COMPARATIVE QUALITY OF PASTURAGE ON WESTERN CANADIAN RANGES

by

Thomas G. Willis

A Thesis submitted in Partial Fulfilment of the Requirements for the Degree of

MASTER OF SCIENCE IN AGRICULTURE

in the

Department of Agronomy

Approved.

for Dept. of Agronomy.

THE UNIVERSITY OF BRITISH COLUMBIA

April, 1947.

TABLE OF CONTENTS

ACKNOWLEDGEMENT

The author wishes to express his gratitude to Mr. L. B. Thomson, Superintendent of the Dominion Experimental Station, Swift Current, Saskatchewan, and to Mr. E. W. Tisdale, Head of the Division of Forage Crops and Rangeland Research at that Station, for their co-operation in furnishing facilities for the collection of samples, and authorizing the use of records and photographs.

A great deal of credit is due to Dr. V.C. Brink, Associate Professor of Agronomy at The University of British Columbia, for his keen interest, which provided inspiration for this problem and for his valuable guidance through the course of this study.

Abstract on p.40

COMPARATIVE QUALITY OF PASTURAGE ON WESTERN CANADIAN RANGES

INTRODUCTION

There is good reason to believe that the quality of range forage is quite as important as the quantity. While much attention has been given to the determination of dry matter yield per acre of the western range forages, studies of their quality have not often led to indicative conclusions.

Range types in Western Canada are fairly easily characterized by definite vegetation associations. Broad associations of vegetation are recognized in the shortgrass, mixed-grass and tallgrass prairies and in the low, mid- and upper grasslands of British Columbia. These associations reflect directly the soil and climate under which the vegetation develops and correlate well with the major soil groupings. Although differences in dry matter yields by zones are well established, variations in quality by zone have not been demonstrated. Many forage species individually have been appraised for quality, but these analyses have given little indication of the zonal picture.

Quality estimates, when related to dry matter yield, are valuable both to the ecologist and the nutritionist. The ecologist can appraise more precisely the value of the different ranges, and the specialist in nutrition obtains a guide for research in animal production. Accordingly, this work was undertaken to assess the quality of range forage in the major zones of the Western Canadian grasslands. In order to characterize the rangeland types, the yields of protein, calcium and phosphorus were determined. Further studies of this nature are necessary and would undoubtedly assist in completing the picture of the quality of vegetation in the different zones.

REVIEW OF LITERATURE

While there are many published papers in the general literature on the values of pastures, few of these refer specifically to the range pastures of the North West.

Clarke *et al* (7) have published on the vegetational composition of the grassland types of Southern Alberta, Saskatchewan, and Manitoba, and have proposed methods of determining the carrying capacity of those rangelands. In British Columbia, Tisdale (39) reported on chemical composition and ecology of the grassland plants. Moss (31) has shown graphically the relative abundance of native grasses in the rangelands of Southwestern Alberta. He has also included extensive descriptive notes on *Bouteloua-Stipa*, Festuca-Danthonia and Agropyron-Stipa-Carex associations. Smith (34) in allied associations proposes methods of estimating forage yields of native pastures.

In a recent bulletin Clarke and Tisdale (9) show the chemical composition of individual range species of the Canadian prairies. Dealing with Manitoba vegetation, Ellis and Caldwell (15) indicate that all low-land grass hays of that province are low in phosphate if measured by standards used elsewhere, and that late cutting of hay after the normal time lowers the phosphate content. Welch (43) reported on mineral deficiencies in forage of Montana range-lands, and Whitman (45) shows chemical analyses of North Dakota grasses. Tables of acreages of grasslands on the Canadian prairies are published along with a report on palatability and chemical composition of certain vegetation of the prairies (Clarke and Tisdale 8). Archibald (1) states that potassium has only minor significance in nutrition of grazing animals, and this appears to apply under western conditions. Other papers deal specifically with the total forage yield of various types of western vegetation. No reports, however, deal directly with forage quality in terms of yield of nutrients per acre.

METHODS

The obtaining of representative samples of vegetation types presents difficulties. In this study, sites which were judged to be typical of the faciation under consideration were selected, using quadrat and point sampling data obtained from previous work. All the sites were located in such a way that they could be clipped at about the same stage of maturity. Selection required the perusal of growth notes accumulated over a period of years.[1] All types studied were collected in the early part of the flowering stage of the dominant species of each association. This is considered the optimum time for cutting many grasses for hay (30,32).

Samples were taken on an acreage yield basis. A quadrat frame, one-half meter ($\frac{1}{2}m^2$) in area was used. To minimize personal bias, it was tossed at random in the selected site. All the forage encompassed by the frame was clipped at one and one-half ($1\frac{1}{2}$) inches above the surface of the soil. Grasses and forbs (broad-leaved plants) were clipped separately and put in separate bags. Care was taken to remove all the old or cured growth so that the sample represented one season's production. The quadrat was cast 4 to 6 times in each site and each clip was kept in a separate container.

---

[1]Data collected by Forage Division, Dominion Experimental Station, Swift Current, Saskatchewan.

Several sites were selected for each zone.

The bagged samples were then placed in a greenhouse and allowed to dry for several days under normal conditions. Weights were taken on a rough balance to the nearest one-tenth gram, and each sample weight was multiplied by a factor of 17.84 to give a yield in pounds per acre. All variates (weights in pounds per acre) for each vegetation type were included in a statistical analysis and standard deviations, means, and standard error of the means determined. The statistics are recorded graphically to show the degree of accuracy of sampling (33). The mean yields are compared with point sampling yield data and the correlation coefficient given.

For chemical determinations, all the material was ground through a 60-mesh screen in a Wiley mill and was dried to constant weight at 90 degrees. Crude protein was determined on the oven dry samples, using the Kjeldahl method essentially as adapted by Loomis and Shull (22), but using Hengar granules as a catalyst. A conversion factor of 6.25 was used on nitrogen assays to estimate crude protein (32). Phosphorus was determined colorimetrically (21) and calcium was determined by a standard macro-volumetric procedure (3). Total ash was determined by a method of Loomis and Shull (ibid) using a controlled muffle furnace. All analyses were reported on a basis of oven dry weight plus ten per-cent moisture. This was done so that results would be comparable with standard feedstuffs analysis (30).

AREA STUDIED

From Manitoba to Central British Columbia, broad soil zones can be characterized on the basis of the colour of the "A" horizon. In grasslands of relatively high effective moisture[1], organic matter tends to accumulate in the upper soil horizons. This, in turn, confers on these horizons a black colour. As moisture effectiveness becomes progressively less, the upper horizons assume dark brown to brown colours. While the zones, "the Black", "the Dark Brown", and "the Brown", extend broadly across the Western provinces, the vegetational associations or types are much more limited. Hence, in a given soil zone, "the Black", the Eastern faciations consist of tallgrasses, viz. Andropogons and Panicums; in the foothills of Alberta, a Festuca-Danthonia association develops. On the other hand, the Black soils which characterize the upper grasslands of British Columbia, include Festuca, Stipa and Poa as dominants. Thus, in order to obtain representative samples of vegetation from each broad soil zone, major vegetation associations within the zone had to be considered.

---

[1]It is recognized, of course, that moisture is not the sole factor conditioning this differential soil development. Complex interactions of moisture, temperature and vegetation are responsible.

BROWN SOIL ZONE

In the Brown soil zone, vegetation from five major associations was collected. These associations are: Shortgrass, Sandhill, Sceptre, Haverhill, all of Alberta and Saskatchewan, and the Lower Grassland of British Columbia. Of the zones considered, the Brown soil zone has developed under the lowest rainfall. It is characterized by a relatively low organic matter content and by a light brown "A" horizon. The upper horizon is invariably shallow with a layer, at a depth of six to fourteen inches, of hardpan with a high calcium content (29).

(a) Shortgrass prairie

The Shortgrass prairie occupies the southwestern section of Saskatchewan and the southeastern portion of Alberta. It comprises a large proportion of the Brown Soil Zone. This association has developed in areas which have a very low effective precipitation. The rainfall is less than fourteen inches per annum and the evaporation rate is high (9). In the faciation, the dominant species which comprises about 61.8 percent of the total grass cover is *Bouteloua gracilis* (blue grama grass). *Stipa comata* (needle-and-thread grass) is a sub-dominant grass which makes up about 24 percent of the grass cover. Other cognate species of grasses and herbs are given in Tables I, II and III.

(b) Sandhill

The Sandhill faciation is found in the region of the Great Sandhills of Southern Saskatchewan. It comprises the vegetation growing in the sandy areas which are stabilized. The samples reported on are from both medium textured and sandy soils. The grasses in the sample are palatable, but their yield is poor (Table I). The forbs and shrubs, which produce a relatively heavy cover, however, are quite unpalatable. The shrubs were not included in the samples.

(c) Sceptre prairie

This faciation is found on heavy textured soils developed on uniform clay deposits occupying the beds of former glacial lakes (29). As the soils are highly productive, the acreage remaining in native pasture is small. Most of the arable land is used for the production of cereal crops. The ecological principle, that fewer native species are found on the more productive soils, is well illustrated in a study of the species composition of this faciation. Hence the grass cover is made up of only three co-dominants, Agropyron dasystachyum (northern wheatgrass), Koeleria cristata (june-grass) and Stipa viridula (green speargrass). There are few forbs of importance.

(d) Haverhill prairie

This vegetational type covers approximately one-half of the area of the Brown soil zone and constitutes the largest unit of "mixed prairie". The species found in Haverhill prairie vegetation are both short and medium-tall grasses forming a mixture which marks a transition between the shortgrass and tallgrass prairies. The principal grasses in order of importance are: Stipa spartea var. curtiseta (short-awned porcupine grass), Koeleria cristata (junegrass), Agropyron spp. (wheatgrasses), and Bouteloua gracilis (blue grama grass) (See Table II).

The above types constitute typical faciations in the Brown Soil Zone of the Prairie Provinces. There are many other vegetational associations withim the zone, but none of these is sufficiently different or important to warrant a special designation here. The samples from the above areas were collected from the Swift Current District in Southern Saskatchewan.

(e) B.C. Lower Grassland

To show a comparison of vegetation of the Brown soils of the prairies and the Brown soils of British Columbia, samples were collected from the Lower Grasslands at Kamloops, B.C. This type is between 1200 and 2100 feet altitude, in a zone of low precipitation and high summer temperatures. The plant cover is sparse and composed chiefly of Agropyron spicatum (bluebunch wheatgrass), Stipa comata (needle-and-thread grass), Sporobolus cryptandrus (sand dropseed), and Poa secunda (Sandberg's bluegrass). Artemesia tridentata (sagebrush) often appears to be co-dominant with the above grasses. Most of the lower grasslands have been overgrazed, but the vegetation from the areas selected for sampling approaches the original climax cover of the lower grasslands.

DARK BROWN SOIL ZONE

The soils of this zone have a darker brown colour, probably because of their slightly higher organic matter content. The zone enjoys somewhat higher rainfall and a lower evaporation rate than the Brown Soil zone. The vegetation makes a denser cover, and taller growth and, in favourable areas, small "bluffs" of trees and shrubs are found, forming parklands. The chief species of this zone are *Agropyron spp*. (wheatgrasses), *Festuca scabrella* (rough fescue), *Koeleria cristata* (junegrass), *Stipa comata* (needle-and-thread grass), *Stipa spartea car. curtiseta* (short-awned porcupine grass), *Festuca idahoensis* (Idaho fescue), and *Poa pratensis* (Kentucky bluegrass). In British Columbia, a principal forb of the Dark Brown area is *Balsamorhiza sagittata* (balsamroot).

BLACK SOIL ZONE

The Black Soil zone of the prairies is coincident with the area commonly spoken of as "the Park Belt". The rainfall is higher and evaporation rate lower than in the Dark Brown zone. The soils are very dark in colour and support a lush growth of vegetation. Although the soils in this zone are fundamentally grassland soils, "bluffs" of trees are very numerous.

The area selected for sampling in Alberta was in the foothills region, west of Muirhead, Alberta. Here the dominant species are: Festuca scabrella (rough fescue), Danthonia Parryi (Parry's oatgrass), and Koeleria cristata (junegrass). The principal forb is Potentilla fruiticosa (shrubby cinquefoil).

Samples representing vegetation of the Black Soils of Manitoba were collected near Balmoral. Two types were sampled. One of them, the native tallgrass prairie association, is made up principally of Andropogon furcatus (big bluestem), Andropogon scoparious (little bluestem), Panicum virgatum (switchgrass) and Stipa spartea (porcupine grass). The other type is made up primarily of Poa pratensis (Kentucky bluegrass), which has invaded the native pastures and now exists in nearly pure stands. Samples of this invader were collected in order to compare it with the native species in reference to yield and quality.

The Black Soils area selected in Saskatchewan was in the high levels of the Cypress Hills. The principal forage species are Festuca scabrella (rough fescue), Danthonia intermedia (wild oatgrass), and Agropyron trachycaulum (awned wheatgrass). Again, Potentilla fruiticosa (shrubby cinquefoil) is the principal forb.

In British Columbia, the Black Soils occur associated with the upper grassland between the altitudes of 2800 and 3100 feet. There is a dense cover of grasses here similar to those in the Black Soils of the Cypress Hills. Stipa columbiana (Columbia needlegrass) is found im addition to those grasses mentioned for the Black Soils of the Cypress Hills. Also, the cover of forbs is important and may constitute a major portion of the grazable forage.

SHALLOW BLACK SOIL ZONE

This zone marks a transition between the Dark Brown and Black Soils zones in Alberta. The relatively shallow nature of the "A" horizon has resulted from a high rate of evaporation and also a fairly high initial lime content of the parent soil (48). These soils are practically all grassland soils in their native state. The principal forage species are Danthonia Parryi (Parry's oatgrass) and Festuca scabrella (rough fescue). The region selected for sampling was west of Cochrane, Alberta.

GREY WOODED SOIL ZONE

Samples of forage from this zone were taken from the lower Montane Forest zone (3000 to 4200 feet altitude) in the Kamloops district. Samples were taken for comparative purposes only and may mot be representative of all Grey Wooded vegetation. The grass cover is made up almost entirely of Calamagrostis rubescens (pinegrass). The more important forbs are Aster conspicuus (showy aster), _Lathyrus ochroleucus_ (pea vine), _Vicia americana_ (American vetch), _Astragalus serotinus_ (timber milk-vetch), and _Arnica cordifolia_ (arnica).

Table I shows the botanical composition of the grass sward in the several vegetation associations. "Stipa units" express the percentage cover of each grass on a comparable basis (7). In the determination of these forage units, all grasses are given values relative to _Stipa comata_, giving it a value of 1.0. The yield in pounds per acre is based on point sampling data, assuming that a cover of 100 percent _Stipa comata_ yields 5000 pounds of dry matter per acre (7). The "Relative percentage" column shows the relative amounts of each species in the total grass cover, based on point sampling only.

Table II shows the botanical composition of the forbs fraction in the different associations. It will be noticed that all of the associations do not have botanical data. The yield data in Table II will be referred to later.

TABLE I[1]

The Relative Percentage Botanical Composition of Range Types and the Yield of Each Type

FORAGE SPECIES	SHORTGRASS PRAIRIE		SANDHILL		SCEPTRE PRAIRIE		HAVERHILL PRAIRIE		SASKATCHEWAN DARK BROWN	
	Stipa units	Rel. %	Stipa units	Rel. %	Stipa units	Rel. %	Stipa units	Rel. %	Stipa units	Rel. %
Agropyron dasystachyum	.35	6.13	.04	.62	5.81	59.34	2.00	17.06	.07	.64
Agropyron Smithii			.21	3.22	.60	6.13	.08	.68	3.71	33.70
Agropyron trachycaulum									.17	.64
Avena Hookeri										
Bouteloua gracilis	3.53	61.82	1.88	28.80			.93	7.93	.58	5.27
Calamagrostis montanensis							.01	.09		
Calamavilfa longifolia			.01	.11						
Danthonia intermedia									.07	.64
Danthonia Parryi										
Festuca idahoensis										
Festuca scabrella							.06	.52	.42	3.80
Koeleria cristata	.14	2.45	.03	.46	2.13	21.75	1.37	11.68	1.16	10.54
Poa secunda	.03	.53	.01	.14						
Poa spp.							.03	.26	.03	.27
Sporobolus cryptandrus			.22	3.38						
Stipa comata	1.40	24.51	3.05	46.71			1.96	16.72	.35	3.18
Stipa spartea var. curtiseta	.14	2.45	.77	11.80			3.70	31.57	2.87	26.07
Stipa viridula					1.14	11.65	.04	.34		
Carex filifolia	.12	2.11	.31	4.76						
Carex heliophila									1.68	15.25
Carex spp.										
Juncus ater										
Eurotia lanata					.11	1.14				
TOTAL FORAGE UNITS	5.71		6.53		9.79		10.18		11.01	
NUMBER POINTS TAKEN	2000		4800		5500		5600		4000	
YIELD IN POUNDS PER ACRE	285		326		489		509		550	

[1] Data consists partly of records of past years collected at Swift Current, Sask.

<u>Table I (continued)</u>

	ALBERTA DARK BROWN		SASK. BLACK		ALBERTA BLACK		ALTA. SHALLOW BLACK	
	Stipa units	Rel. %	Stipa units	Rel. %	Stipa units	Rel. %	Stips units	Rel. %
Agropyron dasystachyum	2.16	17.06						
Agropyron Smithii			.08	.41				
Agropyron trachycaulum			.92	4.74				
Avena Hookeri			.07	.36				
Bouteloua gracilis								
Calamagrostis montanensis								
Calamavilfa longifolia								
Danthonia intermedia			.49	2.53				
Danthonia Parryi					7.81	26.55	10.08	92.59
Festuca idahoensis	2.98	25.62						
Festuca scabrella	2.79	23.99	15.28	78.76	18.90	64.27	1.21	7.41
Koeleria cristata			.03	.15	2.70	9.18		
Poa secunda								
Poa spp.								
Sporobolus cryptandrus								
Stipa comata								
Stipa spartea var. curtiseta			.46	2.37				
Stipa viridula								
Carex filifolia								
Carex spp.			1.98	10.22				
Carex heliophila								
Juncus ater			.09	.46				
Eurotia lanata								
TOTAL FORAGE UNITS	11.63		19.40		29.41		15.12	
NUMBER POINTS TAKEN	2000		3000		2000		2000	
YIELD IN POUNDS PER ACRE	581		970		1470		756	

TABLE II

The Relative Percentage Botanical Composition of Forbs in the Different Range Types[1]

SPECIES	RELATIVE PERCENTAGE OF TOTAL FORBS					
	SHORT-GRASS	SANDHILL	SCEPTRE	HAVER-HILL	SASK. DARK BROWN	SASK. BLACK
Achillea lanulosa						.88
Antennaria microphylla			1.23			
Artemesia cana	33.33	3.05			1.64	
Artemesia frigida	26.93	73.70	13.58	7.39	68.86	.90
Atriplex Nuttallii					1.64	
Cerastium campestre						1.79
Chenopodium leptophyllum		2.54				
Gutierrezia diversifolia		.38				
Lithospernum linaerifolium	.64					
Malvastrum coccinium		.38		.24		
Phlox Hoodii	1.93		6.79	3.15		
Potentilla fruiticosa						76.71
Psoralea lanciolata		.38				
Rosa spp.	.64	5.08		.86		
Selaginella densa	30.77	5.34		78.90	27.86	9.85
Sieversia trifolia						2.99
Solidago glaberrima				.24		3.88
Carex eleocaris[2]	5.76	9.15	77.78	9.21		
TOTAL PERCENTAGE	100.00	100.00	100.00	100.00	100.00	100.00

[1]Relative percentage of total forb cover. Data partly compiled from records at Dom. Expt. Sta., Swift Current, Sask.

[2]Carex eleocaris included with the forbs as it is not given a forage rating but constitutes a major portion of the cover.

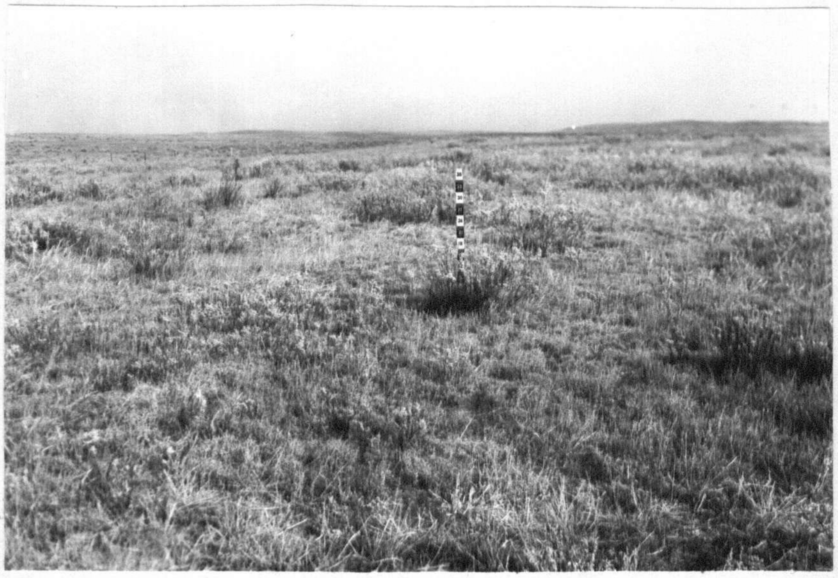

PLATE I. Shortgrass prairie faciation.

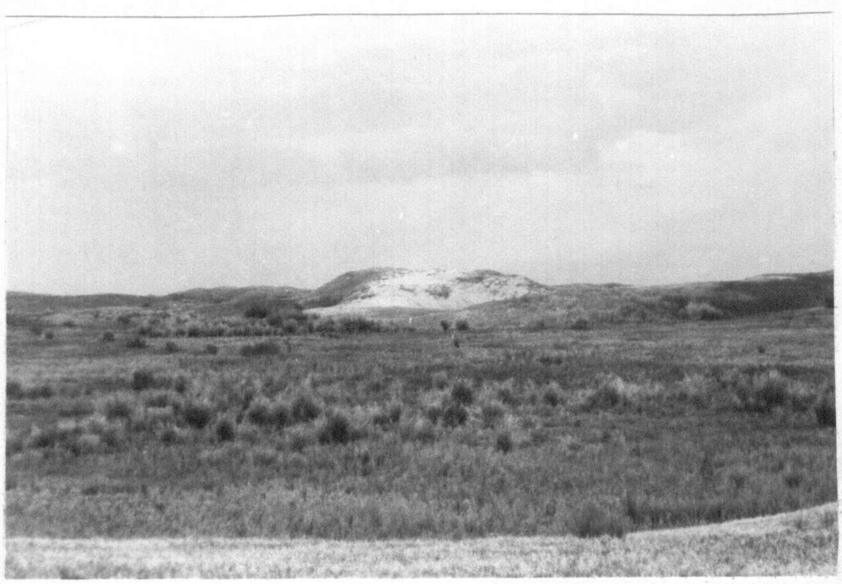

PLATE II. Sandhill faciation.

PLATE III. Sceptre prairie faciation.

PLATE IV. Haverhill (mixed) prairie faciation.

PLATE V. Alberta Black Soils faciation.

PLATE VI. British Columbia mid-grassland.

PLATE VII. British Columbia lower grassland.

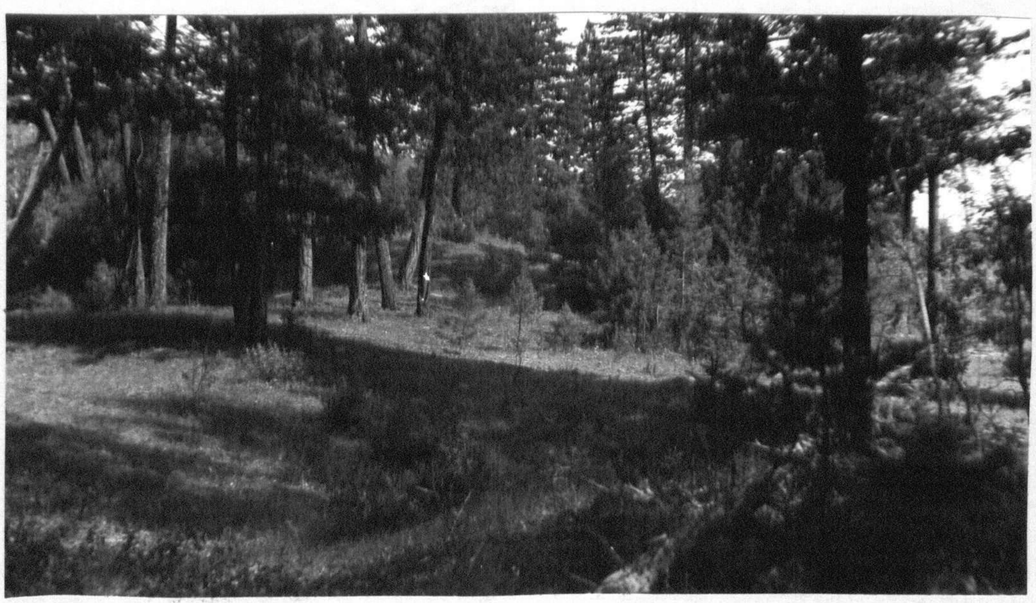

PLATE VIII. British Columbia Grey Wooded.
(Montane forest)

EXPERIMENTAL RESULTS

Figure I illustrates the dry matter yields of forage on different soil types, obtained by clipping. The solid sections of the bars indicate the grass yields and the cross-hatched portions indicate the forb yields. The complete bars show total yields of the associations. The graph shows the progressively higher production from the Brown Soil zone to the Black Soil zone. It also indicates the fact that relatively fewer forbs occur as the more productive zones are approached. For purposes of comparison, yields obtained from point sampling data are, as aforementioned, given in Table I.

Figure II is used to show the accuracy of dry matter sampling. It employs three statistics: the mean yield per acre (the centre cross bar of each graph); the sampling range (the length of the bar above and below the mean); and the theoretical sampling range (the cross-hatched portion). The theoretical range is represented as twice the standard error above and below the mean (33). In associations where the theoretical range approaches the sampling range (e.g., Sceptre prairie), the sampling is obviously more accurate. In the Shortgrass prairie associations, for example, the sampling range appreciably exceeds the theoretical range. Thus, this sampling may not be representative. The graph for forage from the higher yielding types (e.g., Alberta foothills) shows a large difference between actual and hypothetical ranges. In this case it is not serious because the forage yield is over twice as great as the Shortgrass yield, and the error is therefore no greater. It must be borne in mind that if the coefficient of variability were used, the higher yielding associations would show a lower relative error.

The point sampling yields were correlated with the dry matter yields of Figures I and II. A positive correlation of 0.91 was obtained. Accordingly, it can safely be assumed that dry weight sampling as conducted in these experiments would agree with more extensive samplings by the Point Technique.

Table III designates the results of chemical analyses of the forage. The percentage is given for protein, calcium, phosphorus and ash. The yields of the above constituents with the exception of ash are expressed in pounds per acre. Table IV gives the same data arranged to show differences in constituent yields between the major zones.

A very marked increase in the production of protein, calcium and phosphorus from the Brown Soils to the Black Soils is demonstrated. The data for Shallow Black, Grey Wooded and Alluvial Soils are few and hence should only be used for broad comparison. In each type, the grass characterizes the productivity and quality more accurately than the forbs. Hence, the data for grasses and forbs are given separately. Also, the analyses for the broadleaved vegetation are more variable and may be misleading if they are used alone.

FIGURE I

Graph showing Yields of Forage per acre for all Vegetational Associations studied. (Solid portion of bar depicts grass yield; cross-hatched portion-forb yield)

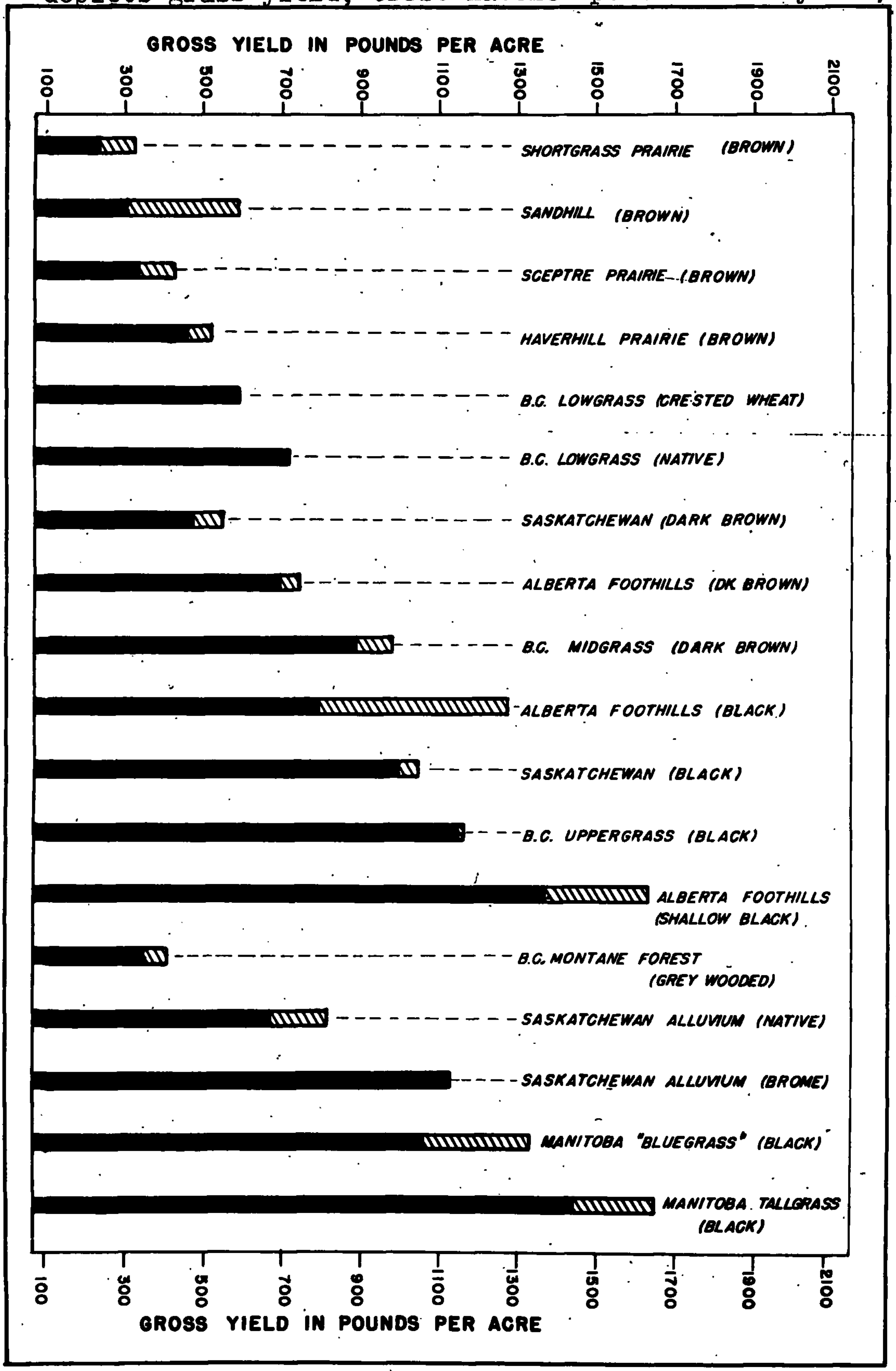

FIGURE II

Graph showing Mean Yields of Forage per Acre and Accuracy of sampling these Yields. (Total bar represents actual, cross-hatched theoretical sampling ranges.)

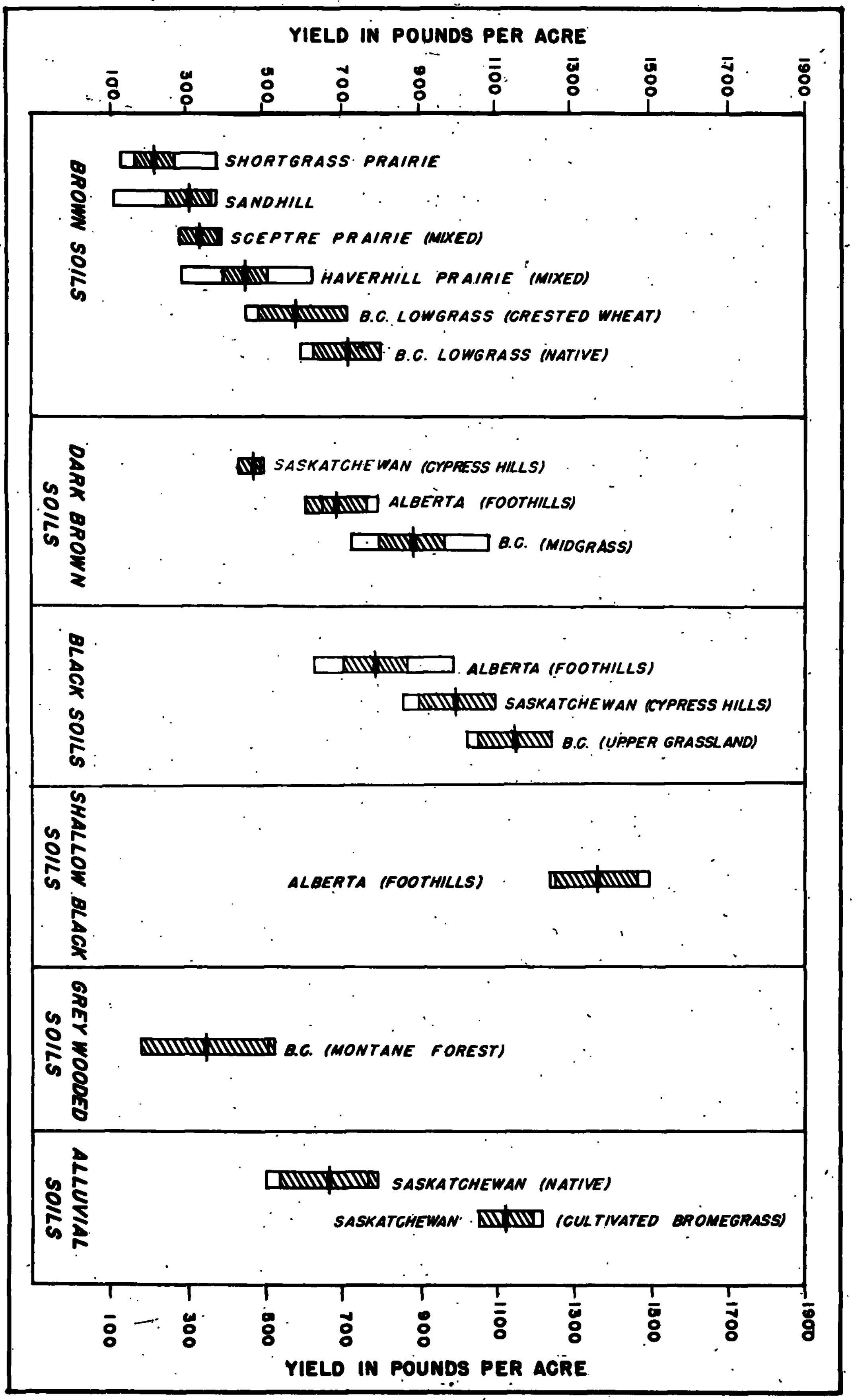

TABLE III

The Chemical Composition of the Grassland Associations and the Constituent Yields per Acre. (Results, Moisture-free plus 10%.)

SOIL ZONE	VEGETATION ASSOCIATION	FORAGE	YIELD lb./A	PROTEIN %	PROTEIN lb./A	CALCIUM %	CALCIUM lb./A	PHOSPHORUS %	PHOSPHORUS lb./A	ASH %	Ca:P RATIO
BROWN	Shortgrass prairie	Grass	218	10.37	22.6	.50	1.1	.18	.4	6.60	2.75:1
		Forbs	105	10.73	11.2	.79	.8	.28	.3	6.66	2.67:1
		Total	323		33.8		1.9		.7		2.71:1
	Sandhill	Grass	305	9.81	29.9	.41	1.2	.19	.6	5.99	1.97:1
		Forbs	286	10.26	29.3	.85	2.4	.06	.2	11.97	12.00:1
		Total	591		59.2		3.6		.8		4.50:1
	Sceptre prairie	Grass	337	9.05	30.5	.50	1.7	.24	.8	8.56	2.12:1
	Haverhill prairie	Grass	452	9.63	43.5	.38	1.7	.18	.8	7.21	2.12:1
		Forbs	61	9.67	5.9	.74	.4	.30	.2	5.92	2.00:1
		Total	513		49.4		2.1		1.0		2.10:1
	B.C. Lowgrass[1]	Grass	584	5.60	32.7	.28	1.6	.23	1.3	8.77	1.23:1
	B.C. Lowgrass[2]	Grass	717	8.82	63.2	.23	1.6	.22	1.6	11.67	1.00:1
DARK BROWN	Sask. (Cypress Hills)	Grass	472	7.20	34.0	.31	1.5	.22	1.0	8.76	1.50:1
		Forbs	70	8.55	6.0	.79	.6	.11	.1	6.91	6.00:1
		Total	542		40.0		2.1		1.1		1.91:1
	Alberta (Foothills)	Grass	691	7.70	53.2	.19	1.3	.18	1.2	8.61	1.08:1
		Forbs	49	8.73	4.3	.82	.4	.19	.1	6.44	4.00:1
		Total	740		57.5		1.7		1.3		1.31:1
	B.C. (Midgrass)	Grass	886	6.37	56.4	.34	3.0	.19	1.7	10.29	1.76:1
		Forbs	93	5.15	5.8	.28	.3	.08	.1	14.06	3.00:1
		Total	979		61.2		3.3		1.8		1.83:1

(Continued)

[1]Crested wheatgrass (reseeded)
[2]Native

Table III (continued)

SOIL ZONE	VEGETATION ASSOCIATION	FORAGE	YIELD lb./A	Protein %	Protein lb./A	Calcium %	Calcium lb./A	Phosphorus %	Phosphorus lb./A	ASH %	Ca:P RATIO
BLACK	Alberta (Foot-hills)	Grass	789	6.65	52.5	.31	2.4	.16	1.3	7.28	1.94:1
		Forbs	484	9.95	4.8	1.98	9.6	.17	.8	7.21	12.00:1
		Total	1273		57.3		12.0		2.1		4.78:1
	Sask. (Cypress Hills)	Grass	998	6.70	66.9	.29	2.9	.19	1.9	11.01	1.53:1
		Forbs	43	10.00	4.3	1.45	.6	.18	.1	8.34	6.00:1
		Total	1041		71.2		3.5		2.0		1.77:1
	B.C. (Upper-Grass)	Total	1150	6.29	72.3	.32	3.7	.21	2.4	9.93	1.54:1
	Manitoba Tallgrass[1]	Total	1330	9.91	131.8	.28	3.7	.15	2.0	6.91	1.85:1
	Manitoba Tallgrass[2]	Total	1645	6.08	100.0	.23	3.8	.13	2.1	7.23	1.81:1
SHALLOW BLACK	Alberta (Foot-hills)	Grass	1364	6.64	90.6	.23	3.1	.10	1.4	5.53	2.21:1
		Forbs	262	7.63	20.0	1.34	3.5	.28	.7	6.15	5.00:1
		Total	1626		110.6		6.6		2.1		3.14:1
GREY WOODED	B.C. (Montane Forest)	Grass	347	6.40	22.2	.13	.4	.20	.7	18.28	.57:1
		Forbs	54	9.77	5.3	1.18	.6	.36	.2	9.61	3.00:1
		Total	401		27.5		1.0		.9		1.11:1
ALLU-VIAL	Sask.[3]	Grass	672	9.47	63.6	.28	1.9	.21	1.4	7.86	1.36:1
		Forbs	139	9.81	13.6	.59	.8	.19	.3	5.74	2.67:1
		Total	811		77.2		2.7		1.7		1.58:1
	Sask.[4]	Grass	1123	6.29	70.6	.40	4.5	.16	1.8	8.05	2.50:1

[1] Invaded by Kentucky bluegrass

[2] Native

[3] Native

[4] Bromegrass (reseeded)

TABLE IV

The Yield of Nutrients per Acre by Major Soil Zone

SOIL ZONE	NUMBER SITES	NUMBER SAMPLES	PROTEIN lb/A	CALCIUM lb/A	PHOS-PHORUS lb/A	FORAGE YIELD lb/A	Ca:P RATIO
BROWN							
Grass			37.0	1.5	.9	435	1.67:1
Forbs			7.7	.6	.1	75	6.00:1
Total	11	48	44.7	2.1	1.0	510	2.10:1
DARK BROWN							
Grass			47.9	1.9	1.3	683	1.46:1
Forbs			4.9	.4	.1	70	4.00:1
Total	4	24	52.8	2.3	1.4	753	1.64:1
BLACK							
Grass[1]			59.7	2.6	1.6	893	1.62:1
Forbs[2]			4.5				
Total[3]	6	36	85.6	5.3	2.1	1288	2.52:1
SHALLOW BLACK							
Grass			90.6	3.1	1.4	1364	2.21:1
Forbs			20.0	3.5	.7	262	5.00:1
Total	2	8	110.6	6.6	2.1	1626	3.14:1
GREY WOODED							
Grass			22.2	.4	.7	347	.57:1
Forbs			5.3	.6	.2	54	3.00:1
Total	2	12	27.5	1.0	.9	401	1.11:1
ALLUVIAL							
Grass			63.6	1.9	1.4	672	1.35:1
Forbs			13.6	.8	.3	139	2.67:1
Total[4]	2	8	77.2	2.7	1.7	811	1.59:1
Culti-vated grass[5]			70.6	4.5	1.7	1123	2.50:1

[1,2] Average for Alberta and Saskatchewan Black Soil Zone.

[3] Average of Total Forage of all Associations in Black Soil Zone

[4] Native Vegetation.

[5] Bromegrass on same soil type as 4.

DISCUSSION

Table III contains the data for all of the grassland associations. Throughout the discussion, however, the same data are reorganized for easy appraisal and for clearer development of the zonal picture.

Calcium.

The Calcium percentage for the vegetation of the major zones does not correlate significantly with rainfall or soil type. In pounds per acre, the calcium, as shown in Table V, increases from the Brown Soils to the Black. The forbs in the Shallow Black zone, it can be seen, show a high calcium yield. This may be associated with the calcium carbonate layer which lies only a few inches below the surface of the soil.

TABLE V
The Percentage and Yield of Calcium by Major Soil Zone

SOIL ZONE	GRASS		FORBS		TOTAL FORAGE	
	% Ca.	lb/A Ca.	% Ca.	lb/A Ca.	% Ca.	lb/A Ca.
BROWN	.35	1.8	.82	.6	.42	2.1
DARK BROWN	.28	1.9	.58	.4	.31	2.3
BLACK	.30	2.6			.25	5.3
SHALLOW BLACK	.23	3.1	1.34	3.5	.40	6.6
GREY WOODED	.13	.4	1.18	.6	.27	1.0
ALLUVIUM	.28	1.9	.59	.8	.34	2.7

Watkins states (42) that the calcium content of forage must not fall below 0.25 percent for the normal nutritional requirement of animals. With the exception of the grasses of the Grey Wooded zone, none of the zonal forage tells a story of calcium deficiency. In the Grey Wooded zone, however, the calcium content of the many palatable forbs is high. Hence, there may actually be no calcium deficiency in the grazed forage of this zone.

Daniel states (13) that when the effective rainfall is low, the calcium content of the forage increases and the phosphorus content decreases. This may account for the high calcium content of the grasses of the Sceptre, Shortgrass and Sandhill associations which are all in a region of extremely low effective precipitation.

Phosphorus

The phosphorus percentage shows a zonal decrease from the Brown to the Black soils (Table VI). On the other hand, the yield in pounds per acre is progressively greater from the Brown soils to the Black soils. The phosphorus content of forage plants for grazing animals, commonly accepted as a minimum, is 0.12 percent (38). None of the samples on this basis, with the exception of the Shallow Black soils vegetation, shows a deficiency of phosphorus at the stage of development at which they were clipped. At maturity, however, the associations which have the lowest phosphorus content according to the data presented would probably be seriously deficient. This is borne out in the literature where statements are made of serious phosphorus deficiencies im certain Shortgrass pastures (9,43,44) and Manitoba meadows (15).

Too much emphasis should not be placed on phosphorus and calcium percentages considered singly. The ratio of calcium to phosphorus is highly important. In general, a ratio between 2:1 and 1:2 is considered optimum for animal nutrition. Although the phosphorus percentage in most of the associations sampled does not appear to warrant concern, the calcium to phosphorus ratio in some of the types is dangerously wide. Phosphorus deficiency must occur at times in the Brown and Shallow Black zones where the calcium to phosphorus ratios are very wide, even in immature forage. (Table VII).

Greaves (17), it might be added, has found that total phosphorus is a general indicator of the nutritive value of the plant. Phosphorus correlates negatively with ash content and positively with protein content. Corroboration of these facts is found in the data in Table I. It is of interest, also, to note that Greaves (ibid) finds high ash content associated with low crude fat, and fat and carbohydrate associated with a decrease in calcium content. This shows that the nutritive values of high calcium plants are as a rule lower than low calcium plants. There is a high correlation between ash and calcium, ash and magnesium, ash and sulfur, and a negative correlation between calcium and nitrogen-free-extract, phosphorus and crude fibre and crude fibre and crude protein (17).

TABLE VI
Percentage and Yield of Phosphorus by Major Soil Zone

SOIL ZONE	PHOSPHORUS					
	Grass		Forbs		Total	
	%	lb/A	%	lb/A	%	lb/A
BROWN	.21	.9	.15	.1	.20	1.0
DARK BROWN	.19	1.3	.11	.1	.18	1.4
BLACK	.18	1.6	.		.16	2.1
SHALLOW BLACK	.10	1.4	.28	.7	.13	2.1
GREY WOODED	.20	.7	.36	.2	.22	.9
ALLUVIUM	.21	1.4	.19	.3	.20	1.7

TABLE VII
Calcium-Phosphorus Ratios by Major Soil Zone

SOIL ZONE	GRASS	FORBS	TOTAL FORAGE
BROWN	1.67:1	6.00:1	2.10:1
DARK BROWN	1.46:1	4.00:1	1.64:1
BLACK	1.62:1		2.52:1
SHALLOW BLACK	2.21:1	5.00:1	3.14:1
GREY WOODED	0.57:1	3.00:1	1.11:1
ALLUVIUM	1.35:1	2.67:1	1.59:1

Protein

Many interesting conclusions may be drawn from the results of the nitrogen assays. It has been common practice in the past to rate all range pastures equally in reference to the production of nutrients. Thus one finds little relationship of the grazing charges on rangelands to their productivity. It was shown that the grasses of the drier areas possessed a higher protein percentage than those of the more humid areas. It was erroneously believed that the low percentage protein and high forage yield on one hand tended to balance the high percentage protein and low forage yield on the other. Some, on this basis, have believed that the protein yields per acre of all pasture types are approximately equal.

TABLE VIII

The Percentage and Yield of Crude Protein (N x 6.25) by Major Soil Zone

SOIL ZONE	PROTEIN					
	Grass		Forbs		Total	
	%	LB/A	%	LB/A	%	LB/A
BROWN	8.59	37.0	10.23	7.7	8.75	44.7
DARK BROWN	7.01	47.9	6.94	4.9	7.01	52.8
BLACK	6.68	59.7			6.72	85.6
SHALLOW BLACK	6.64	90.6	7.63	20.0	6.80	110.6
GREY WOODED	6.40	22.2	9.77	5.3	6.86	27.5
ALLUVIUM	9.47	63.6	9.81	13.6	9.52	77.2

In Table VIII we find a definite decrease in protein percentage in the forage as we go from the Brown soils to the Black soils. In spite of this, the yield of protein in pounds per acre increases as we get into the more humid zones. It follows then that the yield of other nutrients might also be greater in the more productive soils. A consideration of the yields of calcium and phosphorus in Tables V and VI supports this belief.

The question might arise: Why should so much attention be placed on protein when rating the quality of pasturage? The universal importance of protein has been observed for over a century. In fact, the nutritive importance of proteins and the dependence of animals on plants for these substances were first pointed out by G.J. Mulder[1] around 1841 in The Chemistry of Animal and Vegetable Physiology. He said:

> " In both plants and animals a substance is contained, which is produced within the former, and imparted through their food to the latter. It is unquestionably the most important of all known substances in the organic kingdom. Without it no life appears possible on this planet. Through its means the chief phenomena of life are produced. "

A few years later, Boussingault, writing in the Economie Rurale (Paris, 1851) said:

> " The alimentary virtues of plants reside above all in the nitrogenous substances, and consequently their nutritive potency is proportional to the quantity of nitrogen entering into their composition. "

In 1923, Osborne and Mendel summarized the then current ideas on the nutritive values of protein foods as follows:

> " The proportion of protein in the diet may determine whether larger or smaller absolute amounts of the nitrogenous foodstuffs are consumed; but the actual intake of these also is modified by the character of the non-protein ingredients. The individual instinctively strives to satisfy its calorific needs. A diet rich in fats is consumed in smaller quantity than one poor in fats, consequently the absolute protein intake may vary independently of its concentration or percentage in the food. When the absolute intake is small 'the law of minimum' may come into play to limit the efficiency of the whole because of the relative shortage of the essential amino-acid ...

---

[1] Imperial Bureau of Nutrition.
Nutrition Abstracts and reviews. 1946, 16:2 pp.10,11.

" Conversely, when an animal ingests a very large quantity of some protein poor in an essential unit, the absolute amount of the latter thereby available from the great abundance of its precursor may suffice to promote nutritive effects that fail to appear on a lower plane of protein intake. "

More recently, it has been shown by various workers (4, 17) that the quantities of protein are very closely related to the quantities of accessory growth factors in forage. It has been pointed out, furthermore, that protein bears an inverse relationship to fibre and lignin. Thus one may immediately conclude that protein values for forages are good indicators, not only of one important nutrient, protein, but also other intrinsic constituents which are less readily determined or defined.

The assumption seems justified, then, that protein is a very important feature in pasture quality estimation. Higher rates of gain have been noted in higher protein pastures. Why should this occur?

The answer to this question perhaps does not lie only in the relationship of protein to other growth factors but it may also lie in the narrower carbon-to-nitrogen ratio for the bacterial flora in the digestive systems of the grazing animals. If, because of the abundant supply of nitrogen, bacterial activity were stimulated, it would appear logical that more fibre or cellulose would be broken down in the digestive systems of the animals (41). Assuming that such a condition favours cellulose fermentation, it is suggested that the forage is more completely digested and utilized because of the accelerated bacterial activity. Coincident with the breakdown of fibre, there will, of course, be an increase in bacterial numbers. This increase should be reflected in an increase in bacterial protein available to the animal. The possible significance in bacterial feeding of protein has been shown by Scharrer and Strobel (26).

In regard to the vegetation of the Shortgrass region, where the ground cover is sparse but where the forage is high in protein, the pasturage has a high quality. In this region the "fill" of animals is smaller and the digestibility is then increased (4). Again, with the droughty conditions of the region, the feed remains in the digestive systems of the animals for a longer period with a resultant increase in the digestibility. Accordingly, there might, because of these various factors, be a higher percentage digestibility of the forage in the Shortgrass areas. This, in turn, would explain the relatively higher rates of gain of livestock in the region. Final proof of various aspects of this concept must await additional research under controlled conditions. It is seen, however, that the pastures of the Brown Soil zone are high in quality when based on protein content.

Pasture Appraisal in Relation to Protein Production

Knowing that:

(a) An animal must have protein, energy, minerals, vitamins, and other factors less easily defined;

(b) carbohydrate cannot substitute for protein, but protein can act as a source of energy; and,

(c) the caloric values for protein and carbohydrate are almost equivalent (4),

and assuming that all forage associations at equal consumption rates possess equal digestibility,

THEN the ratio of total forage yield per acre to protein yield per acre on any grassland vegetational association should be indicative of the quality of that association in terms of a limiting nutritional constituent.

On the assumption that 36 pounds of crude protein is the maintenance requirement for a thousand-pound cow per month (28) (the protein of pasture herbage is assumed to be 50 percent digestible (24)), that 7.0 percent protein in the pasture forage is necessary for maintenance of mature animals (5) and, furthermore, that carrying capacity is rated on protein yield, then a pasture containing 7.0 percent protein may be designated as a <u>base pasture</u>, provided that it produces 36 pounds of protein[1].

Now any pasture quality ratio (as calculated above) compared to the quality ratio of the base pasture, should be an index of superiority or inferiority of that pasture in terms

---

[1]Brody (4) states daily protein requirement for animals to be:

$$P = 0.88 \times W^{0.743}$$

where P = protein requirement (digestible), and W = body weight of animal in kilograms.

of the base pasture. The index may be conveniently termed the "quality index".

Knowing the dry matter yield of a given pasture and the "quality index" of its vegetation association, one can easily obtain a more acceptible rating of the carrying capacity by simple multiplication.

The above statements and assumptions may be expressed in symbols as follows:

$$\text{Pasture quality ratio} = \frac{F}{P}$$

where "F" = forage yield in pounds per acre

"P" = protein yield in pounds per acre

Then we can state:

$$Q = \frac{\dfrac{\frac{1}{F_x}}{P_x}}{\dfrac{\frac{1}{F_b}}{P_b}}$$

where "Q" = "quality index"

"x" represents <u>any</u> pasture

"b" represents <u>base</u> pasture

Therefore:

$$Q = \frac{1}{\frac{F_x}{P_x}} \times \frac{\frac{F_b}{P_b}}{1} = \frac{\frac{F_b}{P_b}}{\frac{F_x}{P_x}}$$

Knowing that the pasture protein requirement for mature animals is 7.0 percent and that the total protein requirement per animal unit is 36 pounds per month, then the gross yield of the base pasture must be 36/.07 pounds per acre, or 514 pounds.

(Continued next page)

Then $\frac{F_b}{P_b} = \frac{514}{36} = \underline{14.28}$.

Finally $Q = \frac{P_x}{F_x} \times 14.28$

TABLE IX

"Quality Indices" for some Grassland Types in the Four Western Canadian Provinces

Soil Zone	Association	Quality Index
BROWN	Shortgrass prairie	1.5
	Sandhill	1.4
	Sceptre prairie	1.3
	Haverhill prairie	1.4
	B.C. Lowgrass (cultiv.)	.8
	B.C. Lowgrass (native)	1.3
	Alluvium (cultiv.)	.8
	Alluvium (native)	1.5
DARK BROWN	Sask. (Cypress Hills)	1.0
	Alberta (Foothills)	1.1
	B.C. Midgrass	.9
BLACK	Alberta (Foothills)	.9
	Sask. (Cypress Hills)	1.0
	B.C. Upper grass	.9
	Manitoba (tallgrass)	.9
	Manitoba (Kentucky blue)	1.4
GREY WOODED	B.C. Lower Montane	.8
SHALLOW BLACK	Alberta (Foothills)	.8

The "quality index" has been determined for each association sampled (Table IX), and it is found that all of the associations in the Dark Brown soil zone and the Black soil zone have indices approaching 1.0. This indicates that the carrying capacities, when rated on total protein yield, are approximately the same as when rated on total dry matter yield. On the other hand, the grassland types in the Brown soil zone have "quality indices" between 1.0 and 1.5. These indices suggest that the carrying capacity when calculated on protein is greater than the forage yield carrying capacity. Thus, if pasture quality depends on protein production, the pastures in the Brown soil zone should be rated a higher carrying capacity than when rated on forage yield only.

The suggestion that the grasslands of the Brown zone should be given a higher rating is borne out in livestock production. It is well known that the ordinary carrying capacity estimates for the sparse, short grass based on density and dry matter yields alone do not relate accurately to actual numbers of livestock carried and are almost always too low. Accordingly, the use of these "quality indices" for the associations is proposed in order that more acceptible estimates of carrying capacity can be made.

ABSTRACT

An introductory investigation of the quality of range forage of some vegetational associations of the four Western Canadian provinces has been presented. Although the work reported on concerns only four nutrients, viz., protein, calcium, phosphorus and ash, trends of pasture quality by vegetational type have been demonstrated. The determination of crude protein alone has led to interesting conclusions because of the significant interrelationship between protein and other plant constituents. A general picture of vegetational quality has been painted. As a result of this work a method of assessing the grasslands for quality is proposed wherein the relative pasture values are expressed as "quality indices". Protein, deemed the limiting factor in carrying capacity, is assumed to be the most important single criterion for forage quality estimation.

BIBLIOGRAPHY

1. Archibald, J.G. COMPOSITION AND PALATABILITY OF SOME COMMON GRASSES. J.Ag.Res.66:341-7. May 1, 1943.

2. Ashby, E. THE QUANTITATIVE ANALYSIS OF VEGETATION. (Appendix by W.L. Stevens) Ann. Botany, 44:779-802. 1935.

3. Association of Official Agricultural Chemists. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS. Sixth Edition. 1945.

4. Brody, Samuel. BIOENERGETICS AND GROWTH. Reinhold Pub. Corp., New York. 1945.

5. Campbell, R.S. DETERMINATION OF GRAZING VALUES OF NATIVE VEGETATION ON SOUTHERN PINE FOREST RANGES. Ecol., 27:145-204. July, 1946.

6. Clarke, S.E. PASTURE INVESTIGATIONS IN THR SHORTGRASS PLAINS OF SASKATCHEWAN AND ALBERTA. Sci. Agric., 10:732-49. 1930.

7. Clarke, S.E., J.A. Campbell and J.B. Campbell. AN ECOLOGICAL AND GRAZING CAPACITY STUDY OF NATIVE GRASS PASTURES IN SOUTHERN ALBERTA, SASKATCHEWAN AND MANITOBA. Dom. of Can. Dept. Agr. Tech. Bul. 44. 1942.

8. Clarke, S.E. and E.W. Tisdale. RANGE PASTURE STUDIES IN SOUTHERN ALBERTA AND SASKATCHEWAN. Herb. Rev. 4:51-64. 1936.

9. Clarke, S.E. and E.W. Tisdale. THE CHEMICAL COMPOSITION OF NATIVE FORAGE OF SOUTHERN ALBERTA AND SASKATCHEWAN IN RELATION TO GRAZING PRACTICES. Dom. of Can. Dept. Agr. Tech. Bul. 54. 1945.

10. Crampton, E.W. PASTURE STUDIES XIV: THE NUTRITIVE VALUE OF PASTURE HERBAGE. Sci. Agric., 19:345-57. 1939.

11. Crampton, E.W. and R.P. Forshaw. PASTURE STUDIES VI: THE INTRA-SEASONAL CHANGES IN THE NUTRITIVE VALUE OF PASTURE HERBAGE. Sci. Agric., 19:701-711. 1939.

12. Daniel, H.A. THE CALCIUM AND PHOSPHORUS CONTENT OF GRASSES AND LEGUMES AND THE RELATION OF THESE ELEMENTS IN THE PLANT. J. Am. Soc. Agron., 26:496-503. 1934.

13. Daniel, H.A. and H.J. Harper. THE RELATION BETWEEN EFFECTIVE RAINFALL AND TOTAL CALCIUM AND PHOSPHORUS IN ALFALFA AND PRAIRIE HAY. J. Am.Soc.Agron., 27:644-52. 1935.

14. Elliott, W., J.B. Orr, T.B. Wood and W. Godden. THE INVESTIGATION OF THE MINERAL CONTENT OF PASTURE GRASS AND ITS EFFECT ON HERBIVORA. J. Agric. Sci. 16:78. 1926.

15. Ellis, J.H. and O.G. Caldwell. MINERAL CONTENT OF MANITOBA HAYS. Sci.Agric., 16:521-537. 1936.

16. Garrigus, W.P. THE FORAGE CONSUMPTION OF GRAZING STEERS. Proc. Am. Soc. Animal Prod., 1934.

17. Greaves, J.E. THE CORRELATION AMONG VARIOUS CONSTITUENTS OF FORAGE PLANTS. J. Am. Soc. Agron., 30:754-759. 1938.

18. Guilbert, H.R., S.W. Mead and H.C. Jackson. THE EFFECT OF LEACHING ON THE NUTRITIVE VALUE OF FORAGE PLANTS. Hilgardia, 6:13-26. 1931.

19. Johnstone-Wallace, D.B. THE INFLUENCE OF GRAZING MANAGEMENT AND PLANT ASSOCIATIONS ON THE CHEMICAL COMPOSITION OF PASTURE PLANTS. J. Am. Soc. Agron., 29:441-455. illus. 1937.

20. LeClerc, J.A. and J.F. Breazeale. PLANTFOOD REMOVED FROM GROWING PLANTS BY RAIN OR DEW. Yearbook, U.S.D.A. p.389. 1908.

21. Lindner, R.C. RAPID ANALYTICAL METHODS FOR SOME OF THE MORE COMMON INORGANIC CONSTITUENTS OF PLANT TISSUES. Plant Phys. 19:76-89. Jan., 1944.

22. Loomis, W.E. and Charles A. Shull. METHODS IN PLANT PHYSIOLOGY. 1st Edition. 1937. McGraw-Hill, New York and London.

23. Lush, R.H., O.S. Aamodt and W.P. Garrigus. PRELIMINARY REPORT ON PASTURE INVESTIGATIONS TECHNIQUE. J. Dairy Sci. 26:353. 1943.

24. MacEwan, Grant. THE FEEDING OF FARM ANIMALS. Nelson, Toronto, 1945.

25. McCall, R. DIGESTIBILITY OF MATURE RANGE GRASSES AND RANGE MIXTURES FED ALONE AND WITH SUPPLEMENTS. J. Agr. Res., 60:39-50. 1940.

26. Maynard, L.A. ANIMAL NUTRITION. 1st Edition. 6th Imp. McGraw-Hill, New York and London, 1937.

27. Maynard, L.A. INTERPRETATION OF VARIATIONS IN PLANT COMPOSITION IN RELATION TO FEEDING VALUE. J. Am. Soc. Agron., 29:504-511. 1937.

28. Mitchell, H.H. THE MINIMUM PROTEIN REQUIREMENTS OF CATTLE. Nat. Res. Council Bul. 67. 1939.

29. Mitchell, J., H.C. Moss and J.C. Clayton. SOIL SURVEY OF SOUTHERN SASKATCHEWAN. Soil Survey Report No. 12, Univ. of Sask. Col. of Agric. 1944.

30. Morrison, F.B. FEEDS AND FEEDING. 20th Edition. 7th Printing. 1941. pp.39-137. The Morrison Pub. Co., Ithaca, New York.

31. Moss, E.H. THE PRAIRIE AND ASSOCIATED VEGETATION OF SOUTHWESTERN ALBERTA. Can. J. Res. 22: 11-31. 1944.

32. Semple, A.T., H.N. Vinall and C.R. Enlow. A PASTURE HANDBOOK. U.S.D.A. Misc. Pub. 194, 89 pp. illus. (Rev. 1937.)

33. Simpson, G.G. and Anne Roe. QUANTITATIVE ZOOLOGY. 1st. Edition. McGraw-Hill, New York and London, 1939.

34. Smith, A.D. STUDY OF THE RELIABILITY OF RANGE VEGETATION ESTIMATES. Ecol. 25:441-8. Oct., 1944.

35. Sotola, J. THE CHEMICAL COMPOSITION AND APPARENT DIGESTIBILITY OF NUTRIENTS IN CRESTED WHEATGRASS HARVESTED IN THREE STAGES OF MATURITY. J.Agr.Res., 61:303-11. illus. 1940.

36. Sotola, J. THE CHEMICAL COMPOSITION AND APPARENT DIGESTIBILITY OF NUTRIENTS IN BROME GRASS IN THREE STAGES OF MATURITY. J. Agr. Res., 63:427-432. 1941.

37. Stoddart, L.A. THE PALOUSE GRASSLAND ASSOCIATION IN NORTHERN UTAH. Ecol. 22:158-163. 1941.

38. Stoddart, L.A. and A.D. Smith. RANGE MANAGEMENT. 1st Edition, pp. 66-95. 1943. McGraw-Hill, New York and London.

39. Tisdale, E.W. SUMMARY REPORT 1935-1939. Dominion Range Experimental Station, Kamloops, B.C.

40. U.S.D.A. Yearbook, 1939. FOOD AND LIFE. PASTURE AND RANGE LIVESTOCK FEEDING. p.925ff.

41. Waksman, S.A. and R.L. Starkey. THE SOIL AND THE MICROBE. pp. 75-101. Wiley, New York.

42. Watkins, W.E. THE CALCIUM AND PHOSPHORUS CONTENT OF IMPORTANT NEW MEXICO RANGE FORAGES. N.M. Agr. Expt. Sta. Tech. Bul. 246, 1937.

43. Welch, Howard. BONE CHEWING OF CATTLE. Mont. Agr. Expt. Sta. Circ. 122. 8pp. illus. 1924.

44. Welch, Howard. PHOSPHATES FOR LIVESTOCK IN MONTANA. Mont. State Col. Agr. Expt. Sta. Circ. 157. 1940.

45. Whitman, Warren. GRASS. N. Dakota Agric. Col. Expt. Sta. Bul. 300. June, 1941.

46. Williams, Ralph and A.H. Post. DRY LAND PASTURE EXPERIMENTS. Central Mont. Branch Sta., Moccasin, Mont. Bul. 431. 1945.

47. Woodman, H.E. and J. Stewart. THE MECHANISM OF CELLULOSE DIGESTION IN THE RUMINANT ORGANISM. III THE ACTION OF CELLULOSE-SPLITTING BACTERIA ON THE FIBRE OF CERTAIN FEEDING-STUFFS. J. Agr. Sci., 22:527-47. 1932.

48. Wyatt, F.A. SOIL SURVEY OF LETHBRIDGE AND PINCHER CREEK SHEETS. Univ. of Alta. Bul. 32. July, 1939.