GRAY WOODED SOILS AND THEIR MANAGEMENT

COVER PHOTO:

The plaque on a cairn erected at the Breton Plots in 1960 reads:

THE BRETON PLOTS

In this field in 1930 Professors F. A. Wyatt and J. D. Newton began experimental work on the farm of Ben Flesher. These experiments have shown the need for fertilizers coupled with good crop rotations on soils of this type and have led to greatly increased production on the Grey Wooded soils of the west.

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UNIVERSITY OF ALBERTA
Faculty of Agriculture

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CANADA DEPARTMENT OF AGRICULTURE
Research Branch

GRAY WOODED SOILS AND THEIR MANAGEMENT

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PREFACE

This bulletin is a joint contribution of the Canada Department of Agriculture and The University of Alberta.

The previous six editions of "Gray Wooded Soils" were restricted to a presentation of results of work by the Department of Soil Science, The University of Alberta. However, having regard for the important work that has been done by the Canada Department of Agriculture, Research Stations at Beaverlodge and Lacombe, Alberta, and to best serve Alberta agriculture, this seventh edition of "Gray Wooded Soils" is a co-operative contribution of the two agencies.

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GRAY WOODED SOILS OF ALBERTA AND THEIR MANAGEMENT

Introduction

This bulletin is about Gray Wooded soils—distinctive soils of special importance in Alberta.

The Province of Alberta is the most westerly of the Prairie Provinces and lies mainly on the third prairie steppe at elevations usually higher than 1,500 feet above sea level.

Gray Wooded soils were originally identified and described in Western Canada. In Alberta it is estimated that such soils constitute over one-half of the acreage in the current and potential agricultural areas of the province. While these soils occur on only about 15 per cent of the acreage now cultivated in Alberta, it is probable that within a few decades about 40 per cent of the land cultivated here will be of the Gray Wooded type.

It is therefore clear that Gray Wooded soils are now of great importance in Alberta and that they will become increasingly important in the years ahead. It is unlikely that such soils are of comparable significance to the agriculture of any other province or state in North America. If these soils occur more extensively elsewhere in the world it is in the Siberian part of the of the U.S.S.R. where in many ways agricultural, climatic and economic factors are quite different to those applying in Alberta. Thus the unusual importance of Gray Wooded soils in this province makes knowledge of their characteristics, including advantages and disadvantages for agricultural use, as well as recommended management and cropping practices, requisities for their wise and profitable use. In addition, distinctive properties and characteristics of these soils make them of scientific interest if man is to better understand his environment and one of its most vital life-supporting components—the soil.

This bulletin consolidates in a single publication much of the knowledge accumulated during a half century of study and use of Gray Wooded soils in Alberta. The data used are primarily of Alberta origin but other sources have not been disregarded. Because basic scientific principles are broadly applicable it is hoped that the present publication may be of use beyond the borders of this province.

But first, let us consider the Alberta climate, vegetation and Gray Wooded soils in relation to other better known soils of the province.

Climate

The climate of Alberta ranges from semi-arid in the southeastern portion to subhumid adjacent to the mountains and in the northerly half of the province. Annual precipitation varies from less than 12 inches in the southeast to over 20 inches west of Edmonton and decreases gradually from Edmonton northward. Fortunately, 60%-70% of the precipitation falls during the growing season. Precipitation patterns are shown in Figure 1. Further climatic data are given in Figure 2. Growing seasons, based on average temperature above 42°F, range from about April 15 to October 20 in southeastern Alberta and from May 2 to September 28 at Fort Vermilion. Average July temperatures are about 68°F in the southern part and 60°F in the north. Corresponding average January temperatures are 15°F and -6°F. Because of higher temperatures, drier air, and higher wind velocities, evaporation is much greater in southern than in northern Alberta.

Vegetation

The foregoing climatic differences result in two major vegetative regions in Alberta—the grassland region, most of which lies approximately south and east of Edmonton, and the wooded or forested region occupying the rest of the province. The southeasterly portion of the province has short grass prairie vegetation. To the north and northwest the vegetation changes to parkland, or open areas with groves of aspen and shrubs, and then eventually to forest vegetation.

Soils

The climatic and vegetative differences described have resulted in development of soils that are distinctively different. Where grass has been the dominant vegetation for thousands of years, topsoils contain an accumulation of partly decomposed grass residues, called humus or organic matter. In the forested region moister conditions have prevailed, a principal reason for the growth of trees rather than grass there, and as a result the leaves and needles that have fallen to the ground have almost completely decomposed. In areas with trees, the topsoil below the leaf mat is usually rather low in humus content (organic matter) because only small amounts of plant residues remain after leaf decomposition has occurred.

Within the two broad categories of soils just described—those of the grassland region, and those of the forest region—there are a number of distinguishable soil groups which are shown on the map, Figure 3.

In classifying soils, those characterized by the long-time effects of grassland vegetation are called Chernozemic soils. Those in southeastern Alberta have a rather thin layer of brown colored humus-rich topsoil. To the west and north the topsoil layer becomes thicker, higher in humus content and darker in color. These soils comprise the Brown, Dark Brown, and Black soil groups, named after the color of the soil in the freshly tilled fields.

Several soil groups occur in the forested region but a distinctive group, the Gray Wooded soils, is by far the most common. As a result of hundreds of years under tree vegetation, Gray Wooded soils have distinctive profiles as described in this bulletin (Pages 16 - 19). The name of these soils is taken from a gray colored layer of mineral material turned up when plowed. That gray layer is leached and low in humus content. It is usually ash-like when dry.

The Black soils are often separated from the Gray Wooded soils by two other soil groups, the Dark Gray Wooded soils and the Dark Gray soils, which have an appearance and characteristics intermediate between those of Black and Gray Wooded soils. The Dark Gray and Gray Wooded soils were probably once grassland soils and had topsoil rich in humus, but in recent times have been invaded by the forest. Under the cooler, moister conditions accompanying the tree cover, humus—which accumulated under the former grassland vegetation—has gradually decomposed and is disappearing. The Dark Gray soils are higher in humus content and are more like Black soils than the Dark Gray Wooded soils, which have only slightly more organic matter than Gray Wooded soils.

It must be emphasized that the map of Figure 3 over-simplifies the true situation with respect to the distribution of Alberta's major soil groups: in most cases the soil groups are not as distinctively different nor as sharply separated as the map of necessity shows. Since the climate and vegetation gradually change from one area to another the soils

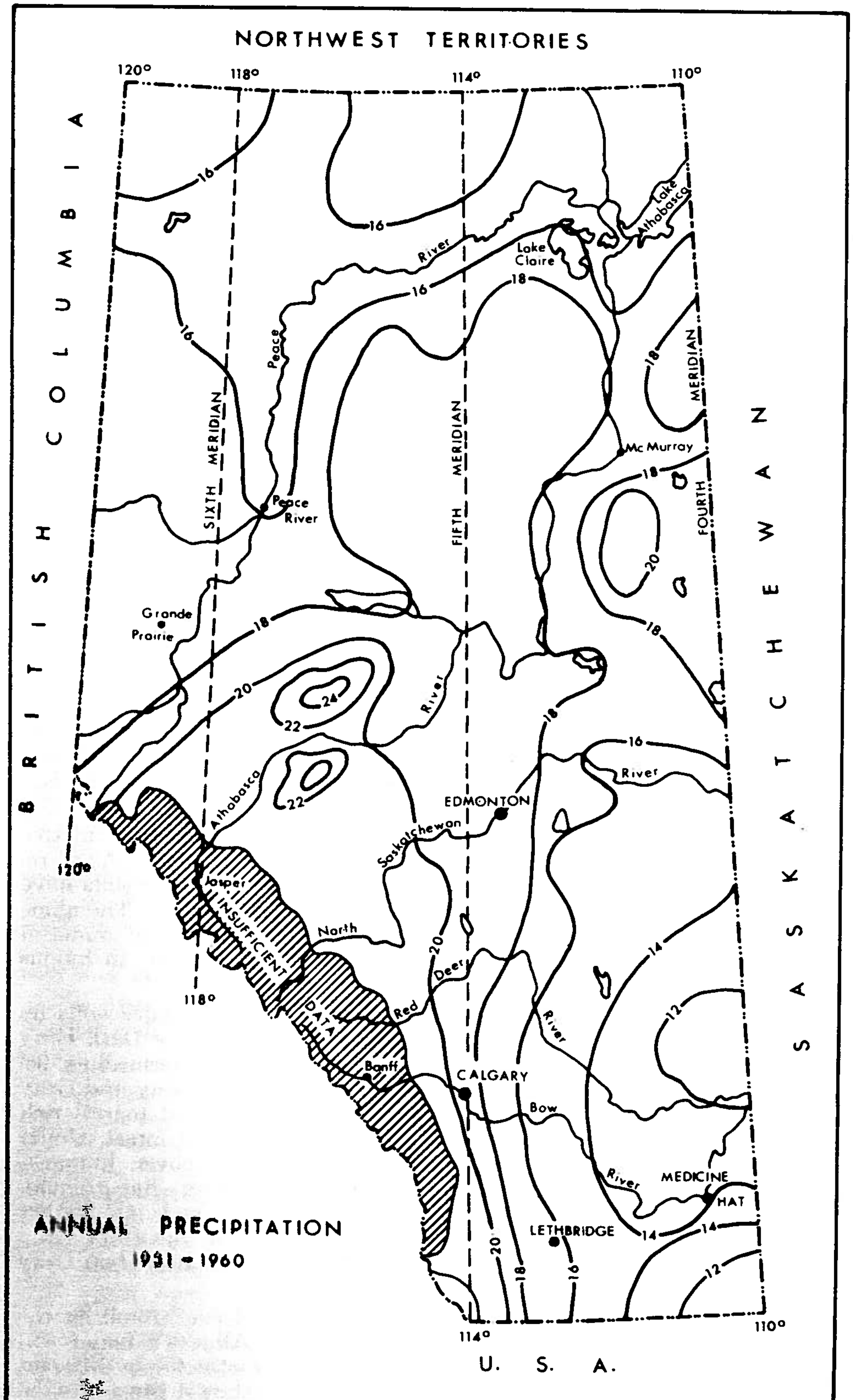


Figure 1 — Rainfall patterns in Alberta. (Average annual precipitation, inches).

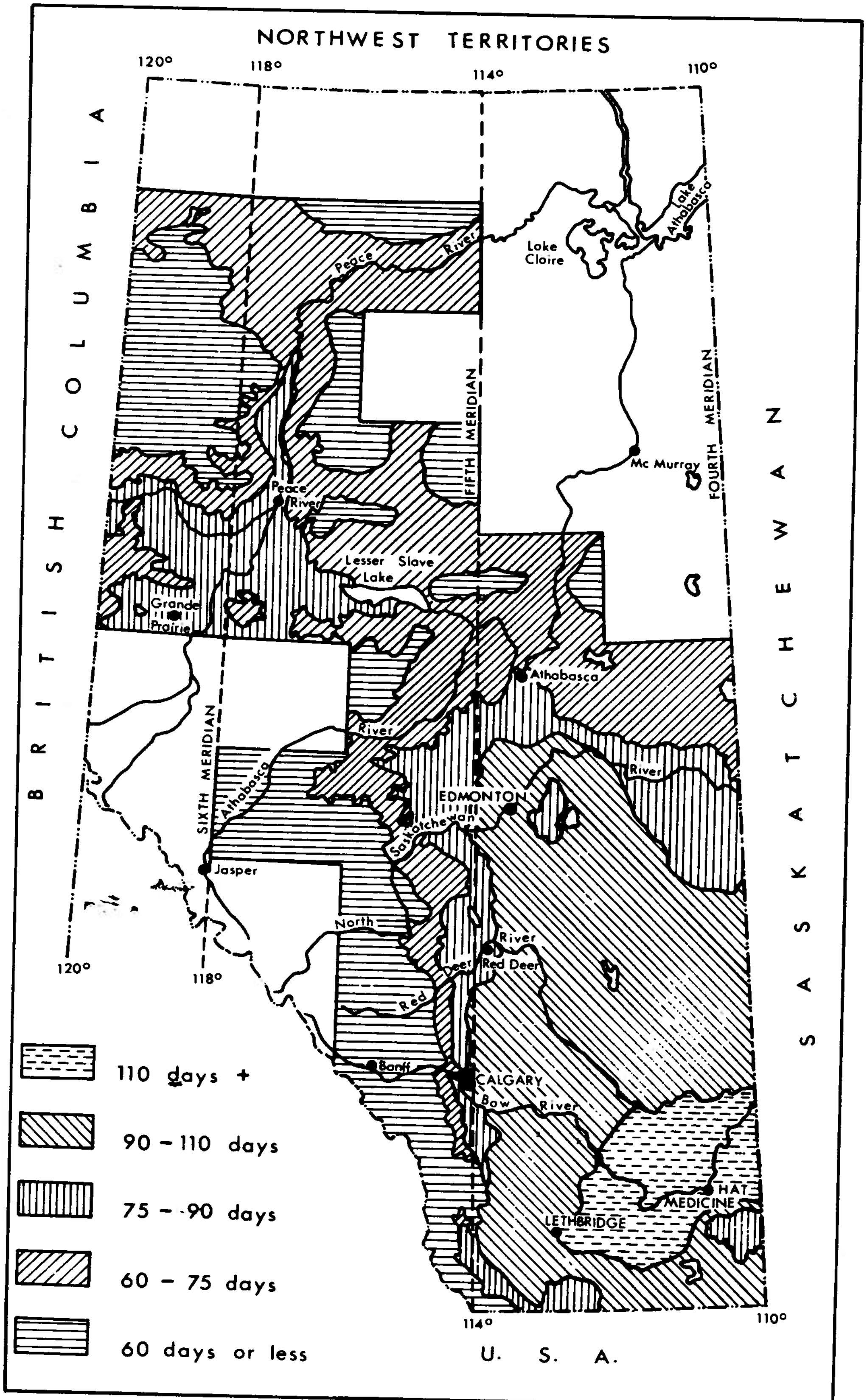


Figure 2—Frost-free periods in Alberta. (Average annual frost-free days).

themselves show this gradual transition. These areas of transition may vary from less than a mile to over 30 miles. This means, in general, the type of farming gradually changes from one area to another. The large areas of particular soil groups are not uniform in soil characteristics. Patches of Dark Gray Wooded soils may be found in the Gray Wooded soil area and, similarly, among the Black soils islands of Gray Wooded soils can be found.

Soil Groups, Agro-Climatic Areas and Farming

Many aspects of soil fertility and management are closely related to soil characteristics that are important in distinguishing soil groups in Alberta. Figure 4 is an agro-climatic map, which divides the province into areas separated on the basis of precipitation, frost free periods and suitability for various types of farming. The agro-climatic areas of

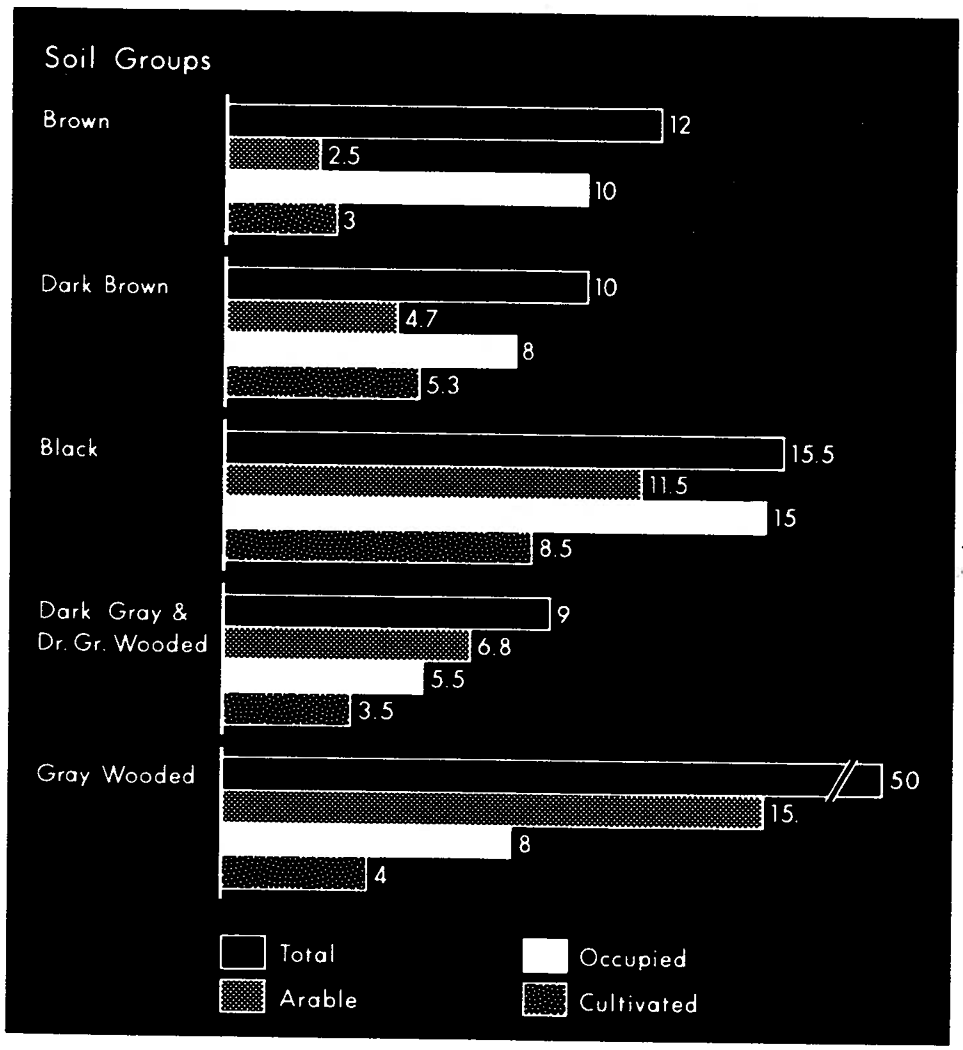


Figure 5—Approximate acreages of total area, potentially arable, occupied, and cultivated land of soil groups in Alberta. (Millions of acres).

Figure 4 are very closely related to the soil group areas of Figure 3—because climate and vegetation have been so important in development of soil characteristics. Thus the agro-climatic areas are ones wherein soils have similar surface characteristics and fertility requirements—and wherein climatic conditions, including frost hazard, are very similar. Gray Wooded soils occur almost exclusively in agro-climatic areas 2H and 3H,—where precipitation has usually been adequate but where frost-free periods range downward from 90 days.

Figure 1 presents meteorological data for the province. Those data may cast some doubt on the statement that moister conditions exist in the wooded region. However, the comparatively small amount of wind and the lower temperatures in the wooded zones result in lower rates of evaporation and transpiration than prevail in the grassland areas. As a consequence soils are moist more of the time in the wooded areas than they are in the more arid grassland region where annual precipitation may be equal or greater.

The importance of Gray Wooded soils to Alberta agriculture is illustrated by Figure 5. Since, within a few decades, Gray Wooded soils may constitute about 40% of all cultivated land in Canada, wise development and use of these soils is obviously in the national interest. Profitable farming on Gray Wooded soils is unusually dependent on improvement of soil fertility by management suited to the particular characteristics of such soils.

A discussion of soil properties that affect crop yields will help understand the needs, and that is done in the section commencing on page 16. But a description of Gray Wooded soils and a discussion of their variations in Alberta will be given first.

SOIL GROUPS OF ALBERTA

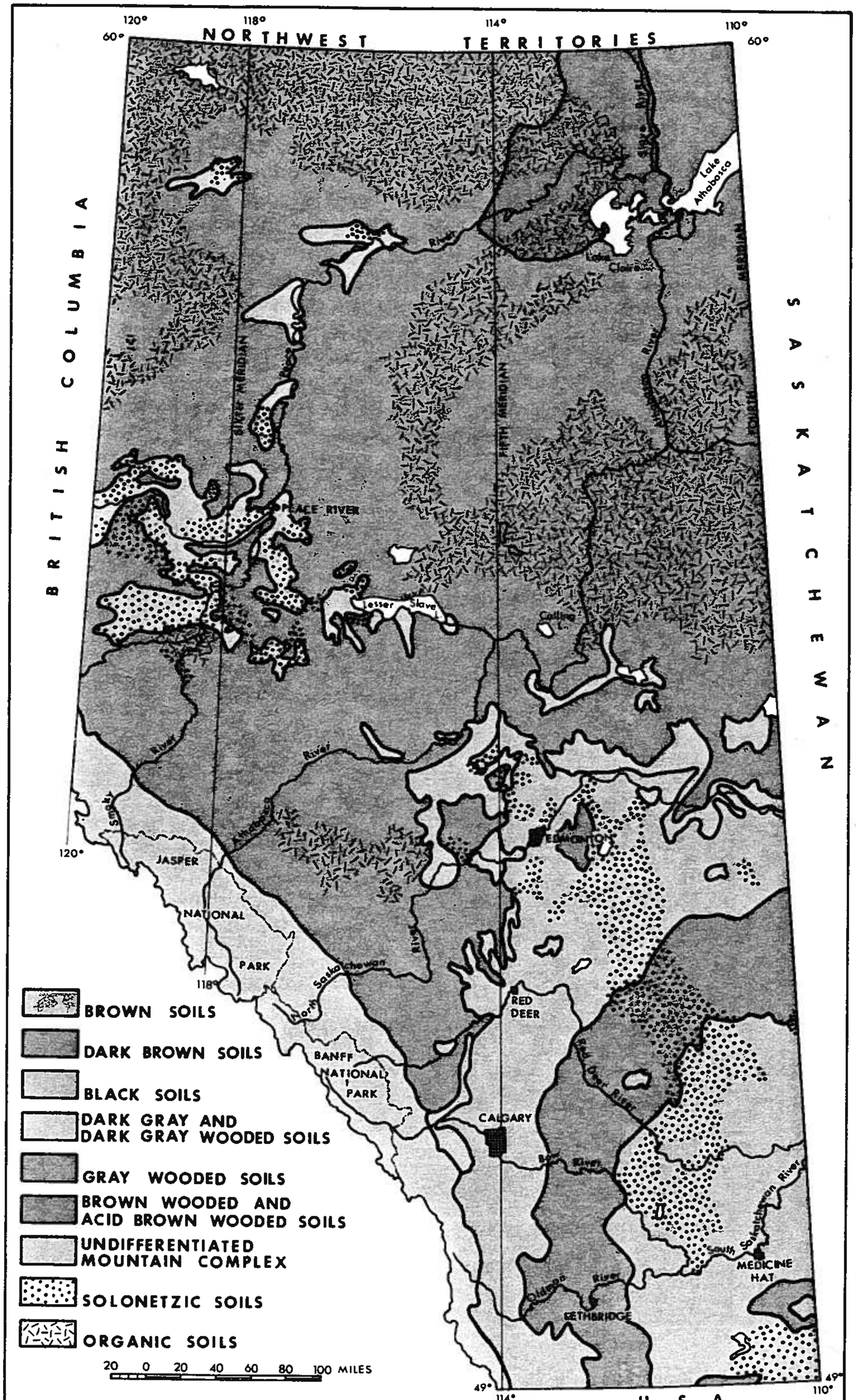


Figure 3—Soil group map of Alberta. (Note: Boundaries are seldom sharp: normally there is a gradual transition from one group to another).

AGRO-CLIMATIC AREAS OF ALBERTA

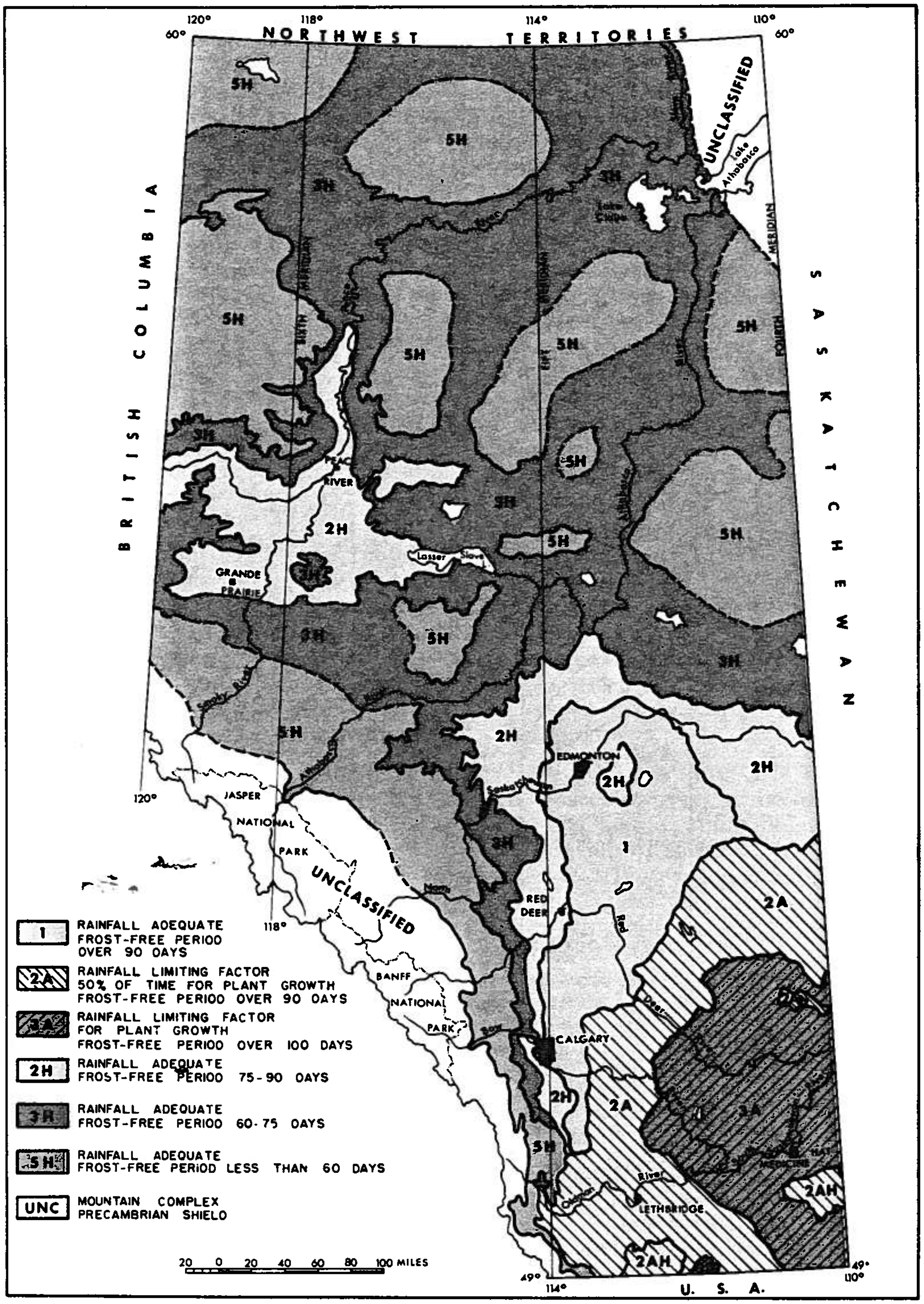


Figure 4—Agro-climatic map of Alberta. (Note: The map shows average climatic hazards to farming and is based on long-term weather records).

SOIL CHARACTERISTICS AND CROP REQUIREMENTS

Description of Gray Wooded Soils

The series of layers or horizons exposed in a vertical section down through a soil into the underlying parent material is called a soil profile. For convenience and brevity, soil scientists have developed a system of identifying the typical horizons (or layers) by a combination of letters. Figure 6 is a schematic drawing showing most of the horizons commonly found in soil profiles. Many soils lack one or more of the horizons shown in the drawing. Moreover, horizon thickness, as well as many other important characteristics, differ between kinds of soils. The most important horizons of a typical Gray Wooded soil may be described in the following way:

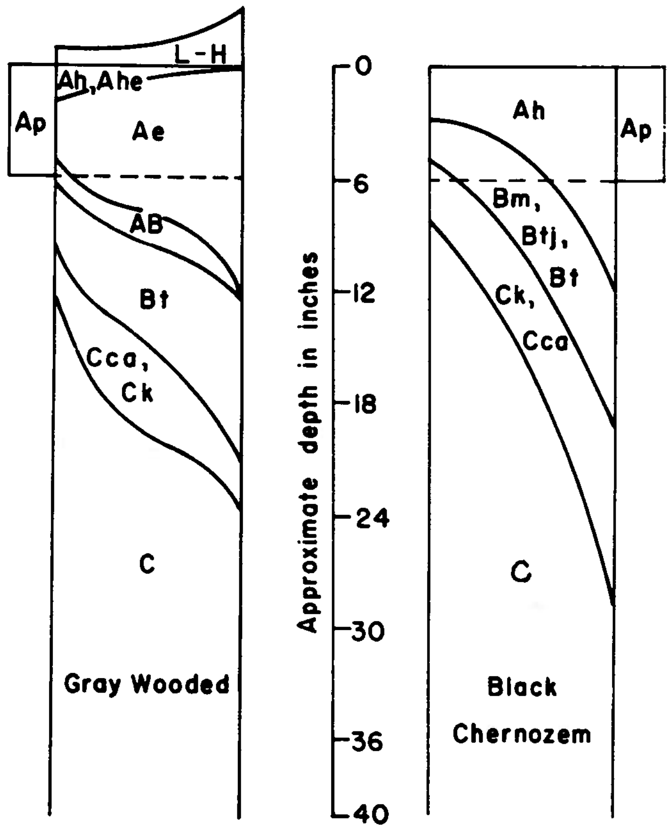


Figure 6—Diagram of a Gray Wood profile and a Black Chermozemic profile showing the various horizons which may be present. (Sometimes a horizon may be divided into an upper and a lower layer as Bt1 and Bt2.

A Gray Wooded soil in its natural state has a surface layer of organic materials consisting mainly of recently fallen leaves and/or needles (the L horizon) which is underlain by a felty or fibrous mat of partly decomposed organic material. The most decomposed layer is called the H horizon, whereas the partly decomposed layer is called the F horizon. These three layers, L, F, and H, may vary from one to five or more inches in thickness. Underlying these horizons is a dark layer; a mixture of humus and mineral matter called the Ah horizon. In Gray Wooded soils it is always less than two inches and usually less than one inch thick.

The Ae horizon is the most distinctive layer in a Gray Wooded soil and it is also the cause of many problems encountered in farming these soils. The Ae horizon is gray in color, low in organic matter (humus) content, and breaks apart in the horizontal plane (has platy structure). This horizon varies from 4 to 12 inches in thickness. The gray color is due to the low humus content and to the effects of many years of leaching. Rain dissolves the chemicals formed from leaf and needle decomposition, and as the water seeps down into the soil the dissolved chemicals slowly act on the clay, silt, and sand in the mineral part of the soil. Very slowly some of the clay is moved downward from near the surface and the materials that are left become grayish in color because of the action of the chemicals on them. It takes hundreds, maybe thousands, of years for these changes to occur so the development of the Ae horizon is a very slow process. When dry the Ae horizon is hard and crushes to an ash-like or flour-like powder. If the gray mineral matter of the Ae horizon is very wet it acts like a heavy paste and becomes very firm and hard when dry. When a Gray Wooded soil is cultivated, the L, F, H, and part of the Ae horizons are mixed by the plowing. The grayness of a field is an indication of how intense the leaching of that soil has been, and it also indicates to a certain extent how thick the leaf mat and the Ah horizon were.

The Bt horizon, the layer commonly called the subsoil, is usually brown, grayish brown, or brownish dark gray in color. This horizon contains the clay and some of the other minerals leached out of the Ae horizon. Because of the increased swelling and shrinking resulting from the higher clay content, this horizon has both vertical and horizontal lines of breakage. As a result the natural soil lumps (structure) in the Bt horizon usually have sharp angular edges and a shape that is rather block-like. When they are dry these soil lumps are so hard that roots may have difficulty penetrating this soil layer.

The Cca horizon is commonly called the lime layer and it is nearly always present in Gray Wooded soil profiles. However, it is usually at considerable depth, being on the average 4 feet or more below the surface. The lime layer represents an accumulation of calcium carbonate (commonly called lime) that was originally distributed throughout the mineral portion of the soil above this layer. Over the thousands of years since the glaciers receded, water moving down through the soil has dissolved the lime from the upper horizons and carried it down to the depth of water penetration where it has accuumlated. Soluble salts may also be leached downward and form a Csa horizon. The leaching of calcium carbonate from the surface few feet of Gray Wooded soils has played an important part in the development of these soils. This is because the acids and other chemicals produced by leaf decomposition can have a much more drastic action on the mineral part of the soil when there is no calcium carbonate present. For this reason the soil horizons nearest the soil surface (the Ah and Ae) have suffered the greatest change due to the effects of chemicals produced when leaves and needles decompose.

Gray Wooded soils have developed on a variety of parent materials such as lacustrine (lake laid) clays, glacial till (the unsorted mixture left by glacial ice), and sandy alluvial (river laid) materials (Figure 7). The Gray Wooded soils that have developed on lacustrine clays are somewhat more fertile than those developed on glacial till. In the Peace River region most of the Gray Wooded soils that are cultivated have developed on lacustrine clay deposits. In Central Alberta most of

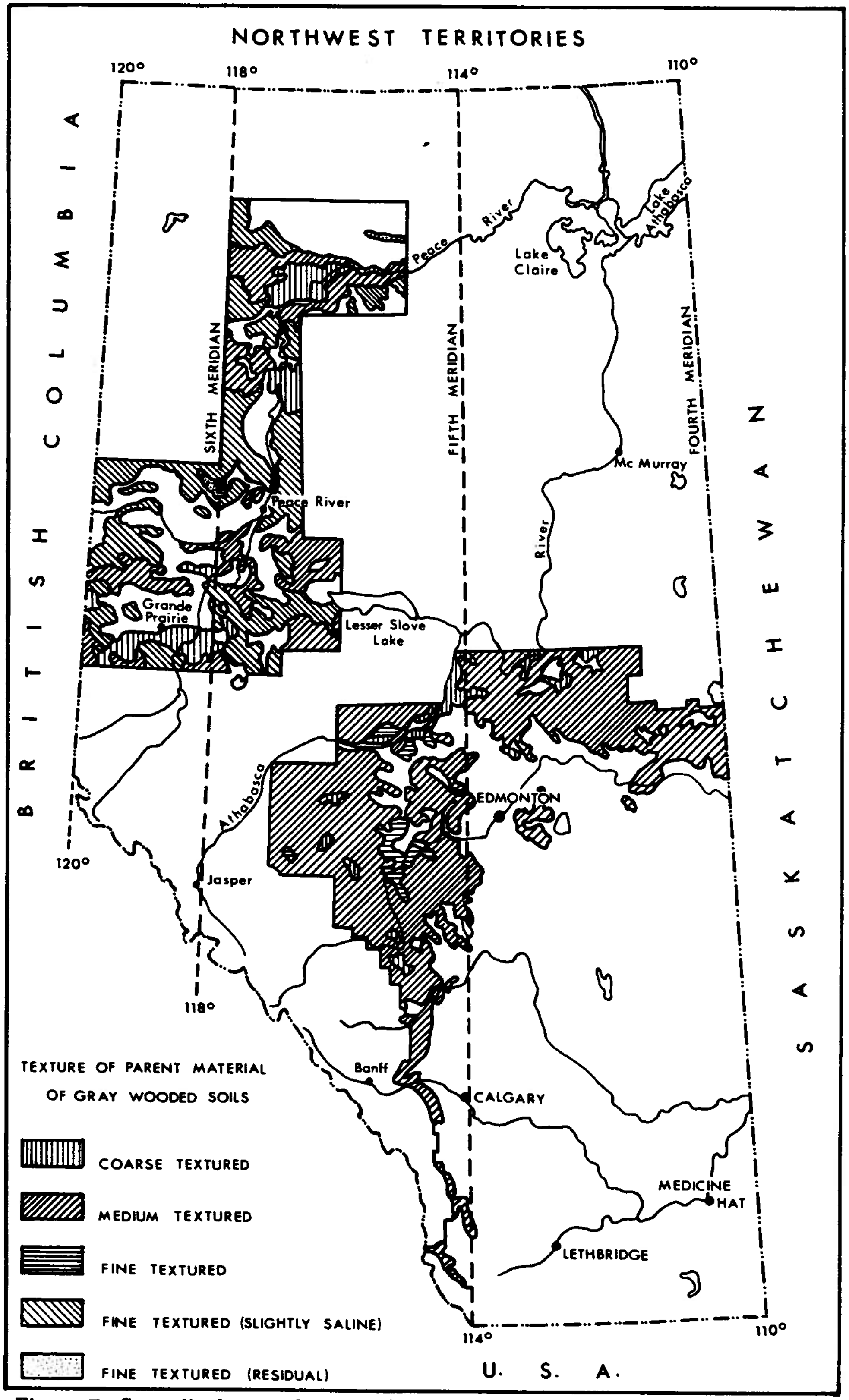
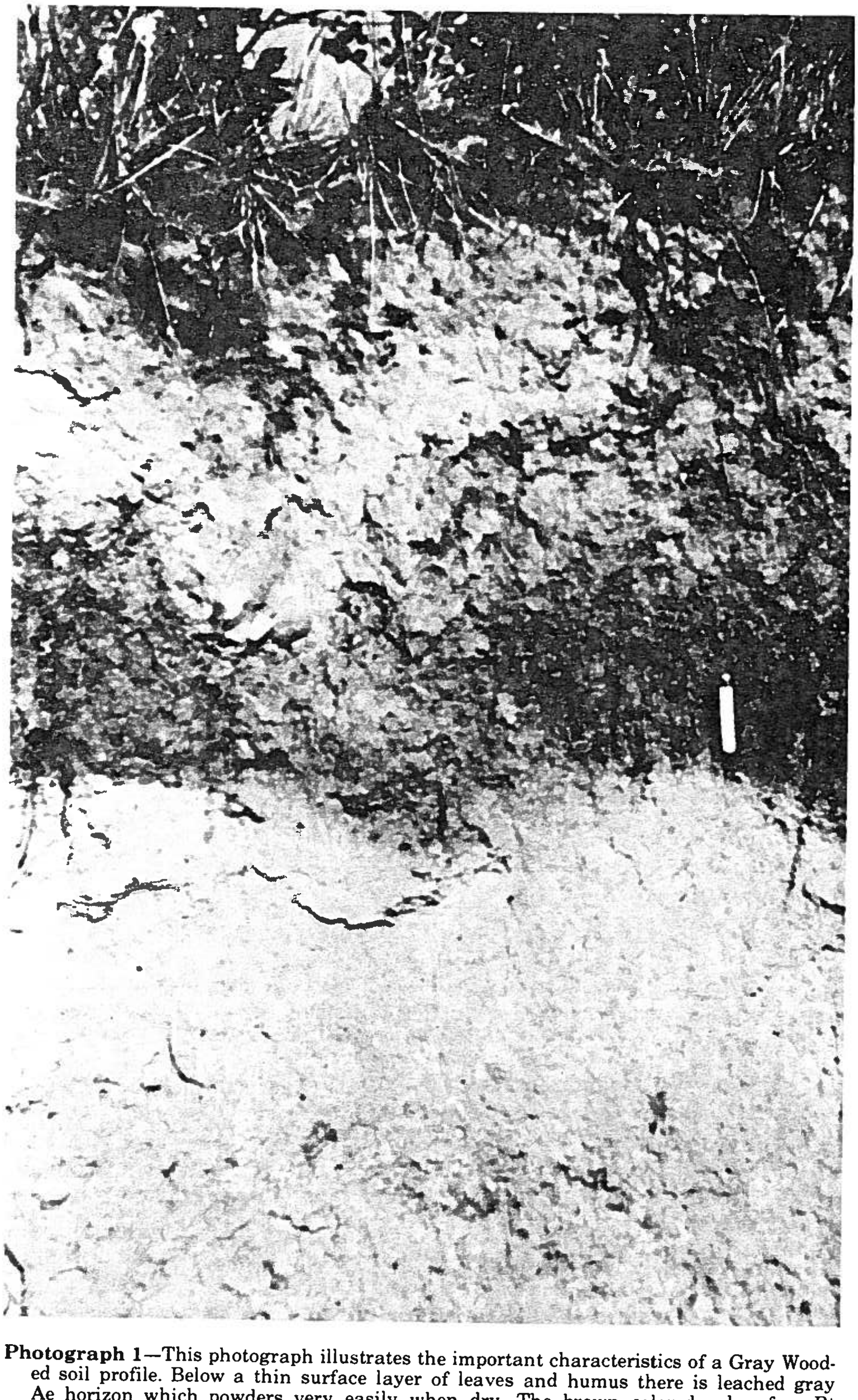


Figure 7—Generalized textural map of Gray Wooded soil parent materials. (Coarse materials are sandy, fine materials are high in clay and medium textured materials usually contain some stones).



Photograph 1—This photograph illustrates the important characteristics of a Gray Wooded soil profile. Below a thin surface layer of leaves and humus there is leached gray Ae horizon which powders very easily when dry. The brown colored subsurface Bt layer is enriched with clay and in this soil is underlain by light colored parent material.

the Gray Wooded soils cultivated have developed on glacial till of loam to clay loam texture. As a rule it is not practical to farm Wooded soils developed on sandy alluvial material because of inherent low fertility of the parent material, low water holding capacity, and water and wind erosion problems.

A photograph of a typical Gray Wooded soil profile is shown in Photograph 1.

Gray Wooded Soils in Comparison to Chernozemic Soils

A century ago soils of the Prairie Provinces gained an international reputation for their unusually excellent fertility and productivity. That reputation resulted from examination of some of the deep humus-rich grassland soils of the prairies, especially in Manitoba where rainfall is somewhat higher and more consistent than it is in much of the open prairie of Saskatchewan and Alberta. In those days, before availability of nitrogen-supplying fertilizers, the organic matter (humus) content of soils was the best indicator of soil productivity. Most of the early settlers in the Prairie Provinces obtained good crops on the virgin soils they started to farm, and in the following rush of settlement the good grassland (Chernozemic) soils were quickly taken up wherever moisture conditions were reasonably satisfactory. The early settlers were not familiar with the prairie climate, erratic rainfall and other hazards. Following development of the practice of summer fallowing, many millions of acres of 'prairie loam'—grassland soils with a generous depth of humus-rich topsoil—were used solely for grain production over long periods. Much prairie land has been devoted to constant grain production for as much as half a century without application of any kind of fertilizer—and still produces fairly good yields.

Gray Wooded soils, the dominant kind of soil in the settled areas of our forested region, do not have the high natural fertility and productivity of the grassland soils of the prairie and parkland areas of Alberta. Tree vegetation results in a rather heavy fall of leaves or needles each year. But the good moist conditions in forested areas results in rather complete decomposition of the forest litter, and except for a mat of decomposing leaves on the soil surface, the humus content of Gray Wooded soils is rather low. When such soils are cleared of trees and cultivated the leaf mat quickly disappears. Crop yields, even on freshly broken land, are usually lower than yields on humus rich soils such as the grassland. If used only for grain production, and without use of fertilizers, yields on Gray Wooded soils usually decline after a very few crops.

The foregoing may be summarized briefly as follows:

Virgin humus-rich (Chernozemic) soils of grassland origin in the prairie and parkland areas of Alberta have very high fertility and can produce good yields for many years, even if recommended soil management practices are not followed.

Virgin Gray Wooded soils in forested parts of Alberta do not possess high initial fertility. If they are used solely for grain production without application of fertilizers yields are usually unsatisfactorily low within a few years. See Figures 8 and 9.

Yet another way of illustrating the difference between Gray Wooded and Chernozemic soils in Alberta is to say that even with poor farming methods the grassland soils usually produce good crops whereas *good farming methods must be followed to obtain satisfactory crop yields on Gray Wooded soils.*

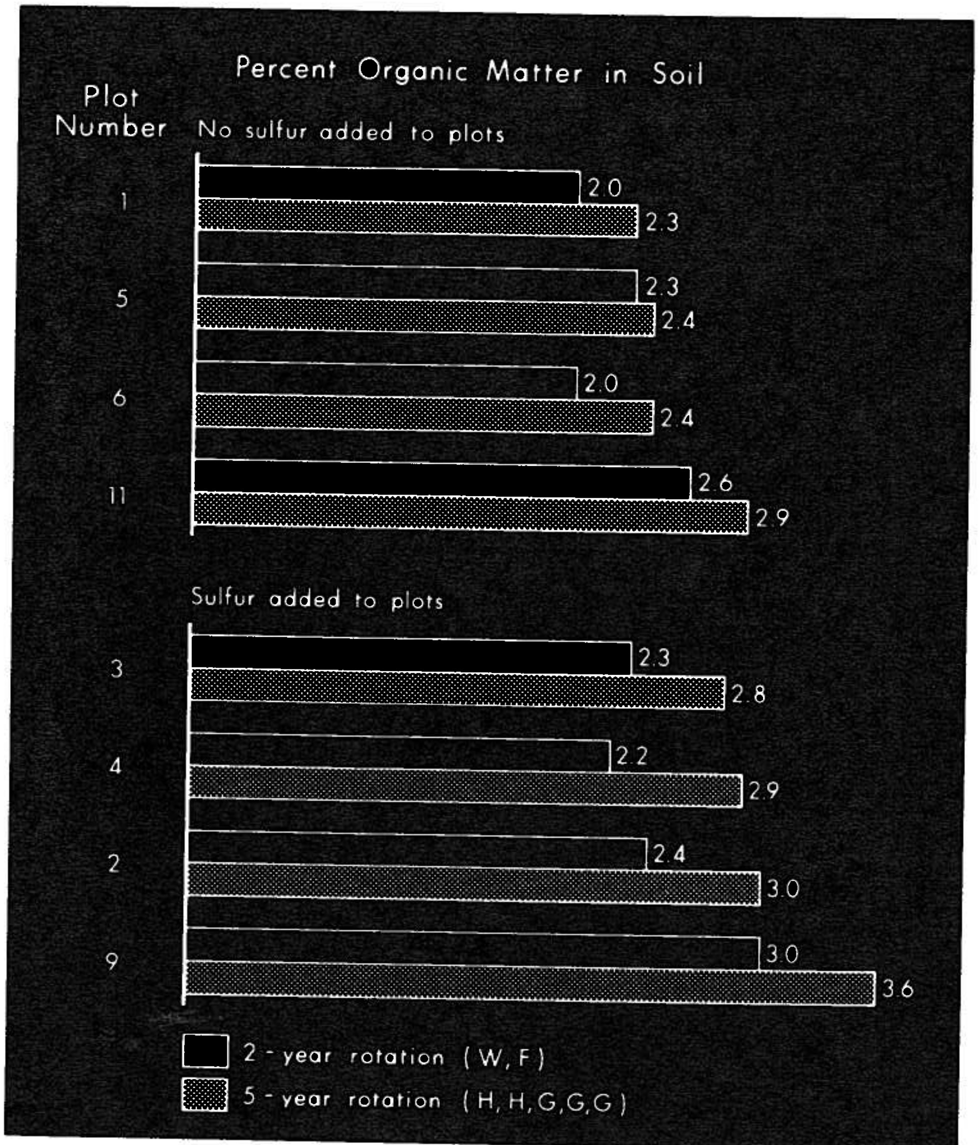


Figure 8—Effects of sulfur fertilization and type of crop rotation on organic matter content of a Gray Wooded soil. (Breton Plots, after about 30 years).

Those farming or planning to farm Gray Wooded soils should be aware of the relatively low natural fertility of such soils.

The differences in fertility of virgin Chernozemic and Gray Wooded soils are illustrated by the data of Figures 9 to 12. As nitrogen is the essential plant nutrient most frequently needed as fertilizer in Alberta, if reasonably satisfactory yields are to be obtained, the superiority of Black soils in this respect is clearly evident. Sulphur is also frequently needed as a fertilizer on Gray Wooded Soils.

The foregoing discussion has emphasized that initially when Gray Wooded soils are cleared and brought under cultivation their natural fertility is usually markedly inferior to that of freshly broken soils of the grassland region. However a great deal of Alberta's Gray Wooded soil area enjoys slightly more reliable moisture conditions than most

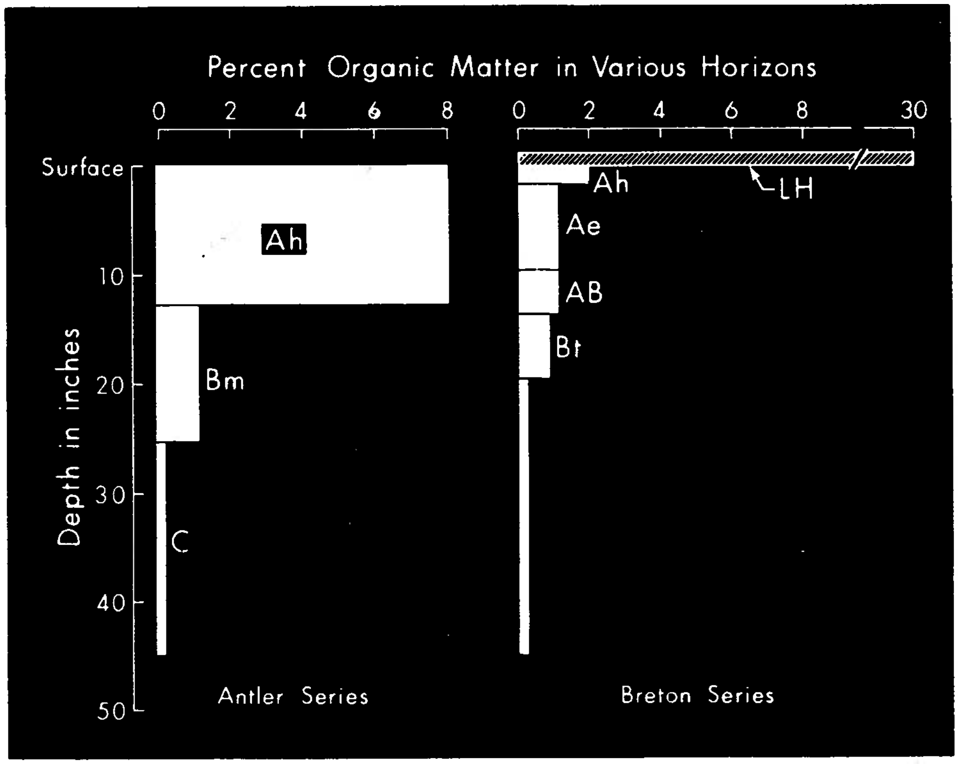


Figure 9—In a Black Chernozemic soil (L) the organic matter (or humus) content is much higher than it is in a Gray Wooded soil. (R)

of the open prairie region. Consequently, by following recommended cropping and soil management practices (that is by good farming) many Gray Wooded soils can be so improved that their crop yields are equal to or better than yields from good grassland soils.

This bulletin describes cropping fertilizing and management practices that have been found to maintain or improve crop yields on Gray Wooded soils under practical farming conditions in Alberta. The practices discussed have some additional advantages: they will improve tilth of the soil and they usually improve the nutritive value of the crops produced.

THE FERTILITY AND PRODUCTIVITY OF SOILS

Soil fertility refers to the supply of nutrients which are essential for plant growth. Productivity of soils refers to their ability to produce crops. These characteristics of soils may be strongly affected by the crops grown, fertilizers used and other soil management practices. A general discussion will enable a better understanding of the soil management needs for successful use of Gray Wooded soils.

A discussion of soil properties that affect crop yields will help understand desirable soil properties.

Characteristics of Good Soils

Since this bulletin is concerned with soil fertility and deals especially with soils that are often rather unproductive, a brief discussion of the qualities that affect the productivity of soils follows.

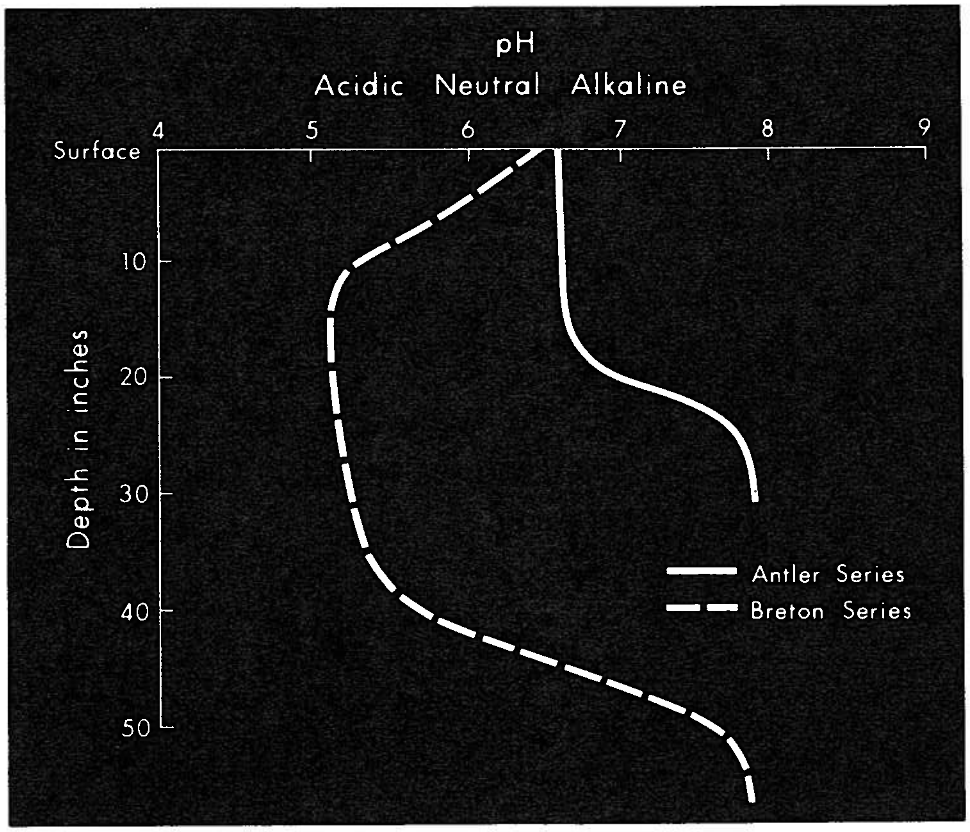


Figure 10—A Gray Wooded soil (L) shows more change in pH down through the profile than a Black Chernozemic soil (R) developed on the same parent material. The soil forming processes are more drastic in the Gray Wooded soil.

Good soils differ from poor soils in either physical or chemical characteristics or in both of these qualities

A soil with desirable physical characteristics is said to have good tilth. When soils have good tilth they do not cake or bake, plant roots and water enter and penetrate easily, there is a granular or crumb structure, and there are many good sized pore spaces to hold the water and air that plant roots require. Soils with good physical properties till easily and provide good seedbeds; they take in rainwater fairly readily and resist erosion.

Chemicals properties of soils may affect crop growth directly. Plants must obtain from the soil certain essential plant nutrients, which are chemical elements. Table 1 lists these essential plant nutrients and gives common names for some of them. An adequate supply of each of these essential plant nutrients is just as necessary to good healthy plant growth as sufficient amounts of vitamins, proteins, carbohydrates, fats and other items of a diet are for animals. Figures 13 and 14 shows the quantities of the more important plant nutrients removed by Alberta's most common crops. Explanations of fertilizer terminology are given in Table 2.

The mere presence in the soil of essential plant nutrients is not always enough; these elements must be in a form that plants can readily

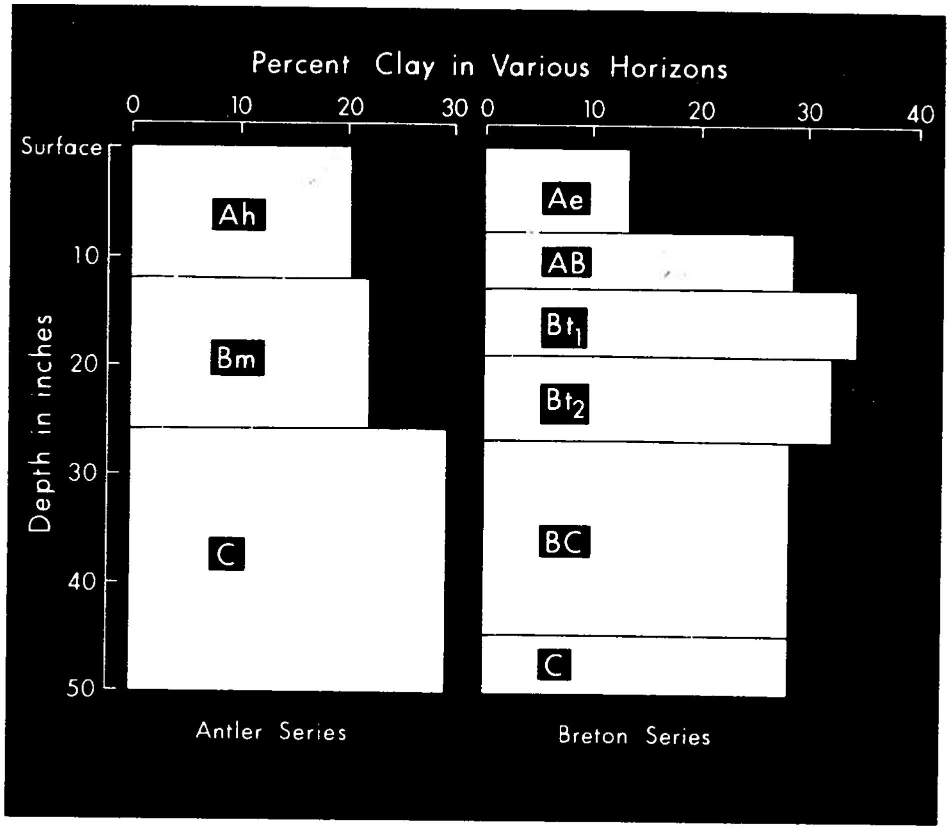


Figure 11—Percent clay in the horizons of a Black and Gray Wooded soil developed on the same parent material show marked differences because of movement of clay from the Ae into the Bt horizon.

TABLE 1: THE ESSENTIAL PLANT NUTRIENTS THAT PLANTS MUST OBTAIN FROM THE SOIL IN ORDER TO GROW, BE HEALTHY AND REPRODUCE

(In addition to the nutrients listed below plants require hydrogen, oxygen, and carbon which are obtained from water and the air).

Macronutrients—needed in relatively large amounts

Chemical Name of Nutrient	Chemical Symbol	Other Names Commonly Used for Materials Supplying this Element
Nitrogen	N	Nitrate, ammonia, urea
Phosphorus	P	Phosphate, phosphoric acid
Potassium	K	Potash
Calcium	Ca	Lime, limestone, marl
Magnesium	Mg	Magnesia
Sulfur	S	Sulfates, sulfides flowers of sulfur

Micronutrients—needed in very minute amounts

Chlorine	Cl	Chloride, muriate
Iron	Fe	Iron chelate
Zinc	Zn	
Copper	Cu	Bluestone
Boron	B	Borax, boric acid
Molybdenum	Mo	"Moly"

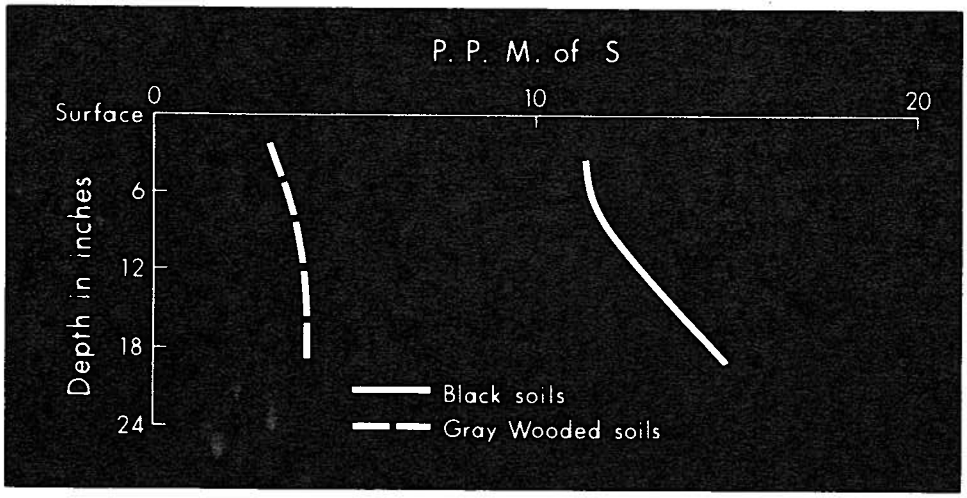


Figure 12—Parts per million (p.p.m.) of sulfur extracted from some Gray Wooded soils were, on the average, much lower than extractions from Black Chernozemic soils. (Averages for about 20 soils in each case).

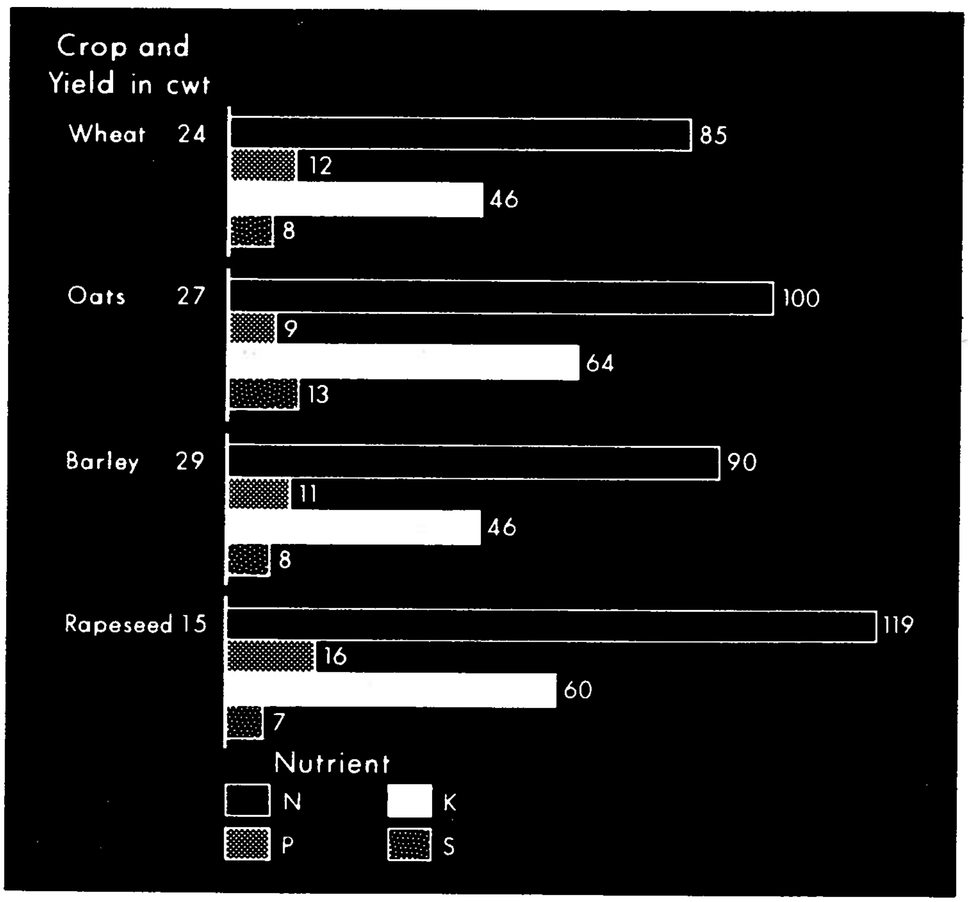


Figure 13—Approximate uptake of four nutrients by some common Alberta crops. (Pounds per acre of nutrients, in grain only).

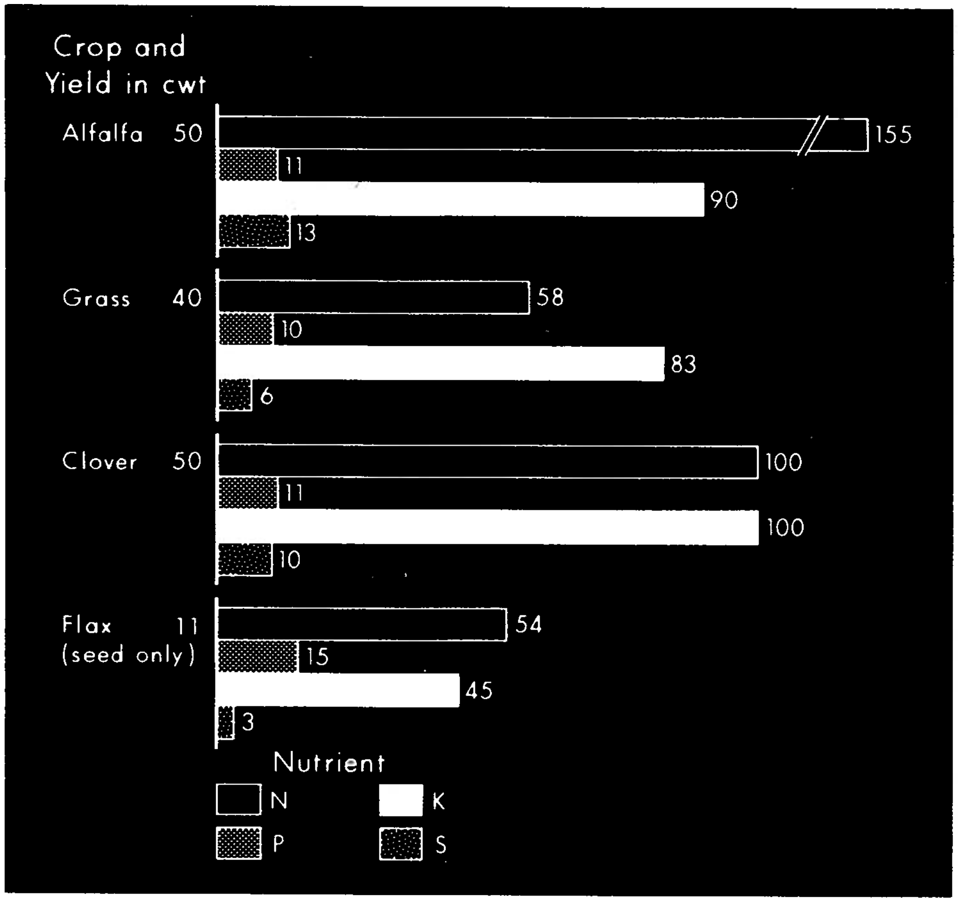


Figure 14—Approximate uptake of four nutrients by some common Alberta crops. (Pounds per acre of nutrients).

take in through their roots. The essential plant nutrients must be in an available form if plants are to use them. In addition to being able to supply plants with adequate amounts of essential nutrients, good soils must not possess chemical properties harmful to plants. There are two well-known chemical conditions of soils that may be harmful to plants: the presence of excess salts (commonly called "alkali") and an unfavorable reaction. Fortunately salts are seldom a problem in the wooded region of Alberta. Soil reaction, or pH as it is commonly called, is important. If soil is too acid in reaction, growth of alfalfa, clovers, and some other crops may be seriously affected. When this condition occurs it can be corrected by suitable applications of calcium carbonate (commonly called lime when used for this purpose). Applications of lime may be beneficial in either, or both, of two ways:—yield depressing acidity may be reduced,—and aluminum and manganese in harmful forms may be changed to forms without harmful effects on crops. (See Page 33 for a fuller discussion of liming and acidity).

Of course good moisture conditions, adequate sunshine, absence of harmful conditions such as hail and frost, as well as good farming practices are all necessary for production of good crops even on the best of soils.

TABLE 2: EXPLANATION OF FERTILIZER SYMBOLS USED IN TABLES AND GRAPHS

I. By convention, and law, the contents of nitrogen (N), phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O) in a fertilizer are shown by numbers as in the following examples:

Fertilizer Analysis Contents of Nutrient† (Shown on the bag, etc.)	N	P_2O_5	K_2O
21-0-0	21%	0%	0%
11-48-0	11%	48%	0%
10-30-10	10%	30%	10%
0-0-60	0%	0%	60%

†The law does not require that the content of sulfur or other elements which may be supplied by fertilizers be shown on fertilizer bags.

II. Some countries now require that plant nutrients in fertilizers by expressed on the elemental basis. That better method of indicating nutrient contents of fertilizers is used in this bulletin. (It is hoped that Canadian law will soon require this simpler way of showing nutrient content of fertilizers).

The following examples show the symbols and conventions used herein:

Nutrient Element	Chemical Symbol	Examples of Rates of Application: Symbol	Meaning
Nitrogen	N	N_{30}	30 pounds per acre
Phosphorus	P*	P_{10}*	10 pounds per acre
Potassium	K°	K_{40}°	40 pounds per acre
Sulfur	S	S_{20}	20 pounds per acre

* To convert phosphorus expressed as P_2O_5 to elemental P, multiply by 0.43; to convert phosphorus expressed as elemental P to the P_2O_5 basis, multiply by 2.3.

° Similarly, potassium expressed as K_2O to elemental K, multilpy by 0.83; to convert potassium expressed as elemental K to the K_2O basis, multiply by 1.2.

III. Usages in this bulletin:

Symbols	Meaning
N P S	Nutrients supplied by fertilizer were nitrogen, phosphorus, and sulfur. (Rates of application not indicated).
N_{40} P_{10} K_{30} S_{10}	The four nutrients were applied at the rates per acre (in Pounds) shown.
M	Farmyard manure.
L	Ground limestone or an equivalent material applied.

HAZARDS AND PROBLEMS

Because of their physical and chemical properties, as well as their geographic location and the moisture relationships that apply, there are some special problems in farming Gray Wooded soils. These difficulties are at least more frequent and serious than comparable problems in areas of Chernozemic soils. To farm Gray Wooded soils successfully the farmer should be aware of such problems in order to plan appropriate strategy to meet them.

Climatic Hazards

One of the most important problems in farming the Gray Wooded soils of Alberta is the hazardous nature of the climate. As stated in the introduction, frost free periods in Gray Wooded soil areas range downward from an average of about 90 days in the most favored locations. Obviously some years will have much shorter frost-free periods than the average for a given area. Poor grain grades are sure to result from early frost and yields will be reduced too. These unfavorable conditions are further complicated and magnified by frequent occurrence of small areas where frost damage is unusually common. Frost damage is exceptionally common on organic soils. Prior to commencement of farming the identification or prediction of frost prone areas is often difficult or impossible. Similarly, there are local variations in amount or time of summer precipitation, which severely affect some local areas in Gray Wooded soil districts. Throughout Alberta, north facing slopes are slower to warm up and dry up than south facing ones. But that problem is greater in Gray Wooded soil districts because they are generally in more northerly locations where the sunlight is at a more oblique angle, and the lighter gray color of clean tilled fields reflects more of the sun's energy. Mixed farming, including raising of livestock, is a recommended type of farming on such soils. But short frost-free periods, few winter thaws and earlier fall snowfall result in a shorter grazing season than in ranching areas of the grasslands. This extends the period when livestock must be fed and that means more work to care for livestock. A final climatic hazard in certain Gray Wooded soils districts is a somewhat less favorable distribution of growing season precipitation than is common in most of Alberta's farming areas: drought in June and early July slows crop growth—rains in late July and August delay and complicate harvesting.

Poor Soil Tilth

Because of a rather low humus content and the powdery nature of the cultivated layer of most Gray Wooded soils, tilth is usually poor. Serious physical problems are therefore common. Tillage of Gray Wooded soils, and harvesting of crops on them, must be delayed until the soil is at a sufficiently low moisture content if impairment of soil tilth is to be avoided! Humus-rich Chernozemic soils can be tilled or can carry harvesting traffic, after rains or the spring melting of snow, sooner than is possible on many Gray Wooded soils. But when thoroughly dried out, the Gray Wooded soils are often baked and hard so that a good deal of power and tillage is needed to prepare a satisfactory seedbed. *Sharp showers or rains, just after seeding, may puddle the surface of Gray soils and subsequent drying may create severe crusting.* Under such circumstances small seeded crops such as grasses and legumes may be unable to push up through the crust. Sometimes even cereals may have difficulty emerging. Upon occasion these problems may be so serious as to necessitate reseeding. Puddling and crusting of Gray

Wooded soil surfaces have other adverse effects. Entry of the moisture of subsequent rains is hampered and runoff may be increased, causing more erosion. Soil pore spaces may become so plugged with soil particles that aeration is reduced, with adverse effects on some crops such as barley, which is susceptible to injury if soil air does not contain a satisfactory amount of oxygen. The compact fine-textured subsoil (Bt horizon) of some Gray Wooded soils hampers root penetration, thereby reducing the depth of soil from which the crop can obtain moisture and nutrients. Fortunately, tap rooted crops like alfalfa can penetrate such layers and over time they will usually improve conditions for other crops.

Photograph 2—Rains following seeding, may cause crusting of Gray Wooded soils and crop emergence may be seriously affected. This is a frequent problem on some Gray Wooded soils.

Crops of Lower Quality

This bulletin has a section (pages 56 to 65) devoted to discussion of the effects of fertilizers and soil management on the nutritive value of crops. Because of the lower average content of such essential elements as nitrogen, calcium and sulfur in Gray Wooded soils as compared to Chernozemic soils, and because of the generally moist conditions in the wooded regions, the nutritive value of crops grown on Gray Wooded soils tends to be clearly inferior to the feed value of crops grown in the other principal farming areas of Alberta. *For example, serious consideration is now being given (1971) to a ban on export of wheat grown on Gray Wooded soils because, on the average, the protein content of wheat grown there is appreciably lower than that of wheat grown on the open prairies.* Figure 15 presents data related to this point. Because mixed farming, including the raising of livestock, is recommended in gray soil areas the animals concerned are likely to make less efficient gains. Worse still, they may be adversely affected in other ways unless farmers follow soil management and feeding practices specifically intended to ensure good rations for their livestock. Fortunately, good

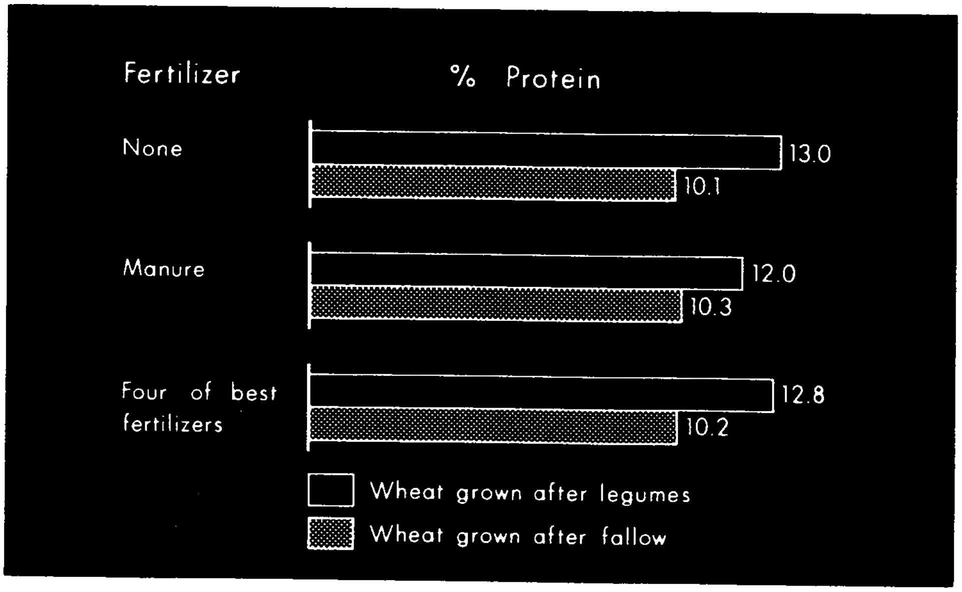


Figure 15—Effects of cropping systems and fertilizers on protein content of wheat at Breton Plots. (Averages for 11 crops 1931-1944).

soil management and fertilization practices result in substantial improvement of the nutritive value of crops grown on Gray Wooded soils. (See the section on crop quality).

For healthy livestock to make efficient gains, properly balanced rations must be fed. Because Alberta crops vary greatly in nutritive value representative feed samples should be sent to the Agricultural Soil and Feed Testing Laboratory, O. S. Longman Building, Edmonton, for analysis. Supplements needed to provide a good ration for the class of livestock concerned can thus be recommended.

Employment of recommended crop rotations, appropriate use of fertilizers, and utilization of available farm manure tend to improve the nutritive value of crops grown on Gray Wooded soils in Alberta and to reduce the cost of providing livestock with the balanced rations they require.

High Transportation Costs

Currently cultivated Gray Wooded soils as well as the extensive areas potentially suited for farming are for the most part at the fringes of Alberta's farming areas, and consequently they are at, or near, the extremities of transportation and communication systems. Goods and supplies purchased by farmers in such districts cost more than similar materials purchased in many other areas:—additional transportation and handling costs must be paid. For similar reasons the prices received by farmers in fringe areas are lower than for similar products elsewhere, as hauling distances are usually longer. Moreover, the small volumes being handed, and the frequency of inferior transportation facilities, also tend to reduce prices paid to farmers in Gray Wooded soil districts. These disadvantages may be partly offset by production of specialty crops such as forage seeds, which are of relatively high value in relation to their weight, and by marketing livestock instead of grains. Nonetheless, relatively high costs for goods, supplies and services, as well as some disadvantages in prices received for products produced, are facts of life which should be recognized by those planning to embark in farming in most Gray Wooded soil areas.

Drainage and Water Problems

Drainage problems are more common in Wooded soil areas and where peats are found than in other farming areas of Alberta. Two types of drainage problems occur. Sometimes the B horizon (subsoil) is so enriched with clay that moisture has difficulty seeping down through that soil layer. The spring thaw, or heavy rains during the growing season, may so saturate the surface soil layers that they become semi-fluid. Such conditions adversely affect crops by keeping the soil cold, by reduction of the oxygen and air content of the soil, by causing excessive caking when soils dry out, and by delaying the farmer's field operations. The second problem is the occurrence of low lying areas where standing water or flooding are fairly common. If drainage ditches can be put in at a practical cost such problems can often be overcome. However, before embarking on a ditching operation it is desirable to obtain professional help to ascertain the need for drainage, the cost, and the prospects for real benefits resulting. The District Agriculturist or extension engineer should be consulted for such assistance.

In parts of the Peace River region an entirely different type of water problem hampers farming on some Gray Wooded soils. In the areas referred to well waters (and sometimes even sloughs) are so salty that they may be unsuitable for household or livestock use. The geological formations in those areas were laid down in sea waters. The salts in well and other waters usually include sodium sulphate (Glauber salts) and magnesium sulphate (Epsom salts). In some rather extensive areas farmers must either construct water holding reservoirs ("dugouts") to catch snow and rain waters, or they must store ice cut from surface waters or rivers in winter to have suitable water for summer. Such water problems complicate family life and livestock production.

'Alfalfa Sick Soil'

Some farmers in a large area of central Alberta have observed that much of their alfalfa is stunted and grows poorly where that crop had previously grown, although no difficulty is experienced in obtaining a good catch. In affected fields, growth is generally poor with patches of normal healthy growth scattered throughout. The difference in vigor between healthy and stunted plants is illustrated in Photo 3. Even in poor areas where most plants are short, spindly, and yellowish-green in color, a few healthy specimens may occur singly or in small clumps as illustrated in Photo 4. Plants in areas of poor growth have either no nodules or nodules in the form of a few large whitish clumps, indicating ineffective strains of Rhizobia, the legume bacteria that take nitrogen from the air.

Since 1961 many field and greenhouse experiments have been conducted in an endeavor to solve the problem of 'alfalfa sick soil'. Those experiments have involved application of many common fertilizers and have also included most of the other essential plant nutrients, all in various combinations. The response from such treatments have been small, indicating that a nutrient deficiency is not responsible for the poor growth. In the greenhouse, soil moisture has been maintained at an optimum level during experiments, and yet the same stunted symptoms observed in the field have occurred. Consequently, the problem is not due to poor soil moisture conditions. The general conclusion now is that the affected soils contain some toxic agent, probably of a biological nature, which is responsible for the poor growth. That conclusion is based on observations that soil sterilization treatments by such means as brief steaming, use of certain chemicals, and gamma radiation have rendered 'sick' soils healthy. Also, water extracts from some of the sick soil produced the symptoms of poor and stunted growth when those extracts were added to soils where plants had previously made normal, healthy growth. However, further information and research is needed to determine the nature of the toxic agent causing poor stunted growth of alfalfa on affected soils.

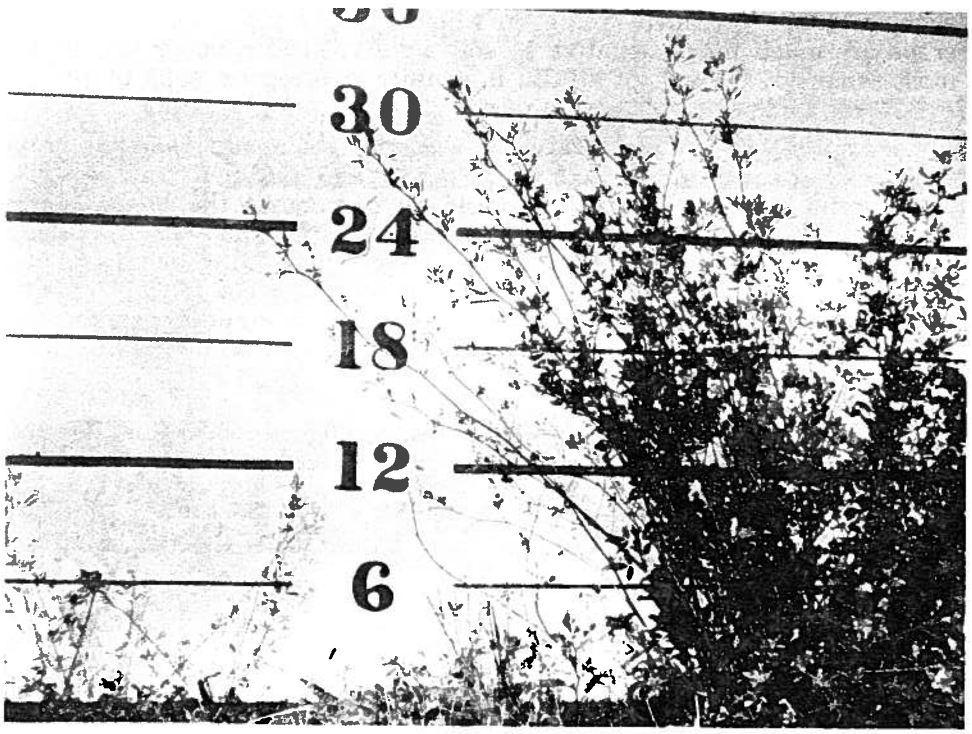
Photograph 3—Alfalfa plants from an area of 'alfalfa sick soil' (centre) with normal plants from areas of good growth on the sides.

Most of the so-called 'alfalfa sick soils' examined to date have been of the Dark Gray or Gray Wooded groups, somewhat acid (pH of 5.8-6.0), sandy loam in texture, and from the area west and southwest of Edmonton. However, a survey conducted during the summer of 1970 revealed that alfalfa stands with symptoms similar to those described have been observed by district agriculturists and farmers over a large area extending from Rocky Mountain House on the southwest, to Bonnyville on the east and Fort Vermilion in the north. The survey is still under way at the time of this writing and hopefully will be expanded in 1971.

In the Spring of 1970, the late W. R. Orchard discovered that the rhizospheres of stunted plants tended to have appreciably higher counts of a nematode species identified by Dr. L. Y. Wu as *Paratylenchus projectus* than occur in the rhizospheres of healthy plants. Nematodes are small, microscopic worms and many kinds of them occur in soils. Very little is known about *Paratylenchus projectus,* but it is parasitic and alfalfa as well as some 88 other plants are reported as hosts. Recently, Dr. E. J. Hawn, Canada Department of Agriculture, Research Station, Lethbridge has been added to the research team trying to solve the 'alfalfa sick soil' problem. He will study the possibilities that the problem is due to nematodes or some plant disease.

It is impossible at this time to give an estimate of the acreage of Gray Wooded soil in Alberta affected by this problem. However, an exceedingly important consideration is the estimate that there are about 500,000 acres of alfalfa (including pure and mixed stands) growing in Alberta on soils regarded as susceptible. Obviously, there is considerable urgency that the cause be determined and a solution found as soon as possible. The research team studying 'alfalfa sick soil' headed by

Dr. G. R. Webster, Department of Soil Science, University of Alberta, Edmonton, would be grateful for any suggestions or information that other scientists, district agriculturists, and farmers may be able to make relative to the problem. Information on the location and cropping history of affected fields would be helpful. Please address all correspondence to Dr. Webster.



Photograph 4—A large healthy alfalfa plant (right) with spindly weak plants on 'alfalfa sick soil' on the left.

Soil Acidity

Gray Wooded soils are developed under a vegetative cover dominated by trees and shrubs. The decomposition of fallen leaves and needles produces organic acids that over a period of many years leach alkaline elements (such as calcium) deep into the subsoil. When leaching is severe the topsoil may as a result become acid. In other instances, Gray Wooded soils are acid simply because they have formed on acid parent materials. The acidity or alkalinity of a soil is expressed in pH units. A pH of 7 means a soil is exactly neutral while a lower pH shows the soil is acid, and a higher pH shows the soil is alkaline. A soil pH of between 6 and 8 is best for growth of most crops. When soil pH is less than 6.0 growth of sensitive crops may be reduced by soil acidity, and when pH is less than 5.0 growth of many crops is seriously restricted.

Although soil acidity has many effects, the primary cause of soil-acidity damage to crops is the high solubility of soil aluminum and manganese that occurs under acid conditions. Both of these elements are harmful to crops when excessive amounts are present in soluble form. In addition, low pH in itself may reduce the ability of legumes such as alfalfa to fix nitrogen. Deficiency of calcium or magnesium may sometimes be another cause of poor growth on acid soils, but such deficiencies are less frequent than once believed. Two other plant nutrients, phosphorus and molybdenum, tend to be less available in acid soils than in neutral soils. However, as repeatedly shown by recent research, the main cause of poor crop growth on acid soils is high solubility of aluminum and manganese.

Crops vary greatly in their tolerance to soil acidity. Some crops, such as oats, grow fairly well even when soils are pH 5.0 or less. Other crops are much more sensitive to soil acidity, alfalfa being one of the most sensitive. Growth of alfalfa is usually reduced on soils of pH 5.5 to pH 6.0, and when pH is less than 5.0 alfalfa will scarely grow.

Liming is the only practical way to correct soil acidity so that crops sensitive to acid conditions can be grown. When sufficient lime is worked into the soil it raises the pH and so overcomes the basic causes of soil acidity damage to crops. The amount of lime required ranges from less than a ton per acre to several tons, depending on the nature of the soil. Suitable, commonly-used liming materials include calcitic lime (calcium carbonate) and dolomitic lime (calcium-magnesium carbonate). Other materials which may be used are hydrated lime, marl or some types of industrial slag.

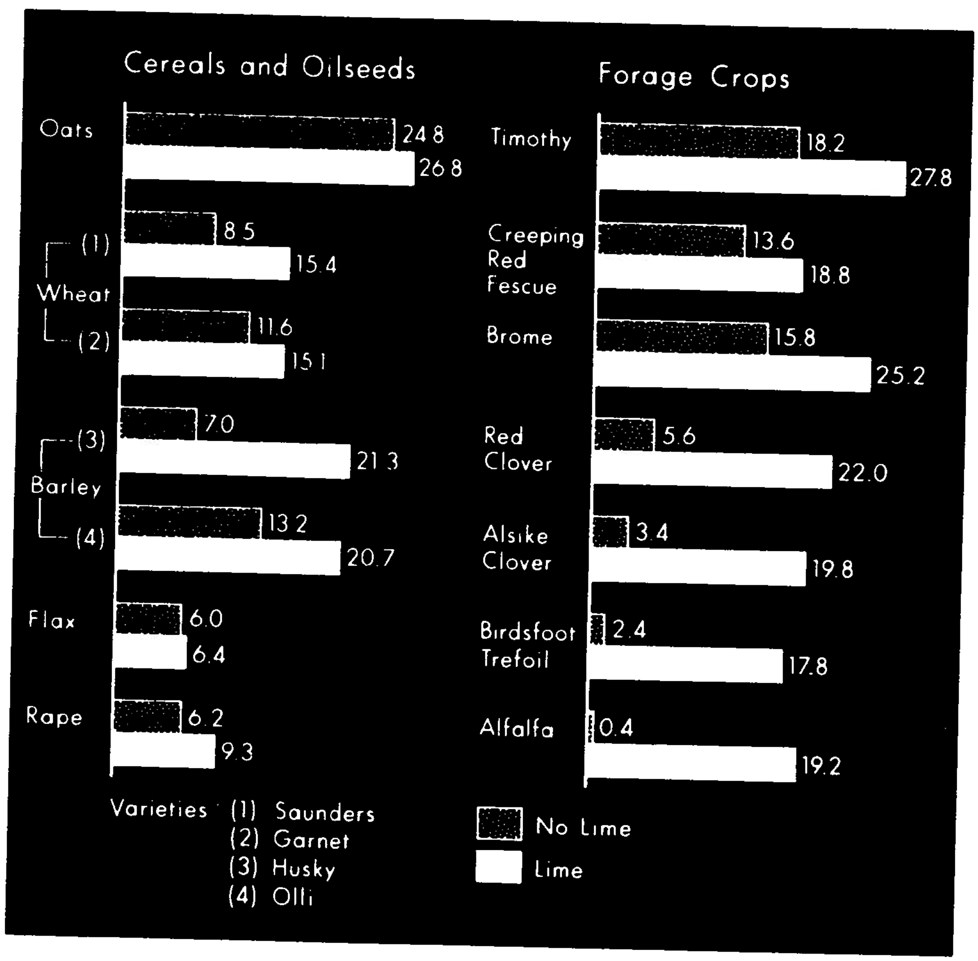


Figure 16—Yields of crops grown on two very acid soils, with and without lime. (2 year average, cwt./acre).

Until recently soil acidity was not considered a problem for Alberta soils. However, extensive field experiments conducted during the past 10 years by the Research Station, Beaverlodge have shown that soil acidity seriously restricts crop growth on certain soils of the Peace River region. Within the Peace River region there are small areas where soils are extremely acid (pH 4 to 5) and there are large areas where soils are moderately or slightly acid (pH 5 to 6). On the extremely acid soils only certain crops grow satisfactorily without liming, as was shown by the results of two field experiments (Figure 16). Oats and

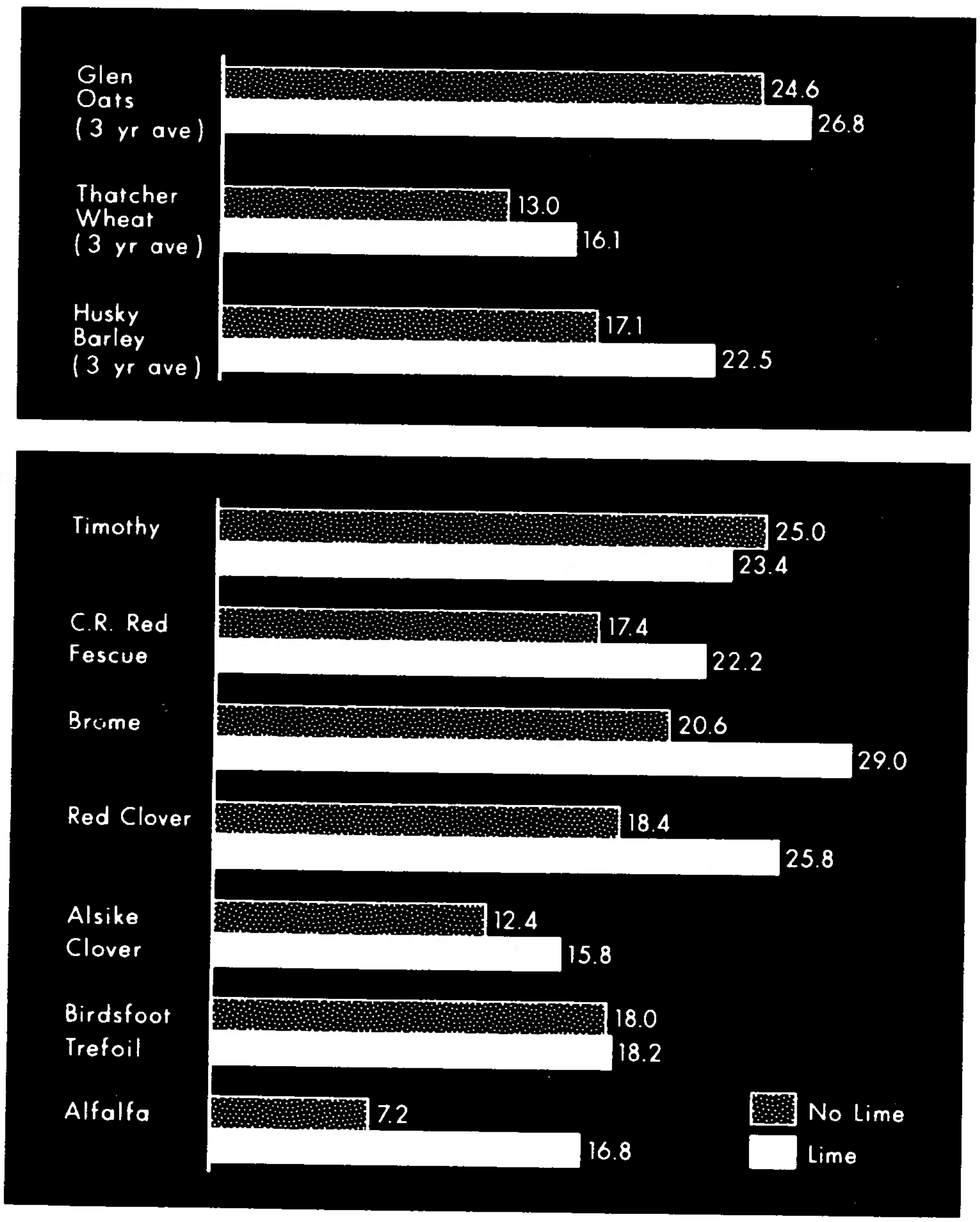


Figure 17—Yields of cereals on a moderately acid Gray Wooded soil, with and without lime. (Cwt. acre).

Figure 18—Yields of forage crops grown on a moderately acid soil, with and without lime. (2 year average, Cwt. acre).

flax were very tolerant to soil acidity, yielding nearly as much on unlimed soil as on limed soil. Rapeseed, wheat and barley, were all sensitive to acidity, and among these barley was the most sensitive. However, for both wheat and barley some varieties were more sensitive than others, and in the case of barley the Olli variety yielded twice as much as the Husky variety on unlimed soil. Grasses (timothy, creeping red fescue and brome grass) were all increased in yield by liming, but yielded fairly well on unlimed soil. The legumes (red clover, alsike clover, birdsfoot trefoil, and alfalfa) produced very little growth unless the acid soil concerned was limed. Among the legumes, alfalfa was the most sensitive. The two field experiments indicated that oats, flax and grasses are the most suitable crops for extremely acid soils.

On moderately acid soils of the Peace River region, liming produces smaller increases in yield, but the increases may still be substantial. In a field experiment on a Gray Wooded soil of pH 5.4, liming increased yield of oats by 6 bushels, wheat by 5 bushels, and barley by 11 bushels, (Figure 17). In a field experiment with forages on a Gray Wooded soil of pH 5.1, timothy grew as well on soil without lime as with lime, (Figure 18). However, yields of both creeping red fescue and bromegrass were increased somewhat by liming. Among the legumes, birdsfoot trefoil grew as well on unlimed soil as on limed soil. red clover and alsike clover benefited slightly from liming, while alfalfa grew very poorly unless the soil was limed. That experiment demonstrated that trefoil, red clover or alsike may be grown successfully on some soils that are too acid for alfalfa.

The soil acidity problem extends to areas of Alberta outside of the Peace River region. Experiments conducted by the Research Station, Lacombe, showed that alfalfa benefited from liming on several acid Gray Wooded soils in West Central Alberta. Results of other, very recent investigations, indicate that a substantial portion of Gray Wooded soils in different areas of the province have pH values in the range of 5.0 to 6.0, and that growth of alfalfa is restricted by the acidity of most Gray Wooded soils with pH values below 6.0. However, the exact extent and importance of the soil acidity problem has not been determined.

The simplest way to tell if a soil is acid is by measurement of soil pH. The Alberta Soil and Feed Testing Laboratory includes pH in the routine analyses performed on all farm samples submitted for soil testing. Those soil samples that are found to have a low pH are also analyzed for soluble aluminum and manganese in order to better estimate the extent to which acidity restricts crop growth. When analysed soils are sufficiently acid to restrict crop growth recommendations are made for use of acid-tolerant crops, or for the use of lime in some instances.

In Alberta little use has been made of lime to correct soil acidity, primarily because the cost of lime has been high. However, in some areas of the province, lime is now available at prices that make its use economic on some acid soils. A factor favoring use of lime is that under Western Canadian conditions the effect of a single lime application will last for many years.

PRACTICAL CONSIDERATIONS AND RECOMMENDED PRACTICES

CLEARING AND BREAKING

Expansion of the cultivated acreage in Alberta must, of necessity, be in the Gray Wooded soils region of the central and northwestern parts of the province. These soils generally have a cover of deciduous or mixed deciduous and evergreen trees of varying size depending on soil and climatic conditions and past fires. Recently burned areas usually have a regrowth of pine on sandy soils, predominantly poplar on the finer textured soils. The numbers and size of trees determine the type of clearing operation and cost. The various types of tree cover are classified in Table 3.

Photograph 5—When Gray Wooded soils are broken, the leached gray colored Ae horizon is exposed. Sometimes patches of the underlying brown colored Bt layer may also be turned up.

Methods of Clearing

When the tree cover is light to medium, brush cutting with a "V" blade has proved effective. The operation is usually done in late fall or early winter when the ground is frozen and snow cover is light. The cut brush is windrowed into piles 200 feet or more apart and may either be burned when dry or left as temporary shelter strips and nesting grounds for native bees. In areas of light tree cover, cutting and piling may be combined in one operation by attaching a cutting bar to an angled bulldozer blade. Where tree growth is not too thick and does not exceed 2 inches in diameter a rotary or gyro-mower may be used effectively.

For medium to heavy tree cover, clearing methods that remove some of the roots are preferred to the "V" cutter. Walking down clearing in late fall or early winter with a raised and angled bulldozer blade is popular. In some cases the walked down cover can be successfully burned without piling if it is left to dry thoroughly. The ball and chain clearing method also removes many of the crown and anchor roots. The method consists of pulling a heavy steel ball (four or more feet in diameter) on the ends of two lengths of heavy chain attached to crawler tractors. Swaths 40 to 70 feet wide can be cleared depending on the type of cover and the power units used. At freezing temperatures, this method has a swathing effect which reduces or eliminates piling costs. The ball and chain method is adapted to large tracts of land but has the disadvantage of removing all growth where small patches might best be left because of topography or erosion hazards.

TABLE 3: CLASSIFICATION, FOR LAND CLEARING PURPOSES, OF TYPES OF TREE COVER

Cover Type	Trees per Acre	Ave. Diameter at 4 ft.
1 light	250 - 1000	up to 2"
2 medium	1000 - 3000	4 - 6"
3 heavy	750 - 2000	4 - 8"
4 heavy	500 - 1500	6 - 14"

TABLE 4: APPROXIMATE COSTS OF CLEARING AND BREAKING
(Dollars per acre)

Type of Cover	Clearing & Piling		Breaking including Burning		Discing & Floating	
	Method	Cost	Method	Cost	Cost	Total Cost
Type 1	Rotary Mower (no piling)	$ 5.00	Disc	$ 7.00	$7.00	$19.00
			Moldboard	9.00	7.00	21.00
			Rotovator	18.00	——	23.00
	Side Cutter (piling in same operation)	10.00	Disc	7.00	7.00	24.00
			Moldboard	9.00	7.00	26.00
			Rotovator	18.00	——	28.00
	"V" Cutter (separate piling operation)	12.00	Disc	7.00	7.00	26.00
			Moldboard	9.00	7.00	28.00
			Rotovator	18.00	——	30.00
Type 2	"V" Cutter (separate piling operation)	15.00	Disc	8.00	8.00	31.00
			Moldboard	10.00	8.00	33.00
			Rotovator	20.00	——	36.00
	Walking (separate piling	20.00	Disc	8.00	8.00	36.00
			Moldboard	10.00	8.00	38.00
			Rotovator	20.00	——	41.00
Type 3 and 4	Walking Down (separate piling operation)	25.00	Disc	10.00	9.00	44.00
			Moldboard	12.00	9.00	46.00
	Ball & Chain* (no piling)	10.00	Disc	10.00	9.00	29.00
			Moldboard	12.00	9.00	31.00
	Ball & Chain (separate piling operation)	15.00	Disc	10.00	9.00	34.00
			Moldboard	12.00	9.00	36.00

*Restricted to large areas

Controlled burning as a method of clearing can be used on any type of cover but is not recommended for the private operator because of the difficulty of providing adequate fire control. The method has been successful on some community pasture projects. Several burnings followed by aerial seeding have resulted in greatly improved range.

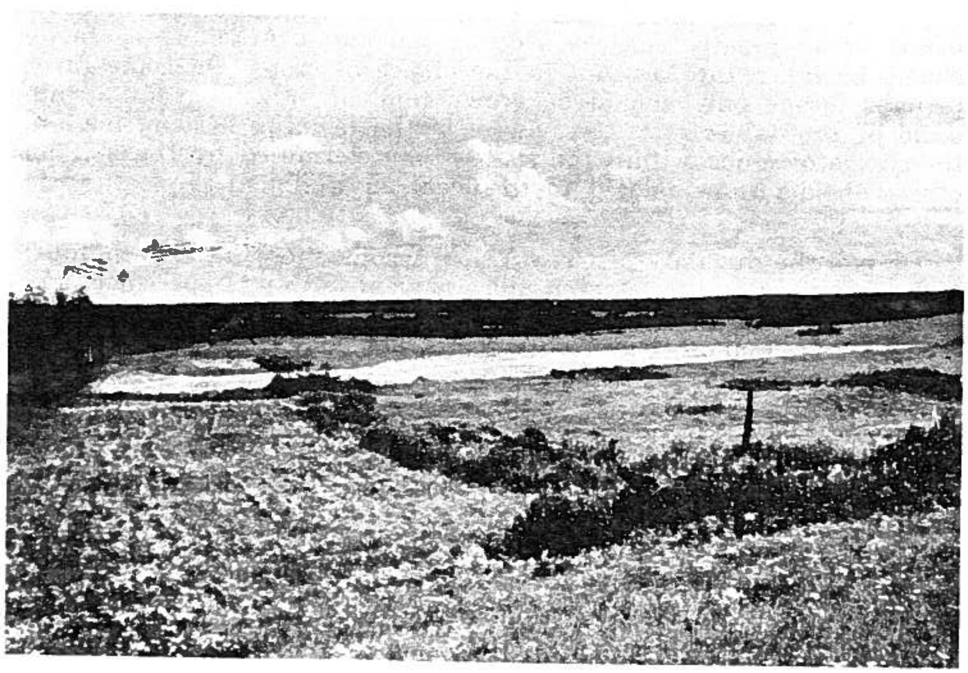
Methods of Breaking

Research by the Beaverlodge Research Station on several different types of Gray Wooded soils has shown that regardless of the machine used for breaking, the operation should be done early (June) and plowing should not be deeper than 4 to 6 inches. The choice of machine for breaking depends largely on the type of tree cover originally present and whether the roots were removed in the clearing operation.

The moldboard plow works well in all types of soil and with all methods of clearing. This method results in a good kill of woody growth but does necessitate reworking and extensive root removal.

Follow-up Operations

Disc plows, unless of the heavy type, will not remove stumps and are used primarily after clearing operations that remove most of the roots. With disc plows the control of regrowth of woody species is not as good as that obtained with a moldboard plow. Disc plows are well suited for minimum surface tillage for the establishment of cultivated pasture species to increase the grazing capacity on rough, stony soils.



Photograph 6—When wooded areas are cleared and broken windrows of brush and earth from the piling operation are often visible for several years.

Rotary cultivators are well adapted to areas of relatively light tree cover or grassy meadows and bogs. They may also be used where the clearing operation removes tree stumps and anchor roots. Although the actual costs of breaking with rotary machines are high, little or no subsequent discing is required, and the land is usually ready for seeding except where root removal is required. Packing may be necessary after rotovating, particularly on peaty soils.

Costs

The type of tree cover is the most important factor contributing to costs, the heavier the tree cover the higher the total cost will be. The methods of breaking and clearing also affect the cost, but to a lesser extent. The approximate costs range from about $20.00 to $50.00 per acre as shown in Table 4. Most disc and mold board breaking will require root raking after the breaking is worked down. This operation adds another $4.00 to $5.00 to the cost of preparing the land for seeding. The final decision regarding selection of suitable methods of clearing and breaking depends largely on the personal preferences of the individual and upon the equipment available.

CHOICE AND SEQUENCE OF CROPS

The choice of crops for Gray Wooded soils is governed by a wide range of soil characteristics and other local environmental factors. Gray Wooded soils vary greatly in texture, permeability of subsoil, and drainage. The topography can be hilly, rolling or flat. The fields can be expansive and uninterrupted, or they can be cut up by sloughs, water courses, very stony areas and so forth. The length of the frost-free period varies greatly in Gray Wooded soil areas. All of these factors should be taken into account in the choice of crops. On some farms, perhaps forage only should be grown and, on others, grain farming could be profitable. Thus, the choice of the farming system, not only the choice of crops within the system, is determined by the soil and other considerations related to the local environment.

Despite the diversity of Gray Wooded soils there have been found, both through scientific research and practical farming experience, some crops particularly well suited to such soils. Legumes, perennial and biennal, grow well on Gray Wooded soils, and they in turn, have special value for improving the soils.

Grains and Legumes in Rotations

The yields of grain in a mixed rotation of clovers and grain are compared to those in a fallow-grain rotation in Figure 19. The yields are for a 41-year period on the Breton plots. (These plots are described in detail on page 67). Where nitrogen plus sulfur fertilizers were applied, wheat after clovers outyielded that after fallow on plots that received recommended fertilizers by 50 per cent or more. The hay crops are of great value in themselves, the fallow is by comparison a loss, so the value of crops produced in the mixed rotation has been much greater than the value of those produced in the fallow-wheat rotation. Where nitrogen plus sulfur fertilizers were not applied, the wheat yields after clovers were only slightly greater than those after fallow. This demonstrated the need to provide a good supply of nutrients to obtain the benefits from forages. Sulfur is the most important nutrient deficiency for legumes at Breton, and indeed, sulfur is deficient in the majority

Photograph 7—The benefits from sulphur fertilization of legumes frequently extend over several years. Two co-operative tests are pictured.

The upper photograph shows alsike clover growing well in strips which had been fertilized the previous year while it has almost disappeared from the unfertilized parts of the field.

The lower photograph shows barley following alsike clover. The best growth (foreground and right) occurs on plots where sulfur fertilizers had been applied to alsike clover the previous year.

of Gray Wooded soils in Central Alberta and in several of those soils in the Peace River region. Phosphorus may be lacking for legumes and, on some soils, potassium too is deficient. Some soils, though, have adequate natural fertility for legumes.

On some Gray Wooded soils, unfertilized legume hay has given good crops. At McLennan in 1961 Figure 20, hay yielded about 3 tons per acre on unfertilized plots. This is typical of the yields obtained on those

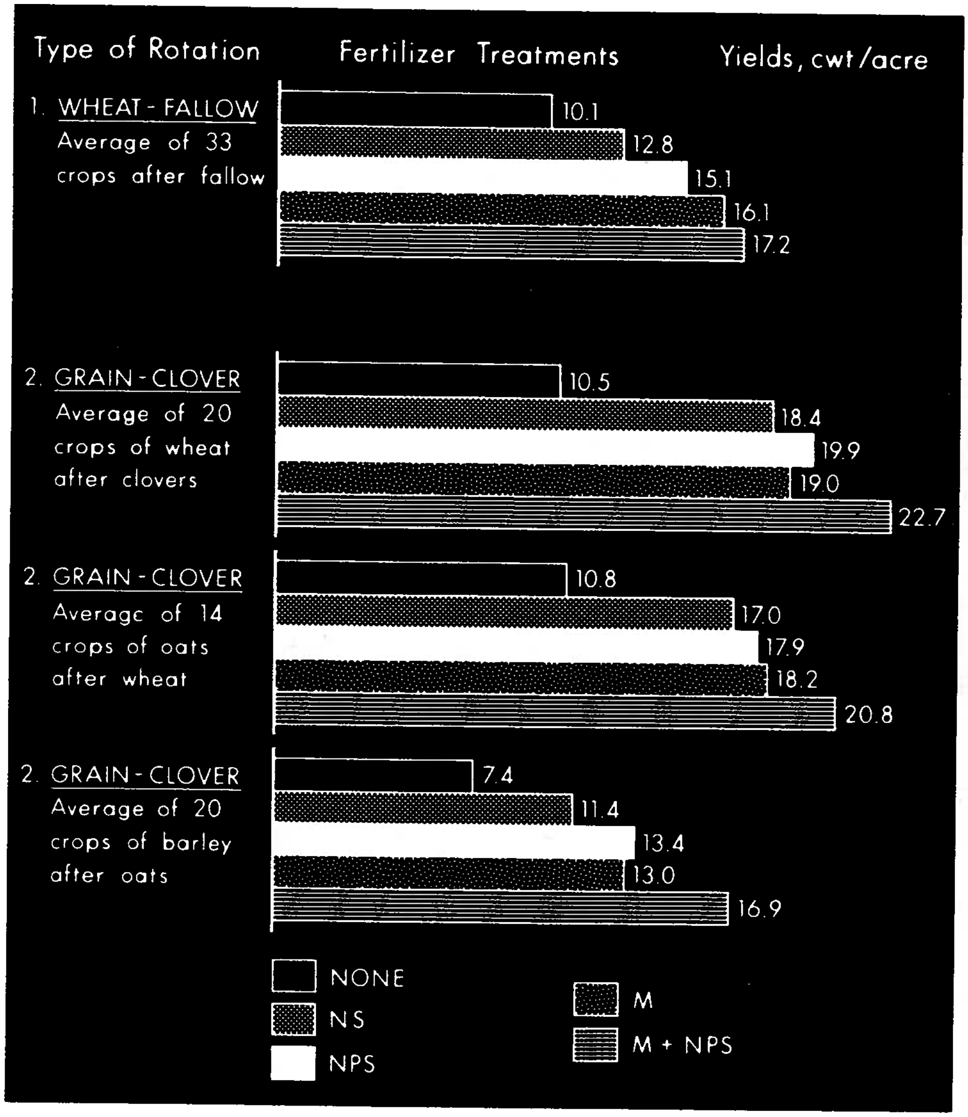


Figure 19—Grain yields of eleven experimental plots at Breton. (1930-1970, Cwt./acre).

plots over several years. In young stands, alfalfa outyielded the bromegrass—alfalfa mixtures, but in the older stands the mixture was best. Bromegrass by itself yielded much less than the bromegrass-alfalfa mixture or alfalfa alone, probably because of nitrogen deficiency when there was no legume present.

The yields of wheat that were grown on the McLennan plots from 1962 to 1970 following the fall ploughing of the forages in 1961 are shown in Figure 21. In 1963, wheat yielded 37.6 bus./acre after alfalfa and only 21.3 bus./acre after fallow (in the fallow-wheat control plots). Wheat on the former alfalfa plots continued to outyield that on the former fallow-wheat plots in the eight succeeding years. In 1970, nine years after the forage plots had been ploughed up, wheat yielded 19.7 bus./acre on the former alfalfa plots compared with only 12.6 bus./acre on the former fallow-wheat plots. During the same period wheat

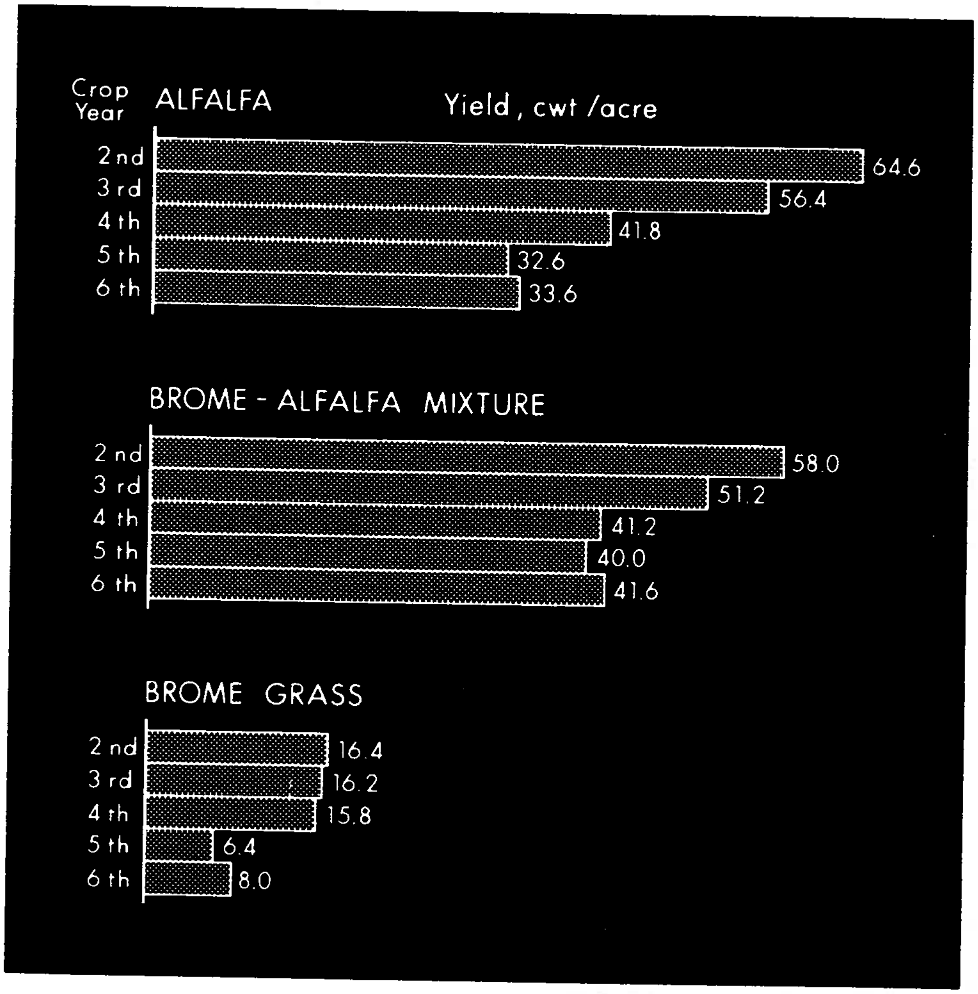


Figure 20—Yields of hay from unfertilized forage in the 2nd to 6th year of production. McLennan, Alberta, (1961-1966, Cwt./acre).

yield after the bromegrass-alfalfa mixture was lower than after alfalfa, but yield was considerably higher than after fallow-wheat plots that had not been seeded to forage. Where wheat followed bromegrass by itself, wheat yield was lower than it was after fallow-wheat for the first two years. However, in the following years, wheat on the plots that had previously had bromegrass, outyielded wheat on the fallow-wheat plots.

Although the forage stands that were plowed up in 1961 varied in stand as they differed in age from two to six years, there were no effects from that fact on the wheat yields. For example, the yield of wheat after alfalfa grown for about 2 years was about the same as that of wheat following alfalfa grown for 6 years.

Results May Vary

In spite of the foregoing, sweeping generalization should not be made. Grain does not always yield better in mixed rotations that include legumes and grain, than in fallow-grain rotations. To date, at Evans-

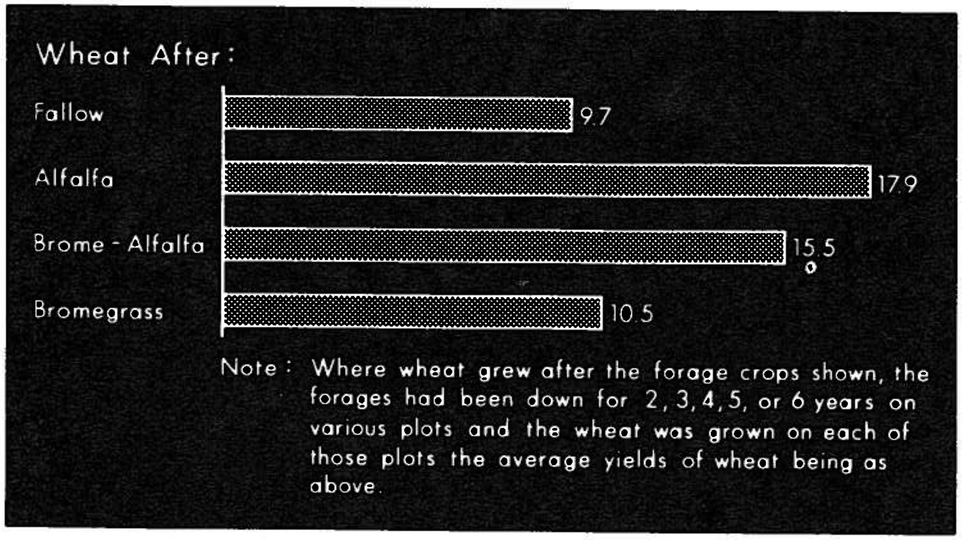


Figure 21—Average yields of seven crops of wheat after a fallow-wheat rotation, and after various forage crops. McLennan, Alberta. (1962-1970, Cwt./acre).

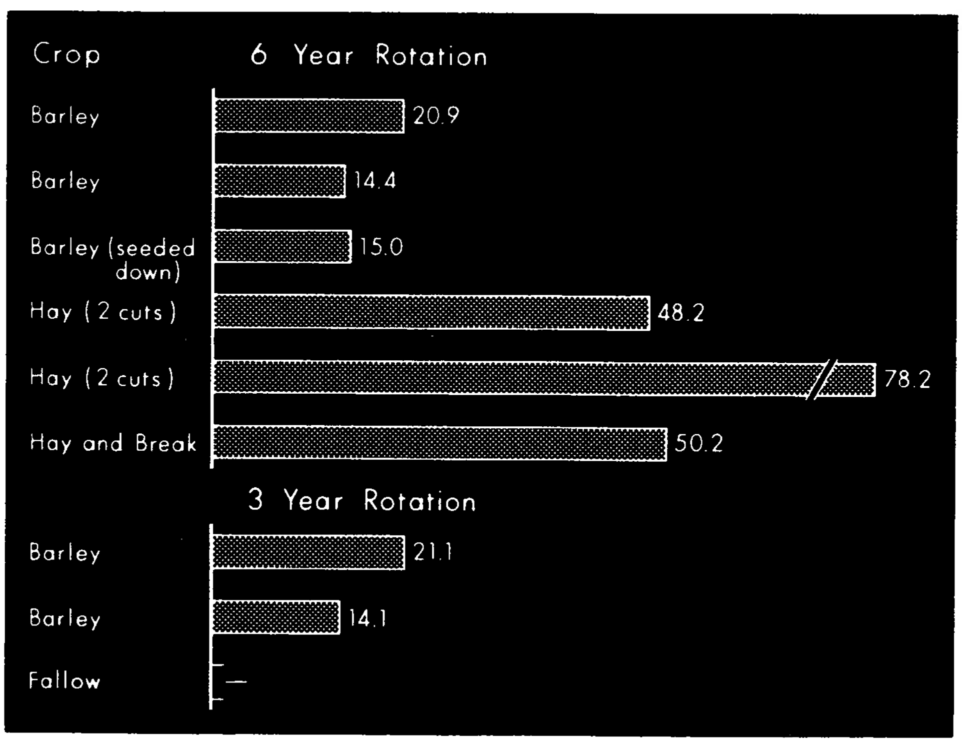


Figure 22—Yield of fertilized hay and grain in two rotations. Evansburg, Alberta. (3 year averages, Cwt./acre).

burg, barley yields in a 6-year rotation of hay and barley are about the same as those in a 3-year rotation of fallow and barley, Figure 22. However, the Evansburg plots were only recently started and perhaps it is too early to assess them.

On a Gray Wooded soil at Cecil Lake, B.C., the first barley crop yielded less after legumes than after fallow, Figure 23. However, the second crop yielded more where it followed legumes than where it grew after fallow. Perhaps yields of the first crop after the legume suffered from lack of moisture whereas that would not apply to the crop on fallowed land. Yield relationships were reversed at High Level, where barley yields were much higher after legumes than after fallow for the first crop, but were only slightly better than on the fallow plots for the second crop.

It will also be noted that in Figure 23 the yields following the three legumes alfalfa, red clover and alsike were quite similar. Whether any or all of these legumes will have the long-lasting effect that alfalfa

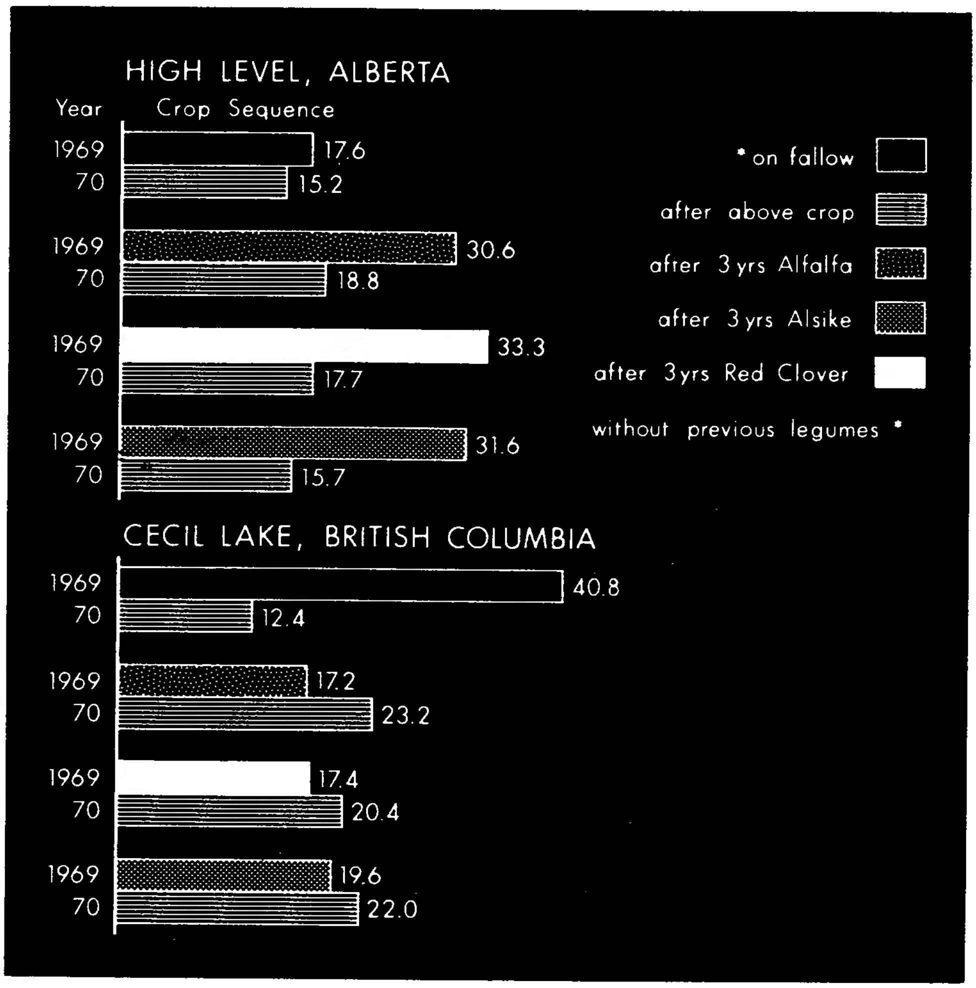
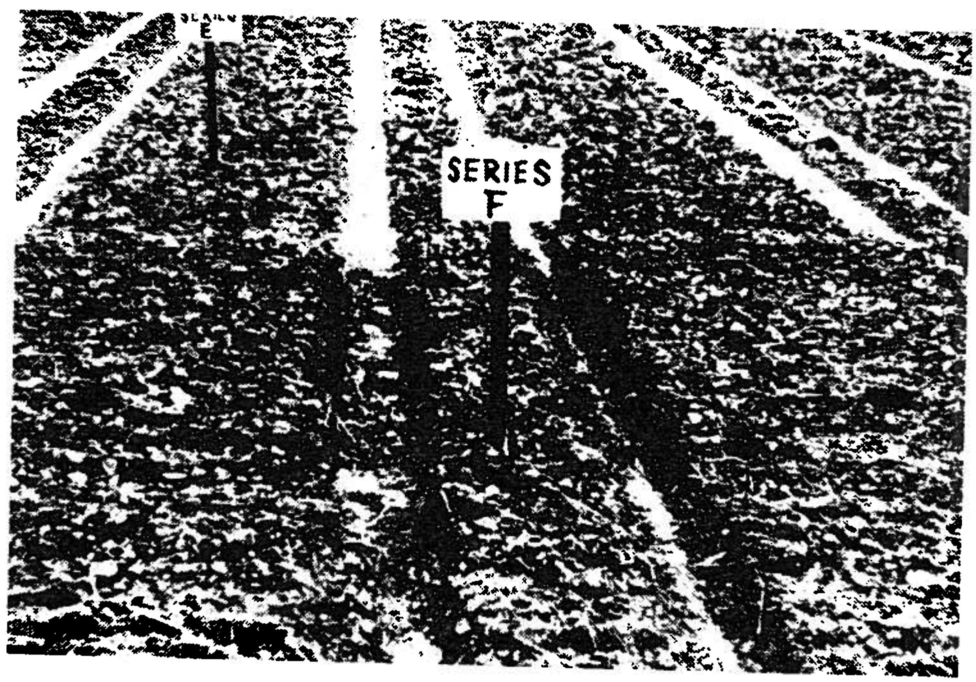


Figure 23—Yield of Galt barley, fertilized with P, K and S, as first and second crops after fallow or after legumes at two Peace River locations (Cwt./acre).

has had at McLennan is yet to be seen. Reasons for the long-lasting effect of alfalfa at McLennan have not been clearly proved. Until further research has been done, exact reasons for the benefits of legumes and the extent of their benefits cannot be predicted with certainty for the individual farm. It should be added here that in some experiments sweet clover has proved beneficial to succeeding crops in a fashion similar to the other legumes.

Much attention has been given to legumes, for they have proved of outstanding beneficial effect on Gray Wooded soils. There have been fewer experiments to measure the effects of grasses on such soils and on yields of succeeding cereal crops. Grasses should have more effect on the soil when fertilized than when grown without fertilization, as was the case at McLennan, Figure 21. Gray Wooded soils are well suited to the seed production of creeping red fescue, bromegrass and many other grasses. Farmers have noted that such grasses add much fiber; thereby protecting the soil against water erosion and improving soil tilth.



Photograph 8—Tilth of the soil at Breton has been improved by the 5 year rotation (foreground) but remains poor on plots cropped continuously to grain (background). Photograph taken after the same spring tillage operation, 1956.

Other Considerations in Cropping Gray Wooded Soils

The suitability of different grain crops to Gray Wooded soils is probably more dependent on the local climate and peculiarities of the individual soil than on general characteristics of the soils. For example, the grain crops chosen should be those that can mature in the area and withstand particular adverse characteristics of individual soils. A specific example is that oats grow well on very acid soils, whereas barley and wheat do not. However, oats may grow poorly on soils with tough solonetzic subsoils because such soils can be droughty, as a result of moisture loss by run-off.

Special mention should be made of rapeseed. This crop appears to produce well on Gray Wooded soils, perhaps because the moisture supply is more favorable than for many other soils. But rapeseed appears to be particularly sensitive to soil fertility and so special attention should be given to proper fertilizer applications on that crop.

Flaxseed production has been quite successful on Gray Wooded soils.

Sometimes continuous grain cropping can be fairly successful. Moderate to high yields of continous barley have been obtained on plots of three Gray Wooded soils in the Peace River region, Figure 24. However, very high rates of fertilizer, at present too costly to be practical, were used. But, the yields obtained do demonstrate that some

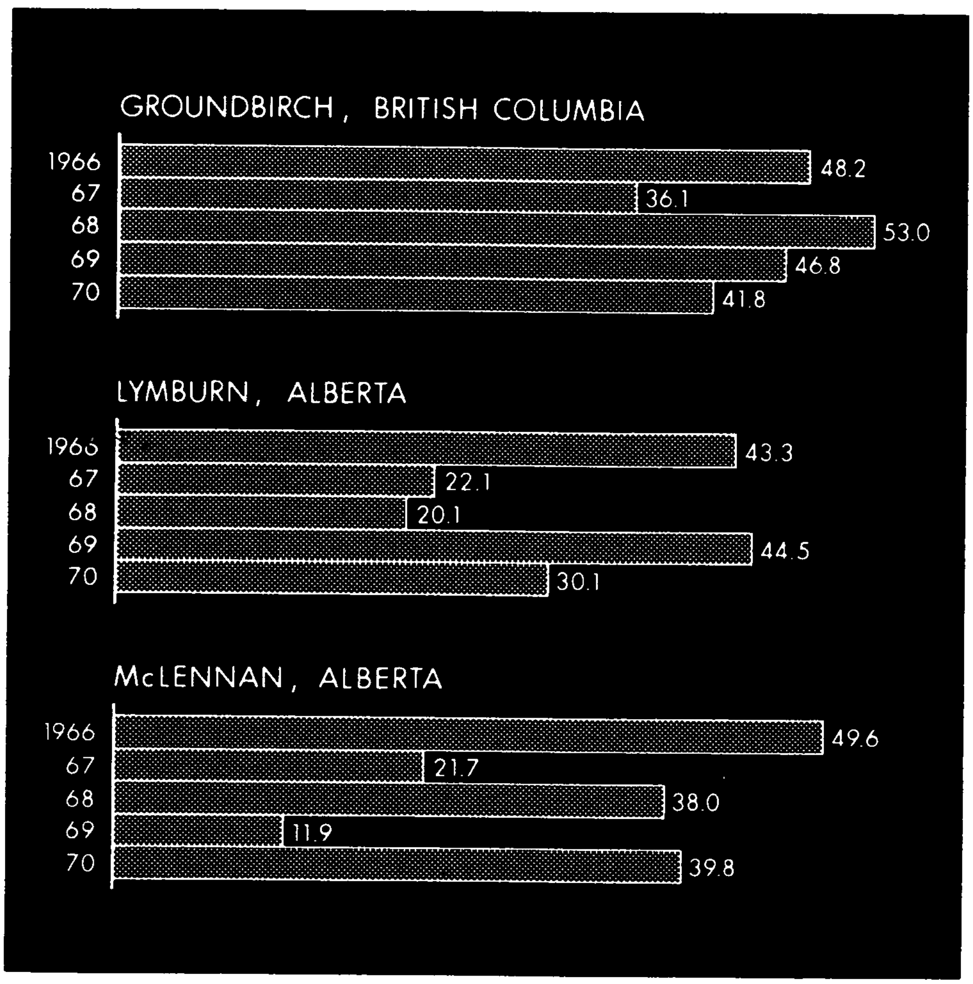


Figure 24—Yield of continuous barley with a very high rate of fertilization (an ave. of N_{115} P_{75} K_{75} S_{20}) at various Peace River locations. (Cwt./acre).

Gray Wooded soils have potential for grain production, if they receive suitable fertilization. See also Figure 25.

It should be mentioned that observations appear to justify the conclusion that crops well produced, using good husbandry for tillage, seeding and fertilization, improve Gray Wooded soils. On the other hand, such soils appear to deteriorate rapidly under poor soil management practices. For that reason, fallow should be used sparingly, preferably only to combat severe weed infestations or in cases of severe drought. When bare Gray Wooded soils are exposed to the weather they deteriorate rapidly in structure, becoming hard and baked, thereby making it difficult to get a good stand when a crop is planted.

In a good rotation for Gray Wooded soils the crops should be arranged for maximum mutual benefit. Because of the complexity of conditions, rotations should be worked out for the individual farm. However, rotations which have two to four years of legume containing

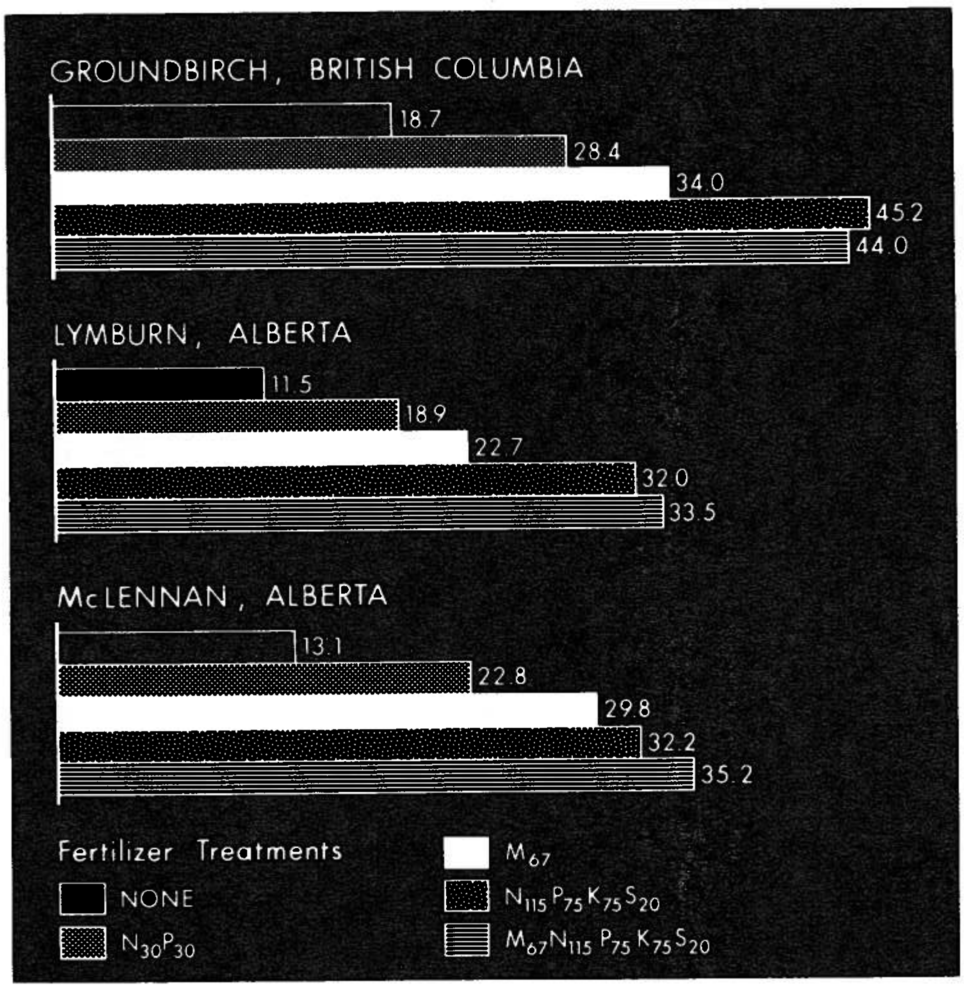


Figure 25—Five year average yields of Galt barley, variously fertilized, at Peace River locations, (1966-1970, Cwt./acre).

hay, followed by a similar number of cereal crops before reseeding to hay, are preferred by many good farmers on Gray Wooded soils. The plan should be to grow a range of crops that will help maintain a balance of nutrients and water in the soil. Every effort should be made to include a perennial or biennial legume crop in the rotation, grown alone, or in mixture with grass. The legume can be grown for herbage or seed, or it can be used as green manure. Thus, a legume crop can and should be included in a rotation for any kind of farming system—including grain farming.

CULTURAL PRACTICES FOR FORAGE CROPS

The low level of organic matter in Gray Wooded soils and problems associated with that condition, as discussed under "Production of grain and oilseed crops", is the cause of many of the problems encountered in forage production on such soils. The frequent occurrence of acidic soils in the Gray Wooded region probably affects forage crop production to a greater extent than is now recognized. Soil acidity certainly affects the choice of legume crops, and may be responsible for the fact that in Gray Wooded soil areas farmers usually grow more alsike and red clover than alfalfa. Alsike and red clover are relatively acid tolerant, while alfalfa is rather sensitive to soil acidity.

Seedbed Preparation and Seeding

On Gray Wooded soils, cultivation prior to seeding forage crops should leave a somewhat cloddy surface, to minimize crusting if heavy rains occur after seeding. If possible, the cloddy surface condition should be obtained with a minimum of tillage, to reduce drying of the surface layer into which the forage crop is to be seeded. If the weed problem is not too severe, seeding may be done directly into stubble land with no prior cultivation. At McLennan, on the Nampa soil series, a very early shallow cultivation followed by a slightly deeper tillage just before seeding has given good weed control, favorable moisture conservation and germination.

The seeding operation should place the forage seed at a shallow depth in the soil. This will generally ensure better and more uniform emergence of the plants than if the seed is broadcast—especially if surface soil moisture is limited. Forage crop seeding may be done with various commercial seeders mounted on double packer units, but farm experience has not shown such machines to have any advantage over broadcast seeding followed by harrowing. Such machines have the added disadvantage of pulverizing the soil excessively, and increasing the possibility of severe soil crusting.

Grain drills are satisfactory for seeding forage crops on Gray Wooded soils, particularly if they are modified. Flanges may be added on the disks to control the depth of seeding, and gear reduction boxes can be used to reduce the rate of feed. This avoids the need to mix the seed with cracked grain or other material to obtain the low seeding rates required. For grasses being sown for seed production a drill provides a convenient method of obtaining any width of row that may be desired. Studies on various soils, including Gray Wooded soils have shown increased seed yields from row seedings. The optimum width between rows for maximum seed production appears to depend more on available moisture than on fertility. The optimum row spacing decreases as available moisture increases. On some rolling soils row seeding is not practical because of the soil erosion that occurs between rows—unless the seeding is on the contour.

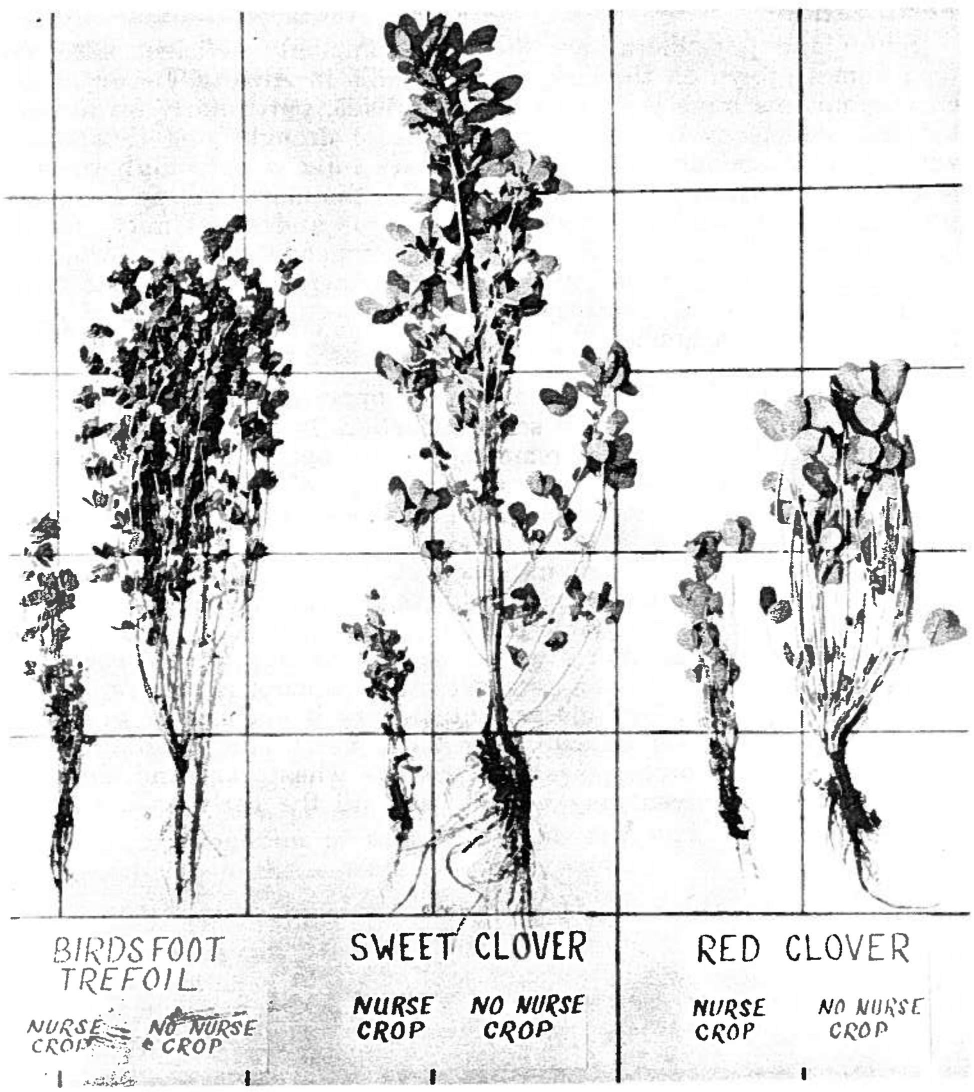
Date of seeding is important if good stands of forage crops are to be obtained. Late fall (near freeze up) or early spring seeding favors establishment of good stands. Surface soil moisture is usually good in the early spring and the lower temperatures result in less surface drying then than later in the season. Dates of seeding on Black soil at Lacombe illustrate the general trend that can be expected from fall forage crop seeding on Gray Wooded soils. Those data (Table 5) generally show that seeding after August 15 and before freeze-up does not allow sufficient development before over wintering and many plants do not survive the following year. Late summer and early fall seedings are vulnerable to damage from erosion associated with spring run-off.

TABLE 5: EFFECT OF DATE OF SEEDING GRASSES AND LEGUMES AT LACOMBE ON PERCENTAGE STAND OBTAINED, 1950-1955

	Seeding Date			
Species	Aug. 15	Sept. 15	Oct. 15	Early Spring
Brome	78	74	99	96
Crested Wheat Grass	62	80	96	96
Creeping Red Fescue	51	75	100	97
Alfalfa	82	62	99	98
Red Clover	6	1	60	98
Alsike Clover	50	30	88	95

It is recommended that forage crops be seeded by themselves. If companion or nurse crops are used they compete with the developing forage stand and tend to reduce the yield of the forage even in the third year hay crop. Studies by the Beaverlodge Research Station have shown that creeping red fescue seeded without a nurse crop will produce a seed crop the first year after seeding, but when a nurse crop is used, the first seed production is obtained the second year after seeding. Similar results were obtained at Lacombe with Russian Wild Rye. Studies at Lacombe showed a reduction of 0.6 to 1.6 tons per acre over a two year period when an oat nurse crop was used with two different forage crop mixtures (Table 6).

Seed for all legume crops should be inoculated just before planting to obtain good inoculation of the legume with Rhizobia bacteria. Those bacteria fix nitrogen from the air for their own use as well as for the host plant. This source of nitrogen is particularly important on the Gray Wooded soils which are usually nitrogen deficient. Even if the legumes are sown on an area that has recently grown inoculated legumes, it is desirable to re-inoculate the seed to ensure maximum inoculation. Farmers should obtain fresh recommended inoculants from seed dealers and follow container directions. Fertilizers should not be applied in direct contact with inoculated seed as the fertilizer may kill or injure the bacteria in the inoculum.



Photograph 9—When a nurse crop (sometimes called a companion crop) is sown with a forage the growth and yield of the forage crop is usually severely reduced.

TABLE 6: EFFECT OF AN OAT COMPANION CROP ON THE YIELD OF TWO FORAGE MIXTURES AT LACOMBE, 1964-1965

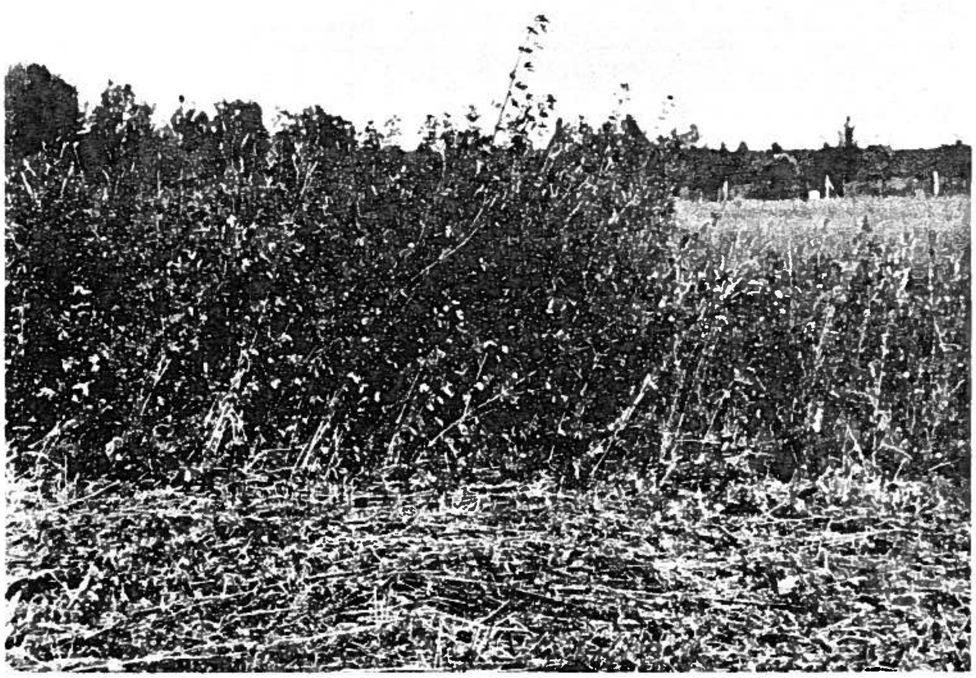
	Yields tons/acre ALFALFA—BROME		
Year	No Nurse Crop	¾ bus/ac oats pastured	oats for silage
1964	1.25	1.23[1]	2.44[1]
1965	4.77	3.66	2.97
Total	6.02	4.89	5.41
	Yield tons/acre ALFALFA—CRESTED WHEAT GRASS		
1964	1.25	1.23[1]	2.44[1]
1965	4.78	3.18	2.40
Total	6.03	4.41	4.80

[1] includes oats.

Fertilization

Sulfur and phosphorus are the most commonly deficient elements for legumes grown on the Gray Wooded soils in Alberta. Boron deficiency symptoms have been seen in some fields, particularly on alfalfa, but that deficiency occurs during periods of drought and disappears when moisture conditions improve. Grasses have a very high requirement for nitrogen and this element is by far the most limiting for grass production on Gray Wooded soils. Phosphorus and sulfur may also be required. As for other crops, general recommendations for fertilizers are not as satisfactory as soil analyses. Farmers are advised to have samples of their soils analysed to obtain an accurate estimate of what fertilizers should be applied.

Time of application of fertilizer may not be important for hay production but is very important for grass seed production. In grasses, floral initiation has very specific requirements for nitrogen, so seed growers should apply nitrogen just prior to this stage of flowering. The best time to apply nitrogen fertilizer to a grass seed stand therefore varies with the grass species. Russian wild rye produces seed from tillers that pass through the floral initiation stage in early autumn of the previous season. Thus, for Russina wild-rye, fertilizing immediately after seed harvest is best. Similar results have been obtained with brome grass in Saskatchewan. For grasses such as creeping red fescue, that initiate heads in early spring, late autumn fertilizing is most effective. Very early spring applications are satisfactory if made prior to spring growth. For those that initiate their floral parts later than creeping red fescue, such as bromegrass, intermediate wheatgrass and timothy, fertilizing with nitrogen may be delayed until the early spring.



Photograph 10—Sulfur fertilization of legumes growing on soils deficient in that element result in dramatic yield increases. (Breton Plots, S fertilized left, no S fertilizer on right).

For established grass seed stands phosphorus fertilizers, when required, are best broadcast in the early fall. However, for soils very deficient in phosphorus, heavy rates drilled in or broadcast and worked into the soil prior to seeding should be beneficial for the life of the grass stand.

Other Factors

Winter killing of forage stands appears more prevalent on many of the Gray Wooded soils than on Chernozemic soils. Although many facets of this problem are not understood, research has shown that clipping or grazing too close to the crown and harvesting between the middle of August and the middle of September result in greater susceptibility to winter killing of legumes.

PRODUCTION OF GRAIN AND OILSEED CROPS

The production of grains, flax and oilseed crops on Gray Wooded soils generally requires more careful management practices than are needed on other soils. Because of low organic matter in Gray Wooded soils water holding capacity is also low and such soils dry out relatively quickly during periods of drought. Their low content of organic matter also makes the preparation of a friable seed bed difficult. The finer textured soils tend to powder if tilled when too dry, and to puddle or form a compact mass if cultivated when too wet. Even when a friable seed bed has been prepared, heavy rains followed by dry hot weather can cause formation of a crust on the soil surface. Such crusts can seriously affect the emergence and growth of crops.

The natural fertility of Gray Wooded soils varies greatly but some generalizations can be made. The low organic matter content, which is the main source of nitrogen in most soils and of sulfur in many soils, cannot maintain adequate rates of nitrogen or sulfur release over the years. As a result, many require high rates of nitrogen fertilization soon after they are brought into cultivation. The same situation applies to sulfur on many Gray Wooded soils, although some soils do have sulfur bearing minerals which maintain an adequate supply of available sulfur for crop growth. Phosphorus deficiency occurs on many Gray Wooded soils as on other soils in the province, while potassium, manganese and boron deficiencies have been found only occasionally. Soil acidity does occur on a significant number of Gray Wooded soils and that affects the choice and production of crops.

Seedbed Preparation and Seeding

If possible, cultivation should be done when the soil is moist but not wet, in order to provide a seedbed with a cloddy structure rather than a seed bed of pulverized or of an excessively lumpy structure. A field with cloddy structure does not puddle and crust when it receives heavy rains, as readily as does a powdery seedbed, and it does not dry out as quickly as a very lumpy seedbed. Cultivation of Gray Wooded soils should not be excessive, as this will dry out the surface layer and has not been shown to be necessary. The limited research on cultivation methods for Gray Wooded soils has shown that best yields are obtained with just sufficient tillage to kill weeds. The testing that has been done also shows that deep cultivation is not advantageous. Seeding should preferably put the seed in moist soil to allow rapid germination and emergence. Maximum seeding depth should be similar to or slightly less than that on soils of higher organic matter content. Soils that are particularly subject to crusting may produce better if seeding rates are somewhat higher than is common on other soils. Studies at McLennan by personnel of the Beaverlodge Research Station have shown that higher rates of seeding barley help to break the surface crust and promote effective seedling emergence.

Fertilization

Proper fertilization of cereals, flax and oilseed crops is essential for good yields on most Gray Wooded soils. As mentioned previously, nitrogen in particular is usually deficient unless the crops are grown on land broken from legume or legume-grass sod land. General recommendations are not as good as field tests or soil analyses; fertilizer requirements should be determined by submitting carefully taken samples for testing.

Rotations

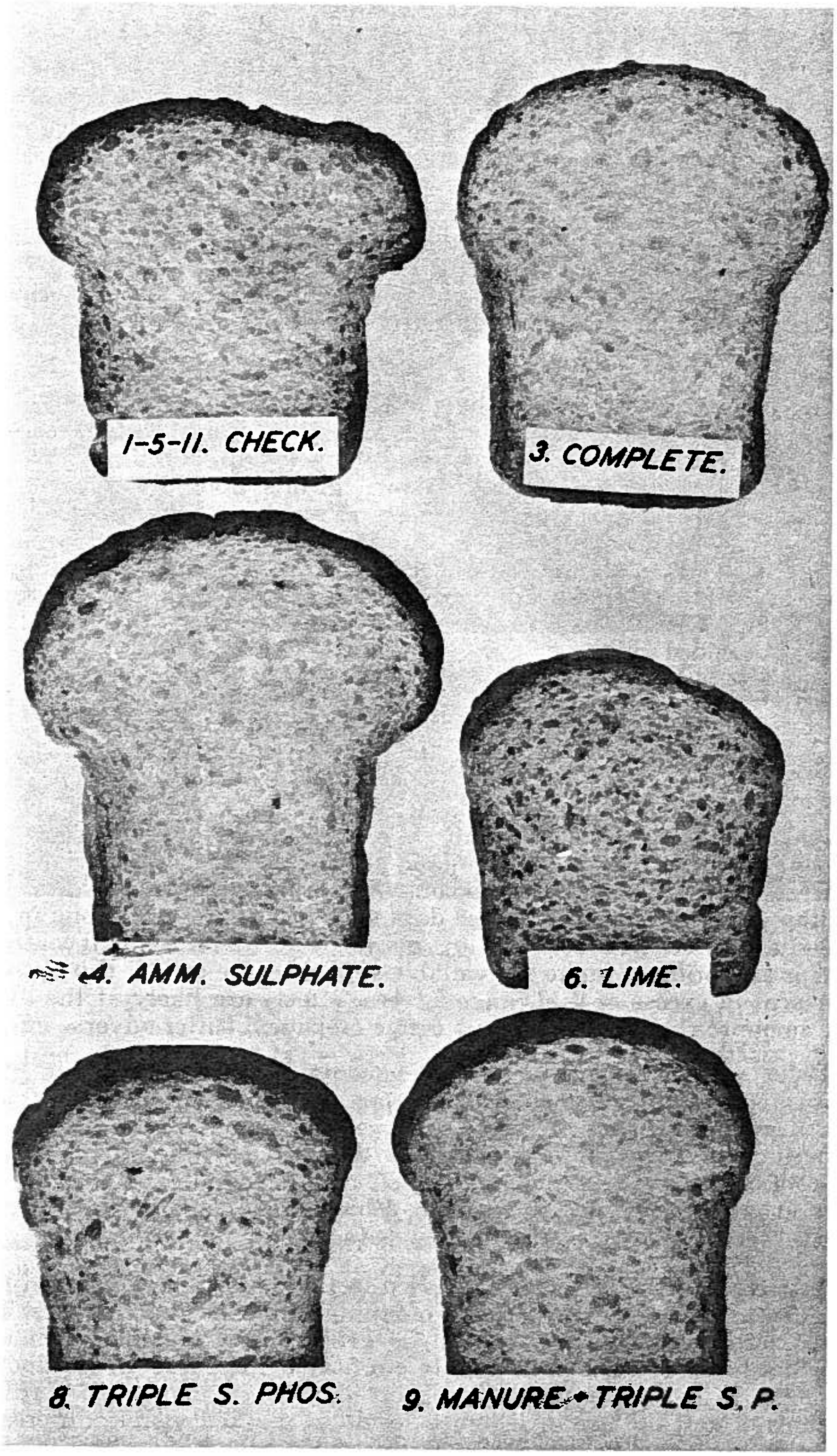
Legumes and legume-grass mixtures are very important in improving soil structure and adding fibre and nitrogen to the soil. The return of crop residues and use of farm manure are recommended soil management practices. On many Gray Wooded soils profitable grain production is possible if grains are grown in a rotation with legume crops. For further details see the section, "Choice and Sequence of Crops", pages 40 to 48.

Harvesting

Harvesting of cereal, flax and oilseed crops on Gray Wooded soils presents no additional problems to those encountered on Black Chernozemic soils. However, all combine straw and crop residues should be worked into the soil so as to add organic matter. *Do not burn combine straw and stubble!*

For further information on crop varieties, fertilization and other practices suitable for Gray Wooded soils, references are suggested:

1. Soil Management in Alberta. Alta. Dept. of Agr. Publ. No. 155.
2. Varieties of cereals and oilseeds for Alberta. Alta. Dept. of Agr. Publ. No. 110/32 (most recent edition).



Photograph 11—Breton Plots 1939. Fertilizer treatments and cropping systems have important effects on crop quality when Gray Wooded soils are farmed.

CROP QUALITY AND NUTRITIVE VALUE OF FEEDS

Everyone knows crop quality is important. A field of vigorously growing forage or cereal having a rich healthy green color is usually preferred by livestock compared to thin unthrifty stands of the same crops in nearby fields. The science of nutrition has revealed, and is continuing to demonstrate, that the nutritive value of grains and hays can be greatly improved by soil management and fertilizer practices especially on certain soils. Some of the most spectacular improvements and effects of that type occur in parts of Alberta's Gray Wooded soils areas.

If present trends continue, the grading of grains and hays may soon include specific consideration of their protein content. That is because higher protein content of crops usually means higher food and feed value. For farmers who feed their own grains and hay to livestock, profits, or even success, may be strongly affected by the nutritive quality of the crops they have produced. As already mentioned, feeds should be sent to the Agricultural Soil and Feed Testing Laboratory, Edmonton for analysis and recommendations so that a properly balanced ration can be fed. These considerations are of great importance when farming Gray Wooded soils.

An understanding of how and why soil management and fertilizer practices can improve the quality and feed value of crops will help farmers with livestock to obtain the best possible results.

Plant Nutrient Content of Crops

Figures 13 and 14, of this bulletin lists some of the essential plant nutrients crops must obtain from soils in appropriate amounts, if normal healthy growth is to occur. Those data show there are variations in the amounts of nutrients required by plants. For an individual nutrient there is an optimum range of available supply in the soil. If the nutrient is present in excess of that range adverse effects are likely; if the available amount is below the optimum range crops will suffer adverse effects.

Deficiencies of any or all of the elements nitrogen, sulfur and phosphorus, commonly adversely affect crops grown on Gray Wooded soils in Alberta. Deficiency of any of those nutrients reduces crop yield. Deficiency of nitrogen and/or sulfur also affect the nutritive (feed) value of crops. The relationships and effects are complicated, and knowledge about them is still incomplete. However, enough is known to be of great benefit to farmers on Gray Wooded soils.

The experiments previously reported in this bulletin have shown that for Alberta Gray Wooded soils, a cropping sequence that includes hay crops containing legumes as well as grain crops, together with suitable fertilization, results in highly profitable increases in production per acre. It has been regularly observed that recommended fertilizer treatments and the use of legumes result in marked visible differences in crops. For example, the sulfur fertilized legumes have a richer, more healthy-looking green color than the sulfur deficient plants. Similar effects are observed on cereal crops when nitrogen fertilizer is applied to nitrogen-deficient soils. Figure 26 demonstrates that on soils suffer-

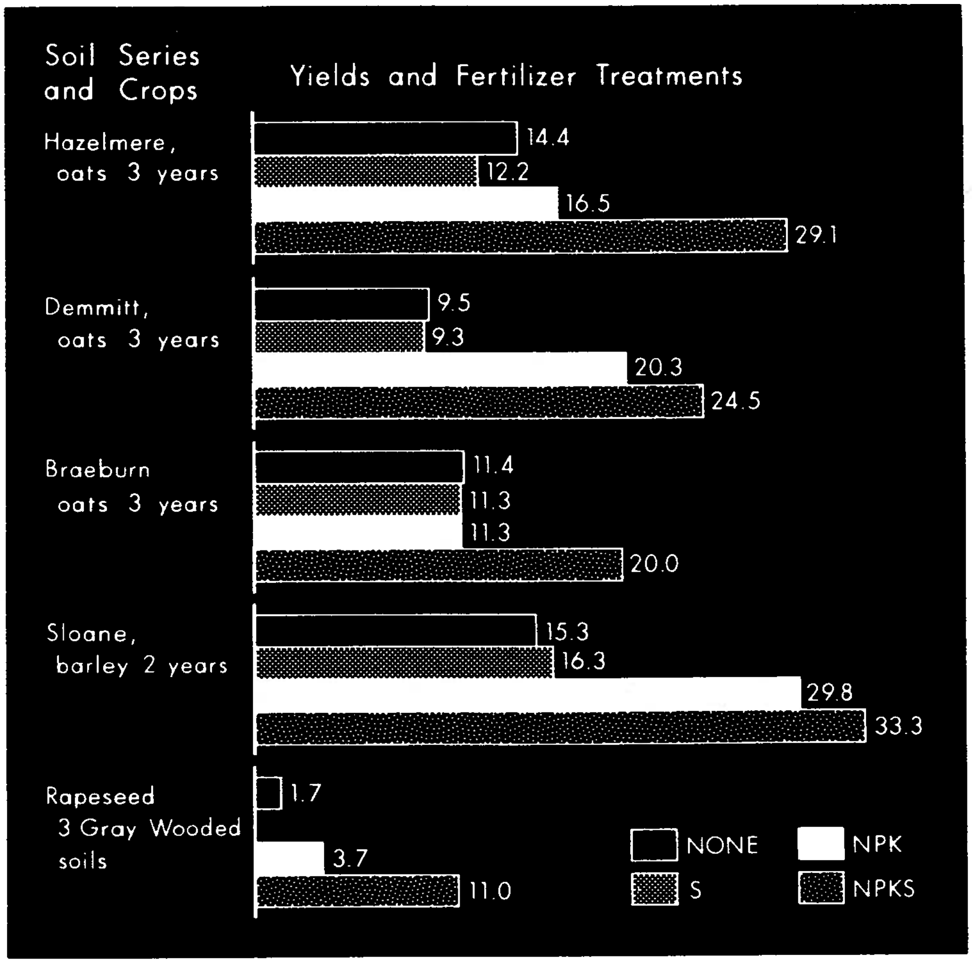


Figure 26—Field responses of some crops to sulfur alone or with nitrogen. Selected Gray Wooded soils in the Peace River region. (1966-1968, Cwt./acre).

ing from deficiency of both nitrogen and sulfur, both nutrients must be supplied in fertilizer form if healthy plants and good yields of cereals and rapeseed are to be obtained. Fertilizer applications, especially those supplying phosphorus, frequently result in earlier heading and maturity of cereals.

The foregoing observations have led to chemical analyses, baking experiments, amino acid determinations, laboratory feeding trials and animal grazing experiments to determine the effects of recommended cropping practices on the quality of crops grown on Gray Wooded soils.

Protein Content of Crops

At the Breton Plots (see pages 67 to 70) wheat grown after legumes has averaged about 25 percent higher protein content than wheat after fallow on adjacent plots where no legumes had been grown. The results of those determinations are summarized in Figure 15. Protein content of grain, grown as the first crop after breaking hay land including a legume, is higher than that of grain grown as the third crop after breaking up a legume-containing field of hay. Breton data in Figure 27 illustrate that point.

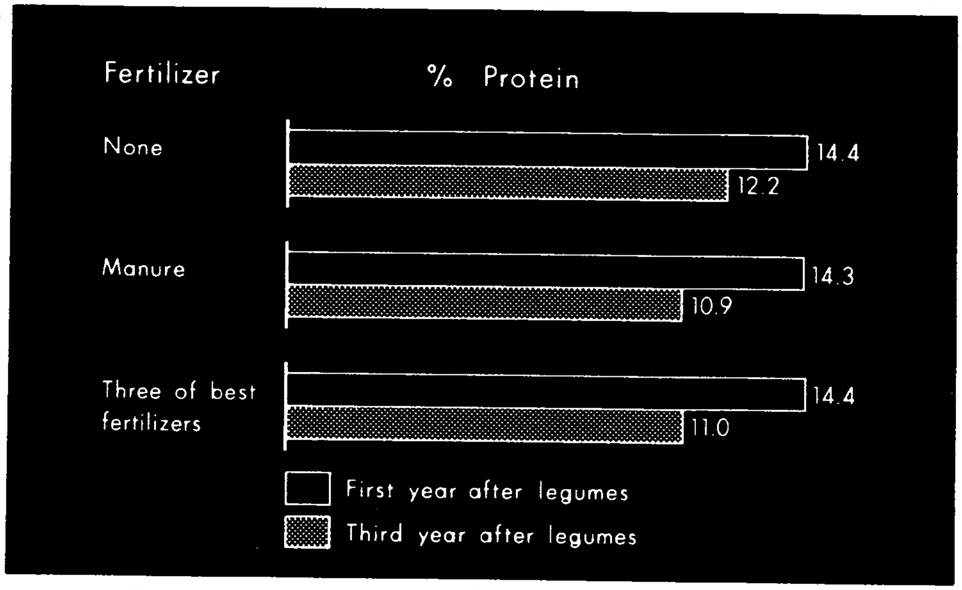


Figure 27—Effects of fertilizers, and of years after legumes, on protein content of Olli barley, Breton plots. (Averages for four years).

There is a logical explanation for the higher protein content of the grain crop grown after legumes. Properly inoculated legumes have, on their roots, nodules in which the legume bacteria live. These bacteria convert nitrogen gas from the air into compounds of nitrogen, which the legume crop and the bacteria themselves use. When a field that has been in legume is plowed up there are many hundreds of pounds of roots and other crop residues. Such materials contain large amounts of protein and as these residues decay and decompose, the protein is converted to compounds of nitrogen, which the grain crops, growing on the land after the legumes, are able to take up and utilize. The decomposition of the legume residues and roots is a continuing process which goes on throughout the growing season, and when legume hay fields are broken up, a number of seasons are required for the complete decomposition of the residues. This ensures that a continuing supply of nitrogen will become available to the grain crops, as the legume material decays over a period of two or three years. Legume residues may be a better source of nitrogen for grain crops than are commercial fertilizers, because continuing decomposition of such residues ensures availability of nitrogen compounds throughout the growing season. However, in fields cropped only to grains a bountiful supply of available nitrogen at the time heads and kernels are forming is unlikely, unless nitrogenous fertilizers are applied at high rates.

The low protein content of barley grown as the third year crop after legume hay, Figure 27 is easily explained. Most of the legume residues would decompose during the first two seasons following breaking up of the legume sod. Hence, during the third year after legumes there is a smaller amount of those residues remaining to be decomposed and consequently there will be smaller quantities of nitrogen available for the growing barley.

It is therefore concluded that on Gray Wooded soils:

1. Grains grown after legumes have a higher protein content than grains grown on fallowed land.
2. The protein content of grain grown after legumes declines quickly and is considerably lower in the third crop than in the first crop after legumes.

It has already been mentioned that legumes grown at Breton on sulfur fertilized plots have a healthier, greener appearance than the legumes grown on the other plot. Table 7 presents data which show that sulfur fertilization increases the protein content of alfalfa, Altaswede, alsike, and sweet clover when they are grown on sulfur-deficient soils. Since protein is one of the important constituents determining the nutritive value of hays, these results lead to the expectation that sulphur fertilization of legumes growing on sulfur-deficient soils will result in crops of improved nutritive value.

TABLE 7: THE PROTEIN CONTENT OF FERTILIZED AND UNFERTILIZED LEGUMES GROWN ON SULFUR-DEFICIENT SOILS

Crop	Location	No. of years	% protein in legume: Not Fertilized with sulfur	Fertilized with sulfur
Mixed alfalfa-altaswede clover, first year hay	Breton Plots	6	12.5	15.0
Mixed alfalfa-altaswede clover, second year hay	Breton Plots	4	13.1	16.2
Altaswede clover, leaves only	Breton Plots	1	16.2	21.2
Altaswede clover, stems only	Breton Plots	1	8.1	8.1
Alfalfa, leaves only	Breton Plots	1	21.9	26.9
Alfalfa, stems only	Breton Plots	1	14.4	16.9
Alsike clover	Near Breton	1	14.4	20.6
Sweet clover	Near Bonnyville	1	14.4	19.4
Alfalfa	6 farms, Gray Wooded soils	1	15.0	17.5

Baking Quality

After it had been demonstrated that sulfur fertilized legumes at Breton and the grains that followed the legume crop were higher in their protein content than the other crops, it became desirable to determine whether the quality of the protein was affected by the treatments.

Baking tests were one of the first ways employed to measure the protein quality in grain crops at Breton. Flour from wheat grown on the fallowed land and flour from wheat grown after legumes was used

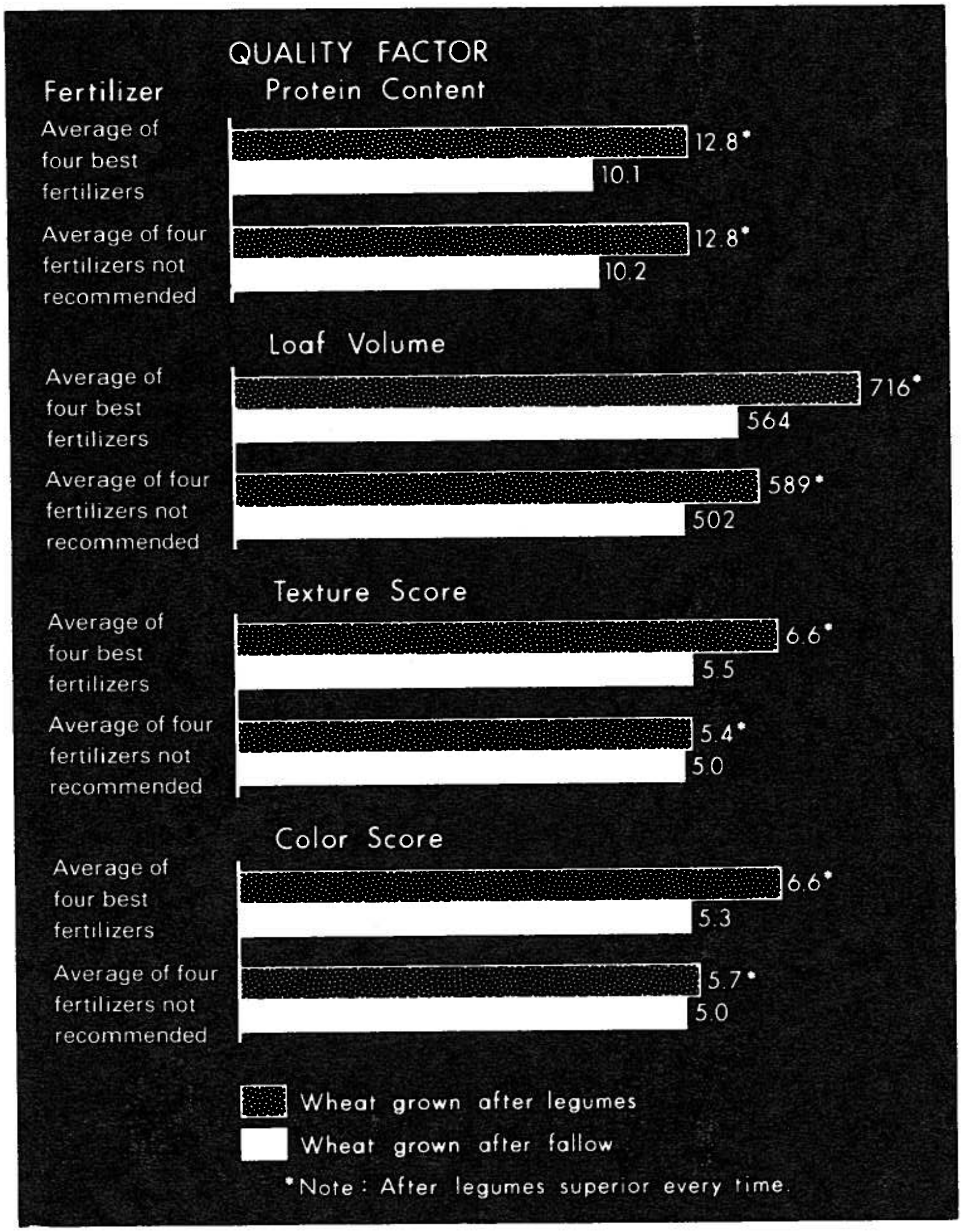
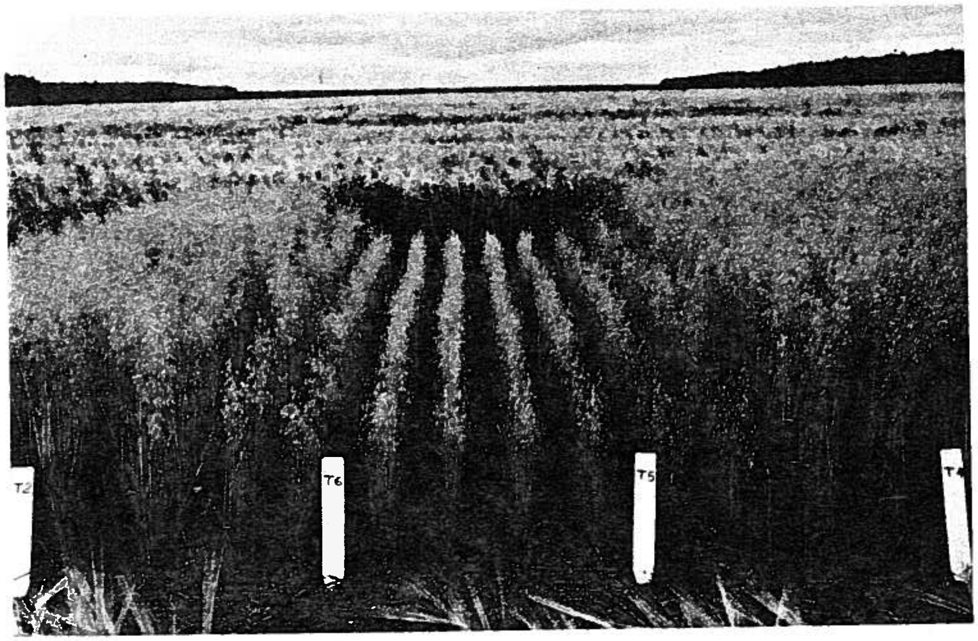


Figure 28—Effects of fertilizers and crop rotation on bread making quality of Breton Plot wheat. (Averages for several years).

to make standard loaves of bread. These baking tests revealed very important differences in the quality of bread produced. As illustrated in Photo 11 the appearance of loaves of bread was greatly affected by the fertilizer treatments and the crop sequence. Data in Figure 28 show how great these differences were. The largest loaves and the best quality of bread were obtained when the wheat had been grown after legumes on plots that had received sulfur fertilizers. The poorest bread was obtained from wheat grown on fallowed land or on plots that received no fertilizers. Since bread quality is closely related to protein quality as well as quantity, these results showed that the fertilizer treatments were causing actual changes in quality of the protein, especially when the wheat grew after the legumes.



Photograph 12—Oats grown after barley have responded to fertilization. Fertilizer treatment and yields of oats in cwt. were:
T2: N P K (41.8), T 6: none (10.5),
T5: P K S (10.3), T 4: N K S (40.2).
Note how adjacent fertilizer benefited the outside rows of T6 and T5.

Amino Acid Content of Grains

Amino acids may be described as the building blocks from which proteins are formed. Certain amino acids are dietary essentials for men and animals. Following the baking test results, nine essential amino acids were determined in some of the Breton grains, to find out whether alterations in their proportions were resulting from fertilization and crop rotation practices. The data from these amino acid determinations are given in Figure 29. Those results show that the better fertilizer treatments, the ones that produced large yield increases because the treatments had supplied sulfur, were affecting the proportion of these nine essential amino acids when wheat was grown after legumes. Surprisingly, the amino acid data show that grains grown after legumes, but not receiving recommended fertilizers, had a lower proportion of the nine amino acids. Grain with smaller proportions of these essential amino acids might be expected to be nutritionally inferior to those grown on fallowed land. Since these analytical results were unexpected, it was decided to determine the nutritive values of wheats grown at the Breton Plots by conducting feeding trials with rats.

Feeding Trials Employing Laboratory Animals

Chemical analyses and even amino acid determinations are not yet able to accurately forecast the actual feeding value of grains. The nutritive requirements of rats are quite close to those of swine (and also

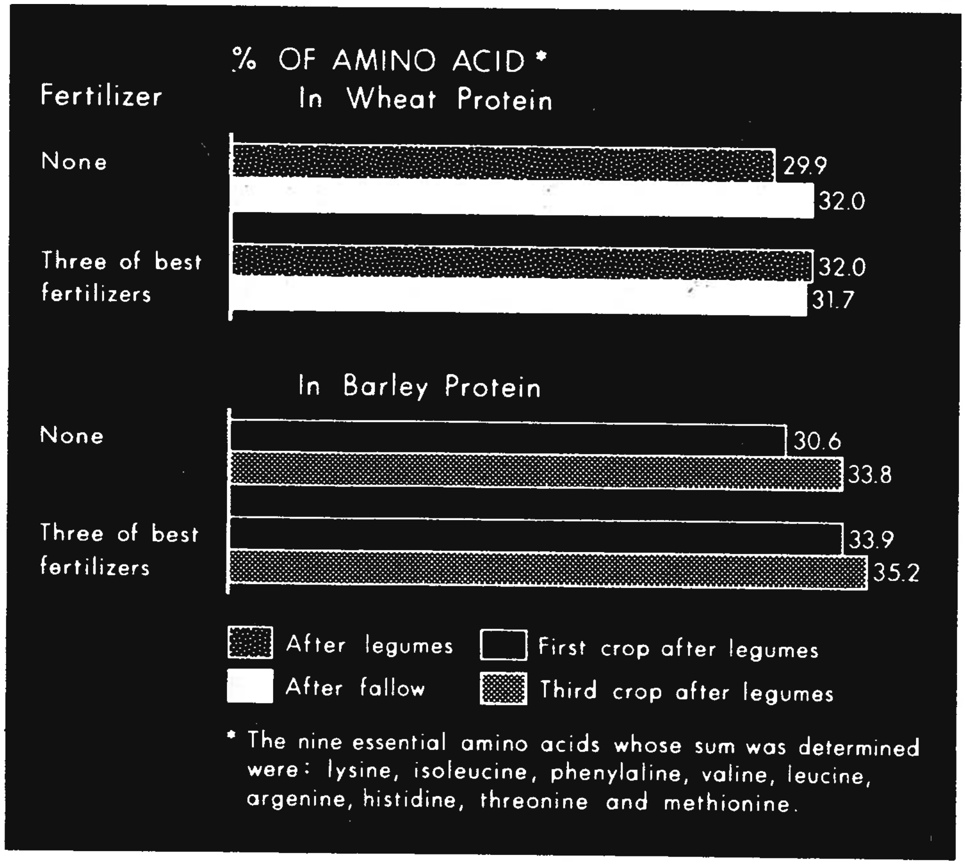


Figure 29—Effects of fertilizers and crop rotation on nine amino acids in Breton Plot grains.

of humans!) because of the similarity of their digestive systems. Therefore Breton Plot wheats grown in 1956 and 1957 were fed to rats, to obtain real measures of the comparative nutritive values of grains grown under the two cropping systems and the various fertilizer treatments employed. Because differences in the protein contents of the various grains were about the same as the differences applying over the years, the feeding trial results are considered representative for wheats grown on the Breton Plots.

Results of the rat feeding trials are summarized in Figure 30. The conclusions are definite and important. Nutritionally, the grain grown after legumes was, for rats, definitely superior to the grain grown after fallow. The rats grew faster and ate less per gram of growth when they were fed the grain grown after legumes. Moreover, grain from plots receiving recommended fertilizers was nutritionally superior to grain grown after legumes that received no fertilizer.

There results are exceedingly important. On a sulfur-deficient soil the recommended practices of growing legumes and of fertilizing them with sulfur-containing fertilizers have resulted in production of wheat of improved nutritional quality. This is an important benefit in addition to the very large yield increases obtained by following the recommended practices of crop rotation and fertilization. Although the

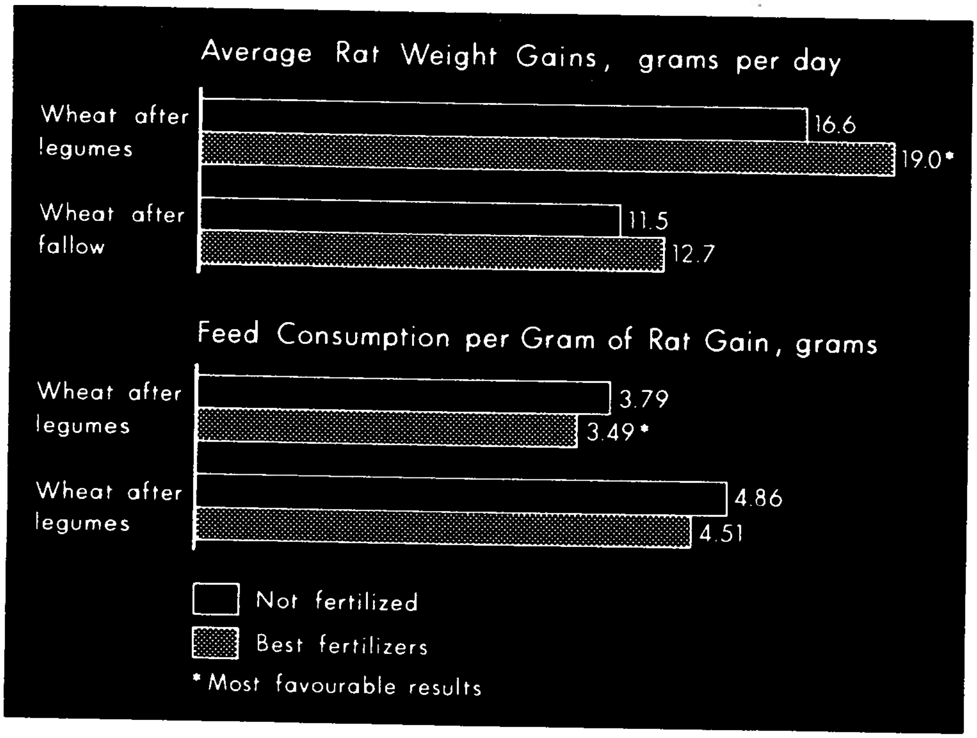


Figure 30—Effects of fertilizers and crop rotation on growth of rats fed wheat grown at Breton Plots. (Averages for two crop years).

data are not included in Figure 30 it should be mentioned that farmyard manure was the only fertilizer treatment that improved the feed value of wheat grown after fallow; however, rats fed wheat grown after legumes and suitably fertilized made even more efficient gains.

The best way to measure the true nutritive value of hays is to feed the forages concerned to the type of livestock being produced. But it is difficult and costly to conduct controlled feeding experiments with cattle. A single well-conducted trial of that kind would cost thousands of dollars, even if it were possible to obtain the large quantities of experimental feeds needed. Fortunately, forage feeding trials employing rabbits as the test aniamls, give results closely approximating the performance of cattle fed the same hays. Feeding trials employing rabbits as the test animal were therefore conducted to determine whether fertilized hays grown on sulfur-deficient Gray Wooded soils differed in nutritive value from unfertilized hay grown in the same fields.

Four rabbit feeding experiments were conducted with legume hays grown on the Breton Plots. The results are summarized in Table 8. Those results show that the recommended fertilizers, which resulted in high yield increases, had improved the feed value of the hays. As measured by average daily gain, the improvements in feed value resulting from fertilization was over 25 percent. Such a result represents an exceedingly profitable additional benefit from use of recommended fertilizer applications.

TABLE 8: EFFECTS OF FERTILIZERS ON NUTRITIVE VALUE OF LEGUME HAYS GROWN AT BRETON PLOTS. AVERAGES OF FOUR EXPERIMENTS WHICH EMPLOYED A TOTAL OF 60 RABBITS.

Treatment	Hay Yield per acre	Average Daily Gain of Rabbits	Mineral Composition of Hay: Nitrogen	Phosphorus	Sulfur
None	0.5 ton	14.1 grams	2.14%	0.26%	0.10%
High Yielding Fertilizers	2.3	17.9	2.29	0.20	0.17

Fertilized and unfertilized hays grown on other Alberta soils that are sulfur-deficient have also been used in experiments with rabbits. The results from these experiments were similar to those obtained with hays from the Breton Plots: in every case hays from plots that received sulfur-bearing fertilizers were nutritively superior by an important margin.

The foregoing discussions of crop quality have been concerned with cropping systems and fertilization practices on sulfur-deficient Gray Wooded soils. But only some Gray Wooded soils are sulfur deficient—although with farming, some soils may gradually become sulfur deficient if their initial content of sulfur was rather low. However, there is additional proof that fertilizer and recommended soil management practices, which increase crop growth and/or protein content, are nutritionally beneficial.

A rat feeding trial employing barley samples differing in protein content as a result of fertilization is summarized in Table 9. The protein difference in the barley samples resulted from applications of ammonium nitrate fertilizer—which supplies only nitrogen as a nutrient. Again, grains of higher protein content, as a result of fertilization, were nutritionally superior.

TABLE 9: EFFECT OF NITROGEN FERTILIZATION OF BARLEY ON PROTEIN CONTENT AND FEED VALUE FOR RATS

(Feeds Used were Composites from Several Farms in Each Case)

	Protein Content of Barley Grain		Grams of Feed* Consumed Per Gram of Rat Gain	
Year Grown	No Fertilizer	Nitrogen Fertilizer	No Fertilizer	Nitrogen Fertilizer
1957	10.8%	16.9%	7.0 gm.	4.2 gm.
1958	10.1%	16.6%	6.0 gm.	3.8 gm.
1957	Above Grains but Supplemented		4.7 gm.	2.6 gm.
1958	With L-Lysine		6.0 gm.	2.7 gm.

* Diets received complete Vitamin and Mineral Supplementation.

Nutritional Complexities

The foregoing data and discussion are not intended to give an impression that soil fertility and crop quality relationships are fully known and understood, or that they are simple. The description of Gray Wooded soils and the discussion of their fertility in comparison to Chernozemic soils emphasize that soils of the wooded region are on the average lower in their content of essential plant nutrients than most other soils now farmed in Alberta. One factor contributing to that situation has been the slow movement of water right down through the soil layers from which plants obtain their nutrients. In some cases water percolating through the soil has dissolved and removed part of the original supply of plant nutrients.

But materials left in various parts of Alberta by glacial action, and which have served as the parent materials of present day soils, often differed from each other in their original mineral and chemical make-up. Some parent materials had more phosphorus than others. In places there were large amounts of sulfur-bearing salts, while in others sulfur was a rather scarce element. Such differences, now reflected in the soils that have developed, affect the quantities of various elements available for crop uptake. And so the nutritional quality of crops may be affected as discussed in this section.

But the supplies of one nutrient element available in a soil may affect the ability of crops to take up other nutrients or elements. For example the data of Figure 26 reveal that on some soils, application of sulfur supplying fertilizers does not benefit a crop of barley or rapeseed if nitrogen is deficient. However, as Figure 26 shows, those crops sometimes respond remarkably to sulfur fertilizer application if nitrogen is also supplied! This suggests that there is a relationship between nitrogen and sulfur requirements of crops. This is indeed the case because both nitrogen and sulfur are constituents of protein. Recent nutritional research suggests that the quality of feeds is adversely affected if the nitrogen to sulfur ratio in a feed is greater than 15. Although, this aspect of crop composition has not yet been studied in Alberta, it may be a factor in determining the feeding value of some crops grown on Gray Wooded soils here. It is therefore desirable that this matter be studied in this Province.

Another nutritional complication related to the soils on which crops are grown may be of importance in some Alberta Gray Wooded soil areas. The cobalt content of crops grown on some soils is very low and that element is needed by livestock. It is difficult to identify areas where low cobalt content of crops may adversely affect livestock, so use of iodized cobalized salt is recommended as a precautionary practice by farmers raising cattle, especially those who have sheep. That recommendation is particularly important in areas where soils are of the Gray Wooded soil group.

A livestock disease known as 'white muscle disease' has affected cattle in some of the Gray Wooded soil areas of Alberta. The disease is not well understood by veterinarians but it is thought to be related to the vitamin E and/or selenium contents of feeds; other as yet unidentified dietary factors may also be involved. Losses from death or poor performance of cattle affected by white muscle disease have seriously affected some farmers. It is possible that fertilization of some forage crops with sulfur-supplying fertilizers may affect selenium content of the feed. As a result studies of the relationship involved are in progress. Present knowledge is too incomplete to justify any suggestions other than to advise farmers to be watchful for symptoms of white muscle disease in their cattle. The disease may cause sudden unexplained deaths of cattle, or it may cause animals to be weak, stiff, unsteady on their feet or to show inability to stand. If the disease is suspected a veterinarian should be called.

ARE FERTILIZERS AND ROTATION ECONOMIC MANAGEMENT PRACTICES?

In previous sections, the problems of farming Gray Wooded soils were discussed, and various management practices including crop rotations and use of manure and fertilizers were suggested. In this section, experimental results that show the effects of these recommended procedures on crop yields are discussed, and data showing the economic returns from fertilizer use are presented.

Two main groups of experiments are presented. The first group consists of two long term experiments in which crop rotations, with relatively low rates of fertilizers, have been studied. The second group involves numerous experiments in which various rates of fertilizers have been tested on various crops. First the results of the rotation experiments are examined.

LONG TERM EXPERIMENTS

The Breton Plots

In 1930 the Soils Department of the University began a series of fertilizer tests on a Gray Wooded soil seventy miles southwest of Edmonton near Breton. From 1930 until 1963 a total of eighteen fertilizer treatments were tried out. All were broadcast applications and at low rates by present day standards. The fertilizers were applied on two cropping systems:

1. Wheat and fallow cropping program.
2. A crop rotation. Initially, this four year rotation was wheat-oats-barley and one year of hay. In 1939 the rotation was lengthened to five years to include two years of hay.

In 1964 the fertilizer treatments were changed to drilled-in annual applications and some of the treatments were changed. For comparisons between the various plots on an elemental basis the fertilizer 16-20-0 at 60 lb./ac. ($N_{10} P_5 S$) was used as a reference. All other commercial fertilizers were adjusted as to rate so that the same levels of nitrogen and phosphorus were used. Again, this resulted in some rather low levels of application of particular fertilizers. Thus, for example, 11-48-0 was applied at only 25 lb/ac, a rate which today is frequently below the economic optimum.

Yields of course varied widely from year to year but on most of the plots reported there are averages covering 30 to 40 years of cropping. Thus there is a good sampling of weather conditions. While check plot yields averaged less than half a ton of hay, the best fertilizers increased the yields five-fold. Yields of wheat in rotation were more than doubled by the best fertilizer treatments. For this report only those fertilizer treatments with high average returns on the investment in fertilizer are reported.

The calculation of average return was made as follows:
1. Calculate the average yield of plot.
2. Calculate average increase in yield over that of unfertilized plot.
3. Calculate cost of fertilizer application at 1970 prices.

4. Using a range of prices for the crop calculate the value of the increased returns from the use of fertilizer.
5. Subtract the cost of fertilizer to get the net return corresponding to the various price levels used for the crop.
6. Divide net return by cost of fertilizer to get net returns per dollar spent.

TABLE 10: NET RETURNS (NR) PER ACRE AND RETURNS PER DOLLAR SPENT (RDS) FOR FERTILIZERS (BRETON PLOTS 1940-1970) AT VARIOUS PRICES FOR HAYS AND GRAINS

A. On First Year Legume Hay in Rotation.

Fertilizer Treatment	Hay Prices							
	$15.00/T		$17.50/T		$20.00T		$22.50/T	
	NR	RDS	NR	RDS	NR	RDS	NR	RDS
S_{10}	$14*	$21**	17	25	19	29	22	32
N_8S_9	16	17	19	19	22	22	25	25
$N_{10}P_5S_8$	17	9	20	11	24	13	27	14

* $14 = value of *increase* in yield less cost of fertilizer. (NR = net return).

** $21 = NR ÷ cost of fertilizer, thus in this case a return of $21 for $1 invested in fertilizer. (RDF = return for dollar spent on fertilizer).

B. On wheat in rotation, first crop after two years of legume hay.

Fertilizer Treatment	Wheat Prices							
	$1.00/bu.		$1.20/bu.		$1.40/bu.		$1.60/bu.	
	NR	RDS	NR	RDS	NR	RDS	NR	RDS
S_{10}	$ 9	$14	11	17	13	20	15	23
N_8S_9	13	13	16	16	18	19	21	22
$N_{10}P_5S_8$	12	6	15	8	17	9	20	11

C. On wheat after fallow, with no crop rotation.

Fertilizer Treatment	Wheat Prices							
	$1.00/bu.		$1.20/bu.		$1.40/bu.		$1.60/bu.	
	NR	RDS	NR	RDS	NR	RDS	NR	RDS
N_3P_5	$6	$6	8	7	9	9	10	10
S_{10}	3	4	4	5	4	6	5	7
N_8S_9	4	4	5	5	6	6	7	7

This procedure does not take into account labor costs for handling fertilizer nor costs of handling increased yields. Also, it does not recognize any improvement in crop quality resulting from fertilization. Furthermore it may be criticized from the standpoint that a fixed price for each fertilizer was used. Results of the study are reported in Table 10 with only the best three fertilizers reported. Net returns (NR) and returns per dollar spent on fertilizer (RDS) are rounded off to the nearest dollar.

The Breton Plots show the large return on investment in certain fertilizers on the particular Gray Wooded soil at that location. Indeed, the check plot yields (0.5 T hay per acre or 7.2 cwt. of barley per acre) indicate that this soil type could not be farmed profitably without the use of fertilizers. The soil, classified as a Breton loam to silt loam, has responded remarkably to applications of sulfur and has shown good responses to additional nitrogen and phosphorus. In the crop rotation sulfur (S_{10}) gave the highest return on the fertilizer dollar for the hay crops while 21-0-0 (N8S) was superior for the grain crops. On wheat after fallow 11-48-0 ($N_8 P$) was the best of the fertilizers tested but yields did not compare well with yield of rotation wheat. See Table 11.

TABLE 11: EFFECTS OF DIFFERING SOIL MANAGEMENT PRACTICES ON WHEAT YIELDS. (BRETON PLOTS, 1930-1970)

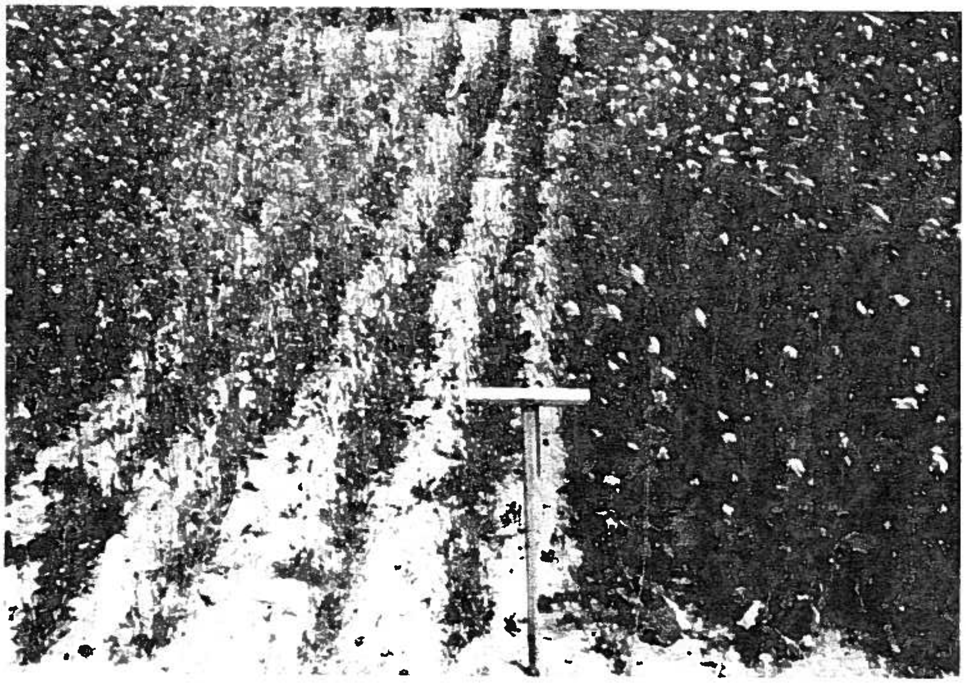
Wheat after fallow, no grass or legume rotation.		
(1) No fertilizer		5.0 cwt/ac/yr
(2) With fertilizer	Actual yield divided by 2;	7.6 cwt/ac/yr
(3) Manured	only one crop in 2 years.	8.2 cwt/ac/yr
(4) Manured and fertilized		8.6 cwt/ac/yr
Wheat in 5-year rotation with grasses and legumes.		
(1) No fertilzer		10.5 cwt/ac/yr
(2) Manured		19.0 cwt/ac/yr
(3) Fertilzed		19.9 cwt/ac/yr
(4) Manured and fertilized		22.7 cwt/ac/yr

The data in Table 11 emphasizes the fact that this soil will respond very well to fertilizing, crop rotation, and applications of manure. Without these good management practices such soils are very unproductive.

The value of manure must not be overlooked. The cost of application is so variable that it has not been included in the comparisons of inorganic fertilizers (Table 10). The value of manure in improving the physical properties of Gray Wooded soils, quite apart from the economic value of the nutrients present, makes its careful use by all progressive farmers desirable.

In assessing the economic return from the use of fertilizers and rotations one may be misled by the Breton Plot data. A tabulation of average grain yields for Plots 1-11 was given in Figure 19, page 42. It is noteworthy that while fertilizers and rotations doubled or even tripled the yield, yet the maximum yields attained do not compare well with good yields on Black soils. The best plots of wheat for example averaged less than 24 cwt. per acre, oats less than 21 cwt. and barley less than 17 cwt. per acre; on a Black soil one might expect yields of 30, 28 and 24 cwt. respectively on well fertilized fields. A counter argument, and one with some validity, is that higher rates of application of fertilizer would have resulted in higher average yields of all crops on the Breton Plots.

The yields of hay, which increased five-fold from half a ton per acre on check plots to two and a half tons per acre on the best-fertilized plots, are still not very high. Heavier applications of fertilizer, and taking second cuts of hay, might well increase the potential to four tons per acre. There is no question, as Table 10 indicates, that returns on dollars spent on fertilizer were far greater for the hay crops than they were for the grain crops. Net returns for the second-year hay were 20 to 25% higher than those for first-year hay; net returns for oats and barley in rotation were considerably less than those shown for wheat in the rotation in Table 10.



Photograph 13—If adequate N is supplied cereal crops, such as the rapeseed plot on the right, are very responsive to S fertilization when sown on S-deficient soils.

The Chedderville Plots

In 1951, the Lacombe Research Station initiated three rotations on the Gray Wooded soil, Caroline silt loam, at a site near Chedderville. The three rotations were as follows:

1. A two year sequence of barley alternating with sweet clover which was plowed down for green manure.
2. A six year sequence of barley, sweet clover for green manure, barley, hay, hay, hay and break.
3. A six year sequence of barley, barley, hay, hay, hay, and break.

Several fertilizers were broadcast annually in the spring. Manure was added every sixth year at 15 tons per acre. The total yields of grain plus hay during the 13 year experimental period are shown in Figure 31.

All fertilizers increased the total yields in the three rotations. The better fertilizers increased barley yields (not shown) by 60 to 80 percent over the unfertilized plots (20 to 23 cwt. compared to about 13 cwt). Hay yields were tripled. There were no consistent differences amongst three of the fertilizers used—$N_{20}S_{35}$, $N_{16}P_9S_{14}$, $N_{10}P_{13}K_8S_5$. Sodium sulfate (S_{12}) which provides only sulfur was less effective than the other three fertilizers. Manure applied at 15 tons per acre every sixth year also produced lower yields than the $N_{20}S_{35}$ and $N_{16}P_9S_{14}$ treatments. It is concluded that the nitrogen and sulfur contained in the fertilizers were mainly responsible for the marked yield increases. The phosphate in the $N_{16}P_9S_{14}$ treatment had only a small effect in this experiment. As was the case at the Breton plots, the rates of nitrogen are much below crop removals while the sulfur rates are about equal to the crop uptake of that element. Hence, the main reason for the effectiveness of these fertilizers is that the sulfur greatly stimulated the legume crops, which added substantial nitrogen to the soil. The nitro-

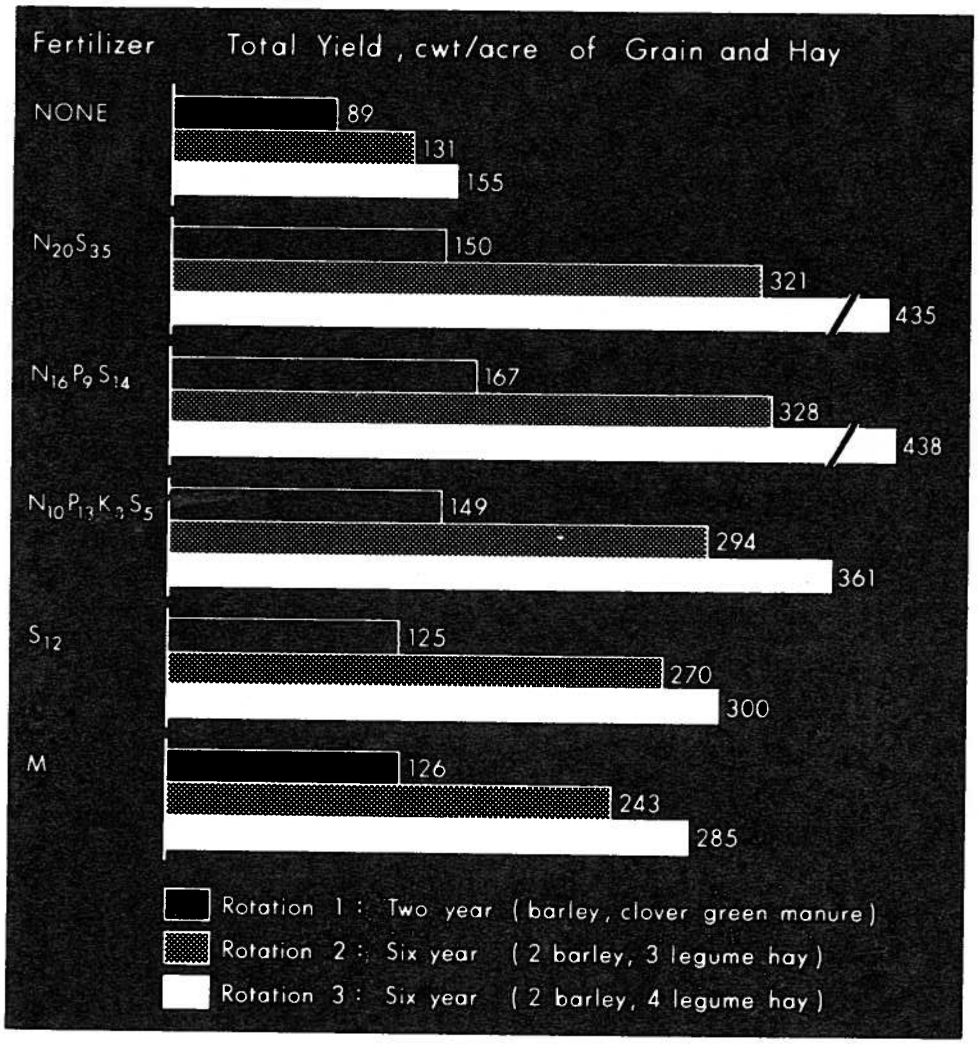


Figure 31—Total production of grain plus hay over a 13 year period for each of three rotations at Chedderville. (1951-1963, Cwt./acre).

gen added by the legumes together with the fertilizer sulfur increased the yields of subsequent barley crops. These results are the same as those obtained on the Breton plots and emphasize the importance of sulfur in crop production on many Gray Wooded soils as well as pointing out the very beneficial effects of legumes on yields of subsequent crops.

What are the differences among the three rotations? In 13 years rotation 1 produced seven harvested crops while rotation 2 produced 11 and rotation 3 produced 13. Thus the total production (Figure 31) for 13 years is only half as much in rotation 1 as in rotation 2. Rotation 3 has even higher total production. Effects of rotations become ap-

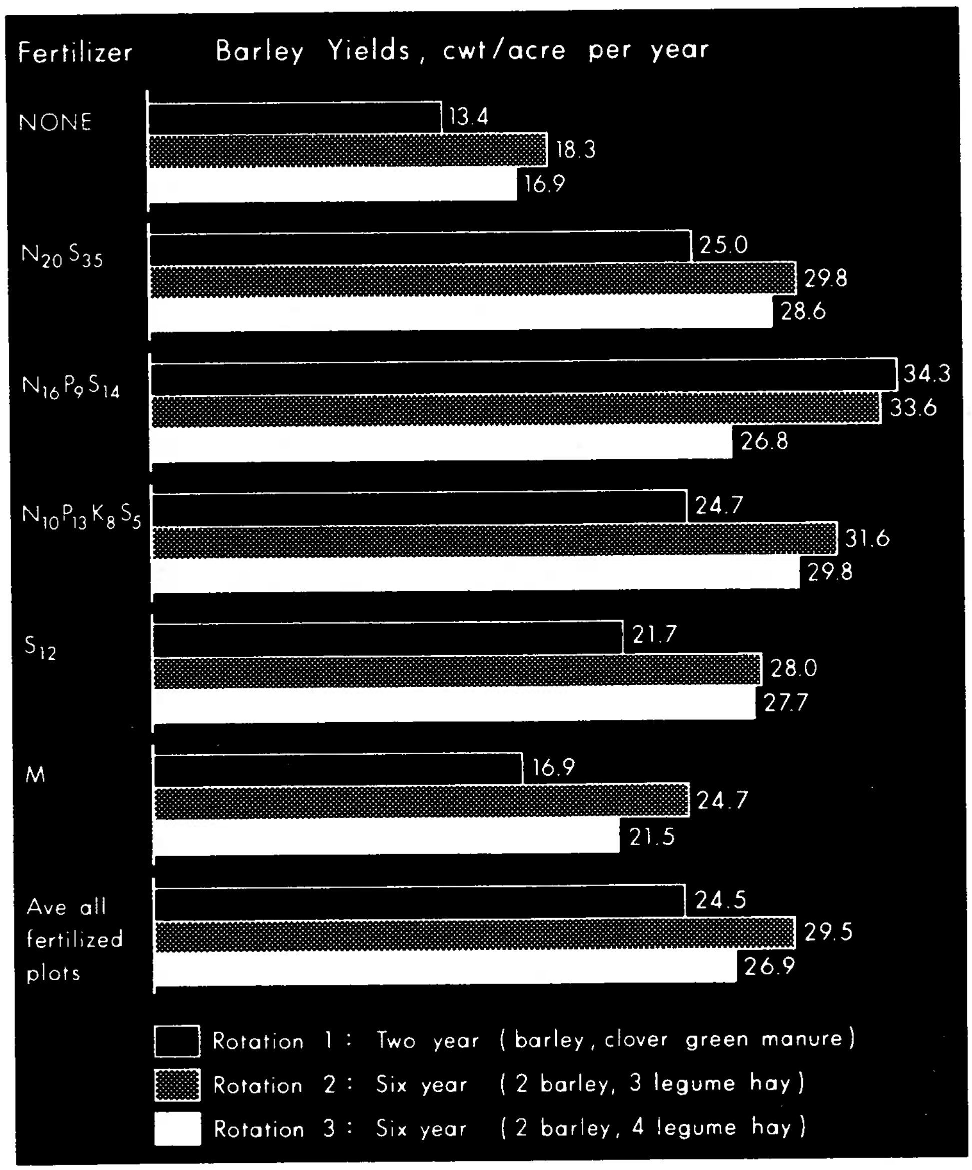
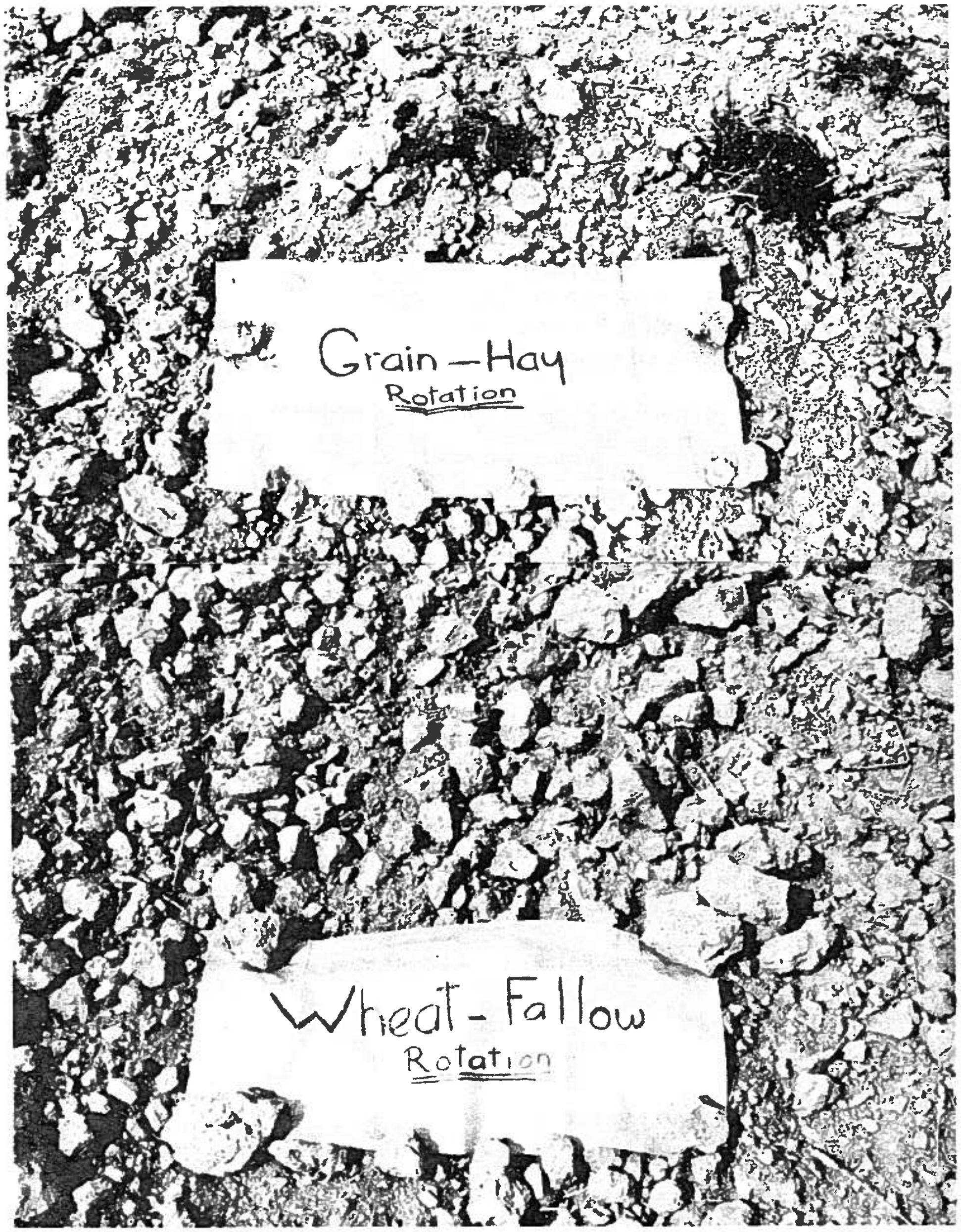


Figure 32—1963 Barley yields in each of three rotations at Chedderville. (Cwt./acre).

parent only after they have been in effect for some years. For the Chedderville plots some evidence for differences among rotations is shown in (Figure 32) where the 1963 barley yields for all rotations are shown. Note that the yields on the unfertilized plots are higher for rotations 2 and 3 which were seeded to hay about half the time. This same trend is clear for all fertilized plots, except the one receiving $N_{16} P_9 S_{14}$ which seems to be an erratic result.

The Chedderville results can be summarized as follows:

- All fertilizers tested increased yields appreciably. This is attributed mainly to their sulfur content, which increased legume yields. The result was addition of nitrogen to the soil, which together with the added sulfur, increased yields of cereal crops.
- After the rotations had been in effect 12 years, barley yields in the 13th year were greater in the two barley-hay rotations than in the barley-green manure rotation.
- Total production over 13 years was much greater in the rotations where crops were harvested most or every year.
- The Chedderville experiments do not provide information on rotations that include fallow. One would judge from the results of the Breton plots that such rotations would be inferior to the three tested. Indeed, there is little reason to consider such rotations because, as noted, the total production is higher where crops are grown every year.
- These rotations do not provide a comparison of continuous cash crop production where adequate nutrients are supplied and all crop residues are returned to the soil.



Photograph 14—Plots at Breton after wheat was seeded 1957. Twenty-five years of cropping to à grain-hay rotation has noticeably improved the physical characteristics of the soil (upper photograph) compared to soil cropped to wheat-fallow (lower photograph).

SHORT TERM EXPERIMENTS

Numerous experiments have been done to determine the rates of nutrients required to produce maximum yields and maximum economic returns from fertilizers. Most of these experiments have been done with cereal crops. The results of some of the more complete and more recent are summarized in this section.

Experiments with Barley

One experiment at three locations for four years was especially designed to find the maximum yield of barley if all nutrients were supplied in adequate amounts. For comparison, there were plots that received a commonly recommended rate of 23-23-0 ($N_{24} P_{13}$) and a relatively high rate of manure. The results are shown in Figure 33.

The average yield of the unfertilized plots was 15 cwt. per ac.; this was the average but yields ranged from 5 to 30 cwt. per ac. The average

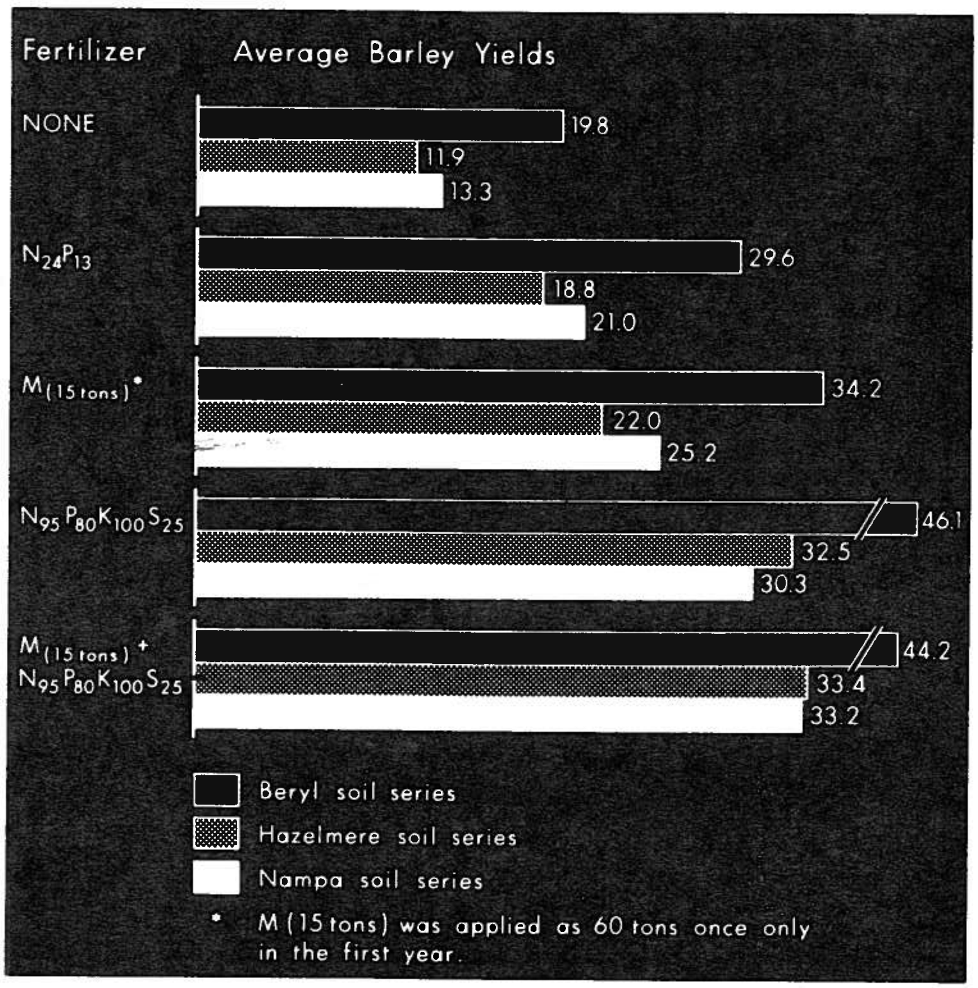


Figure 33—Effects of high rates of fertilizers, and or of manure, on barley grown on three Gray Wooded soils. (Four year averages, Cwt./acre).

yield obtained with $N_{24}P_{13}$ was 23 cwt. per ac., an increase of 8 cwt. per ac. over the unfertilized plots. If nitrogen is priced at $0.10 per lb., phosphorus at $0.18 (phosphate = $0.08) and barley at $1.67 per cwt. $N_{24}P_{13}$ will result in a net return of $8.60 per acre and a net return per dollar invested of about $1.80 (i.e.: a return of 155% on investment).

The average production from the complete nutrients ($N_{95}P_{80}K_{100}S_{25}$) was about 36 cwt. per ac. Manure in addition to the complete nutrients did not increase yields. Manure alone produced an average of 27 cwt. per ac. Manure was as effective as the complete fertilizer nutrients in the first year, but its effectiveness declined over the four years.

Note that the crop on the Beryl fine sandy loam soil consistently yielded about 45 cwt. per ac. This soil has a very friable structure throughout its profile and allows very good rooting by cereals. On the other two sites the maximum yields were much more variable, ranging from 12 to 57 cwt. per ac. with averages of about 35 cwt. per ac. The soils at these two sites have less favorable physical conditions in their lower horizons than the Beryl soil. It is not suggested that the complete nutrient treatment is economic, but it does show what the upper limit of yields is, given current varieties and normal weather conditions.

Several groups of experiments have been conducted by the Beaverlodge and Lacombe Research Stations and the University of Alberta to determine the economic optimum rates of nitrogen and phosphorus for cereal crops, especially barley. The method of evaluating the economics of the fertilizer treatments was similar to that discussed earlier (Page 67). Net returns (NR) were obtained by subtracting the cost of the nutrient (either N or P) from the value of the yield *increase* resulting from the application of that nutrient. Returns per dollar spent (RDS) were calculated by dividing NR by the cost of the fertilizer used. Note that when nitrogen is being considered, the yields presented are those with other nutrients (P and sometimes K and S) provided in adequate amounts. For example, to evaluate the effect of 40 pounds of N per acre, the plots compared were one with N_{40} PKS and one with only PKS. This means that nitrogen is evaluated with adequate levels of other nutrients and similarly, phosphorus is evaluated with other nutrients.

Rates of Nitrogen and Phosphorus for Cereals

First, the results for nitrogen will be presented. For barley, Table 12, the greatest net returns (NR) per acre were obtained with nitrogen applied in the range of 50 to 100 lbs. per ac. When barley is priced at $1.67 per cwt., the maximum net returns varied from about $10.00 to $12.00 per acre. Higher values were obtained in one experiment (Table 12A). At these rates of application the net returns per dollar spent (RDS) were between $1.30 and $1.90. Of course, each table represents averages of a number of tests. Hence there were some tests in which the net returns were very small, and others in which they were larger. It is interesting, however, to note the uniformity of the three groups of tests reported in Table 12 B,C,D.

Fewer tests have been done using oats as the test crop (Table 12 A,B,C.) The maximum net returns (NR) were obtained with nitrogen added in the range of 40 to 80 lb. per ac. Pricing oats at $1.47 per cwt., the net returns ranged from about $3.00 to $12.00 per acre. The two groups of experiments in the Peace River region had net returns of $9.00 and $12.00. Of the eight tests conducted by the Lacombe Research Station (Table 12C), four showed very low yield responses while the other four showed very large yield responses. Hence, on the average, the net returns were smaller than those for the Peace River region. Considering all the tests, the net returns per dollar invested (RDS) ranged from $0.60 to $3.00 at the point of maximum net returns (NR) per acre.

Nearly all the nitrogen experiments with oats and barley were on fields which had been in crop the previous year. In nearly every case the available nitrogen soil test value was very low. It is concluded that, on the average, and given prices similar to those used in these calculations, it is usually economic to add nitrogen at rated of 60 to 80 lbs. per acre to cereals grown on stubble land with low levels of available nitrogen.

Applied phosphorus generally had smaller effects on yields of cereal crops. Indeed, in some groups of experiments, phosphorus did not increase yields sufficiently to pay for itself. In one group of experiments (Table 13B), most of the tests were on soils having medium to high available phosphorus, hence fertilizer phosphorus had little effect. Results compiled by the Agricultural Soil Testing Laboratory and from various research projects indicate that a significant portion of the Gray Wooded soils, especially in West Central Alberta, have medium levels of available phosphorus in their surface horizons.

On two groups of experiments (Table 13 A & C) economic returns were obtained with phosphorus applied at rates of 20 to 35 lbs. per ac. (phosphate at rates of 45 to 80 lbs. per ac.). With barley priced at $1.67 per cwt. and phosphorus at $0.18 (phosphate = $0.08) per pound, the net returns (NR) ranged from $2.50 to $5.00 per acre and net returns per dollar invested (RDS) from $0.40 to $1.60. In one group of oat experiments (Table 13) the 18 lb. rate of phosphorus was economic, with net returns of $1.40 and net returns per dollar invested of $0.40. It is concluded that phosphorus fertilizers will frequently result in economic yield increases of cereal crops. It is advisable to have the soil tested to obtain some guidance concerning the rate of phosphorus to apply. It is also desirable, even when the soil phosphorus is high, to add 5 to 10 lb. of phosphorus to replace that which the crops remove and to maintain the soil level of that element.

It is emphasized that, in these calculations of the economics of fertilizer use, only the actual fertilizer costs have been considered. The costs of application and the cost of handling the extra yields produced have been disregarded. Further only a single price for nitrogen and phosphorus were used. Nevertheless, the results do indicate that the use of fertilizers is generally a very sound investment.

Soil Tests and Fertilizer Recommendations For Gray Wooded Soils

A soil testing service is provided by the Alberta Department of Agriculture. For a nominal fee farmers and gardeners can get a

TABLE 12: YIELDS AND RETURNS FROM NITROGEN APPLIED TO BARLEY AND OATS

A. Beaverlodge Research Station Tests* (1966-1968)

2 Test with Galt Barley				6 Tests with Glen Oats			
P, K, S plus N at:	Yield cwt/ac	Priced at $1.67/cwt NR	Priced at $1.67/cwt RDS	P, L plus Nat:	Yield cwt/ac	Priced at $1.47/cwt. NR	Priced at $1.47/cwt. RDS
0	9.4	—	—	0	14.6	—	—
25	16.2	8.80	3.50				
50	21.1	14.50	2.90	40	25.4	11.90	3.00
75	23.8	16.50	2.20	80	28.1	11.80	1.50
100	29.0	22.60	2.30				

* All tests on stubble land very low in available nitrogen.

B. Beaverlodge Research Station (1968, 1969) Average of Ten Tests †

	Husky and Galt Barley			Glen Oats		
P, K, (S)° plus N at:	Yield cwt/ac	Priced at $1.67/cwt NR	Priced at $1.67/cwt RDS	Yield cwt/ac	Priced at $1.47/cwt. NR	Priced at $1.47/cwt. RDS
0	10.9	—	—	10.6	—	—
20	13.3	1.90	1.00	13.3	2.00	1.00
40	19.0	9.40	2.30	18.3	7.30	1.80
80	22.9	12.00	1.50	22.2	9.10	1.10
120	24.5	10.60	0.90	22.0	4.70	0.40

† Most tests on stubble land. All soils very low in available nitrogen.
° S_8 applied 1969 only to all plots.

sample of their soil tested at the Agricultural Soil and Feed Testing Laboratory in Edmonton. The laboratory reports the levels of available plant nutrients and other characteristics of the sample such as soil pH, salts and texture. Based on these soil results and the farmer's information, recommendations are made for fertilizer use and soil management. Full instructions on how to take soil samples and how to send them to the laboratory are available at District Agriculturist offices.

As pointed out earlier in this bulletin Gray Wooded soils are known to be of low nutrient status. Can soil tests help to assess nutrient levels and thus improve fertilizing programs for Gray Wooded soils? To study this question a set of plots was established in 1964 near Breton, southwest of Edmonton on Gray Wooded and Dark Gray Wooded soils. The plots included the following cropping programs and fertilizer treatments:

A. Cropping programs
  1. Wheat—fallow sequence
  2. A 5-year crop rotation of hay-hay-wheat-oats-barley.

C. Lacombe Research Station (1965-1969).

P plus N at:	38 Barley tests over 5 years (4 or 6 varieties, 2 sites, soils low in N) Yield cwt./ac.	Priced at $1.67/cwt. NR	RDS	8 Oat tests (4 varieties, 2 years) (Small incr. 1968, large incr., 1969) Yield cwt./ac.	Priced at $1.47/cwt. NR	RDS
0	16.6	—	—	22.6	—	—
50	25.4	9.60	1.90	28.0	2.80	0.60
100	27.3	7.80	0.80	29.8	0.40	0.00
150	27.8	3.60	0.20	30.5	3.60	—

D. University of Alberta, Productivity-Economic Experiment. (7 stubble tests 1965-1968. Available nutrients by soil test: N_{10} P_{40} .)

P, K plus N at:	Calc. Yield cwt./ac.	Gateway Barley Priced at $1.67/cwt. NR	RDS
0	12.8	—	—
20	16.6	4.50	2.20
40	19.8	7.70	1.90
60	22.1	9.50	1.60
80	23.7	10.20	1.30
100	24.4	9.40	0.90

NR: Net Returns. (Value of yield increase, less fertilizer cost).
RDS: Returns Per Dollar Spent. (Net returns divided by cost of fertilizer).

B. Fertilizer treatments
1. Check plots, no fertilizer
2. Standard fertilizer treatments based on general recommendations for Gray Wooded soil.
3. Specific fertilizer recommendations provided by the Soil Testing Laboratory and based on analyses of soil samples collected as follows:
   - For grain crops: sampled in early May, just prior to seeding, at 0.6" depth.
   - For hay crops: sampled in September, two weeks prior to fertilizer application.

The results of the tests for the 7-year period 1964-1970 are given in Table 14.

From Table 14 is seen that in every case the average yield was greater when fertilizer was applied according to a recommendation from the Soil Testing Laboratory. The value of the increased yield may be approximated by assigning a value of $2.00 per cwt. to grain and of $1.00 per cwt. to hay, as shown in Table 15. The slightly different cost of fertilizer, usually higher for the Laboratory's recommended rates, have not been considered in this table.

It is quite obvious that soil testing pays good dividends and should be a regular practice followed by all progressive farmers. A soil test costs only a little time and trouble and an outlay of a few dollars. Careful sampling is important, however, to ensure a representative sample and reliable recommendations. Depending on the variability of the soil only a few samples would need to be collected, say one composite sample for every 20 to 50 acres. The only alternative to soil testing is a lifetime of experience in management of a soil. An experienced farmer, who has used fertilizer for years, and made very careful assessments of its effects in his soils, may have a very good idea as to the best kinds and rates of fertilizers to use. A soil test however would give him good supporting evidence and cost little in time and trouble.

TABLE 13: YIELDS AND RETURNS FROM PHOSPHORUS APPLIED TO BARLEY AND OATS

A. *Beaverlodge Reseach Station*, Two tests on stubble land 1967.

N, K, S plus P at:	Yield cwt./ac.	Galt Barley Priced at $1.67/cwt. NR	RDS
0	21.5	—	—
28	24.4	2.60	1.10
57	24.9	1.10	0.20
115	27.9	1.40	0.20
230	29.0	-4.90	—

B. University of Alberta, Productivity-Economic Experiment (7 stubble tests, 1965-1968. Available nutrients by soil test N_{10} P_{40}).

N, K plus P at:	Yield cwt./ac.	Gateway Barley Priced at $1.67/cwt. NR	RDS
0	20.4	—	—
5	21.0	0.00	—
10	21.4	-0.20	—
20	22.1	-0.90	—

C. *Lacombe Research Station* (1965-1968).

N plus P at:	38 barley test over 5 years (4 or 6 varieties, 2 sites)			8 oat tests (4 varieties, 2 years)		
	Yield cwt./ac.	Priced at $1.67/cwt. NR	RDS	Yield cwt./ac.	Priced at $1.47/cwt. NR	RDS
0	21.7	—	—	26.5	—	—
18	26.7	5.10	1.60	29.6	1.40	0.40
35	27.1	2.60	0.40	29.6	-1.80	—
53	27.5	0.10	0.00	29.0	-5.90	—

NR: Net Returns. (Value of yield increase, less fertilizer cost).
RDS: Returns Per Dollar Spent. (Net returns divided by cost of fertilizer).

TABLE 14: RESULTS OF FERTILIZATION BY "STANDARD RATES" AND ON THE BASIS OF "SOIL TEST RECOMMENDATION". (BRETON PLOTS, 1964-1970)

	Fertilized at Standard Rates		Fertilized According to Soil Test Data	
	Ave. Yield cwt./ac.	Ave Increase over check	Ave. Yield cwt./ac.	Ave. Increase over check
Wheat after fallow	13.6	1.9	17.8	5.5
Wheat in rotation	23.9	5.6	26.5	8.2
Oats in rotation	22.0	6.7	24.0	9.0
Barley in rotation	18.0	5.6	19.6	7.8
Hay, 1st year	25.6	4.6	27.0	6.3
Hay, 2nd year	38.7	11.9	43.1	16.0

TABLE 15: COMPARISON OF RETURNS FROM FERTILIZATION BY "STANDARD RATES" AND BY "SOIL TEST RECOMMENDATIONS"

	Value of Yield Increases Over Unfertilized Checks		
	Fertilization By General Recommendation	Fertilization By Soil Test Recommendation	Approximate Additional Profit By Using Soil Test Recommendation
Wheat after fallow	$ 3.80/ac.	$11.00/ac.	$7.20/ac.
Wheat in rotation	11.20	16.40	5.20
Oats in rotation	13.40	18.00	4.60
Barley in rotation	11.20	15.60	4.40
Hay, 1st year	4.60	6.30	1.70
Hay, 2nd year	11.90	16.00	4.10

PEATS: PROBLEM SOILS OF THE WOODED REGION

Peat soils, commonly called muskegs, are prevalent in the Gray Wooded soil areas of Alberta and vary in size from small patches to thousands of acres. The estimated area of peat in Alberta is about 25 million acres, most of it occurring in the non-agricultural areas of Northern Alberta. See Figure 34.

Peat soils consist of an accumulation of undecomposed and/or partly decomposed plant material underlain by impervious or slowly permeable mineral material, usually of fine texture. Peats are highly variable in depth, acidity, fertility, depth to water table, frost hazard and ease of cultivation. Sometimes there are buried stumps and fallen trees inbedded in peat. Occasionally when peats are burned off (following drainage) very stony material is exposed. In Alberta, peat soils are classified as sedge peats (named the Eaglesham soil series) and moss peats (the Kenzie soil series). Some peats are mixtures of the two types of material with a layer of one type over a layer of the other kind. Sedge peats are composed predominantly of the residues of sedges, grass-like water loving plants, often called "slough grass". Shrubs, small trees and mosses may be mixed in with the sedge if past water levels varied over periods of several years.

Moss peats are composed primarily of sphagnum mosses, although feather mosses are also common. Such peats have a variable type of cover such as shrubs, Labrador tea and trees including black spruce, tamarack and swamp birch.

Utilization

In their natural state, peat soils act as water reservoirs delaying runoff and releasing water slowly to natural water courses. Thus large peat areas are important regulators of stream flow in the districts where they occur. For many of the peat areas this role should probably continue.

Some moss peats are used as a source of horticultural peat, which is a commercially processed product used by gardeners making potting soil, wrapping roots of plants for transplanting, covering lawns to improve germination, improving flower bed soils and so forth. The main requirement of peat used for this purpose is a high water holding capacity. Undecomposed sphagnum moss, because it will retain up to 12 times its weight of water, is an ideal product. There are now several small peat processing plants operating in Alberta.

Limited areas of peat soils are being utilized for the production of agricultural crops. However, only the shallower peats have been farmed successfully. There is considerable debate regarding the advisability of opening up extensive new peat areas for agriculture. Some argue such development should await a much greater demand on soil resources for food production. That view results from the fact that there are several limitations that must be considered if peat soils are to be developed for agricultural use.

- Firstly, the reaction of peat soils ranges from extremely acid (pH 3.5) to quite alkaline (pH 8.3) and there is great variability —sometimes even on one farm. Only peats of pH above pH 5.5 should be considered for cropping.
- Short frost-free periods are common on peat soils. They are cold soils since they normally occupy depressional areas. The frost-free period may be 10 to 15 days, or even more, shorter than on adjacent mineral soils (see Table 16).
- Drainage, which may be costly, is frequently necessary to control the water table at a level where it will not adversely affect crop growth.
- Choice of crops for peats is very limited because of the short growing season, occasional flooding and complexities of plant nutrient deficiencies—including deficiencies of micro-elements. Generally, grasses for hay or pasture are the most successful crops for peat soils, but fertilization is usually necessary for good yields.

TABLE 16: FROST FREE PERIODS FOR TWO PEAT SOIL EXPERIMENTAL SITES.

	Days	
LESLIEVILLE	28°F	32°F
1962	57	16
1963	104	17
1964	84	25
1965	103	74
1966	115	52
1967	61	46
Ave.	87.3	38.3
NITON JUNCTION		
1968	92	9
1969	92	47
1970	88	67
Ave.	90.7	41.0
LACOMBE (For comparison purposes).		
62 year Ave.	118	87

Developing New Peat Areas

Clearing, when required, is most easily done in winter when the peat is frozen, but this leaves the roots in the soil where they will interfere with the breaking operation. Care must be exercised in burning windrowed material because, if dry, the peat may be burned off too, exposing rather barren mineral material. If the area is dry enough to clear in the summer, many of the roots will be removed. A gyro mower may be used to clear light brush shrubs on peaty areas. Such residues can be worked in without the necessity of burning. Drainage of peats is usually required to ensure that flooding will not be a problem. Shallow ditches at quarter mile intervals are often all that is necessary. Dynamite and back-hoe ditching have been used successfully for ditching. A flail type of ditcher recently developed in Alberta is both effective and economical.

Breaking of newly cleared peat can be difficult, especially if there are many roots. Heavy duty roto tillers or large single bottom plows are the most satisfactory breaking implements, because gang plows tend to plug. Once the peat has been cultivated to a workable surface it must be packed to make a firm seedbed. Since peat is generally loose and fluffy, special packing practices must be used. Crow foot or spiral packers are not satisfactory; a heavy roller has proved best.

Conventional seeding equipment such as the double disk drill is quite satisfactory on well prepared peat. Broadcast seeding is however more satisfactory than on mineral soils, because peat is usually moist to the surface when it is well packed. But combine harvesting of crops is hindered by moisture under swaths, since peat soils tend to remain moist on the surface even when the water table is at a depth of three or more feet. Swaths must be well supported off the soil surface and if possible straight combining is preferable. Because of frost hazards and slow maturity of grains on peats, their use for production of greenfeed or silage, especially during the first few years of cropping, should be considered.

Productivity

Limited forage yield data are available for the peat soils of Alberta. Table 17 contains fertilizer responses of three grass species at Niton Junction. Reed Canary Grass and timothy were adapted to the particular peat but brome grass was killed by excess water in 1970. Alsike and red clover have shown some adaptability but their potential is unknown. Creeping foxtail *(aloperurus arundinaceae)* is adaptable to cold, wet soils and appears to have potential for use on peat soils.

Fertilizer requirements of peat soils are rather high and they are exceedingly variable. Soil analyses and field fertilizer trials are necessary for specific recommendations of fertilizer for peats. High rates of nitrogen fertilization, especially in the early years of cropping are frequently required.

TABLE 17: YIELD OF GRASS HAYS ON PEAT AT NITON JUNCTION, WITH AND WITHOUT FERTILIZER.

	Yield cwts. per acre		
Fertilizer	Reed Canary 3 yr. Ave.	Timothy 3 yr. Ave.	Brome 2 yr. Ave.
Nil	12.3	7.9	13.8
N	19.1	23.8	24.7
NP	25.0	27.9	25.6
NPK	27.2	28.1	29.9

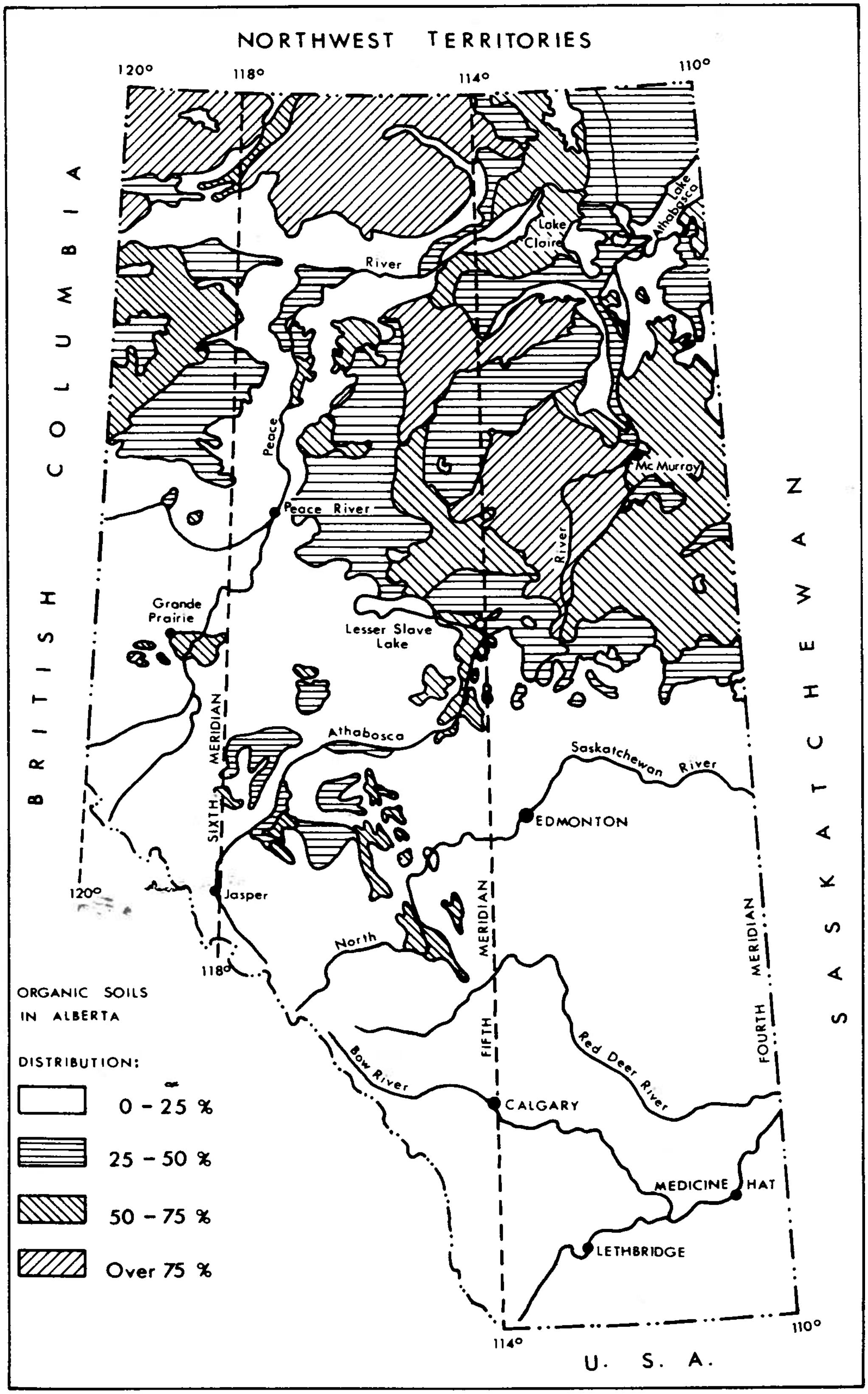


Figure 34—Organic, also called peat or muskeg, soils in Alberta. (Small areas of organic soils occur in most parts of the wooded region).

SUMMARY AND RECOMMENDATIONS

1. Gray Wooded soils are very important in Alberta because they constitute over thirty per cent of the potentially arable land in the province. (Page 8).

2. Gray Wooded soils vary greatly (Page 16) and usually have less favorable physical and chemical properties than Chernozemic soils of the grassland regions (Page 20).

3. Many problems and complexities, in combination, tend to make farming Gray Wooded soils more difficult and hazardous than farming on most other Alberta soils. (Pages 28 - 36).

   However soil management and farming practices can partially reduce some hazards and in certain Gray Wooded soil areas moisture conditions are quite favorable enabling rather consistent high yields under good management.

4. Extensive field experiments, and many years of farming experience by good farmers, have proved that recommended combinations of crop rotations and fertilization result in very good yields and improved physical properties of most Gray Wooded soils being farmed.

   - Two or three years of legume containing forage crop followed by two or three years of cereal or oilseed crops, have provided a suitable crop rotation in many cases.
   - Wheat is not a recommended crop.
   - In some Gray Wooded soil areas seed production of some forage crops is successful and fits in very well with the recommended cropping pattern.
   - Farm manure is an excellent fertilizer for such soils, and it has the additional merit of improving the physical properties of Gray Wooded soils.
   - Farmers are urged to have samples of their soils tested at the Agricultural Soil and Feed Testing Laboratory, O. S. Longman Building, Edmonton, for recommendations concerning fertilizer needs.

     Nutrients frequently deficient in Gray Wooded soils are: nitrogen, sulfur, phosphorus and potassium.

     Suitable fertilization often more than doubles the yield where nitrogen and/or sulfur are deficient.
   - Some Gray Wooded soils are acid and benefit substantially from application of a suitable form of lime. (Page 33). A soil test will determine whether liming is needed.

5. The nutritive quality of crops grown on Gray Wooded soils may be lower than that of most crops of the same kind grown on other Alberta soils.

   Fortunately, recommended cropping systems and suitable fertilization (Item 4 above) usually result in important improvements in the nutritive value of crops grown on Gray Wooded soils. (Pages 56 - 65).

6. Skillful farmers, who follow recommended cropping and fertilization practices, can and do farm Gray Wooded soils with success, profit and satisfaction. (Pages 67 - 77).

7. Although Alberta has tens of millions of acres of peatland, those soils are not recommended for arable agriculture at present. A minor exception is small areas of peat occurring in fields of mineral soils being farmed. When farmed peats usually require fertilization. (Pages 82 - 84).

OTHER SOURCES OF INFORMATION

This bulletin summarizes, in moderately non-technical terms, a great deal of research work and field investigations regarding Gray Wooded soils.

Those interested in more specific information, in most cases discussed and described in technical terms, may wish to consult some items among the following scientific reports. Most of the articles listed will be available from District Agriculturists, The University of Alberta Extension Department, in university libraries or in the Canada Department of Agriculture library, Ottawa (which has a loan service).

'ALFALFA SICK SOIL'

1966—Poor alfalfa growth on some Alberta soils. Agriculture Bulletin 5: p. 20-21. (G. R. Webster).

1967—Poor growth of alfalfa *(Medicago sativa)* on some Alberta soils. Agron. J. 59: p. 37-41. (G. R. Webster, S. U. Khan and A. W. Moore).

1968—Influence of partial soil sterilization on nodulation of alfalfa. Short communication. Plant and Soil 28: No. 3, p. 476-477. (S. U. Khan, A. W. Moore, and G. R. Webster).

1969—Selection in *Medicago sativa* for tolerance to alfalfa sick soils in Central Alberta. Agron. J. 61: p. 589-591. (B. P. Goplen ~~and~~ G. R. Webster).

1970—Effects of root temperature and a suspected phytotoxic substance on growth of alfalfa. Can. J. Plant Sci. 50: p. 307-311. (J. D. McElgunn and D. H. Hendricks).

1970—Nutrient status of alfalfa showing poor growth on some Alberta soils. Can. J. Plant Sci. 50: p. 277-282. (G. R. Webster and P. C. DeKock).

CEREALS FOR GRAY WOODED SOILS

1964—Soil Management in Alberta. Alberta Dept. Agric. Pub. No. 155.

1971—Varieties of Cereals and Oil seeds for Alberta. Alberta Dept. Agri. Pub. No. 110/32.

CLEARING AND BREAKING WOODED SOILS

1964—Clearing, breaking and initial cropping of northern bushlands. In Research Highlights, Can. Dept. Agr. Res. Sta., Beaverlodge. (A. Guitard, J. L. Dobb, and A. M. F. Hennig).

1965—Brush control in Western Canada. Can.-Dept. Agr. Pub. 1240. (H. A. Friesen, M. Aaston, W. G. Corns, J. L. Dobb and A. Johnston).

1965—Effect of method used to break virgin wooded soils on the yields of wheat and flax. Can. J. Soil Sci. 45: p. 281-288. (A. M. F. Hennig).

FORAGE PRODUCTION ON GRAY WOODED SOILS

1957—Studies on the establishment of cultivated grasses and legumes on burned over land in northern Canada. Can. J. Pl. Sci. 37: p. 97-101. (C. H. Anderson and C. R. Elliott).

1963—Reed Canary Grass. Can. Dept. Agric. Pub. 805. (B. P. Goplen, S. G. Bonin, W. E. P. Davis and R. M. MacVicar).

1964—Soil Management in Alberta. Alberta Dept. of Agric. Pub. No. 155.

1966—Crested Wheatgrass. Can. Dept. Agr. Pub. 1295. (R. P. Knowles and E. Buglass).

1967—Creeping Red Fescue. Can. Dept. Agric. Pub. 1122. (C. R. Elliott and H. Baenziger).

1968—Hay and Pasture Crops for Alberta. Alberta Dept. Agriculture Pub. 120/20-1. (O. G. Bratvold).

SULPHUR AND GRAY WOODED SOILS

1955—Fertilizer studies with radioactive sulphur. II. Can. J. Agri. Sci. 35: p. 264-281. (C. F. Bentley, D. J. Hoff and D. B. Scott).

1956—Fertilizers and nutritive value of hays. Can. J. Agric. Sci. 36: p. 315-325. (C. F. Bentley, L. Gareau, Ruth Renner and L. W. McElroy).

1960—Fertilizers and the nutritive value of wheat grown on a sulphur-deficient Gray Wooded soil. Can. J. Plant Sci. 40: p. 146-155. (C. F. Bentley, J. A. Carson and J. P. Bowland).

1960—The nutritional value of increased levels of protein resulting from nitrogen fertilization of barley. Can. J. An. Sci. 40: p. 57-66. (D. K. McBeath, C. F. Bentley, D. L. Lynch and J. P. Bowland).

1961—Sulphur fractions of legumes as indicators of sulphur deficiency. Can. J. Soil Sci. 41: p. 164-168. (D. R. Walker and C. F. Bentley).

PEAT SOILS

1953—Farming Muck and Peat Soils in Wisconsin. Wisconsin Agricultural Extension Circular 456.

1959—Organic Soils, their formation, distribution, utilization and management. Special Bulletin 425. Department of Soil Sciences, Ag. Expt. St., Michigan State University.

1968—Proceeding—Third International Peat Congress, Quebec, Canada.

1970—Farming Peat Soils. #519 Alta. Dept. Agr.

SOIL SURVEY REPORTS (Available from the Extension Department, The University of Alberta, Edmonton).

Grande Prairie and Sturgeon Lake Sheets	1956
Rocky Mountain House Sheet	1958
Beaverlodge and Blueberry Mountain Sheets	1961
Edmonton Sheet	1962
Cherry Point and Hines Creek Area	1965
Buck Lake and Wabamun Lake Areas	1968
Grimshaw and Notikewin Area	1970
Hotchkiss and Keg River Area	1970
Whitecourt-Barrhead Area	1971