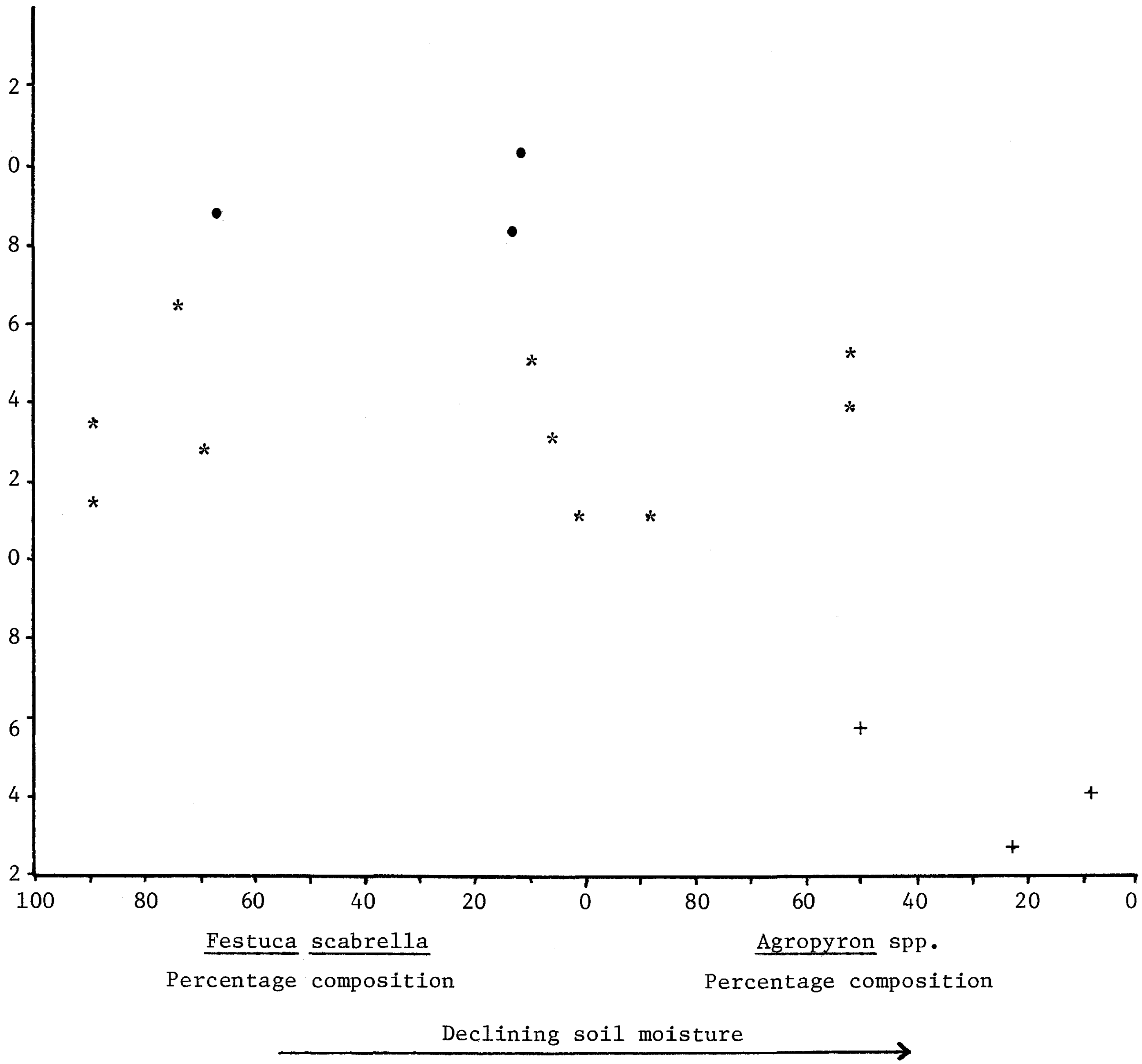

Fig. 11. Distribution of ungrazed sites according to weight of soil organic matter to a depth of 35 cm (less organic weight of underground plant parts) and soil moisture approximated by floristic composition of vegetation. The symbols designate soil texture (+ - sand, * - loam, • - clay). Site number is shown with each symbol.

Table 15. A comparison of the mean organic matter percent in soil in ungrazed natural grassland sites located in the Saskatoon and in the southwest regions. Sites were located in sand, loam and clay soil near Saskatoon and in loam soil in the southwest.

	Saskatoon region			Southwest region
Depth (cm)	sand	clay	loam	loam
No. of sites sampled	3	3	6	4
0-2	5.6	16.5	14.6	15.7
2-4	4.2	13.4	14.3	14.2
4-6	4.0	10.4	11.8	9.7
6-15	3.5	7.5	7.0	6.2
15-25	2.8	6.2	4.7	4.5
25-35	2.5	6.0	4.4	4.0

the upper 2 cm to 2.5 percent in the 25-35 cm layer. Values in the loam and clay soils were 14.6 percent and 16.5 percent, respectively, in the upper 2 cm layer and 4.4 percent and 6.0 percent, respectively, in the 25-35 cm layer. Loam sites in the southwest had a slightly higher percentage content in the upper layer and somewhat lower values throughout the remainder of the profile than loam sites near Saskatoon.

Percentage soil organic matter in ungrazed natural grassland varies considerably. Dormaar (1975) found that organic matter content at two different locations averaged 3.3 and 5.7 percent in the upper 13 cm of natural grassland soil in Alberta. Smoliak et al. (1972) reported organic matter levels of 1.9 to 2.3 percent in the 0-15 cm layer in ungrazed rangeland at Manyberries, Alberta. Martel (1972) found levels of 4.5 percent in clay soil in southcentral Saskatchewan and 9.3 percent in loam soil north of Saskatoon in the upper 10 cm of virgin grassland. Lodge (1954) reported values ranging from 4.8 to 7.9 percent in the top 10 cm of ungrazed natural grassland in southcentral Saskatchewan. Soil zone has a major influence on organic content in a soil. Levels of organic matter in soil of similar texture is lowest in brown soil and highest in black soil, the darker colour signifying a higher organic matter content. All the values cited above were from the brown soil zone except for the 5.7 percent value in Dormaar (1975) and the 9.3 percent value in Martel (1972), both of which were in black soil. Values in the present study were in dark brown soil near Saskatoon and in brown soil in the southwest.

Taking into account differences in soil zone and soil texture, values in the present study are higher than those reported above. This is likely to the methodology used in determining organic matter, discussed previously under methods (Section 4.5.2).

Mean total weight of soil organic matter, in ungrazed sites near Saskatoon, was greater in the clay soils (29.6 kg/m^2) than in the loam (25.9 kg/m^2) or sand soils (15.2 kg/m^2) (Table 16). Mean weight in loam sites in the southwest was 23.9 kg/m^2, slightly lower than that in loam sites near Saskatoon. The total weight and the difference in weight of organic matter between clay and loam soil would likely be less were hydrated water accounted for; however, weight of organic matter in these soils would still be considerably higher, likely significantly higher, than in sand.

Russel and McRuer (1927) also found texture to be the outstanding factor determining organic matter content in prairie soils. They reported that organic matter content was highest in fine-textured prairie soil and lowest in coarse-textured soil. The lower organic content in the sand soil is the result of several factors. A lower inherent capacity for biomass production means that a smaller amount of plant material is available for decomposition in sand soil than in finer-textured soil. A typically dry layer at the surface of coarse-textured soils is effective in reducing evaporative losses (Weaver 1958) which in conjunction with relatively good aeration provides conditions more conducive to oxidation of organic matter in coarse- than in finer-textured soil (Buckman and Brady 1962).

Table 16. A comparison of the mean weight of soil organic matter to a depth of 35 cm (including organic content of underground plant parts) and the percentage of the total soil organic matter in each soil layer in ungrazed natural grassland sites. In the Saskatoon region sites were located in sand, loam and clay soil and in the southwest region sites were in loam soil. Weights are g/m^2, ash-free basis.

Depth (cm)	Saskatoon region						Southwest region	
	Sand		Clay		Loam		Loam	
	Weight	Percent	Weight	Percent	Weight	Percent	Weight	Percent
0-2	1 308	8.6	2 157	7.3	2 069	8.0	1 933	8.1
2-4	988	6.5	2 027	6.8	2 266	8.7	2 142	9.0
4-6	1 030	6.8	1 956	6.6	2 285	8.8	1 999	8.3
6-15	4 303	28.2	7 559	25.6	7 318	28.2	6 634	27.8
15-25	4 004	26.3	7 791	26.3	6 151	23.8	5 866	24.6
25-35	3 592	23.6	8 122	27.4	5 852	22.5	5 295	22.2
TOTAL	15 225	100.0	29 612	100.0	25 941	100.0	23 869	100.0

7.2 EFFECT OF GRAZING

Substantial reductions in percentage content of organic matter occurred in the upper 15 cm of soil as the result of grazing. These reductions were statistically significant ($P < 0.05$) in the 0-6 cm layer. Mean values for the ungrazed and grazed sites in this layer were 13.6 and 11.0 percent, respectively (Table 17). In the upper 15 cm, organic matter content declined by an average of 16.0 percent. Below this layer, grazing had little affect on content of organic matter.

Weight of soil organic matter, on an unadjusted basis (Table 18), showed a different trend to that observed in percentage content data. Weights of organic matter increased in the 0-4 cm layer from 4.3 kg/m^2 in the ungrazed sites to 4.6 kg/m^2 in the grazed sites. In the 4-15 cm layer, weights decreased from 9.6 to 8.8 kg/m^2, respectively. Within the top 15 cm, the weight of organic matter declined from 13.9 to 13.3 kg/m^2 or by 4.5 percent as a result of grazing.

In interpreting changes in weight of organic matter resulting from grazing, a change in bulk density of the soil should be considered. Increased soil bulk density in grazed sites results in a situation where an equal volume of soil from a grazed site contains a greater weight of soil than in the ungrazed site. Therefore a volume of soil in the grazed site will have a disproportionately greater weight of soil organic matter than if this soil were in the ungrazed site. Calculations to determine the effect of grazing on weight of organic matter in soil should

Table 17. Organic matter percent in various soil layers, to a depth of 35 cm in grazed and ungrazed natural grassland sites in loam soil near Saskatoon.

Depth (cm)	Site 7	8	9	10	11	12	Mean*
a. Grazed sites							
Percentage of the original plant cover remaining	11	42	32	63	68	43	43
0-2	12.6	13.2	17.6	11.0	12.0	10.6	12.8[a]
2-4	8.4	12.0	17.8	9.5	9.1	8.9	11.0[a]
4-6	8.0	9.0	12.5	7.9	8.7	8.9	9.2[a]
6-15	6.9	5.4	6.6	6.0	5.7	6.5	6.2[a]
15-25	4.6	4.4	4.6	4.7	4.8	5.3	4.7[a]
25-35	3.8	5.1	4.2	4.7	4.4	4.2	4.4[a]
b. Ungrazed sites							
0-2	18.2	10.4	17.0	12.3	13.7	15.8	14.6[b]
2-4	15.6	12.8	19.7	13.1	15.1	9.6	14.3[b]
4-6	11.5	11.0	16.6	10.2	13.3	8.1	11.8[b]
6-15	7.1	5.6	9.0	6.7	7.5	5.8	7.0[a]
15-25	4.4	4.8	5.3	4.6	4.2	4.7	4.7[a]
25-35	4.2	4.5	4.2	4.8	4.2	4.5	4.4[a]

* Mean values from the same depth followed by the same letter are not different at the 5 percent level of significance (unpaired student's t test).

Table 18. Mean weight of organic matter (including weight of underground plant parts) in layers of soil at various depths, to 35 cm, and percentage change in organic content in ungrazed and grazed natural grassland sites in loam soil near Saskatoon. Unadjusted and adjusted* weights are given for the grazed sites. Values are the mean of six sites, weights are g/m^2.

		Grazed		Percent Change	
Depth**	Ungrazed	Unadjusted	Adjusted	Unadjusted	Adjusted
0–2	2 069	2 278	1 777	+10.1	-14.1
2–4	2 266	2 282	1 665	+0.7	-26.5
4–6	2 285	2 038	1 732	-10.8	-24.2
6–15	7 318	6 719	6 442	-8.2	-12.0
15–25	6 151	6 188	6 257	-0.6	+2.2
25–35	5 852	5 873	5 784	+0.4	-1.2
TOTAL	25 941	25 378	23 687	-2.2	-8.2

* Weight of organic matter was adjusted according to comparable weight of mineral soil in grazed and ungrazed sites.

** Depth increments in the adjusted case were 1.6, 1.5, 1.7, 8.6, 10.2 and 9.9 cm, respectively, from the surface layer downwards.

therefore be based on the organic matter associated with equal weights of mineral soil to provide a common base for comparison.

The adjustment was achieved by calculating an adjusted depth increment for each soil layer in the following manner. The weight of mineral soil in the various soil layers was calculated by subtracting weight of organic matter in the soil from the total weight of soil. The weight of mineral soil in each layer of soil in the ungrazed sites was then divided by the weight of mineral soil in the equivalent layer of soil from the grazed counterpart and the resultant quotient was multiplied by the depth of the soil layer to obtain the adjusted depth. If the mineral soil weight in the grazed site was greater than that for the same layer in the ungrazed site, as was usually the case, the adjusted depth increment was less than the unadjusted depth. If the mineral soil weight in the grazed site was less than that for the same layer in the ungrazed site, the adjusted depth was taken to be the greater of the two. The adjustment was based on mineral soil weight rather than total soil weight to remove the influence of the variable organic matter content, associated with the latter, from the calculation.

On the adjusted basis, weight of organic matter declined in each soil layer above 15 cm and changed little below this depth as a result of grazing (Table 18). The greatest reduction occurred in the 2-6 cm layer where weights declined from 4.6 kg/m^2 in the ungrazed sites to 3.4 kg/m^2 in the grazed sites, or by 25.4 percent. In the top 15 cm, the weight of organic matter declined from 13.9 to 11.6 kg/m^2 or by 16.7 percent, as a result of grazing. Although the distribution of soil organic matter did not differ greatly between the ungrazed and grazed sites, values presented in Table 19 indicate that organic matter in the grazed sites tended to be more concentrated at depth.

The distribution of the paired grazed and ungrazed sites, shown in Fig. 12, indicates that the total weight of organic matter in the soil profile (to the depth of sampling) was lower in the grazed sites in all cases. Reduction in weight was highest in Sites 7 and 9, averaging 3.7 kg/m^2, lowest in Sites 8, 10 and 12, averaging 0.8 kg/m^2, and intermediate in Site 11, with a reduction of 2.4 kg/m^2. Sites with the highest reduction in weight of organic matter are also the sites with the lowest percentage of the original plant cover remaining.

Studies made in Alberta and Saskatchewan show variable effects of grazing on percentage soil organic matter content. A study by Lodge (1954) measured the effect of grazing on four sites in mixed prairie of southcentral Saskatchewan. Organic content in the upper 10 cm layer of soil declined by 42 and 18 percent in two of the grazed sites, remained the same in one set of plots and increased by 13 percent in the other. None of the differences were considered significant. Smoliak _et al_. (1972) found that after 19 years of grazing by sheep in mixed prairie in southeastern Alberta, total carbon content in the upper 15 cm of the soils remained unchanged under light and moderate grazing, but increased significantly on heavy grazing. They attributed the increase in soil organic matter to an increase in shallow-rooted species and the deposition of manure by the sheep. Johnston _et al_.

Table 19. Percentage of the total organic matter weight, to a depth of 35 cm, in each soil layer in ungrazed and grazed natural grassland sites in loam soil near Saskatoon. Adjusted weights and adjusted depths were used in the case of the grazed sites. Values are the mean of six sites.

Depth (cm)*	Ungrazed	Grazed
0-2	8.0	7.5
2-4	8.7	7.0
4-6	8.8	7.4
6-15	28.2	27.2
15-25	23.8	26.5
25-35	22.5	24.4

* Depth increments in the grazed sites, adjusted weight basis, were 1.6, 1.5, 1.7, 8.6, 10.2 and 9.9 cm, respectively, from the surface downwards.

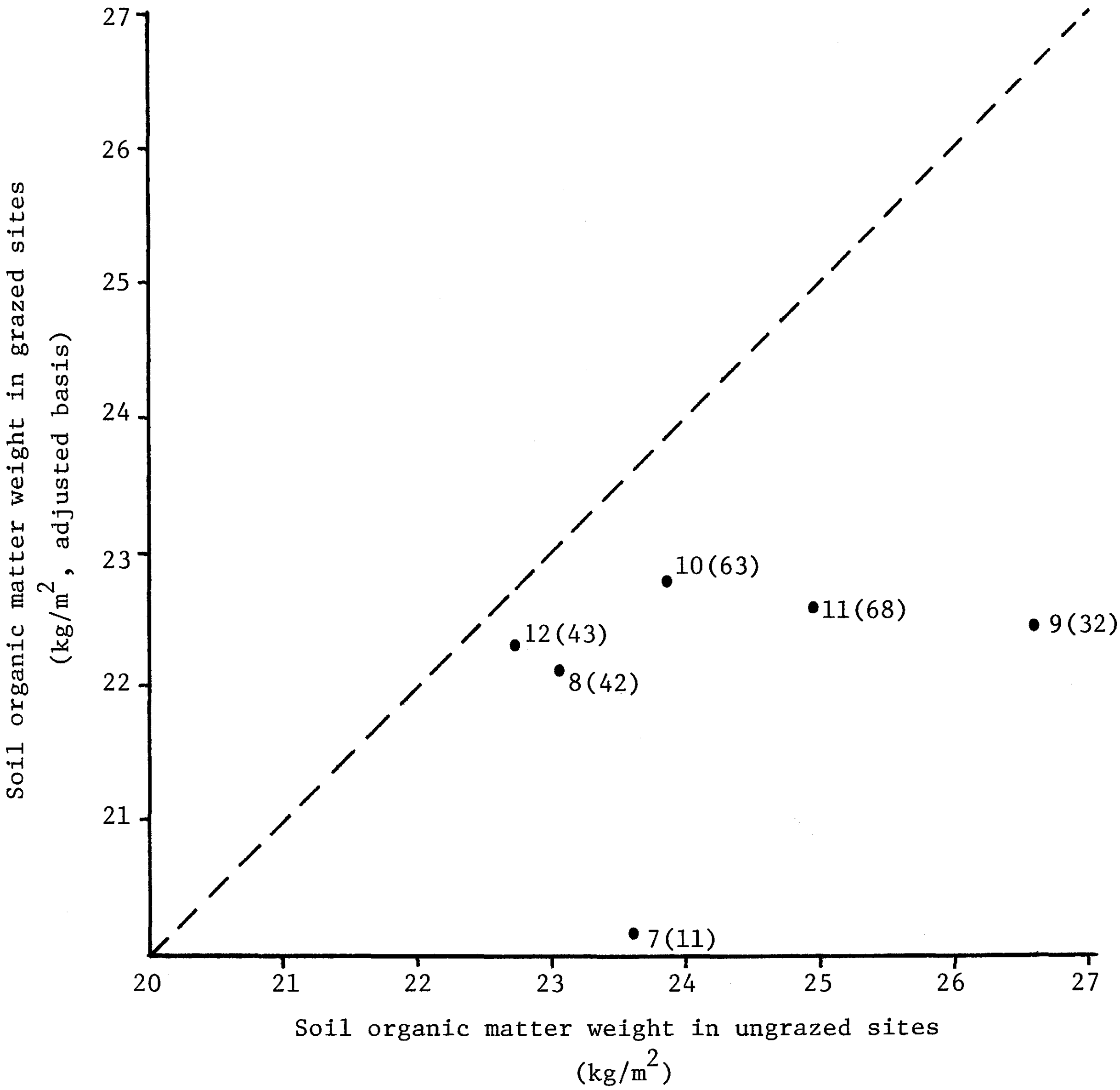

Fig. 12. Weight of soil organic matter to a depth of 25 cm (less organic weight of underground plant parts) in ungrazed and grazed sites near Saskatoon. Adjusted weights and depths were used for the grazed sites. Site number and the percentage of the original vegetation remaining in the grazed sites (in brackets) are indicated.

(1971), in fescue prairie in Alberta, showed that organic matter in soil decreased as rate of grazing increased from moderate to very heavy; however, differences were not significant.

Some studies report reductions in percentage content of organic matter in soil of similar or greater magnitude to those found in the present study due to grazing. A study in southeastern South Dakota (Beebe and Hoffman 1968) found reductions in organic matter content of 35 to 65 percent in the upper 60 cm of soil. Kucera (1958) showed that grazing of the Missouri tall grass prairie resulted in changes similar to those noted here. Organic matter was reduced by 11 percent in the upper 10 cm and increased slightly in the 10-15 cm layer. Sant (1966) found significant decreases in organic matter to a depth of 25 cm on moderately- and heavily-grazed fields in India subjected to a continental climate.

The studies cited above, which investigated the effect of grazing on organic content of soil, measured changes in percentage organic content of soil. None of these studies reported the effect on the actual content of organic matter. Adjustment to compensate for a change in soil bulk density, resulting from grazing, was therefore not required.

7.3 EFFECT OF CULTIVATION

Cultivation for a period averaging 21 years, caused a marked decline in soil organic matter, especially in the cultivated layer (Table 20). Mean percentage organic matter content (which includes contributions from underground plant parts as

Table 20. Organic matter percent in soil in cultivated and in ungrazed natural grassland sites at various depths in loam soil near Saskatoon*.

Depth (cm)	Site 7	8	9	10	11	12	Mean
a. <u>Cultivated sites</u>							
Years cultivated	30	18	20	25	10	22	21
0 - 6	7.4	7.0	8.0	9.2	7.1	8.6	7.9[a]
6 - 15	6.0	6.1	7.9	8.3	5.9	6.3	6.8[a]
15 - 25	3.7	4.5	6.1	6.7	4.8	5.0	5.1[a]
25 - 35	3.5	4.8	4.4	5.5	4.0	4.2	4.4[a]
b. <u>Ungrazed sites</u> (natural grassland)							
0 - 6	15.1	11.4	17.8	11.9	14.0	11.2	13.6[b]
6 - 15	7.1	5.6	9.0	6.7	7.5	5.8	7.0[a]
15 - 25	4.4	4.8	5.3	4.6	4.2	4.7	4.7[a]
25 - 35	4.2	4.5	4.2	4.8	4.2	4.5	4.4[a]

* Mean values from the same depth followed by the same letter are not different at the 5 percent level of significance (unpaired student's t test).

well as buried straw in the case of cultivated sites) decreased from 13.6 to 7.9 percent in the upper 6 cm of soil and from 7.0 to 6.8 percent in the 6-15 cm layer or by an average of 26 percent in the plough layer, when compared to ungrazed natural grassland.

Mean weight of organic matter, without allowing for the change in bulk density caused by tillage, declined from 6.6 to 4.7 kg/m^2 in the 0-6 cm layer and from 7.3 to 7.0 kg/m^2 in the 6-15 cm layer as a result of tillage (Table 21). Mean reduction in the 0-15 cm layer was 2.2 kg/m^2.

Comparisons between cultivated and ungrazed sites made on the basis of adjusted weights, following the same procedure as outlined for grazed sites, shows that mean organic content declined from 6.6 to 3.6 kg/m^2 and from 7.3 to 6.8 kg/m^2, respectively, in the 0-6 and 6-15 cm layers. Mean organic weight loss in the cultivated layer over the 21-year period was 3.6 kg/m^2 or 25.5 percent of the original content.

Organic content in the 15-35 cm depth was similar in the cultivated and ungrazed natural grassland soils. However, the data suggest that in the 15-25 cm layer the organic content is 3 percent higher in the cultivated soil than in the uncultivated soil, while in the 25-35 cm layer the reverse is the case. The higher content of organic matter between 15 and 25 cm depths, if it could be substantiated, might be explained by a higher degree of leaching from the 0-15 cm layer in the cultivated soil than in the uncultivated soil.

The loss in percentage organic matter content in the top

Table 21. Mean weight of organic matter (g/m^2) in layers of soil at various depths in ungrazed natural grassland and cultivated sites in loam soil near Saskatoon. Unadjusted and adjusted weights are given in the case of the cultivated sites. All weights include organic matter weight of underground plant parts and buried straw in cultivated sites. Values are the means of six sites.

Depth	Ungrazed	Cultivated		Percent change	
(cm)	(g/m^2)	Unadjusted	Adjusted*	Unadjusted	Adjusted
0-6	6 620	4 674	3 615	-29.4	-45.5
6-15	7 318	7 035	6 766	-3.9	-7.5
15-25	6 151	6 179	6 331	+0.5	+2.8
25-35	5 852	5 892	5 671	-0.7	-3.1
Total	25 941	23 780	22 383	-8.3	-13.7

* Mean depth increments in the adjusted case were 4.6, 8.7, 10.2 and 9.6 cm, respectively, from the surface layer downwards.

15 cm (calculated from data in Table 20) in relation to the years under cultivation is shown in Fig. 13. It is evident from the wide-ranging distribution of the sites in the graph that the percentage reduction in organic matter content was not proportional to the period of cultivation. For example, Sites 7 and 11 both lost 37 percent of the organic matter in the plough layer; however, Site 7 had been cultivated 20 years longer than Site 11. Site 10, cultivated for 25 years, had lost only 4 percent organic matter.

Adjusted weight of organic matter in cultivated sites, to the depth of sampling, ranged from 19.0 to 28.2 kg/m^2 (Fig. 14). Compared to ungrazed sites, total weight of organic matter declined in all sites with the exception of Site 10, where it was higher than the uncultivated ungrazed control. This site had been seeded to grass for four years, following 20 years of cultivation, and returned to cultivation one year prior to sampling.

Several other studies have reported reductions in organic matter based on percentage of weight of soil as a result of tillage. Brown _et al_. (1942) and Doughty (1948) found reductions in organic matter of 20 to 24 percent in the first 28 to 30 years of cultivation in some western Canadian prairie soils. Martel (1972) reported a 22 to 60 percent reduction after 15 to 20 years of cultivation in Saskatchewan. Jenny (1930) determined that over a period of 20 to 40 years of cultivation soil in the wheat-growing regions of the Great Plains had lost 20 to 40 percent of the original organic matter.

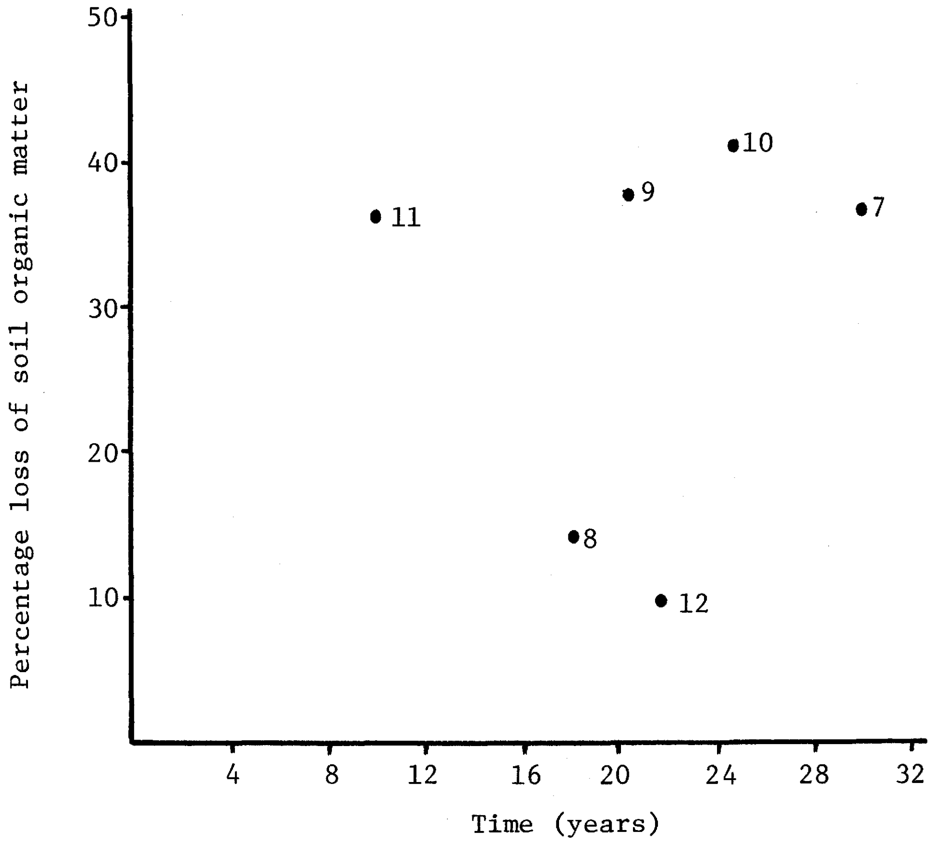

Fig. 13. Percentage loss of organic matter in the top 15 cm of soil, based on percent organic matter content of soil, in sites near Saskatoon cultivated for 10 to 30 years.

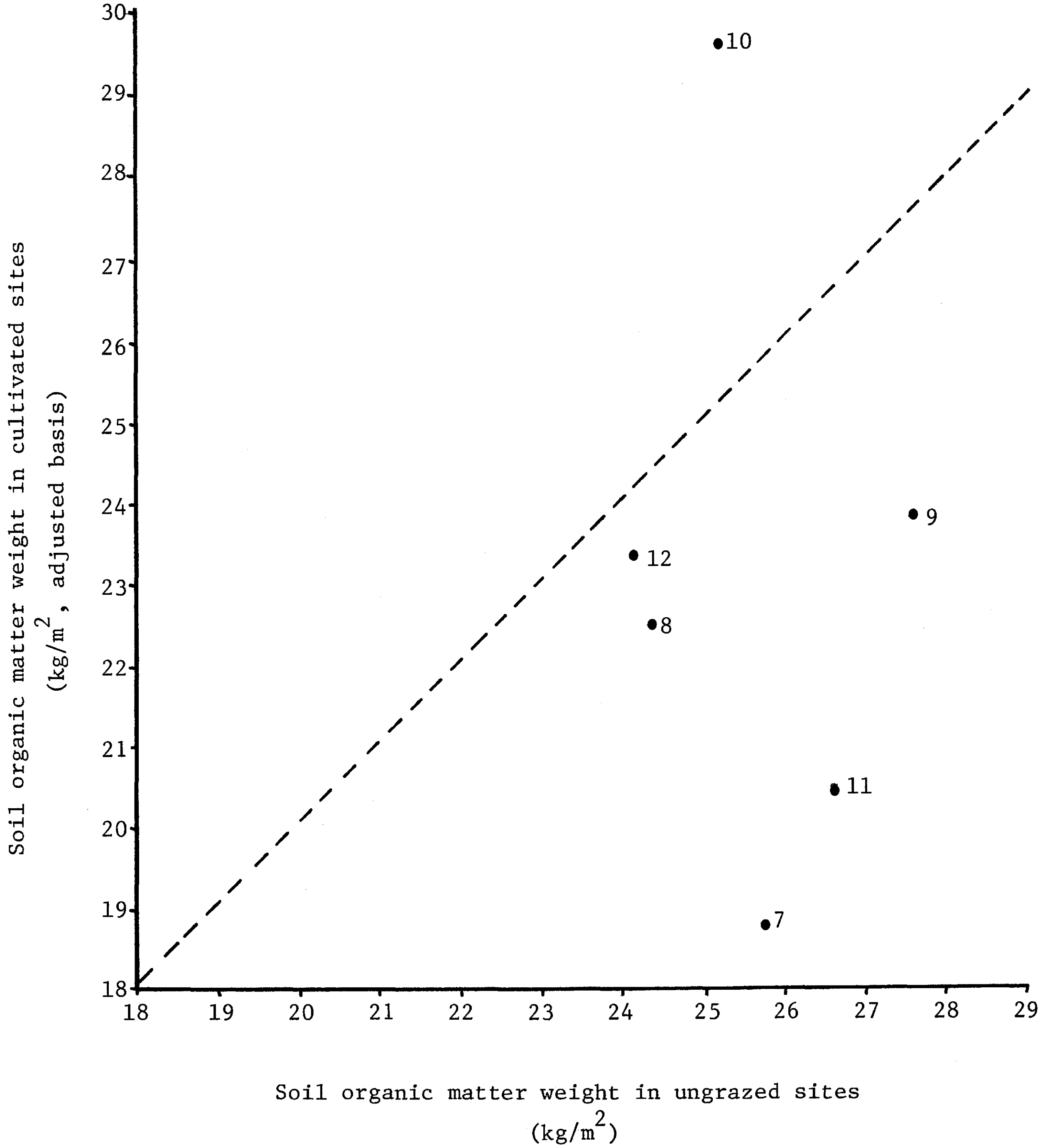

Fig. 14. Weight of soil organic matter in kg/m^2 to a depth of 35 cm in ungrazed and cultivated sites in loam soil near Saskatoon. Weights include organic matter weight of underground plant parts, and buried straw in cultivated sites. Adjusted weights and depths were used for cultivated sites. The numbers in the figure designate site number.

Tillage disrupts soil aggregates and microsites exposing organic matter not previously accessible to microbial attack and stimulates the activity of the microorganisms (Porter 1969, Martel 1972, McCalla 1967). The decline in organic matter which occurs as a consequence is rapid when prairie soil is first brought under cultivation (Brown et al. 1942, Caldwell et al. 1939, Doughty 1948, Newton et al. 1945). This rapid loss is attributed to the rapid breakdown of the starches, sugars and other carbohydrates in the fresh plant material which are easily decomposed (Doughty 1948, Martel 1972). Following the initial stage of rapid decomposition, the rate of loss declines with the period of cultivation. Newton et al. (1945) found that the average annual loss of organic matter from fields cultivated for an average of 28 years was approximately half that of fields cultivated for an average of nine years. Jenny (1933) quantified the loss of fertility due to 60 years of cultivation under Missouri conditions, in terms of reduction in soil nitrogen. He determined that 25 percent N was lost in the first 20 years, 10 percent in the second 20 years and 7 percent in the third 20 years. There is a tendency to reach an equilibrium point, even under a grain and fallow system, at which losses caused by decomposition, crop absorption, leaching and other factors are balanced by gains in organic matter from plant growth. Bartholemew and Krickham (1960), cited in Porter (1969), calculated that the rate of establishment of steady state equilibrium conditions in grassland soils as influenced by cultivation requires 50 to 100 years.

Land management practices likely account for the fact that the percentage loss of organic matter in this study is not proportional to the length of time under cultivation. Bartholemew (1957) reported that wheat with alternate fallow caused the largest overall losses of soil organic matter among the cropping systems studied. The least decline in organic matter occurred under continuous wheat. In long-time rotations, which included legumes and clean fallow, the losses in organic matter were intermediate between those in continuous wheat and those under wheat-fallow. In the present study the grassing of Site 10 for four years restored the majority of the organic matter which had been lost from the plough layer in 20 years of cultivation.

The practice of grassing adds organic matter to the soil through contribution from plant roots and aboveground biomass. Work by Jenkinson (1977) at Rothamsted in England indicates that the rate of decomposition of plant material also declines when soil is growing grass. He measured the loss of carbon from ^{14}C-labelled ryegrass roots decomposing under field conditions and found that decomposition was considerably slower in soil growing grass than in the same soil kept bare. On removal of the grass he found that decomposition proceeded at twice the rate of that in soil that had been bare throughout. The most probable reason given for the decreased rate of decomposition under plant cover was that during the summer the growing plants desiccated the soil and so slowed decomposition. Bare soil does not lose water by transpiration, so that it was presumably moister during summer when temperatures are near optimum for decomposition.

Due to the rapid reduction in organic matter in the first years following sod breaking, much of the dramatic increase in organic matter content, achieved by placing cultivated land in sod, is lost when the land is returned to cultivation. Doughty (1948) found that as much organic matter as had been accumulated in four years in bromegrass and crested wheatgrass was lost in two years after breaking at Swift Current, Saskatchewan. The regular introduction of grass or grass-legume mixtures into a crop rotation has, however, been shown to greatly reduce the rate of organic matter reduction and in some instances to increase the organic content. A nine-year rotation at Indian Head, Saskatchewan, consisting of wheat, oats, fallow, wheat, oats (seeded down to grass and alfalfa), hay, hay or pasture, pasture (broken), and corn (manured) greatly reduced losses of organic matter as compared to a three year grain-fallow rotation (Newton _et al_. 1945). Loss of organic matter, to a depth of 30 cm, after these rotations had been followed for 29 years was 4.5 kg/m^2 in the case of the 9-year rotation and 9.9 kg/m^2 in the case of the 3-year rotation. A seven-year rotation at Lacombe, Alberta, increased the organic matter content of the soil by 2.0 kg/m^2, while the conventional 3-year wheat and fallow rotation resulted in a reduction of 7.1 kg/m^2 following a period of 26 years under these rotations (Newton _et al_. 1945). The seven-year rotation consisted of wheat, oats, fallow, wheat (seeded to alfalfa and ryegrass), hay (manured), hay (broken early) and potatoes.

8. ORGANIC MATTER IN THE SYSTEM

The purpose of this chapter is to summarize the organic matter contents of the various subsystems into a total systems content. Included in the summation in Table 22 are the aboveground biomass, the underground plant parts in the upper 35 cm of soil and the soil organic matter within this layer.

Within this chapter, soil organic matter refers to the corrected value, after deducting the weight of underground plant parts. In the case of the grazed and cultivated sites, the weight of soil organic matter is the adjusted weight based on a comparable weight of mineral soil.

8.1 EFFECT OF TEXTURE

The weight of organic matter in ungrazed natural grassland increased with increasing fineness in soil texture. Near Saskatoon mean weights in sand, loam and clay were, respectively, 15.7, 25.6 and 30.1 kg/m^2. In the southwest region the weight in loam soil was 24.7 kg/m^2. As discussed earlier the weights of organic matter recorded for clay and loam soil are likely to be disproportionately higher than those in sand soil due to method of analysis.

The distribution of organic matter within each of the subsystems was also influenced by texture. The greatest proportion of the total system weight in the aboveground and underground plant parts compartments was found in sand soil (3.1 and 6.4 percent, respectively), followed by loam (2.4 and 5.6 percent) and clay soil (1.7 and 4.1 percent). Accordingly the proportion

Table 22. Summation of aboveground and underground organic matter weight in ungrazed, grazed and cultivated grassland soils of different texture near Saskatoon and in southwestern Saskatchewan. Weights are g/m^2, ash-free basis. Bracketed values are the percentage that the weight of organic matter found in each subsystem is of the total weight of organic matter in that system.

	Saskatoon region					Southwest region
	Ungrazed sand	Ungrazed clay	Ungrazed loam	Grazed loam	Cultivated loam	Ungrazed loam
Aboveground						
Canopy	213 (1.4)	262 (0.8)	358 (1.3)	82 (0.3)	588* (2.6)	396 (1.6)
Mulch	274 (1.7)	263 (0.9)	299 (1.1)	186 (0.8)		425 (1.7)
TOTAL	487 (3.1)	525 (1.7)	657 (2.4)	268 (1.1)	588 (2.6)	821 (3.3)
Underground						
Plant parts	1 004 (6.4)	1 218 (4.1)	1 482 (5.6)	1 471 (6.2)	22 383** (97.4)	1 468 (6.0)
Soil organic matter	14 221 (90.5)	28 394 (94.2)	24 459 (92.0)	22 216** (92.7)		22 401 (90.7)
TOTAL	15 225 (96.9)	29 612 (98.3)	25 941 (97.6)	23 687 (98.9)		23 869 (96.7)
TOTAL	15 712 (100)	30 137 (100)	26 598 (100)	23 955 (100)	22 971 (100)	24 690 (100)

* Estimated value from Coupland (1973)

** Adjusted weights, based on a comparable weight of mineral soil of the total weight as soil organic matter was highest in clay soil (94.2 percent) lowest in sand soil (90.5 percent) and intermediate in loam soil (92.0 percent).

8.2 EFFECT OF GRAZING

The organic matter weight in the system was reduced from 26.6 to 24.0 kg/m^2, or by 9.8 percent as a result of grazing. The largest weight reduction occurred in soil organic matter, which declined from 24.5 to 22.2 kg/m^2, although aboveground weights also declined considerably (from 657 to 268 g/m^2).

The influence of grazing on the distribution of organic matter was greatest aboveground. The proportion of organic matter in this compartment decreased from 2.4 to 1.1 percent as a result of grazing while the proportion as underground plant parts increased from 5.6 to 6.2 percent and that as soil organic matter increased from 92.0 to 92.7 percent.

8.3 EFFECT OF CULTIVATION

The weight of organic matter in cultivated soil includes contributions from root material and from buried straw. Aboveground biomass has, to this point, not been included and measurements of standing crop in cultivated fields were not made in this study. Coupland (1973) measured standing crop of wheat (*Triticum aestivum*) growing in heavy clay near the Matador IBP research station. Maximum standing crop in fertilized cropland was 959 g/m^2 in the first crop and 806 g/m^2 in the second crop. (Standing crop included contributions from wild oats (*Avena fatua*) and broad-leaved weeds, which combined were less than

5 percent of the total.) Assuming that cropland is fallowed every third year, average annual standing crop would be 588 g/m^2.

If the figure of 588 g/m^2 is used as an average weight for aboveground biomass for the present study, total organic matter weight in the cultivated system would be 22.9 kg/m^2. Compared to ungrazed natural grassland, this represents a reduction of 3.5 kg/m^2 or 13.6 percent in organic matter content as a result of tillage.

The distribution of organic matter in the cultivated sites, including the estimated aboveground biomass, is similar to ungrazed natural grassland. However, if the proportion of the organic matter in the mulch compartment in the ungrazed sites is added to the underground biomass rather than the aboveground biomass, to compensate for the buried straw (mulch) in the cultivated sites, the proportion of organic matter aboveground would be roughly twice as great in the cultivated sites as in the ungrazed natural grassland.

9. GENERAL DISCUSSION

This study has shown that soil texture plays a very important role in determining the amount of organic matter in various components of the ungrazed system and that grazing and tillage have seriously depleted organic matter levels in the medium-textured soils.

The marked influence of soil texture on organic content in the system was discussed earlier with respect to moisture relations and soil fertility. Floristic composition, also influenced by soil texture, is another factor which may affect system organic content through differential rates of decomposition of shoot material from different species. A relatively high negative correlation between percentage composition of *Agropyron* spp. and standing dead biomass ($r = -0.53$) (Table 23), although not significant at the five percent level, would appear to indicate that as the percentage composition of *Agropyron* spp. increases, the rate of transfer from the canopy to mulch increases. Moisture relations are likely not a major variable in this case as the percentage composition of *F. scabrella* and *Stipa* spp., found at opposite ends of the moisture gradient, show no correlation to standing dead biomass. A decline in standing dead biomass with increased presence of *Agropyron* would be consistent with the decomposition studies in the greenhouse which showed that *Agropyron dasystachyum* and *Festuca scabrella* lost more weight initially than *Stipa spartea* var. *curtiseta* and at a more advanced stage of decay (weight losses exceeding

Table 23. Correlation coefficients to show relationships among organic matter contents in the system and floristic composition in ungrazed sites near Saskatoon (n = 12).

	1.	2.	3.	4.	5.	6.	7.	8.
1. Mulch weight	1.00							
2. Standing dead	0.56	1.00						
3. % soil organic matter (0-2 cm)	0.12	0.08	1.00					
4. Soil organic matter weight (0-35 cm)	-0.05	-0.42	0.87**	1.00				
5. Underground plant parts (0-35 cm)	0.09	0.05	0.71**	0.42	1.00			
6. % *Stipa* spp.	-0.13	0.17	-0.82**	-0.70*	-0.68*	1.00		
7. % *Agropyron* spp.	0.17	-0.53	0.04	0.20	0.25	-0.54	1.00	
8. % *F. scabrella*	-0.11	0.19	0.64*	0.46	0.68*	-0.75**	-0.12	1.00

* $P < 0.05$, when $r \geq 0.58$

** $P < 0.01$, when $r \geq 0.71$

50 percent of the original weight) A. dasystachyum had lost significantly more weight than either of the other two species (Table 12). Mulch, which is at a more advanced state of decay than standing dead plant material, was, however, unrelated to floristic composition in the field (Table 23). Other studies (Abouguendia 1973, Wiegert and Evans 1964) also found differential rates of decomposition related to floristic composition during the early stages of decay but not thereafter.

The influence of texture appears to be of primary importance in the relationship between floristic composition and weight of underground plant parts (Table 23). The percentage composition of Stipa spp. was negatively correlated ($P < 0.05$) and the percentage composition of F. scabrella was positively correlated ($P < 0.05$) with underground plant parts. Stipa spp. were most abundant in coarse-textured soils where deep rooting, a relatively low fertility compared to finer-textured soils and a consideration of the fact that sampling was only to a depth of 35 cm, would appear to explain the declining root biomass with increasing presence of Stipa spp. F. scabrella was most common in fine-textured soils, where within the depth of sampling, it roots more prolifically than Stipa spp. (Coupland and Johnson 1965). The deeper distribution of roots in sand is presumably because of the increased penetration of moisture into the profile while the trend towards shallower rooting in finer-textured soils likely reflects more dependable supplies of soil moisture.

Total organic matter weight in soil varying in texture was positively, but not significantly, related to weight of underground plant parts to a depth of 35 cm (r = 0.42) (Table 23). The relationship between root biomass and soil organic matter within each of the various soil layers in ungrazed sites near Saskatoon was positive (r = 0.46) but also not significant. Sprague (1933) also found no significant correlation between root depth of six perennial grasses and organic carbon content in a Podzolic soil in New Jersey. Weaver et al. (1935) found that the relationship of root material to organic matter in the upper layers in grassland soils in Nebraska was not linear, however, to depths of 1.2 and 3 m they found an approximately linear relation between the two. The explanation given in Weaver et al. (1935) for the lack of a strong linear relationship in surface layers would appear to apply to this study as well. They stated that the presence of a large amount of living plant parts in the surface soil and the favourable conditions for decomposition of dead plant material increases the proportion of root material to soil organic matter.

Intensity of grazing based upon the percentage of the original vegetation remaining was found to be unrelated to the weight of underground plant parts. It would appear that approximating intensity of grazing on the basis of the percentage original vegetation remaining does not reflect the fact that other species replace the climax species and these maintain the root biomass.

The reduction in content of organic matter in the soil under grazing would appear to be due to the removal of a large proportion of the aboveground biomass and a marked reduction in the plant material returned to the soil for decay and maintenance of soil organic matter levels. That the reduction in soil organic matter is related to intensity of grazing appears logical since sites with the lowest percentage original vegetation remaining have presumably been grazed heaviest and have experienced the removal of greater amounts of plant material than sites with a floristic composition closer to the original. An increase in the rate of decomposition of plant residues in the soil could also contribute to the decline of organic matter in this compartment. Coleman (1973), however, found that this was not the case and that rate of decomposition in soil was not significantly changed as a result of grazing.

Heavy grazing by livestock, for a relatively short time, has had a severe impact on the grasslands under study. The compaction of soil and the marked reduction in aboveground biomass found under heavy grazing in the present study causes increased runoff and erosion as shown in other studies. Rauzi and Hanson (1966) found that water intake more than doubled and runoff was practically eliminated on a lightly grazed area as compared to a heavily grazed area in South Dakota. Dunford (1954) reported that seven times as much erosion occurred on an area without mulch as compared to an area where mulch had accumulated for seven years on pine grasslands in Colorado. Heavy grazing and the accompanying erosion eventually leads to an alteration in the physical structure of surface soil from a desirable crumbly or granular structure to a platy or evenly-dispersed condition (Rauzi *et al*. 1968).

In addition to changes in soil structure and the decline in soil organic matter, overuse of rangeland will lead to radical changes in vegetation cover. Results of the present study showed that the mid-grasses were being replaced with short grasses and sedges, and forbs and shrubs had increased. Allowed to continue long enough, overuse will lead finally to a range dominated by unproductive weedy species.

Once the vegetation and soil characteristics of a range site have been altered by overuse, time and management are needed to change them. The time required to change a range from the poor condition class to the good or excellent condition class does not depend solely on the management of grazing. Vegetative changes and soil changes are much slower in semi-arid regions than in subhumid regions. Within a climatic region the time required varies also with soil type (Rauzi et al. 1968). Thus, in the management of rangeland, potential conditions and time required for restoration depend on climate as well as vegetative and soil characteristics.

The grazing load in Saskatchewan has almost doubled within the last twenty-five years, while the area of land available to grazing has declined slightly (Fig. 3 and 4). Indications are that the number of livestock on the Canadian prairies will continue to increase (Johnston 1972). The depletion of rangeland found in this study can only intensify unless land is taken out of crop production and put into forage production or seeded pasture.

The greater reduction in system organic matter under tillage as compared to that under grazing is reasonable when the degree of disturbance caused by these two land uses is considered. Grazing and cropping both remove a portion of the aboveground biomass which would normally be returned to the system to maintain organic matter levels, while tillage also stimulates microbial activity (Martel 1972, McCalla 1967, Porter 1969) and increases the decomposition of organic matter in soil. The grain and fallow system of land management, typical in the prairie region, has undoubtedly been responsible for the loss of large quantities of organic matter from soils. Reductions in the content of organic matter in soil leads to a deterioration of physical structure of the soil and a decline in the nutrients available for plant uptake as decomposition proceeds. It is recognized that it is impractical to attempt to maintain organic matter at original levels as biomass production can be maintained and even increased with addition of fertilizer nutrients but only as long as the physical structure of the soil does not become limiting. Thus it would appear that a minimum tolerable level of organic matter exists under which it may become uneconomical to produce cultivated crops. Practices such as grassing and minimum tillage must be employed to reduce the losses and stabilize the organic content at a level where productivity of the soil is not seriously impaired.

10. SUMMARY AND CONCLUSIONS

Quantitative data was collected on organic content of plant biomass aboveground and in the soil as underground plant parts and humus in the upper 35 cm layer in natural grassland in medium-textured soils near Saskatoon, Kyle and Maple Creek, Saskatchewan. The effect of texture of soil and of grazing and cultivation in soil of medium texture in modifying the distribution and amount of organic matter in the various subsystems was measured in sites near Saskatoon. Each system was sampled once, between late May and the end of July in 1974.

10.1 ABOVEGROUND BIOMASS

Total aboveground biomass and canopy biomass in ungrazed grasslands were significantly greater in loam soil than in sand soil. Weight of aboveground biomass was 657, 525 and 488 g/m^2, respectively, in loam, clay and sand soil. Canopy biomass followed the same trend; respective weights were 358, 262 and 214 g/m^2. Standing dead biomass was greatest in sand soil, although green-shoot biomass was considerably lower than in either loam or clay soil. Mulch and total dead biomass (mulch plus standing dead) varied little in soils of different texture. Weights of mulch were 299, 274 and 263 g/m^2 and weights of total dead biomass was 453, 444 and 403 g/m^2, respectively, in loam, sand and clay soil. Presumably more favourable conditions for decomposition in the more productive soils of medium and fine texture, due to better moisture conditions at the soil surface, results in a similar dead plant biomass in coarse-, medium- and fine-textured soils.

Greenhouse and field data indicated that floristic composition may affect weight of aboveground biomass in ungrazed sites through differential rates of decomposition of shoot material. Decomposition studies in the greenhouse showed that dead shoot material of *Agropyron dasystachyum* decomposed at a faster rate than either *Festuca scabrella* and *Stipa spartea* var. *curtiseta*. Standing dead biomass decreased with increased presence of *A. dasystachyum* ($r = -0.53$) in the study sites. Mulch weight was, however, unrelated to floristic compostion.

Heavy grazing reduced the percentage composition of *Agropyron* spp. and *F. scabrella* from 35 and 42 percent, respectively, to 20 and 6 percent, respectively, and increased percentage composition of *Stipa* spp. (from 13 to 26 percent), *K. cristata*, *B. gracilis*, *Carex* spp. and xerophytic forbs and shrubs. Aboveground biomass was reduced from 657 to 268 g/m^2. The greatest reduction occurred in the canopy biomass where mean weight declined from 258 to 82 g/m^2, while mulch weights were reduced from 299 to 186 g/m^2. A substantially higher organic content of mulch in the grazed sites compared to ungrazed sites appeared to indicate that trampling was a significant factor in transfer of canopy to mulch.

10.2 UNDERGROUND PLANT PARTS

Soil texture in ungrazed grassland significantly affected weight of underground plant parts in the upper 35 cm soil layer.

Weights in sand soil (1 004 g/m^2) were significantly lower than those in loam soil (1 480 g/m^2). In clay soil weight was intermediate at 1 218 g/m^2. Roots were more concentrated near the surface in clay and loam soil than in sand soil.

Grazing did not alter weight of underground plant parts, in the upper 35 cm soil layer. Mean weight in grazed and ungrazed sites was 1 475 g/m^2.

The deeper distribution of roots in sand presumably is due to the increased penetration of moisture in the soil profile, while the trend towards shallower rooting in finer-textured soils likely reflects more dependable supplies of soil moisture. Underground biomass was apparently maintained under grazing by the replacement of the dominant grasses with more xerophytic shallow-rooted species such as *Koeleria cristata*, *Carex* spp., *Bouteloua gracilis* and *Phlox hoodii*.

10.3 SOIL ORGANIC MATTER

Organic content of soil increased with increasing fineness of soil texture. Mean weight of soil organic matter, including weight of underground plant parts, in sand, loam and clay soil was, respectively, 15.2, 25.9 and 29.6 kg/m^2. Increased biomass production aboveground and underground and increasingly poorer aeration in finer-textured soil, resulting in less favourable conditions for decomposition, are likely explanations for the higher organic content in these soils.

Heavy grazing caused a 16.7 percentage decline in the content of organic matter in the top 15 cm of soil and had little effect below this depth. Weight of organic matter in this layer declined from 13.9 to 11.6 kg/m^2.

Cultivation for an average of 21 years reduced the soil organic matter content by 26 percent within the plough layer. Weight of organic matter declined from 13.9 to 10.4 kg/m^2 in this layer. Lower soil layers had undergone little change.

The decline in soil organic matter levels in grazed and cropped land is attributed to a reduction in the amount of plant material returned to the soil under grazing and cropping and the increase in the rate of decomposition as a result of tillage.

10.4 SOIL BULK DENSITY

Grazing and cultivation increased bulk density within the top 15 cm of soil. Under grazing, the largest increase occurred in the 2-4 cm layer where values increased from 0.79 to 1.04. Under cultivation, the largest increase occurred in the upper 6 cm layer of soil where values increased from 0.82 to 1.01.

10.5 TOTAL ORGANIC MATTER IN THE SYSTEM

Clay soil with 30.1 kg/m^2 had the greatest combined above-ground and underground weight of organic matter in ungrazed grassland to a depth of 35 cm. Loam soil had slightly less with 26.6 kg/m^2 and sand soil with 15.7 kg/m^2 had half that in clay soil. Sand soil had the largest proportion of the total system organic content aboveground; respective percentages in sand, loam and clay soil were 3.1, 2.4 and 1.7.

Grazing reduced organic matter in the system by 9.8 percent and cultivation reduced it further, by 13.6 percent. Weight losses were greatest in the soil organic matter compartment.

10.6 STUDY APPLICATION

Heavy grazing and intensive cultivation have seriously depleted organic matter levels in a relatively short time. With continued intensive use, the reduction in organic matter will eventually lead to a deterioration of soil physical structure and a lowered capacity for the production of grain or forage. Coarse-textured soils, with a considerably lower organic content than soils of finer texture are most susceptible to mismanagement. The judicious placement of cropland into forage production or seeded pasture would reduce grazing pressure in rangeland and at the same time reduce the loss of organic matter in the soil.

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APPENDIX A. Location and legal description of study sites.

Location	Site no.	Legal description*
Saskatoon	1	NE5-34-4
	2	SE1-36-6
	3	SE18-35-5
	4	NE8-37-4
	5	NW30-37-6
	6	SE34-36-3
	7	NE2-36-2
	8	NE8&NW9-38-3
	9	NE19&NW20-38-3
	10	SW29&NW20-38-1
	11	NW9&SW16-38-2
	12	NW13-38-1
Kyle	13	SW34-23-16
	14	NE32-23-16
Maple Creek	15	NW22-10-24
	16	NW34-10-24

* All sites were west of the third meridian.

APPENDIX B. Characterization of Soils in Study Sites.

In the following appendix the parent materials and textural range of the soils in the study sites are described.

B-1. Sites in Sand Soils

Sites 1, 2 and 3 were located in the Dune Sand Association. This association consists chiefly of very coarse to moderately coarse-textured Regosolic and weakly expressed Chernozemic soils developed on aeolian or wind-worked sandy glaciofluvial and lacustrine deposits. Surface textures of the Dune Sand soils are dominantly sand and loamy sand (Acton and Ellis 1978, Ellis _et al_. 1968).

B-2. Sites in Loam Soils

Sites 7 to 12 were in the Weyburn Association and sites 13 to 16 were in the Haverhill Association (Action and Ellis 1978).

The Weyburn Association comprises a group of Chernozemic Dark Brown soils formed under a grassland vegetation, developed in medium- to moderately fine-textured unsorted glacial till and occurring on undulating and rolling landforms. Loam, sandy loam and sandy clay loam parent material textures are most common. On the surface, loam textures are most common (Acton and Ellis 1978).

The Haverhill Association consists chiefly of Chernozemic Brown soils of medium- to moderately fine-texture, developed on unsorted glacial till. The parent material varies from loam to sandy clay loam in texture. Loam surface textures are most common (Ellis et al. 1968). Typical particle size distributions for the above two associations are given in Table B-1.

Table B-1. Typical particle size distributions of soil in the Weyburn and Haverhill Associations.

	Particle Size Distribution (%)		
Soil Layer	Sand	Silt	Clay
Weyburn:			
0-10 cm	52.8	28.9	18.3
10-20 cm	56.0	20.2	23.8
20-25 cm	58.8	20.4	20.8
25-48 cm	59.5	20.7	19.8
Haverhill:			
0-15 cm	48.2	28.8	23.0
15-25 cm	54.5	19.3	26.2
25-35 cm	44.7	28.9	26.4

After Action and Ellis 1978, and Ellis et al. 1968.

B-3. Sites in Clay Soils

Sites 4, 5 and 6 were situated in fine textured soils.

Site No. 4 was in the Sutherland Association. This Association comprises a group of chernozemic dark brown soils formed under grassland vegetation in moderately fine- to fine-textured glacio-lacustrine deposits. The parent material is usually clay textured but clay loam and heavy clay textures may also be encountered. Surface textures are primarily clay and clay loam. A typical particle size distribution of soil in the Sutherland Association is given in Table B-2 below.

Table B-2. Typical particle size distribution of soil in the Sutherland Association.

	Particle size distribution (%)		
Soil layer	Sand	Silt	Clay
0 - 5 cm	10.0	30.4	59.6
5 - 23 cm	9.2	33.7	57.1
23 cm +	6.6	78.0	65.4

After Acton and Ellis 1978.

Site No. 5 was situated in the Bradwell Association (Acton and Ellis 1978). Typically these soils have formed in medium- to moderately fine-textured, sandy glacio-lacustrine deposits and occur primarily on nearly level and undulating landscapes. The parent material is predominantly of a loam, fine and very fine sandy clay loam with clay loam, fine and very fine sandy clay loam textures occurring less frequently. The sandy lacustrine deposits are often quite shallow overlying glacial till, gravel, coarse sands and clays. Site No. 5 was situated on a side slope of a shallow depression in soil with clay texture.

Site No. 6 was located in an area with clay-textured soil originally mapped as Eston clay (Mitchell *et al.* 1944) and recently remapped as Runway Complex (Acton and Ellis 1978). The Runway Complex includes Chernozemic, Regosolic and Gleysolic soils of variable texture developed on a wide variety of glacial and recent deposits.