ETIN 392 MARCH 1947

Principal Soil Regions OF MINNESOTA

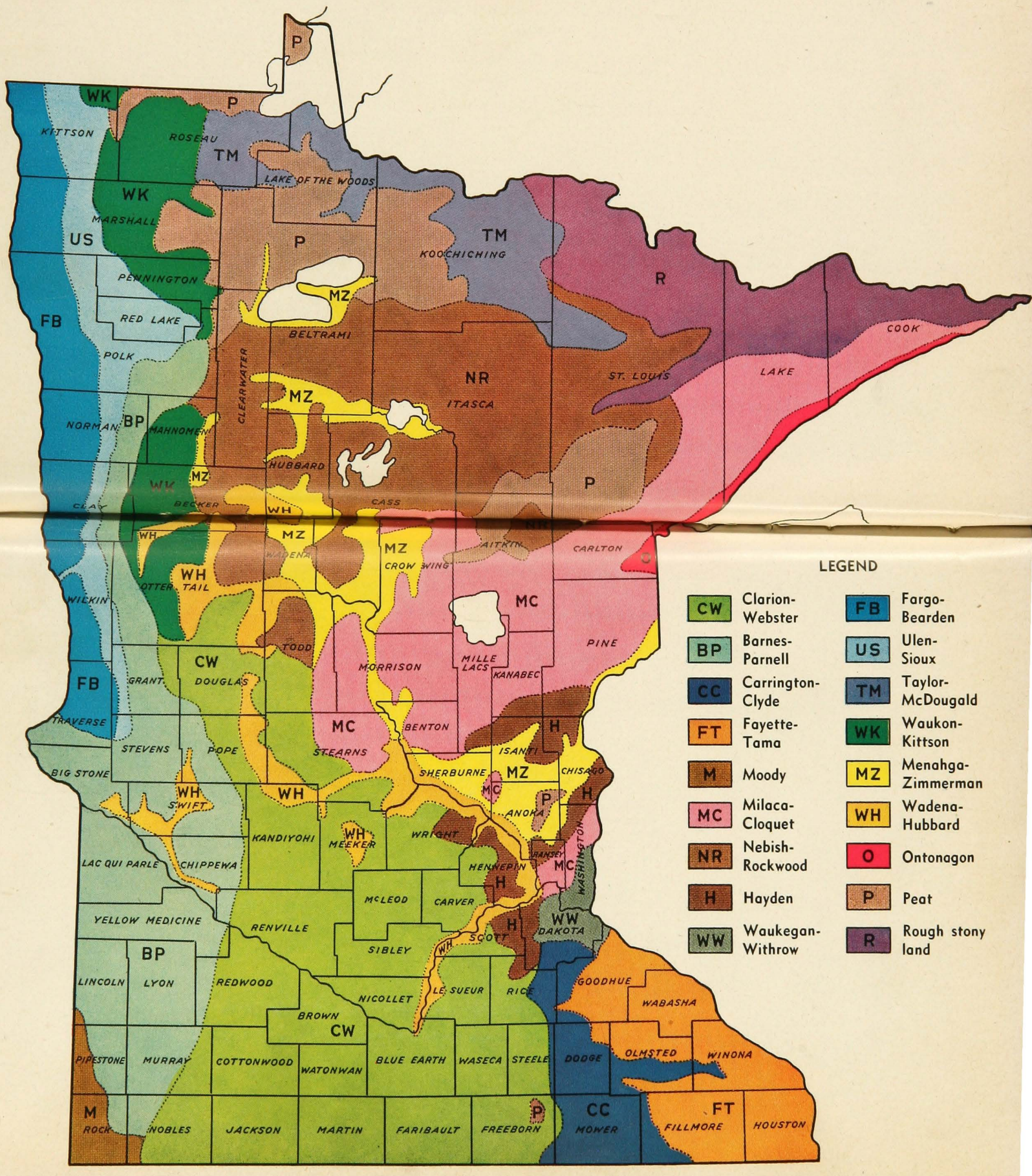
P. R. McMILLER

Agricultural Experiment Station
UNIVERSITY OF MINNESOTA

THIS bulletin attempts to bring together and group the soils of Minnesota into several large categories. These are shown on the colored map. Because of the small scale of the map it has not been possible to show the soil types in each area but only the features of broad significance. Descriptions of the various categories and the general characteristics of the important soil types comprising them are included. The data used in preparing the map were collected from various sources, particularly from soil surveys made cooperatively by the Minnesota Agricultural Experiment Station and the Division of Soil Survey of the Bureau of Plant Industry, Soils, and Agricultural Engineering, and more recently with the Soil Conservation Service of the United States Department of Agriculture. The contributions of the Minnesota Geological Survey to the knowledge of the surface formations of the state also have been helpful in areas where no soil surveys have been made. Much of the basic soil knowledge has been accumulated during the many years that the author has been a member of the staff of the Division of Soils of the University of Minnesota. The assistance of others who have worked and collaborated with the author is hereby gratefully acknowledged.

Submitted for publication April 4, 1946
7500—3-47

BROAD SOIL ASSOCIATIONS OF MINNESOTA



Principal Soil Regions of Minnesota

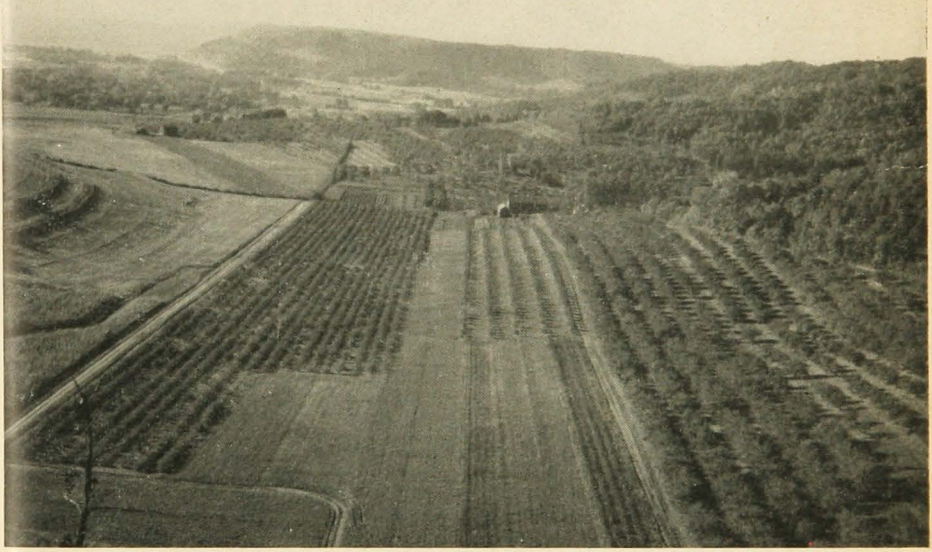


FIG. 1. A fruit-growing valley in Houston County in the Fayette-Tama area

THE AGRICULTURAL WEALTH of Minnesota lies in great measure in its large areas of productive soils. Their productivity is largely due to glacial materials that were well supplied with plant nutrients. It is from such materials that the soils were formed. While developing, the soils were influenced by various factors which contributed to their productivity. Two of importance were the composition of the glacial material and the character of the native vegetation which covered the land. A climate prevailed over the state which was favorable for plant growth, producing both tall grasses and trees in dense stands. The proportion within the state of forest and grassland vegetation is about equal. The prairies, generally speaking, are confined to the southern and western portions and the timbered regions to the north central and northeastern parts. The soils that develop under a grass vegetation are richer generally in plant nutrients than those formed under a forest vegetation. The grass vegetation produced enormous quantities of fibrous roots, most of which are concentrated in the upper 6 to 14 inches of the soil. This concentration of organic matter not only was a storehouse of plant nutrients but its influence on the structural qualities of the soil was of great importance in providing a favorable condition for plant growth after the land was cultivated.

Most of the prairie lands of the state are now included in farms and are under cultivation, whereas the wooded lands of the cutover region have large areas of undeveloped land. However, in this area are many farms whose soils originally were heavily forested but which are now well developed and are being successfully farmed.

Most of the surface of the state is between 1,000 and 1,500 feet above sea level. The greatest altitude, 2,240 feet, is in north central Cook County in the northeastern part of the state; the lowest elevation, 602 feet, is the level of Lake Superior. The level of the Mississippi River where it crosses the state line in the southeast corner is 620 feet, and that of the Red River of the North, in the northwest corner, is 753 feet. A narrow belt below 1,000 feet occupies the Red River Valley and an area in the southwestern corner lies above 1,500 feet.

Practically all of Minnesota is covered with thick deposits of glacial materials resulting from the action of the glaciers which moved across the state in successive advances and retreats, leaving an intricate pattern of materials on which soils later developed. After the retreat of the last glacier other deposits, mostly sediments borne by streams, were laid down in some of the broader valleys, and peat accumulated in many of the poorly drained depressions. Water from the melting ice was impounded by the receding glacier in the Red River Basin to the height of the lowest point at the south end of the basin, where it found an outlet to the Minnesota River. The lake thus formed, known as glacial Lake Agassiz, existed for thousands of years, but finally was drained by the opening of a lower outlet.

The soils of Minnesota vary greatly in composition. This is due chiefly to the complex nature of the glacial materials from which the soils were formed and to some extent to the climatic conditions prevailing in different parts of the state. The topography or surface relief also has some influence on composition, but differences in relief are more closely related with cultural and management problems in handling the land than with productivity.

The kinds of crops that can be grown in a region are determined to a large extent by the character of the soil and by the prevailing climate. The agricultural prosperity of a region from year to year depends largely on the weather and on prices received and paid by farmers, but, in general, the rainfall and temperature are favorable over most parts of the state for producing high yields of the crops adapted to the region, and crop failures occur only rarely.

Minnesota has a continental climate, characterized by wide variations in temperature both in winter and summer, and an average annual precipitation that ranges from about 20 inches in the northwestern part to 32 inches in the southeastern corner. Summer temperatures above 90° F. and winter temperatures below −20° are not uncommon. The average annual temperature in Minnesota ranges from 35° F. along the northern border to 45° in the southeastern corner with an average of 41° for the state as a whole. The coldest month is January, and the warmest, July. During the midwinter season subzero weather occurs frequently in every part of the state, although, as a rule, temperatures below zero do not continue for more than four or five days, except in the northern portion. The zones of approximately equal temperatures in Minnesota are shown in figure 2.

The average annual precipitation decreases from approximately 32 inches in the extreme southeastern corner to 20 inches in the extreme northwestern counties, as shown in figure 3. The northwestern and west central parts of the state have considerably less pre-

cipitation than the eastern, south central, and southeastern counties, whereas those in the extreme northeast have nearly the same as those in the southeast. Less precipitation occurs in the winter months than in the other months of the year. Beginning with May and continuing until August, when the crops are making their heaviest demands on water, 55 per cent of the annual rainfall is normally received. Evaporation is less rapid in Minnesota than in the states farther south and, consequently, the demands of vegetation for water are not so great; therefore, the average annual rainfall of 25 inches in Minnesota is more effective in crop-producing power than greater amounts in areas farther south.

The length of the growing season over the greater part of the state is of sufficient duration for the maturing of all the common agricultural crops adapted to this section of the country. Corn, grown extensively in the central and southern sections of the state, is not so well adapted to the northern part, although early-maturing varieties are often grown successfully. Rather wide variations in the number of frost-free days occur between southern and northern Minnesota, a distance of more than 400 miles. As shown in figure 4, the number of days without killing frost ranges from 100 to 110 in the northern part of the state to from 130 to 160 in the other sections. The average date of the last killing frost in the spring varies

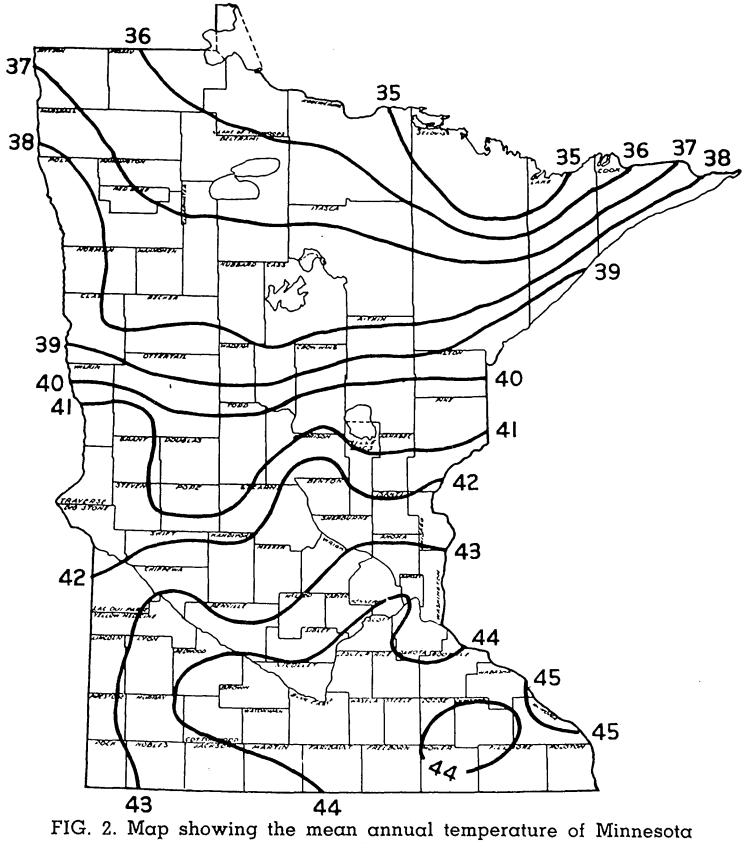


FIG. 2. Map showing the mean annual temperature of Minnesota (degrees Fahrenheit)

from May 5 in the southeast to May 30 in the extreme north. The average date of the first killing fall frost is September 9 in the northeastern counties and October 5 in the southeastern section. For the state as a whole, the average growing season is approximately 133 days.

In most parts of the state where the land is farmed, the surface has slopes that range from nearly level to gently rolling, thus permitting the efficient use of power machinery. In some places, though, the land is strongly rolling to hilly and the cultivated fields are small and irregular in shape, thus making the use of motor-driven machinery less adaptable. However, these areas occupy relatively small sections and are confined generally to some of the southeastern counties and parts of the cut-over region of north central and northeastern Minnesota. Land with steep slopes also occurs along the bluffs of some of the larger streams, particularly along the Mississippi River and its tributaries in southeastern Minnesota.

Many different kinds of soils occur in the state. A large number have already been recognized and mapped, but many more still remain to be identified, mapped, correlated, and classified.

At the present time about 40 per cent of the total area of the state has been covered by soil surveys. During the last few years soil conservation sur-

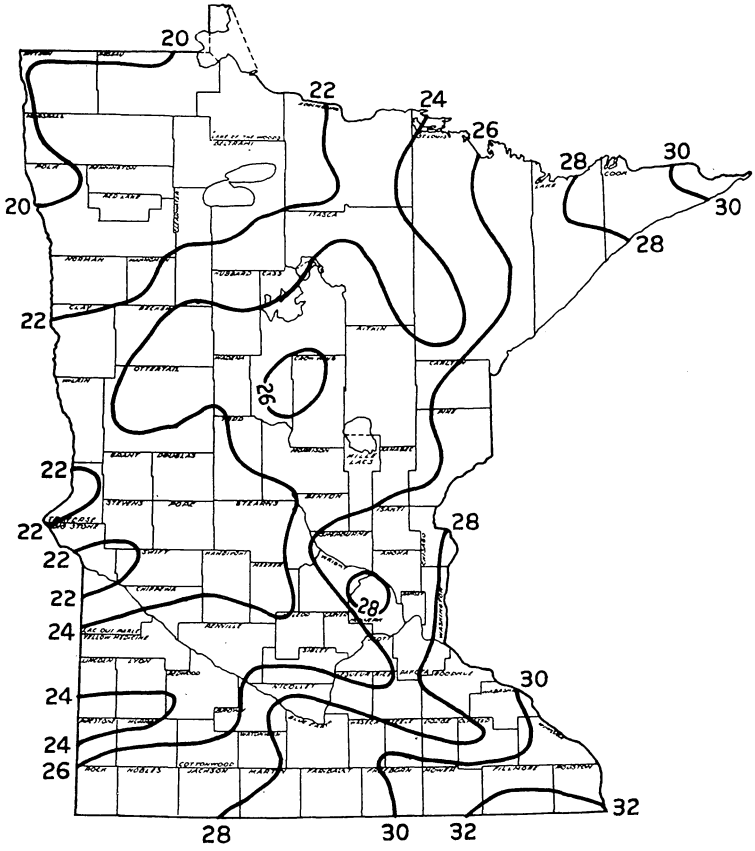


FIG. 3. Map showing the average annual precipitation in inches for Minnesota

veys have been made in different parts of Minnesota where Soil Conservation Districts have been organized. Under this program very detailed maps are made which show not only the different kinds of soils but the slope of the land and the degree of erosion as well.

In order to show the differences that exist between broad soil groups, the state has been divided into 19 regions, called *soil associations*. Each soil association is confined to an area where the soils within the association have characteristics that reflect the influence of climate, native vegetation, and parent material on their development. Each association is composed of many different soil types, all of which are closely related. It is further characterized by having the same general type of relief and similar drainage conditions. Each association carries a proper name, more often a combination of two names, such as Clarion-Webster. These terms represent *soil series* names. In the system of soil classification in use at the present time, the *soil series* is the most important group of soils in a county or area. A soil series consists of a group of soils which have similar surface soil and subsoil characteristics and have developed on a particular kind of geological material. The texture of the surface soil, that part which is commonly plowed, may vary significantly within a series, thus giving rise to soil types. Soil types are subdivisions within a series. The name of each soil type, Clarion silt

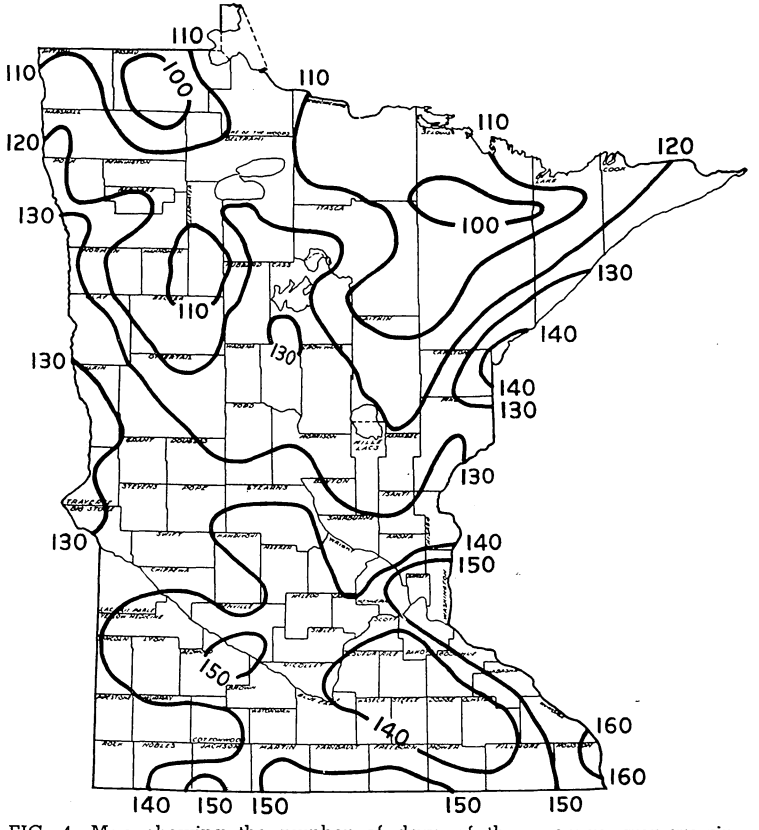


FIG. 4. Map showing the number of days of the average crop-growing season in Minnesota

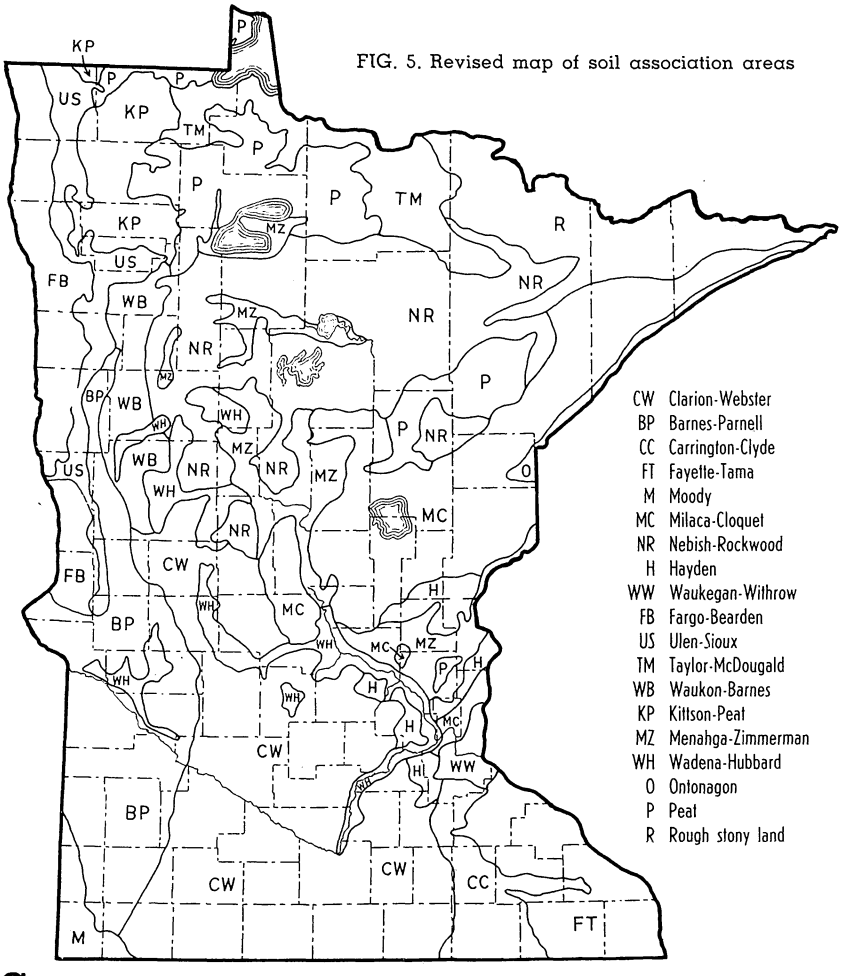


FIG. 5. Revised map of soil association areas

SINCE less than half of Minnesota has been covered by a soil survey it is not possible to make a soil map with the degree of refinement that would be possible if the state were wholly surveyed. However, there is sufficient information already available regarding the properties and distribution of the soils to justify the preparation of a map that will to a large extent meet the demands of those interested in the characteristics and distribution of the principal soil regions of the state. As the soil survey progresses new information continually becomes available, so a map made now, obviously, will be less accurate than one made later.

The colored map in the center of this bulletin first appeared in Minnesota Agricultural Extension Folder 131. The map shown above is based on field studies made since the publication of the colored map. If the two maps are compared it will be seen that some major changes have been made in the delineation of the boundaries of some of the soil association areas, particularly in the northwestern part of the state. The Waukon-Kittson association shown on the colored map has been divided into two separate units, one named Kittson-Peat association, the other, Waukon-Barnes association. The descriptions of the various soil associations in the bulletin are based on the areas shown on the above map.

loam, for example, consists of two parts. The one called the *soil class* name indicates the texture of the surface soil, silt loam in this case, while the other, known as the *soil series* name, is some geographic name from the vicinity of the place where the soil was first mapped. Clarion silt loam and Clarion clay loam are two soil types within one soil series. Except for the differences in the texture of the surface soil the two soil types are about the same.

This bulletin does not attempt to give detailed information on the large number of soil types included in the 19 associations; brief descriptions are given only of the principal ones. For additional information on the nature and distribution of these soil types the reader is referred to the soil survey reports of the counties where soil surveys have been made. A list of the counties already covered by soil surveys may be obtained from the Division of Soils, University Farm, St. Paul 1.

The 19 soil associations of Minnesota, approximate acreage of each, and the proportion of the state they occupy are listed in table 1. Their location and distribution are shown in figure 5 and on the colored map in the center of this bulletin.

Table 1. Approximate Acreage and Proportionate Extent of the Soil Association Areas in Minnesota

Soil association	Acres	Per cent
Clarion-Webster	9,947,000	18.3
Nebish-Rockwood	6,919,000	12.8
Milaca-Cloquet	6,126,000	11.3
Barnes-Parnell	4,605,000	8.5
Peat	3,956,000	7.3
Rough stony land	2,985,000	5.5
Menahga-Zimmerman	2,792,000	5.2
Fargo-Bearden	2,457,000	4.5
Fayette-Tama	2,242,000	4.1
Wadena-Hubbard	2,212,000	4.1
Taylor-McDougald	1,977,000	3.7
Kittson-Peat	1,694,000	3.1
Ulen-Sioux	1,601,000	3.0
Carrington-Clyde	1,301,000	2.4
Waukon-Barnes	1,236,000	2.3
Hayden	921,000	1.7
Moody	510,000	0.9
Ontonagon	372,000	0.7
Waukegan-Withrow	321,000	0.6
TOTAL	54,174,000	100.0

FIG. 6. The Clarion-Webster area is the most important one in Minnesota

Clarion-Webster Association (CW)[1]

This association covers a large part of south central Minnesota and has a total area of nearly 10 million acres, which is slightly more than 18 per cent of the total area of the state. The surface ranges from nearly level to strongly rolling. Large areas have a nearly level surface where drainage conditions are somewhat restricted and often interfere with the preparation of the land for spring seeding, particularly in unusually wet seasons. Where adequate drainage, such as tiling, has been provided, these difficulties are largely overcome. The greater proportion of the area, however, has a sloping surface where natural drainage is excellent, and seldom are crops affected by too much water. Throughout the whole area are many large and small depressions which collect water from the surrounding higher lands and remain permanently wet most of the time. Peat of variable depth is found in many of the depressions. In some places these areas have been artificially drained and have become very productive.

Belts of morainic hills ranging in width from one to more than five miles with a wide range of topographic features occur within the region. Near some of the larger streams the land is often sharply rolling and in some places is rather stony, preventing its use for agricultural purposes except permanent pastures. Many of these stream-bordered areas are forested with mixed hardwoods. The greater proportion of the land is generally free from stone. Boulders are often more prevalent where the surface is strongly rolling, with the most stony land confined to the crests of the hills and the upper slopes. In some swales and depressions boulders on and below the surface are often obstacles to cultivation.

[1] This symbol is used on the soil map to identify the association.

The native vegetation of this area was tall, deep-rooted grasses on the prairies and deciduous trees on the lands adjacent to the rivers and surrounding the lakes. The prairies were covered with a sod whose fibrous roots were particularly dense in the top six inches and with many roots extending down for two feet or more, particularly where moisture was plentiful, such as on the broad upland flats and in the depressions. The organic matter within the soil was derived from these roots and its amount varies from place to place, depending to a considerable extent on the slope of the land and the texture of the soil.

The whole area has been overrun by one or more glaciers, with the result that a thick deposit of limy glacial material now covers it. From this material the soils have developed. On large areas this material is remarkably uniform in composition, but there are places where differences occur, chiefly owing to the various geological agencies involved in its deposition. Throughout the area, usually occupying relatively small tracts too small in size to be shown on the map, are sandy soils, often occurring adjacent to some stream channel. In general they occupy nearly level plains or old stream terraces, all of which are now well above overflow. In these places the soils are similar to those found and described under the Wadena-Hubbard association (see page 28). Within the area, too, are bottomland soils nearly always subject to flooding at some time of the year, more particularly in wet springs when the streams overflow their banks. Peat soils of variable depths are found in some of the depressions.

The climatic conditions prevailing in this association are fairly uniform. The average length of the growing season ranges from 130 days in the northern part to 150 days in the central and southern sections, a frost-free period of sufficient length to insure the ma-

turity of corn, an important crop in the region. The average annual precipitation ranges from 24 to slightly more than 30 inches, with the greatest amount occurring in the more southerly counties.

Erosion is most serious on the rolling lands, particularly those commonly utilized for corn and other intertilled crops. In some sections wind erosion is removing some of the topsoil, particularly in the early spring when the ground is unprotected by vegetation. Some fields are disfigured by gullies, especially on rolling lands where soil management is poor.

The soils are dark colored, generally well supplied with organic matter, and have medium- to fine-textured topsoils and subsoils. In practically all cases the subsoils are well supplied with lime, eliminating the need for it for crops sensitive to a lime deficiency.

The principal soil types of this association are Clarion loam, Clarion silt loam, and Clarion silty clay loam, all of which occupy the undulating and rolling lands. They all have good surface and underdrainage and are adapted to all crops grown in the state. Webster silty clay loam and Le Sueur silty clay loam are developed on the broad, nearly level upland plains and are somewhat imperfectly drained. Unless artificially drained, these soils remain wetter in the spring than the Clarion soils, and preparation of the land for seeding is often delayed. When adequately drained they are some of the best corn soils in the state. Dickinson fine sandy loam occurs in areas of the Clarion soils where the surface is rolling or hilly. This soil has a fine sandy loam topsoil and a sandy subsoil interbedded with layers of fine-textured material, such as silt and clay. Storden loam occupies the strongly rolling areas where the surface soil is very shallow, the grayish-yellow limy subsoil frequently being exposed. In the areas originally timbered the principal soils are Lester loam and Lester silt loam. These soils are similar to the Clarion soils in relief and texture but they have somewhat lighter-colored topsoils and a lower content of organic matter. Glencoe silty clay loam is a poorly drained soil and is widely scattered throughout the area, occupying the most poorly drained positions. It occurs in depressions, shallow valleys, along intermittent stream channels, and marginal to peat lands. This soil is highly productive when provided with adequate drainage. Where the soils are sandy, Wadena sandy loam, Esterville sandy loam, and Hubbard sandy loam are the most prominent soil types. These are described more fully where the Wadena-Hubbard association is dealt with. Lamoure silty clay loam and Wabash silty clay loam are associated with the bottomlands in the valleys, which are often subject to overflow.

This association is the most important one in Minnesota because of the high proportion of arable land, the high level of fertility of the soils, and the high production of corn, small grains, livestock, and livestock products.

The area is adapted to a wide variety of crops. Small grains are grown on a large acreage of the cultivated land. Corn and soybeans are the dominant intertilled crops, the yields of both being high in favorable seasons. Tame hay does exceptionally well on nearly all the soils. The soils are unsurpassed by any others in the state for growing corn. Some crops are sold but most of them are utilized as livestock feed. Intensive livestock production is the principal agricultural enterprise.

Nebish-Rockwood Association (NR)

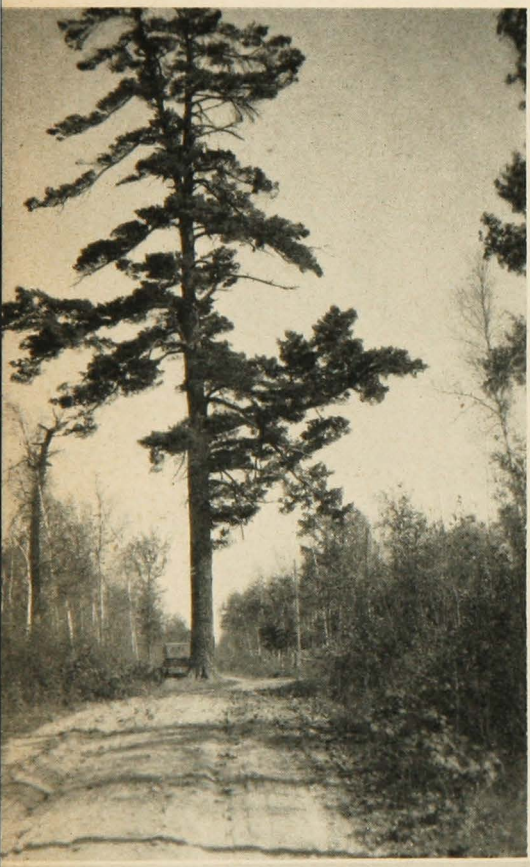
This association is confined to the wooded portion of north central Minnesota, generally known as the cutover region. In this respect it is similar to the Milaca-Cloquet association, which is

also regarded as a part of the cutover region. It occupies approximately seven million acres, which is nearly 13 per cent of the total area of the state. In addition to large areas of well-drained uplands it has many poorly drained depressions and small and large peat bogs. Most of the bogs are covered with spruce and tamarack. Many are perpetually wet and only a few small ones have been drained and used for agricultural purposes. Christmas trees are harvested from some of the larger bogs and are a source of income.

The surface ranges from nearly level to rolling with some areas strongly rolling and hilly. Natural drainage is good to excellent on all the sloping lands; on the broad flats and depressions it is somewhat restricted, particularly where the fine texture of the soils retards the rate of percolation of water.

Stones are present on and below the surface, particularly in places where the land is hilly or where it adjoins a stream or natural drainageway. Rather extensive tracts occur where the soils are practically stone-free and in these places tillage operations can be performed with little difficulty. In other places the stones are rather numerous but they can be removed so that tillage is possible; however, the cost of stone removal is usually high.

Originally the area was forested with pines and hardwoods. Some of the finest stands of white pine in the state formerly covered parts of this district, but now practically all of the merchant-



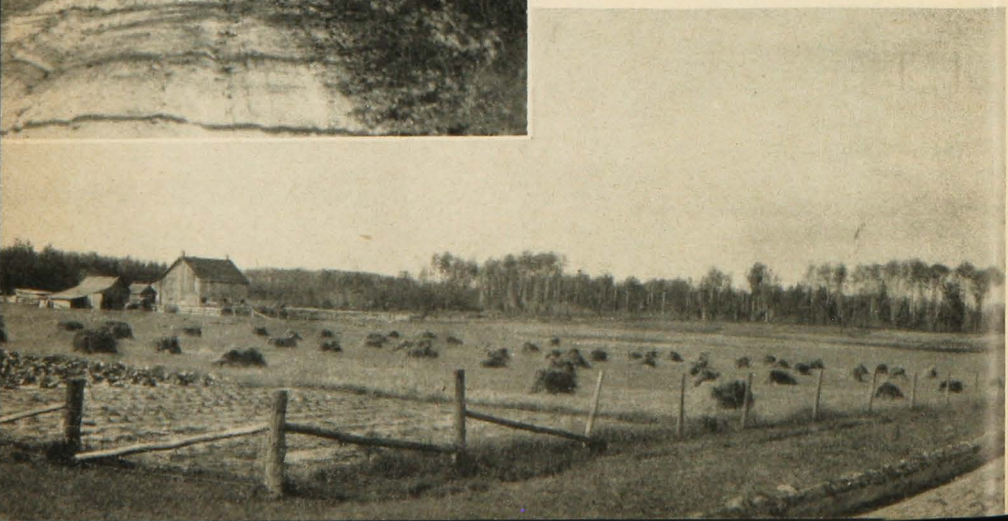


FIG. 7. Left: Remnant of the virgin forest in the Nebish-Rockwood area. Below: A typical farm scene in the area

able timber has been cut. Norway and jack pines occupied the drier sandy plains and gravel ridges which make up a considerable part of the region. Forest fires have repeatedly swept over parts of the area, destroying much valuable timber. On these burnt-over areas a second growth of hardwoods has gained a foothold and many of the trees have now reached a size suitable for commercial use. Many of the burnt-over areas of sandy soils are now producing another stand of jack pine which is making a substantial growth and if protected from fires will in time produce profitable returns.

The soils have developed from glacial material derived from rocks of mixed lithological composition, the majority of which are limestones and shales. Leaching has removed only a small part of the lime from the soils, with the exception of some of the more sandy ones; therefore it is only seldom that lime is needed for crops, even for those most sensitive to a deficiency of it, such as alfalfa and sweet clover. With some of the coarse sandy soils the subsoil in general is well supplied with lime, but the topsoil is acid and frequently crops are benefited by an application of lime.

The climate of this part of the state is more severe than in areas farther south and thus limits the variety of crops that can be profitably grown. The average length of the frost-free period is from 110 to 130 days. The days have a greater proportion of sunshine than the southern areas, which compensates

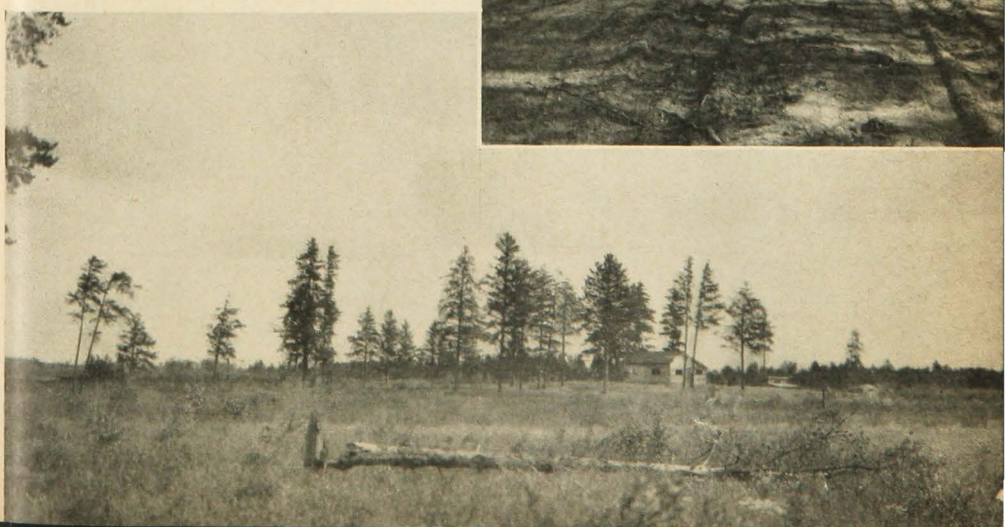


FIG. 8. Right: Remnant of the virgin forest in the Menahga-Zimmerman area. Below: Some farmer has partly cleared the land

to some extent for the shorter growing season. The average annual precipitation ranges from 20 to 26 inches, most of which is received during the crop-growing season.

Erosion is somewhat severe on the cultivated sloping lands, particularly where intertilled crops and small grains are grown. In the spring before the land is protected with vegetation there is some soil drifting, but this is confined chiefly to the areas with lighter-textured soils.

The soils are derived from glacial till of moderately heavy texture, being composed of a relatively large proportion of disintegrated limestones in various degrees of fineness. Some areas have a very heavy subsoil through which water percolates very slowly, thus restricting its use for some crops. The lighter-textured soils are more generally confined to the areas where the surface is more rolling. Stony and gravelly ridges are distributed throughout the region but generally where the surface is strongly rolling. Narrow bottomlands along the streams, subject to frequent flooding, occur in all parts of the area. These are generally used for permanent pastures, although wild-grass hay is harvested from many of them, as well as from some of the drier potholes and depressions in the uplands.

The soils have light-gray or brownish-gray topsoils ranging from fine sandy loams to loams with calcareous subsoils of clay loams or sandy clay loams. The supply of organic matter in the surface soil is generally low, as it is in all wooded soils; when the land is cleared and put into cultivation, a soil management program should include the addition of this important constituent, thus improving the fertility and assuring a seedbed that maintains a favorable tilth. On the smoother sandy plains scattered over the area the surface soil is often a loose sand or a sandy loam, with a subsoil of sand or gravel or a mixture of them. The depth to the gravelly material ranges from 12 to 30 inches below the surface. The thickness of the overlying layer, provided it is not too sandy, has a marked influence on the productivity of these sandy soils.

The well-drained, finer-textured soils of the uplands which occur on undulating to rolling areas are Nebish loam and Rockwood loam. Nebish loam has a heavier-textured subsoil than Rockwood loam and in general is less stony. Rockwood loam has a sandier surface than Nebish loam and the lime has been leached to a greater depth, but this does not necessarily mean that this soil needs added limestone for plant growth. The extreme stoniness of the Rockwood soils has been one of the reasons why these soils are not more extensively farmed. Some other soils of variable texture are associated with

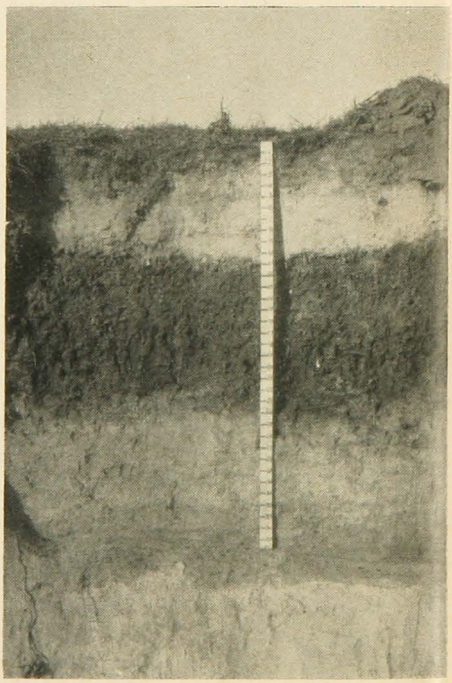


FIG. 9. Typical profile of a forest soil in the Nebish-Rockwood area

the Nebish and Rockwood soils and occur in an intricate pattern on a wide variety of slopes. The soil occurring in the poorly drained depressions is Bluffton silty clay loam. Frequently it is too wet to be plowed and often very stony.

The fine- and moderately fine-textured soils with good natural drainage are potentially fertile. Inasmuch as they are rather low in organic matter they are well adapted to tame hay crops, including the common clovers and alfalfa. A considerable proportion of the cultivated land is devoted to these crops. An abundance of fair to good pasture is available on the uncleared wooded portions of the farm. The soils are well supplied with lime and the content of phosphate and potash is generally adequate for crop production. Corn is grown in limited quantities and is generally cut before it becomes fully matured and is used for feed. The comparatively short growing season and relatively low yields do not encourage the use of any great amount of cleared land for it. Potatoes are grown rather extensively and produce tubers of good quality with comparatively high yields. Alfalfa can be grown with little difficulty if the seed is inoculated. If it is cut too often in one season there is considerable danger of winterkilling. Oats are the principal small grain crop; most of the farm-produced crop is fed to livestock. A large quantity of concentrated feeds is shipped in from outside sources and fed to poultry and dairy stock. In some parts of the area sulfur has proved beneficial, especially for tame hay. The most important principle of management of these soils is to increase or maintain their supply of organic matter.

FIG. 10. Typical profile of a prairie soil in the Kittson-Peat area

Agricultural development is very limited in this region, with probably less than 25 per cent of the area in farms and of this only a small proportion under cultivation. The high cost and difficulty of clearing the land and its remoteness from the larger centers of population are primary reasons for the limited development. Settlement, in general, is confined to the areas of the better soils. Most of the farms are small, with dairying the most common type of farming.

Milaca-Cloquet Association (MC)

This association occupies a large porton of the cutover region of northeastern Minnesota. It has a total area of slightly more than six million acres, which is approximately 11 per cent of the total area of the state. Many large and small peat bogs, mostly tree covered, comprise a large part of the area. The region is characterized by extreme variations in topography, ranging from gently undulating to strongly rolling

to steep and hilly. The area also includes many narrow belts of hilly land with short, steep slopes. Swales and depressions, many of the latter containing peat, are associated with all the better-drained lands. In the southern part of the association the surface is smoother, the slopes less steep, and more of the land is better suited for agricultural use.

Stoniness is a characteristic feature of practically all the soils. The amount of stone varies greatly from place to place, even within short distances. The stones are particularly numerous in many of the swales and depressions. Some of the fields under cultivation have had most of the stones removed, and periodic pickings are made to keep the land free of them. In some areas they are so numerous as to make the cost of removal prohibitive, while in other places patches are found that are almost stone-free. In some places nearly bare knobs of bedrock are exposed, or are only thinly covered with soil.

The area originally was heavily forested with mixed conifers and hardwoods, Norway and white pine predominating. Practically all of the original timber has been removed and a second growth of various species of hardwoods now covers a large proportion of the uncleared land. Forest fires have repeatedly swept over parts of the region.

Glaciers deposited the material from which the soils have developed. As the glaciers retreated they left a reddish-colored mixture of variable quantities of gravel, stones, and sand, embedded in silt and clay. In most places coarse-textured material predominates, with stones scattered over the surface and embedded in the soil. In some places the glacial material is uniformly fine textured, such as a clay loam or a sandy clay loam. However, the bulk of the material consists of a loose sandy till with large and small boulders commingled with the finer-textured material. In some places where the surface has a broken relief, such as a series of hills and knobs pitted with depressions, the soil material is sandy both in the surface and subsoil. In other places similar sandy soils occupy undulating positions which in general are comparatively free of stones.

The climatic conditions are more variable in this association than in any other in the state. The average length of the growing season ranges from 100 days in the most northerly section to 150 days in the single isolated area near the Twin Cities. In the immediate vicinity of Lake Superior the frost-free period is considerably longer than in areas farther from the lake. The average annual precipitation ranges from 26 to 30 inches, the greatest amount occurring in the extreme northeast portion of the region.

Soil erosion either by water or by wind is not a serious problem. Much of the land is uncleared and the water is readily absorbed by the soil, which is protected by a layer of leaf mold on the forest floor. Where the land is cultivated, particularly in places where the surface is rolling, water erosion is severe and gullies have formed on some of the soils most susceptible to erosion. Wind erosion is less severe because of the protection provided by groves which constitute a part of every farm.

The soils have developed on reddish glacial material which contained little or no lime. In no other large soil association in the state are the soils as mixed as they are in this one. Marked changes in the texture of both surface soil and subsoil occur within short distances and almost every quarter section has some poorly drained soil or peat. The upland soils are predominantly gray sandy loams and loams with reddish sandy clay loam subsoils. In the lower-lying places, excluding the peat bogs, the surface soils are darker and the subsoils are somewhat heavier textured.

The predominant soils of the uplands are Cloquet sandy loam, Scandia fine sandy loam, and Milaca very fine sandy loam. The first two are developed from sandy and gravelly material where the topography is "choppy" or where it consists of a series of hills with rounded tops and short, steep slopes. Milaca very fine sandy loam, in general, occupies the smoother portions of the area and the soil material is heavier textured. Freer silt loam occurs in areas where drainage is somewhat slow and Adolph silty clay loam occupies the poorly drained depressions. Where sandstone rock, both fragments and disintegrated portions, constitutes a relatively large proportion of the soil material, which otherwise has characteristics similar to the Milaca soils, the soil is Askov very fine sandy loam. Terraces with rather smooth surfaces near some of the streams and lakes occur in scattered areas throughout the region. The soils formed on them are Onamia loam, Onamia fine sandy loam, and its somewhat wetter associate, Warman loam. The broad sand plains, predominantly covered with jack pine in their virgin condition, have subsoils of sand or sand mixed with gravel and cobbles. The soils occurring in these situations are Omega loamy sand and Chetek loamy sand.

The productivity of the soils ranges from poor to good. Such factors as relief, drainage, texture of surface soil and subsoil, and stoniness greatly influence the productivity and the agricultural use of these soils. The most productive ones are those that are well drained. Their natural supply of organic matter and nitrogen is low, compared with the black soils of the prairie regions. This necessitates the growing of clover or alfalfa which, along with the use of manure produced on the farm, furnishes a supply of organic matter sufficient to maintain productivity at a fair level. While the soils, in general, are acid, not all of them are lime deficient. This is particularly true of the finer-textured soils. With the sandy soils, however, liming is necessary, especially for the growth of alfalfa and sweet clover. Some difficulty is experienced in keeping the heavier-textured soils in good tilth, since they have a tendency to bake when dry and to form a hard, compact, surface crust. This can be attributed in part to a deficiency of organic matter in the surface.

In the northern part of the area there are large areas of cutover land with only a limited agricultural development. Settlement is sparse and is generally confined to local communities. Only a minor part of the land is in farms and the acreage of cultivated land per farm is small. Self-sufficient and part-time farms predominate. Agricultural development in the central and southern parts, however, is more intensive, with a high proportion of dairy farms. General farming is second in importance. Much of the land is in pasture and hay, although a variety of other crops such as small grains and corn are grown. Some income is derived from potatoes and clover seed.

Barnes-Parnell Association (BP)

This association occupies a relatively narrow belt paralleling most of the western border of the state. It begins in east central Rock County and projects northward to southeastern Norman County. Its greatest width is approximately 70 miles, its narrowest less than six miles. Its total area is slightly more than four and one-half million acres, which is about 8½ per cent of the total area of the state.

The surface ranges from undulating to strongly rolling. In the rolling sections the land is a succession of knolls, intermediate slopes, and depressions. Broad upland flats with soils that are somewhat imperfectly drained and poorly drained potholes and depres-

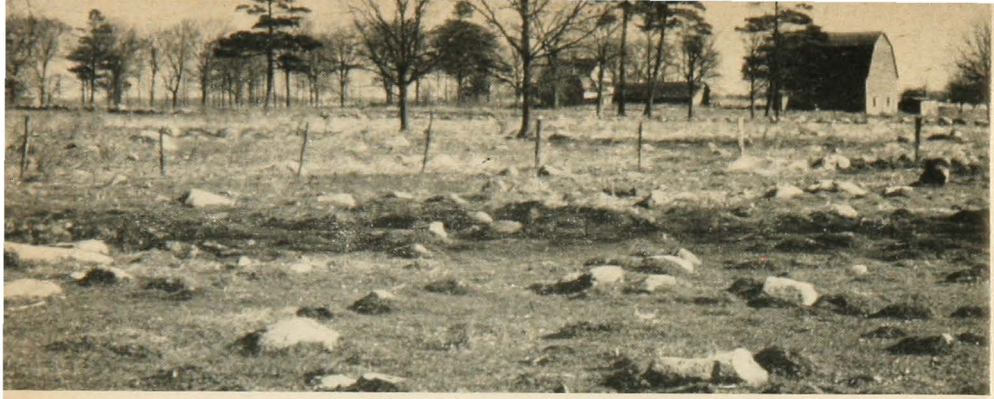


FIG. 11. Boulders are often so abundant in the Milaca-Cloquet area that the cost of removing them is almost prohibitive

sions occur throughout the whole area. Marshes and shallow lakes, some of which become dry in years of less than normal rainfall, are common features of the landscape.

Drainage conditions vary according to differences in topography. They are generally excellent in the undulating and gently rolling areas but are somewhat poorer on the broader flats; in the slight depressions and potholes the drainage is very poor, and the soils are wet most of the time. On the more rolling lands with steeper slopes losses of water by runoff are considerable and erosion is removing the soil.

In some places boulders are present on and below the surface and must be removed before the land can be efficiently farmed. Stones are more abundant in the rolling areas. In some places they are so numerous that removing them is impracticable, but the land is suitable for pasture and much is used for this purpose. In addition to stones, gravel is occasionally present at the surface, but these areas in general are confined to the sharp knolls or occur in association with the coarser-textured soils.

This association is confined to the prairie region of the state and the soils were developed under the influence of a grass vegetation. In the most northerly portions of the region there has been some encroachment of trees from the hardwood forests of the east, with the result that the soils have a smaller amount of organic matter and are somewhat less productive than those developed entirely under the influence of grass vegetation. These soils, however, are not to be regarded as of low quality, and under good soil management they can be made as productive as the more typical soils of the association.

The soils are derived from moderately heavy glacial till which carries much lime. Some sandy soils occur in scattered areas in the association with the heavier upland soils.

The climate is subhumid with long cold winters and short summers. The average number of days without killing frost ranges from 120 to 140, with the longer period in the southern portion. Hot drying winds in the summer occasionally damage the crops. Precipitation decreases northward from around 26 inches in the southern part to 22 inches annually in the northern sections.

Water erosion is somewhat severe on the rolling lands, particularly where small grains and intertilled crops are grown in long rotations without an occasional grass or legume crop. Some soil drifting occurs in dry springs before and during the time the land is being prepared for seeding and before the ground is protected by vegetation. Gullies are also forming in some of the fields which, unless corrective measures are employed, will eventually ruin many acres of good land.

The surface soils are dark colored and in general are well supplied with organic matter, with the exception of those in areas where the surface is

FIG. 12. Soils of the Barnes-Parnell area are well adapted to small grains, and a large acreage is devoted to them

strongly rolling. The crests and upper slopes have only a thin layer of topsoil.

The principal soil types are Barnes loam, Barnes silt loam, and Barnes silty clay loam, which occupy the well-drained, gently rolling uplands. Aastad silty clay loam and Flom silty clay loam occur on the smoother uplands, where surface drainage is somewhat poorer and the upper part of the subsoil is finer textured and more or less compact. Parnell silty clay loam is a wet soil and occurs in all parts of the area in poorly drained depressions. In the bottomlands along the streams and drainageways where flooding often occurs, the heavy-textured soil is Lamoure silty clay loam which is heavily charged with lime. The sandy soils underlaid with beds of sand and gravel at rather shallow depths are Sioux sandy loam, Esterville sandy loam, and Sverdrup fine sandy loam. Pierce loam and Pierce gravelly sandy loam are associated with the Barnes soils and occur in areas which are strongly rolling. They commonly occupy the stony and gravelly ridge tops and upper slopes of the hilly areas. Buse loam occupies the areas with strong relief, where the surface soil is very shallow and in many places the grayish-yellow limy subsoil is exposed at the surface. These areas are very susceptible to erosion, particularly if planted to small grains and intertilled crops.

The productivity of the soils that are fine- to moderately fine-textured in the topsoils and subsoils is high, such as the Barnes silt loam and silty clay loam. The soils occupying the more strongly rolling areas are somewhat less productive, owing to the generally lower content of organic matter in the surface, the susceptibility to erosion, and the insufficient amount of water, a large part of which is lost by runoff. Flom silty clay loam and Aastad silty clay loam, which occupy the smoother portions of the uplands, generally are less productive than the Barnes soils, owing to the farmer's inability to get onto the land early enough in the spring to prepare a proper seedbed. This difficulty is accentuated in unusually wet springs. When provision has been made for drainage, these soils are as productive as those which are naturally well drained. The Parnell silty clay loam is often too wet to be used for cropland. Very few areas of this soil have been drained. They are commonly used as meadows or pastures, and wild-grass hay is harvested from many of them. Where the soils are sandy both in the surface and subsoil, crop yields are often adversely affected by drouth during the early part of the summer.

Wheat, oats, barley, and flax are the principal grain crops; corn and some soybeans, usually used for hay, are the important intertilled crops. Tame hay is grown on nearly every farm and supplies most of the roughage needed for livestock. Wild-grass hay is harvested from many of the low-lying, poorly drained areas.

A large proportion of the land in this region is under cultivation. The farms

in general are larger than in the regions in the southern part of the state, and power farming is common on many. Most of the farms are well improved and have good, substantial buildings. The production of small grains for sale and the raising of livestock are the principal agricultural enterprises. Dairying is important in many sections.

Peat Association (P)

Peat is found in large and small bodies in all parts of the state except the southeastern and southwestern sections, where it is of minor importance. Much of the peat in the southern areas occurs as small, isolated bogs, although some occupies narrow, branching, drainageways. In some of the northern counties peat covers whole townships. The smaller areas are not shown on the map, but it should be pointed out that peat is found in all of the 19 soil associations, with the exception of the Fayette-Tama and the Moody areas, and even in these a few small bogs may be present. The peat areas shown on the map occur in five different localities; the largest one is north of Red Lake and occupies several townships. Another large area lies northwest of Duluth. In all the larger areas some "islands" of mineral soils surrounded entirely by peat are found, but the bulk of the land consists of peat. The total area of peat soils shown on the map is approximately 3,956,000 acres, which is slightly more than 7 per cent of the total area of the state. If the acreage of all peat soils included in the other associations were included in these figures, the total acreage would be approximately doubled. The peat from bog to bog is extremely variable in thickness, ranging from less than one to more than 20 feet. In many places where the peat was comparatively shallow, particularly in parts of northern Minnesota, forest and prairie fires have completely or partially consumed the peat cover, leaving the underlying, often stony, mineral soil exposed. In places where the peat was deeper the fires have consumed only a portion of the peat, leaving an uneven, hummocky surface, with the result that the deeper burnouts collect water and form miniature ponds. If a fire has left a clean burn and the new land surface thus formed is not too stony or sandy, the land is frequently cropped, particularly if the season is not unusually wet so that the land can be worked and seeded early enough in the season to assure maturity of a crop.

FIG. 13. Most of the peat layer has been burned from this bog

Most of the bogs in the northern part of the state are covered with thick stands of tamarack and spruce, often mixed with white cedar and balsam fir with an undercover of sphagnum and other mosses, heath shrubs, and related species. In some bogs the ground cover is mosses and shrubs and there are no trees except a few dwarf tamarack and spruce, whereas in other bogs willow, alder, and swamp birch occur. Some of the bogs have been burned over repeatedly, killing all live vegetation and leaving exposed the underlying mineral soil, frequently strewn with boulders. The tree vegetation, chiefly black spruce, often attains a fair size and is suitable for commercial uses, principally for pulpwood. On some of the wetter bogs the trees are often small, stunted in growth, and have no

value even as firewood. Within recent years considerable income has been derived from the sale of pulp logs. Some of the grass-covered peat bogs form natural meadows on which wild-grass hay is cut. The hay in general is of an inferior quality and its feeding value is low when compared with that from clover and tame grasses.

Peat soils consist chiefly of the remains of plants in various stages of decomposition and are in marked contrast to mineral soils, which are composed mostly of finely disintegrated rocks and minerals mixed with variable amounts of organic matter in the surface soil. Peat has formed and accumulated in permanently wet situations, such as wet potholes in the uplands, wet swales, on poorly drained flat valley floors, on slopes kept permanently wet from seepage water, and in some shallow lakes or ponds which have become partly or completely filled with water-tolerant plants.

The character of the peat on the surface is not always an indication of its nature at lower depths, owing to changes in the character of the vegetation during different stages of its formation.

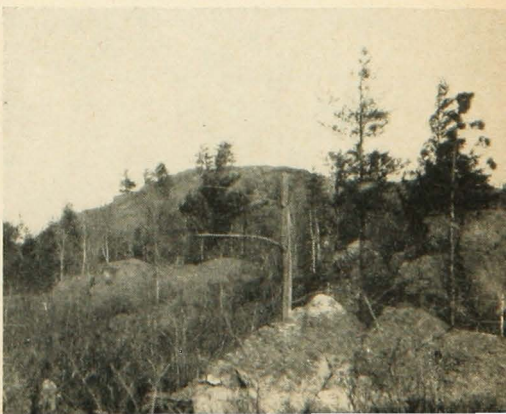
Compared with mineral soils, peat soils suffer from serious handicaps. Most bogs in their natural state are poorly drained and in some places it is impossible to provide satisfactory drainage because of a lack of a suitable outlet. In places where an outlet is available and a drainage system has been installed there is still the possibility of flooding at times of exceptionally heavy rains. Crops then are ruined if water stands on the land for any length of time. Even if adequate drainage is provided and crops are planted they may be damaged by summer frosts which may occur at any time during the growing season, particularly in the northern part of the state. Grasses and clovers are practically immune to injury from moderately severe frosts and are the safest crops on peat soils.

When peat has been adequately drained and cleared of trees, the living sphagnum moss removed, which is common in many bogs, and a seedbed prepared, it is necessary to treat the peat with mineral fertilizers, chiefly phosphate and potash. On some of the northern bogs only phosphate is necessary, but usually after a few years of cropping, potash also becomes necessary. Occasionally a bog is found that requires only potash, but these are few. On the high-lime peats the supply of nitrogen will last indefinitely and an application of it is only advisable when truck crops such as celery, lettuce, onions, and carrots are grown.

From the standpoint of suitability for agricultural use, peat soils are classified into two groups, high-lime peats and low-lime peats. The former are well supplied with lime, the latter are not. Most of the peat soils in Minnesota are of the high-lime type. Some peats in the northeastern part are low in lime, and to make them productive an application of lime in addition to phosphate and potash is necessary. At the present time very few of the low-lime peats are under cultivation.

Most of the peat lands under cultivation are in the central and southern sections of the state. Tame hay utilized as hay meadows or pastures is the most

FIG. 14. This forest vegetation is typical of much of the rough stony land



dependable crop. Potatoes, fodder corn, and truck crops are grown on a limited scale. Of the small grains, rye is the most satisfactory crop and flax generally does well on land newly broken, if the peat has not been burnt-over.

Only a small number of farms are located on lands which consist almost entirely of peat. On such farms a large proportion of the land is devoted to tame hay and potatoes, with a limited acreage to small grains. In the southern part of the state a considerable acreage of peat is devoted to specialized crops such as potatoes, onions, carrots, and other root crops. Where small areas of peat occur on farms composed mostly of mineral soils, they are often drained and utilized for pasture or tame hay meadows and frequently corn, small grains, and other crops are grown satisfactorily.

Rough Stony Land (R)

This association occupies a comparatively large area in the northern parts of Cook, Lake, and St. Louis counties and a small part of eastern Koochiching County in northeastern Minnesota. It is an area of rough stony land with many peat bogs, swamps, lakes, and outcrops of bedrock over the whole area. It occupies approximately three million acres and constitutes about 5½ per cent of the total area of the state. While most of the area has a rough surface, some comparatively small parts of it are rather smooth. In these places generally only a thin coating of soil material, usually stony, covers the underlying bedrock. In some places between the bare rock ridges a rather thick deposit of glacial material, consisting of gravel and stones imbedded in silt and clay, is found. It is in some of these places on the most stone-free land that small patches are farmed.

Nearly all the land originally supported a forest vegetation of mixed conifers and hardwoods, but most of the merchantable timber has been logged off. In a few places the original forest still stands, but these places are small and are usually found in state and federal forest reservations. At various times in the past forest fires have destroyed some of the original forest vegetation and a second growth of mixed hardwoods has established itself in favorable situations. Since a large part of this region now is included in a national forest, more adequate fire protection is provided and the danger of fire is less serious.

The soils are derived from stony glacial drift and are extremely variable in texture, both in surface and subsoil. They have light-gray topsoils with reddish-brown subsoils. In some places where bedrock is close to the surface the subsoils are often mixed with broken fragments of angular, hard rocks. Where the soils have made any appreciable development they are similar in many respects to those of the Milaca-Cloquet association, with the exception that more boulders are present on and below the surface. Settlement is very sparse and very little land has been developed.

The generally poor soils, abundance of stones, numerous swamps and lakes, and unfavorable climate make this region unsuitable for farming but adapted to forestry and recreation.

Menahga-Zimmerman Association (MZ)

This association consists of sandy soils with sand or gravel subsoils developed under the influence of a forest vegetation and comprises five separate bodies located in the east central and north central parts of the state. The largest one begins a few miles north of the Twin Cities and occupies the broad upland terraces of the Mississippi River and its tributaries. They all lie within the drainage basin of the Mississippi

River with the single exception of one, which borders a portion of Red Lake, whose drainage waters flow northward in tributaries of the Red River of the North. The total area is approximately 2,792,000 acres, or 5.15 per cent of the state. These areas occupy the smooth to undulating sandy plains on the river terraces or the sandy plains of the glacial upland. Some areas where ridges and dunelike knolls are prominent have a broken surface, but these areas are relatively small. The soils are generally free from boulders, although in the areas where the surface is somewhat dissected some are present on and below the surface.

In the northern areas the land originally was covered with jack and Norway pines, while in the more southerly ones oaks predominated. On much of the land in the northern sections the pines have been cut for timber. Some of this land has been cleared of stumps and brush and put into cultivation, but much has been left idle for reforestation by natural means. In many places where the pines were removed the forest growth has been naturally reestablished and will in time, if protected from fires, produce additional timber.

The soils are excessively drained, their porous nature permitting the water to drain through them freely. In a few places where the land lies on about the same level as the peat bogs, a condition not uncommon in this region, the soils are often too wet to be farmed. Open ditches have been helpful in the reclamation of some of these wetter soils.

The materials on which the soils have developed are of glacial origin and consist of mixtures of sand and gravel or of sand of various grades of fineness. In some places fine and coarse gravels with a considerable number of pebbles and small cobbles constitute the soil mass, while in others the sand particles are more or less uniform in size, having been sorted by wind movements.

The climatic conditions prevailing in this association have a rather wide range because of the scattered distribution of the areas. The length of the growing season ranges from 135 days in the area nearest the Twin Cities to around 115 days in the most northerly area adjacent to Red Lake. The average annual precipitation is approximately 27 and 21 inches respectively for the corresponding areas.

Wind erosion is severe in some areas where the soil is loose and low in organic matter. This is serious where the fields are large and unprotected by groves of trees or other barriers. In the rolling situations some gullies have formed which if neglected will expand and eventually prevent the use of the land for crop production.

The soil pattern is less complex in these regions than it is in the other associations where the soils have formed on materials of more variable composition. The soils have coarse-textured surface and subsoils. They are low in organic matter, subject to drifting in unprotected places, and provide a poor seedbed for small seeds, such as those of the clovers and alfalfa. In some places the subsoils contain much coarse gravel, while in other places fine sand predominates. Much of the latter kind is found in parts of Anoka, Sherburne, and Isanti counties, where most of the sands are of wind-blown origin.

The organic matter content of these soils is low and, after they have been cleared and farmed a few years, the yields decline rapidly unless some provision is made to supply organic matter and mineral nutrients. This can be accomplished by using farm manure and crop residues to supply organic matter and by the addition of commercial fertilizers to furnish the necessary plant nutrients. The lime content of the soils is variable. The soils are generally acid in the southern districts and often require lime for such crops as alfalfa and sweet clover, while in the northern areas

the lime supply on the whole is quite sufficient and liming is seldom necessary. Sulfur in some soluble form is often needed in some of the northern areas, especially for the leguminous crops. The low water-holding capacity of these soils greatly restricts their use, since drouth injury frequently results in very low yields. They are therefore regarded as low-grade soils for farming.

A comparatively large proportion of these sandy soils has been cleared and brought under cultivation, largely because of the comparative ease with which it could be cleared and prepared for cropping. The proximity of some of the soils to the Twin Cities and other good markets also was a contributing factor to their development.

Menahga loamy sand is one of the principal soil types of this region. It is developed from sandy material that carries some gravel. It occupies a large proportion of the well-drained land of the northern areas originally covered with jack and Norway pines. Zimmerman loamy fine sand is the dominant soil type of the southern area and occupies upland areas similar in position to that of the Menahga soils but is developed under a forest vegetation of scrub oak. The Zimmerman soils are derived from a fine sand which is very loose and incoherent. It drifts readily and in some places dunes have formed. In some of the larger cleared fields blowouts occur, mostly because of an insufficient ground cover to hold the soil in place. Nymore loamy sand is associated with the Menahga soils and occupies similar positions, but it differs from the Menahga in that its surface is slightly darker owing to a higher content of organic matter. Isanti loamy fine sand and Sebeka loamy sand are low-lying imperfectly drained soils occurring in areas where the Menahga and Zimmerman soils are found. They have moderately dark-colored topsoils and contain a fair amount of organic matter and nitrogen. They occupy low-lying flats and depressions and commonly surround the peat bogs. Peat bogs are numerous in these areas, being interlaced among the higher, better-drained soils. The Zimmerman and Isanti soils are generally acid and often need lime, whereas the lime supply on the Nymore and Menahga soils is on the whole quite favorable.

Owing to their very sandy nature these soils are subject to drouth and only in years with normal and well-distributed precipitation during the growing season do crops do well. Rye is the principal small grain crop. Some corn and potatoes are grown, but not a large acreage is devoted to them. Of the tame hays, alfalfa probably does the best, since it has a deep root system and can extract water from the deep subsoil. Difficulty in getting a satisfactory stand of legumes is often experienced because of the small amount of water in the soil, looseness of the seedbed, susceptibility to soil drifting, blowing out of the seed, or injury to the stand when the plants are small.

General farming is practiced, with dairying the most important. The farms are small and the annual income from all farm products is low. Many farmers supplant their income by outside employment during parts of the year.

Fargo-Bearden Association (FB)

This association is confined to the Red River Valley in the northwestern part of the state. It is about 200 miles long from north to south with an average width of 20 miles. It includes more than two and one-third million acres, which is approximately 4½ per cent of the total area of the state. This area occupies a part of the bed of glacial Lake Agassiz and has a nearly level or flat topography. In many places there

is less than 12 inches difference in elevation in one mile.

The natural drainage of this area varies from generally good to poor. The better-drained areas are those that lie closest to the Red River and its principal tributaries. The drainage waters are carried by the Red River northward to Canada, eventually discharging into Hudson Bay. Numerous shallow water courses, most of which are dry the greater part of the year, remove a large part of the surface water during the spring thaw. These are supplemented by an extensive network of artificially constructed ditches, mostly along the section lines, making much of the land adaptable for farming. Some areas still are inadequately drained. Only a very small proportion of the land has been drained by tile. The large open ditches have increased the acreage that could be cultivated. However, in times of excessive precipitation in the fall, winter, or spring many acres remain wet too long and preparation of the land and seeding is delayed so that often the land is allowed to remain idle for the balance of the year. In these cases the land is frequently summer fallowed and a crop planted the following year.

The presence of stones on and below the surface is practically negligible although in some of the swales a few are scattered on the surface.

Originally the area was open natural grassland covered with tall wild grasses. The natural forest vegetation is confined to narrow strips of bottomlands and banks bordering the larger streams such as the Red River and its principal tributaries.

The climate of the area is rather severe, with long winters and warm summers. Short periods of severe winds often occur in the spring and fall, seriously damaging the growing crops, particularly in the spring when the plants are small. The growing season ranges from 130 days in the southern part to 110 days in the northern end. For the entire area the average annual precipitation is about 21 inches, of which about three-quarters falls from April to September.

The soils are derived mainly from clay and silt carried in by streams which flowed into the lake during its existence and were deposited later in beds of varying thickness. The finer clay particles settled out in the deeper parts of the lake, the silts in shallower water, and the fine sands in still shallower water near the shore lines where beaches were built up. These deposits of clay, silt, and sand extend north and south in more or less distinct belts parallel to the Red River. Only the soils developed on the finer sediments—clay and silt—are included in this association, whereas those developed on the coarser sediments are included in the Ulen-Sioux association. Both the clay and silt sediments are remarkably uniform throughout their occurrence and both occupy large areas. The soils developed on the heavy clays are Fargo clay and Fargo silty clay loam. The outstanding characteristics of both are the extremely heavy texture of both the soil and subsoil, as well as the underlying substratum, and the black color of the surface soil, underlaid by an olive-gray clayey subsoil. These soils are often referred to locally as "gumbo" because of their intractable nature. Within areas of the Fargo soils are small slightly depressed tracts which are impregnated with alkali salts. The soils in these areas are very compact and dense, often having a waxy appearance. When the soil is dry it becomes very hard and breaks into large, hard clods. In some places the upper part of the surface soil is somewhat coarser textured and lighter in color and rests on a black, very dense layer which on drying breaks into small irregular prisms or columns.

Bearden silt loam is developed from the smooth silty material and areas of both it and the Fargo soils are closely

associated. Like the Fargo soils it has a black surface soil well supplied with organic matter. The surface soil is somewhat shallower than that of the Fargo soils and is underlaid by a light-grayish limy layer, 8 to 10 inches thick, which in turn grades into a yellowish-brown silt loam. This gradually merges at variable depths into a heavy limy olive-gray clay or clay loam. Closely associated with Bearden silt loam are Glyndon loam and Glyndon very fine sandy loam. These soils have somewhat coarser-textured surface soils and subsoils, the latter consisting of a grayish-brown limy layer, 6 to 8 inches thick, which in turn grades into a light-yellowish-brown or pale yellow very fine sand layer of varying thickness. Below this is heavy olive-gray silty clay loam. The surface soils of the Bearden and Glyndon soils do not crack as readily in dry periods as do the Fargo soils and less power is required in farming them. Lime is abundant in these soils even in the surface layer. Lime concretions or nodules are common in the Fargo soils at depths ranging from 12 to 24 inches below the surface.

When satisfactorily drained, the Fargo, Bearden, and Glyndon soils are very productive. They are rich in organic matter and nitrogen and are generally well supplied with other plant nutrients with the possible exception of phosphorus. Their fine texture favors the retention of large quantities of moisture available to growing plants. Many of the soils respond to superphosphate fertilizers, but potash is generally abundant, although when used on sugar beets and potatoes it often gives profitable returns. The smooth, nearly level surface and freedom from stone favors the production of small grain crops at a comparatively low cost under a system of large-scale power farming.

Nearly all these soils are under cultivation. Small grains, principally wheat, oats, barley, and flax, are the dominant crops. A smaller acreage is devoted to corn, potatoes, and sugar beets, more on the Bearden and Glyndon soils than on the heavier Fargo soils. Both soils are utilized for growing tame hay, such as grass mixtures and alfalfa and sweet clover. During unfavorable seasons corn does not always mature but is utilized for forage.

A considerable proportion of the small grains produced is sold on the market, the remainder being used as feed. Formerly wheat was the principal crop, but the present acreage is less than half of what it was some 30 years ago. The livestock industry has developed rapidly since the decline of wheat production. At present dairying is an important enterprise. Some sheep are raised but the total number is not large.

Fayette-Tama Association (FT)

This association occupies more than two and one-fourth million acres in southeastern Minnesota. All of Houston, Wabasha, and parts of Fillmore, Winona, Olmsted, Goodhue, and Dodge counties are included in it. A large part of the region has a rugged topography which is more pronounced near the Mississippi River and its larger tributaries. It is dissected by many streams which have cut deep gorges in the sandstone and limestone formations which underlie the mantle of silty material covering them.

At the time of settlement a large part of the region was covered with a hardwood forest of oaks and other species, such as basswood, butternut, and hickory. Many of the southward-facing slopes are treeless, principally because of the direct sunlight they receive which causes a rapid drying out of the soil and prevents establishment of a forest. Nearly all the rougher portions of the area, such as the steep slopes bordering the valleys, the valleys them-

selves, and the terraces within the valleys, were originally covered with a dense forest. Outside the valleys on the broad ridge tops where the surface is smoother, prairie vegetation prevailed with occasional patches of trees.

The climatic conditions in this region are favorable for the production of the crops generally grown. It has a longer growing season than any other region in Minnesota and a greater average annual precipitation. The average frost-free period is about 150 days with May 1 about the date of the last killing frost in the spring. The average annual precipitation is about 30 inches, most of which falls from April to October.

Most of the uplands of this area are covered with a stone-free, smooth, silty material of wind-blown origin, called *loess*. In general its thickness ranges from 8 to more than 20 feet, but it is not uncommon to find this material underlaid with ledge limestone at comparatively shallow depths—three feet or less. The larger proportion of the land covered with the loess is timbered, but areas are rather common where the original vegetation was grass. As the distance from the valleys increases, the loess becomes thicker and the surface smooths out to a rolling topography with long gentle slopes. In the broader valleys old stream terraces, well above the present stream channels, occupy undulating positions and make up a large proportion of the cropland. In the lower bottomlands, adjoining the streams and not many feet above the water level, a variable assortment of both dark- and light-colored soils is found, nearly all of which are subject to periodic flooding during flood stages of the rivers. Many of these valley lands are included in farms, and substantial buildings comprise the farm unit. Many of these farms include land both in the valley and on the ridge top. The lower valley lands are generally level but frequently are dissected by small creeks and drainageways.

It is not uncommon to find on the bottomlands deposits of silty material washed down from the steep slopes or carried in by streams from the ridge tops. Some of the lower valley lands have been made practically useless for farming because of the deposition of material eroded from the higher land. Occasionally deposits of stony material dislodged from the limestone outcrops in the gorges of the valley are spread out over cultivated fields and pastures. This occurs most frequently during rains of high intensity and creates a considerable problem for the farmers.

The soils on the ridge tops, developed under a grass cover, are high in organic matter, unless erosion has been severe, and have a permeable silt loam subsoil. The principal soil developed here is Tama silt loam. However, where it developed under a forest vegetation with a subsoil similar to that of Tama silt loam, the soil type is Fayette silt loam. It has a topsoil with a low content of organic matter. Its surface is generally more sloping than that of Tama silt loam. Downs silt loam has about the same surface relief as Tama and Fayette, but the surface soil is somewhat lighter colored than Tama silt loam but not as light colored as Fayette silt loam. This can be regarded as a transitional soil with characteristics slightly different from those of either the Tama or Fayette silt loam.

The three soil types mentioned above are all developed on thick deposits of loess where the limestone bedrock lies at a depth of 40 inches or more below the surface. Where the mantle of loess ranges from 14 to 40 inches in thickness, Dodgeville silt loam and Dubuque silt loam are the recognized soil types, the former having a dark-colored topsoil, the latter a light-colored one. The imperfectly drained soils associated with the Tama silt loam are Muscatine silt loam and Cashton silt loam and those associated with Fayette silt loam are Estella silt loam and Traer silt loam.

Judson silt loam is a dark-colored soil developed from material carried down by erosion from the dark-colored upland soils. It usually occupies the gentle slopes between the terraces and adjacent bluffs and the foot slopes along streams and drainageways.

The bottomlands, subject to periodic flooding and overflow, are Wabash silt loam, which has a dark fine-textured surface soil with a heavy dark-colored subsoil, and Cass fine sandy loam, which also has a black surface soil but is underlaid by a layer of loose sand at depths ranging from 12 to 18 inches. In some places the surface soil is a loam or silt loam. Soils with light-colored topsoil occupying similar bottomland positions are Sarpy fine sandy loam, Sarpy loam, Genesee loam, and Ray silt loam. Ray silt loam consists of light-colored materials overlying dark-colored alluvial sediments deposited from the silt-borne streams during overflow.

The well-drained upland soils on the ridge tops are acid in contrast to those in the valleys, which are generally neutral or alkaline. On the acid soils lime is necessary for some of the legumes, particularly alfalfa and sweet clover. Limestone rock is everywhere plentiful and many local limestone quarries are scattered throughout the area where the lime rock is crushed by portable crushers and sold to the farmers.

The soils are well adapted to corn, small grains, soybeans, and tame hay. Corn is grown extensively on the smoother, dark-colored soils and a considerable acreage of the lighter-colored ones is also devoted to it, but the yields are somewhat lower owing to a nitrogen deficiency. The better bottomland soils in the valleys often equal or outyield those on the uplands, but are subject to the hazard of flooding, which results in reduced yield or crop failure. All the soils respond to good soil management practices, which include the use of suitable crop rotations, use of lime when necessary, proper use of farm manure, and the addition of commercial fertilizers.

The cropping systems on many farms are gradually being changed to diminish erosion. Formerly little attention was given to preventing soil losses from erosion, but through the organization of soil conservation districts the seriousness of this destructive force has been recognized and remedial measures are being employed on many farms. Recommended practices for erosion control often result in a reduction in the acreage devoted to cultivated crops with a corresponding increase in the acreage of hay and pasture crops. At present a large part of the hilly wooded land is used for pasture. As much of it is overgrazed, this results in the formation of gullies.

This area is one chiefly of livestock farming with dairying most important.

Wadena-Hubbard Association (WH)

This association consists of a group of sandy soils which in some respects are similar to the soils of the Menahga-Zimmerman association. It occupies approximately two million acres, somewhat smaller in total acreage than the Menahga-Zimmerman group. It occurs in several areas scattered over the central part of the state and occupies the higher terraces along the streams and the sandy plains within the glacial upland. These areas are most extensive where they border the Minnesota and Mississippi rivers and their tributaries. The largest continuous body occupies both sides of the Minnesota River beginning at a point in southern Nicollet County, continues northward to its confluence with the Mississippi River at Fort Snelling, and thence northwestward along the Mississippi River to near St. Cloud. From here a tongue extends westward terminating in eastern Douglas County. Since many areas

of these soils occupy comparatively small tracts in most of the associations, they are not shown on the map because of its small scale.

The surface of practically all the soils included in the group is gently undulating with sufficient slope to carry away the excess water. Only in a few places is the land too hilly to prevent its use for agricultural purposes. Stones are generally nonexistent and seldom does coarse gravelly material occur close to the surface.

Originally the soils were covered with prairie grasses, although in some places trees in thin stands occupied portions of the open grasslands, particularly along the streams and lakes. The roots of the prairie grasses imparted to the surface soil considerable amounts of organic matter, giving it a dark color. When settlement began on these soils in some of the northern areas much of the land consisted of so-called "prairie openings" with scattered patches of jack pine and scrub oak, which necessitated a certain amount of grubbing when the land was prepared for farming. In many places the surface soil is rather loamy and contains a fair to liberal supply of organic matter and makes a very satisfactory seedbed. The soils are comparatively easy to cultivate and require less power than the finer-textured soils of some of the adjacent associations. In some places the surface soil and upper subsoil are fairly retentive of moisture, but the coarse-textured subsoil consisting of sand and gravel has a low water-holding capacity with the result that the plant roots have a restricted zone from which to secure their needed moisture.

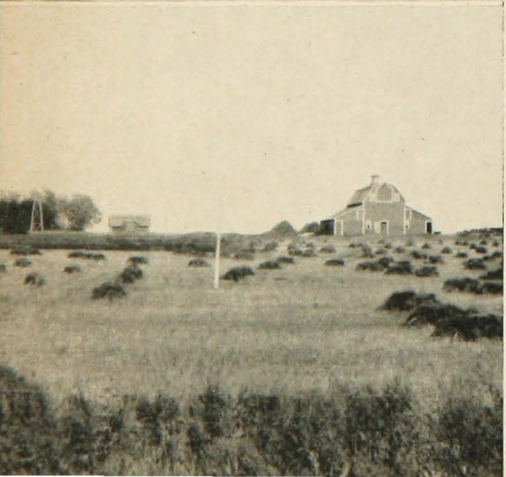
Associated with all the soils are peat bogs, some with grass and sedge vegetation, a few with trees, mostly spruce and tamarack.

Wind erosion is often a serious problem on many of these sandy soils. Although the effects of soil drifting are probably not as serious as on the looser soils of the Menahga-Zimmerman association, growing plants are often seriously damaged by blowing sand in dry seasons and there is considerable loss of the soil itself. Along many fence rows where weed growth generally is abundant, the drifting soil is caught and held, ridges built up, and fence posts buried.

Although these soils are widely distributed over the central and southern portions of the state, the climatic conditions are fairly uniform in all areas. In the southern areas the average growing season is approximately 140 days, whereas in the northern areas it is about 135 days. The average annual precipitation ranges from 24 to 28 inches, the majority of the rain coming during the growing season from April to September.

The soils are derived from glacial outwash sands and gravels which originally were well supplied with lime, but leaching has removed practically all of it from the upper soil layers and in many cases from the lower ones as well. Most of the soils, therefore, are acid.

The principal soil types fall into two categories: the one where the upper subsoil contains a considerable proportion of fine material to give it a better water-holding capacity, thus mitigating the seriousness of drouth; the other where the surface soil and subsoil are dominantly sandy and free of any great amount of fine material to enhance its water-holding ability. Of the former, Wadena sandy loam, Hubbard sandy loam, Fairhaven sandy loam, and Kasota sandy loam are the principal soil types. The surface texture of these soils ranges from a sandy loam to a heavy loam. Beneath the dark surface soil, which ranges from 8 to 10 inches in thickness, is a dark reddish-brown heavy sandy loam layer which when wet is more sticky than the overlying layer but when dry is so hard that it is often difficult to penetrate with a



spade or soil auger. Locally it is often referred to as a "hardpan," but it is not a true hardpan since it is no obstacle to the penetration of plant roots or to the percolation of water when the soil is moist. In some of these soils the finer-textured upper subsoil layer is not as pronounced as in others and in places it may be only slightly developed in texture, color, and in the degree of compactness.

The soils of the second group are less extensive than those of the first but occur in association with them. Frequently the soil pattern is such that the soils of both groups are closely commingled with each other, thus giving a small area a spotted appearance of two or more soil types with different characteristics. The soil types of this group include Hubbard loamy sand, Esterville loamy sand, Central loamy sand, and Sparta loamy sand. These soils are characterized by a preponderance of sandy material with little admixture of silt and clay throughout the whole soil profile. They have a lower content of organic matter, are loose and incoherent, and have a very low water-retaining capacity. They, with the exception of the Esterville soils, are generally leached of lime in the upper layers and frequently have little or no lime in the subsoil, although there are exceptions to this general characteristic.

All the soils of these two groups have a moderate content of organic matter and mineral nutrients; but with repeated cropping they decline rapidly in fertility unless provision is made for growing more legumes, making use of all available farm manures (which necessitates the keeping of livestock), and the application of mineral nutrients in commercial form. The lime supply in most of these soils is ample

FIG. 15. Top: Root crops are grown successfully in the Fargo-Bearden area. Center: A clearing on the Fayette soil. Bottom: Small grain harvest on the Tama soil

for the common clovers but is generally insufficient for alfalfa and sweet clover. All these soils should be tested for acidity before any lime is applied—the need and amount to be judged by the degree of acidity of the soil. The somewhat inferior quality of these soils lies in the fact that the deeper subsoil, commencing at depths ranging from 16 to 30 inches below the surface, consists of coarse sand or gravel with a very low water-holding capacity, thus permitting no water reserves for crops during the growing season when the need for water is most urgent. In years of liberal and well-distributed rainfall they give fair to good yields.

The principal crops grown are small grains, such as rye and oats, corn, soybeans, and tame hay including the common clovers, alfalfa, and sweet clover, but for some of these legumes the soils are not well adapted. Of the small grains, rye and oats do the best but barley generally does not do well. For the production of ear corn they are sometimes better than the heavier-textured soils, particularly in some of the northern districts. The common clovers often do well in seasons of normal rainfall but not every year is it possible to secure satisfactory stands. When gravel underlies these soils comparatively close to the surface they are not adapted to alfalfa, being much inferior not only to the heavy-textured soils, but also to the better types of well-drained light sands, such as those included in the Menahga-Zimmerman association where the subsoil and substratum consist largely of sands with little gravel. Although these soils are fairly well supplied with organic matter, a nitrogen fertilizer may be ad-

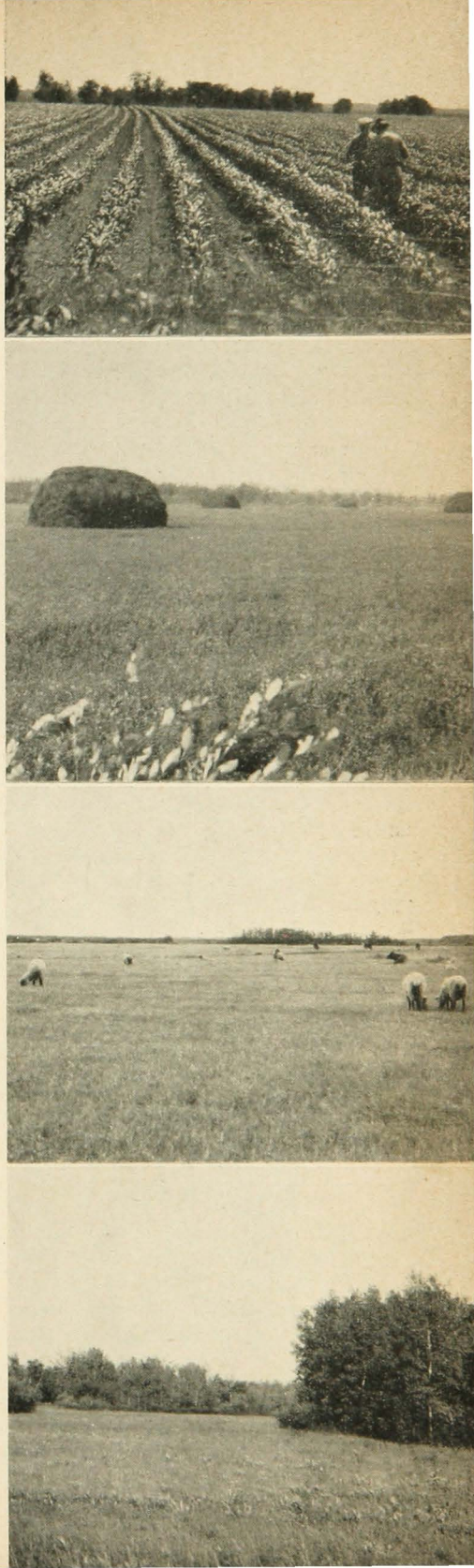


FIG. 16. Top: Intertilled crop in the Wadena-Hubbard area. Upper center: Tame hay predominates in the Taylor-McDougald area. Lower center: Many sheep are raised in the Kittson-Peat area. Bottom: Tree-covered areas intermingled with grass-covered peat bog (Kittson-Peat)

vantageously used for some crops, particularly corn and potatoes. Potash should also be included when mineral fertilizers are used for these crops. Some of these soils, more particularly those in the northern sections, are deficient in sulfur and this element should not be overlooked when supplying mineral nutrients. Phosphate fertilizers when used alone generally give little or no response. Liming the soils, as noted previously, will depend upon the acidity as determined by soil tests.

The limiting factor in crop production for many of these soils is available moisture since they are all regarded as drouthy, but it should be emphasized that there is considerable variation in the degree of drouthiness among the various soil types of this association. Relatively little can be done to reduce their drouthiness or to increase their water-holding capacity, although certain measures can be taken to prevent them from becoming more drouthy. All stable manure produced on the farm should be properly cared for and used to the best advantage, and a sufficient acreage of legume hay crops grown in a suitable rotation, provided the soil is adapted to alfalfa. With normal rainfall well distributed during the growing season some of these better sandy soils produce nearly as high yields as those of the adjacent heavier soils, provided they are properly managed.

Taylor-McDougald Association (TM)

This association lies along the international border in the extreme northern part of the state. It occupies a part of the forested portion of glacial Lake Agassiz and comprises nearly two million acres which is nearly 4 per cent of the total area of the state. The area has a smooth or nearly level surface except near some of the streams where the surface is more undulating. Many peat bogs, some covered with wild grasses and sedges, others with spruce and tamarack, occur in large and small bodies throughout the area. These are closely associated with the slightly higher, better-drained lands. In many places a coating of peat, of variable thickness, once covered a large proportion of the land, but fires have burnt off much of it leaving the underlying heavy-textured mineral soil exposed. Natural surface drainage is generally poor, but where the land adjoins some stream channel the drainage conditions are much better. Most of the area is generally free of stones. In some places, however, they are so numerous as to make the use of tillage implements almost impossible. Occasionally in places where the peat layer has been destroyed by fire the underlying soil is so stony as to make it useless for crops.

Originally the area supported a fair to good stand of pines and hardwoods but much of the merchantable timber has been removed and a second growth of hardwood and brush now covers the land. Many of the peat bogs have good stands of fair-sized spruce and tamarack, but fires have destroyed many of them.

The rather severe climatic conditions prevailing in this region limit the crops that can be successfully grown. The frost-free period ranges from 100 to 110 days but the longer hours of sunshine in the summer months make up in part for the short growing season. The average annual rainfall ranges from 20 to 24 inches, the major part of which is received from April to September.

The soil materials comprising the old lake bed on which the soils were developed were modified to a considerable extent by wave action during the existence of the glacial lake. This resulted in much sorting of the material, leaving in some places nearly pure deposits of sands, in others silts, and in still others clays. Frequently the de-

posits consisted of mixtures of all three ingredients in varying proportions. In parts of this region the glacial lake was comparatively shallow and only slight modification of the parent materials took place. In these places the materials are very similar in composition to those that occupy the uplands outside the lake bed and the soils are not markedly different from each other in either location. Where the lake waters were deeper, conditions were favorable for the deposition of sorted materials, and relatively large areas are composed of sediments of very uniform composition. These differences in the character of the parent materials account for the peculiar arrangement of the soils in this area. Aside from the peat bogs the soils show the influence of the forest vegetation which originally covered the land. They consist of light-gray sands, sandy loams, loams, and clay loams with subsoils of similar textures. They are all low in organic matter and nitrogen, generally acid in the surface soil, but the subsoil is abundantly supplied with lime.

Loss of soil through water erosion is practically negligible because of the nearly smooth surface. Wind erosion is practically nonexistent because of the protection given by the groves of trees abundantly scattered throughout the area.

The principal soil types are Taylor silt loam, which is derived from heavy-textured lake-laid clays and slightly modified heavy glacial till exposed at or close to the surface; McDougald fine sandy loam developed from sandy material, which covers either heavier-textured assorted lake sediments or glacial till; and Baudette very fine sandy loam formed from smooth silty materials. Wildwood silty clay loam and Chilgren clay loam have heavy surface soils and subsoils with fair to poor drainage. Hiwood loamy fine sand is developed on deposits of uniform fine sand which were laid down by wind or water or by a combination of both. Faunce sand is similar to Hiwood loamy fine sand but is developed from poorly assorted sands with pebbles and some stones on and below the surface and occupies the higher sandy plains and ridges. Mahnomen gravelly sandy loam occurs on old beach ridges from 5 to 20 feet above the adjacent more level areas. Spooner very fine sandy loam is a medium-textured soil associated with the better-drained McDougald fine sandy loam but it has only fair to poor drainage. Potamo loamy sand is a very poorly drained soil occurring in areas where the Faunce and Hiwood soils are found. Probably much of it originally was coated with a thin layer of peat. The wet conditions that prevailed in this area before its agricultural development and the lack of drainage favored the formation of peat over many of the soils. When the surplus water was artificially drained off, allowing the surface to dry out, forest fires, running wild, destroyed much of the peat layer. This left exposed the underlying mineral soil, and in many places it now constitutes the surface soil.

Peat soils, both the shallow and deep phases, prevail in a large part of the area. In their present state they are largely uncultivated, although in some places where adequate drainage has been provided they are used for crops. However, there are so many hazards in connection with farming these soils that only a small acreage is cropped.

The productivity of the soils of the area depends upon the drainage conditions and on the texture of the surface soil and subsoil. The heavy soils which have satisfactory drainage are well adapted to the small grains, such as oats and barley, and to tame grasses, including the common clovers, alfalfa, and sweet clover. The short growing season does not encourage the growing of corn to maturity but some is grown for silage and fodder, principally the

latter. Potatoes and root crops do exceptionally well but only a limited acreage is devoted to them.

Dairy farming is the most prevalent type of farming in this region. A considerable acreage of the hay crops is used for producing grass and legume seed, and in favorable seasons moderate to high yields are obtained.

Kittson-Peat Association (KP)

The Kittson-Peat association occupies two separate tracts in the basin of glacial Lake Agassiz in the northwestern corner of the state. Together they occupy approximately one and three-fourths million acres, slightly more than 3 per cent of the state.

The surface is nearly level or flat except near some of the streams where there is a gentle slope to the channels. Surface drainage is generally poor owing to the flat surface; in some places artificial drainage has been provided by open ditches to remove the surface water. In many areas the soils show a rather complex pattern of moderately well-drained and poorly drained areas with no uniformity on any comparatively large tract. Intermingled with these areas are peat bogs occupying only slightly lower positions which generally remain wet the greater part of the year, drying out sufficiently by midsummer so wild-grass hay can be harvested.

Stones on and below the surface are more or less numerous on all the soils except the peat, although where the peat is shallow the underlying mineral soil is often stony. Stones are somewhat more abundant on land bordering the more poorly drained soils and the peat bogs.

There is practically no water erosion on the soils of this area. Even on windy days there is little soil drifting because of the relatively fine texture of the surface soil, its relatively high content of organic matter, and the protection afforded by natural aspen groves which surround many of the cultivated fields.

The climate of this area is rather severe, the winters are long and cold and the summers short with warm days and cool nights. Snow covers the ground throughout most of the winter. Freezing temperatures usually prevail from the middle of October to late in March, and occasionally killing frosts occur in mid- or late August. The average annual precipitation is approximately 20 inches, nearly two thirds of which falls during the spring and summer months. The average frost-free period ranges from 100 to 120 days. The climate is favorable for the production of small grains and forage crops. The growing season is too short and too cool to produce good corn for grain, except in an occasional year when some early-maturing varieties may ripen. Cold wet springs often delay planting and frequently early fall rains interfere with the harvest.

Most of the soils comprising this group, excluding the peat, have black to very dark grayish-black topsoils. They have developed under the dominant influence of native tall grasses. They are moderately high in organic matter, nitrogen, and lime and do not differ greatly from the dark-colored soils developed on the limy glacial till on the rolling upland outside the basin of Lake Agassiz. Much of the land originally was covered with a rather thin stand of aspen trees with interspersed areas of tall grasses and brush Many slightly depressed areas as well as peat bogs with comparatively shallow peat are associated with the slightly higher better-drained mineral soils.

The soils are derived from lake-washed pebbly glacial till which was less affected by the wave action that modified the sediment in the lake where the water was deeper. This resulted in less sorting of the materials into particles of sand, silt, and clay and their deposition into strata of more or less

uniform thickness. In some of the soils, such as those of the Foxhome and Pelan groups, a pebbly or cobbly band of varying thickness occurs just below the surface soil. At one time this probably was the original surface but subsequently was covered with fine sediment.

The principal soils in this association are Kittson silt loam, occupying the better-drained areas and derived from slightly modified glacial till of the lake plain, and Nereson silty clay loam, occupying a similar position and similarly derived but which has a lower content of organic matter owing to its development under a mixed forest and grass vegetation. The subsoils of both are similar and consist of limy clay loam till. The Pelan and Foxhome soils of which the loam and fine sandy loam predominate have moderately fine-textured surface soils and are also characterized by having an accumulation of gravel and small stones in a conspicuous layer underneath the surface soil. These soils generally are more stony on the surface than the Kittson and Nereson soils. Gatzke clay loam, a soil of limited extent, is developed from stone-free lacustrine clay or heavy clay till similar to that from which the soils of the Fargo series are developed, but has a lower content of organic matter. The surface soil ranges from a grayish-brown to dark gray clay and the subsoil is olive gray and heavy textured. Barnett clay loam is closely related to the better-drained soils mentioned above but differs from them mainly in that it has poorer surface and internal drainage. In many places the surface soil is mucky and often is thinly covered with peat. Only a small portion of it is under cultivation, but is often used for pasture or for wild-grass hay of rather poor quality.

Within the area are some sandy plains and low sand and gravel ridges. They occur in association with the heavier-textured soils and are extremely variable within short distances. On the nearly level sandy plains Ulen loamy fine sand and Poppleton loamy sand are the important sandy soils. The wet poorly drained soil associated with them is Arveson fine sandy loam. The sandy and gravelly soils occurring on the ridges are members of the Sioux group and are moderately dark at the surface and have sandy or gravelly subsoils. In parts of Marshall, Pennington, and Red Lake counties the soil pattern is very complex with a considerable acreage occupied by the better-drained Sioux soils and the poorly drained Barnett and Arveson soils.

The productivity of the soils of this association does not measure up to that of the uplands outside the lake bed. This is due chiefly to inadequate drainage. Much of the cultivated land has been made suitable for cropping by some form of artificial drainage, usually by deep and shallow ditches. Practically none of the land has been tiled. In unusually wet years even if the land has some kind of artificial drainage many fields remain too wet to be worked and cropped early enough in the spring to permit harvesting a mature crop. A large part of the cultivated soils is devoted to small grains. Tame grasses, alfalfa, sweet clover, and the common clovers are also grown rather extensively. Corn for grain is grown only to a limited extent. Some beef cattle and many sheep are raised; some farmers derive a considerable income from dairy products. Poultry are raised on nearly every farm.

Ulen-Sioux Association (US)

The soils of this association occur in the bed of glacial Lake Agassiz, and in this respect are similar to those of the Fargo-Bearden group. They occupy the outer portions of the lake bed where the waters of Lake Agassiz were comparatively shallow and the coarser material, carried in by streams during

the existence of the lake, settled out more rapidly than the finer sediments which were carried farther inward. This area occupies a comparatively narrow north and south belt running parallel to that occupied by the Fargo-Bearden association which borders it on the west. Its total area is approximately 1,601,000 acres (some 600,000 acres less than the area occupied by the Fargo-Bearden group). This belt forms a continuous unbroken strip from the northwestern part of Stevens County to Kittson County on the international boundary line. It is comparatively narrow at its southern end but becomes wider to the north, reaching its greatest width of some 30 miles in Polk and Red Lake counties. Included in this group are the soils developed on the beach ridges of this prehistoric lake. The beaches are long narrow ridges with smooth gentle slopes. They are composed of stratified sand and gravel with a few boulders on and below the surface in scattered places. They were built up by the action of the waves and ice movement near the shore lines. As the lake stood at various elevations during the time of its existence and remained at a more or less constant level for varying lengths of time, a beach was built up, the size of which depended on the length of time the lake maintained that level. On the lake side of many of these ridges swampy depressed areas parallel them. Similar low-lying areas not associated with the beaches also occur in the central part of the valley. The soils in both these situations are variable in texture, usually sandy, and were developed under excessively wet conditions. A heavy clay commonly underlies the sandy coating which contributes to their wet condition.

Although the region is part of the lake bed, its relief is not as smooth and level as that portion occupied by the Fargo-Bearden association. The surface ranges from nearly level to undulating, the latter occurring adjacent to and on the shore lines. The ridges have the most pronounced slopes and are from 3 to 12 feet higher than the lake bed proper.

The drainage conditions prevailing in this region range from poor to excellent. The largest areas of poorly drained soils are those associated with the sandy and gravelly ridges as previously mentioned. The soils on the ridges are the best drained and because of their sandy and gravelly surface soil and subsoil are extremely drouthy.

Boulders are more numerous on the wetter soils than on the better-drained ones and where the sandy layer is very shallow they are often rather numerous. On many of the larger areas where the sand is deep, boulders in general are absent.

The natural vegetation on about three fourths of the area was largely prairie grasses and on the remainder a condition existed where areas of grassland were interspersed with those that were tree-covered. In these places aspen, mixed with birch and willow bushes, predominated. In the peat bogs and wet depressions a luxuriant growth of grasses, shrubs, reeds, and sedges is found.

The climatic conditions prevailing in this area are very similar to those of the Fargo-Bearden association. The average frost-period ranges from 110 days in the northern part to 130 days in the southern portion, while the average annual precipitation ranges from 20 to 22 inches of which more than two thirds is received during the frost-free period.

The soils of the nearly level prairie lands are most everywhere exposed to wind movements. Relatively high winds are likely to occur in any month of the year but are most common in the spring just before or during the time of seeding. During these periods when the land is unprotected by crops, drifting soil not infrequently seriously damages the seedbed, or the crop itself if the plants

are small. Where the land was tree-covered the fields are generally smaller and are more or less protected by groves which reduce wind erosion. On the very sandy soils the surface soil is so loose that the moving sand has built up sand dunes. These are prominent in parts of Norman and Polk counties. Peat bogs and large bodies of relatively low wet land occur in association with the better-drained soils.

The soils in this group are much more variable than those of the Fargo-Bearden association owing to the more complex character of the material from which they were formed and to the character of the original vegetation which covered the land.

This association is predominantly a region of sandy soils. The topsoil and subsoil textures range from a gravelly sand to a fine sandy loam. In many places the sandy material reaches to a depth of several feet and is often deeper, particularly on the ridges. In other places the sandy coating is less than 18 inches thick and is underlaid by a heavy clay or clay loam.

The surface soils range from loamy fine sands to sandy loams with subsoils of similar texture. They are both dark and light colored, the former occurring in the areas that were originally grass covered and the latter in places that were covered with trees. In some places, more particularly the areas that are flat and where the soils are imperfectly drained, alkali spots are rather common.

There are many more soil types in this association than in the Fargo-Bearden region because of the more variable nature of the materials from which the soils were formed and the character of the native vegetation. The principal soil types originally covered with prairie grasses are Ulen loamy very fine sand and Ulen fine sandy loam, both having dark-colored sandy surface soils and yellowish-brown or gray sandy subsoils to a depth of 36 inches or more. The Grimstad fine sandy loam is associated with the Ulen soils but has heavier material underlying the sandy coating at depths ranging from 16 to 24 inches. The light-colored sandy soils of the forested areas are Poppleton loamy fine sand and Poppleton fine sand. The soils of the swampy lands occurring within the sandy regions of the prairie areas are Tanberg fine sandy loam and Tanberg loam, whereas the corresponding soils associated with the Poppleton soils developed under the influence of forest vegetation are the Arveson soils. The principal soil types of the gravelly ridges are Sioux gravelly sandy loam and Sioux loam. Benoit sandy loam is a poorly drained soil associated with the Sioux soils.

The Tanberg and Arveson soils are generally too wet to be farmed and most of them are devoted to wild-grass hay meadows and pastures. While these soils are often used for pasture in the drier years some are broken up and put into crops, flax being commonly grown. The Sioux soils generally are too drouthy to be used for all small grains but are devoted chiefly to rye which generally matures before the moisture in the soil is completely exhausted. The principal limiting factor in crop production of these soils is their inability to hold much water; hence the crop yields vary considerably from season to season, depending upon the amount and distribution of the rainfall.

A large proportion of the Ulen soils is under cultivation. The surface drainage is usually adequate to permit early preparation of the seedbed although many fields have slight depressions which remain too wet to be seeded at the time that the surrounding higher land is sown. Owing to the sandy character of these soils they are often the first to be seeded in the spring. If the underlying heavier material, which is present underneath all the sandy soils, is not too far below the surface, the moisture supply available for crops is

frequently sufficient during the entire crop-growing season except in unusually dry years.

The Grimstad soils do not have a tendency to dry out as rapidly as the Ulen soils owing to the closeness to the surface of the heavier underlying substratum, which is generally encountered at a depth of 24 inches or less below the surface. Owing to the sandy nature of the surface soil it has a tendency to drift but probably less so than the associated Ulen soils. Care must be used in managing these soils to guard against wind erosion. The Poppleton soils have a low content of organic matter in the surface soil; they are loose, drift easily, and have a low water-holding capacity. A considerable acreage is cleared and cultivated. It is not a good soil for farming, chiefly because of its drouthiness. Where the fields are comparatively large and unprotected by wooded areas, the soil is easily eroded by the wind. Sioux loamy sand and Sioux fine sandy loam are the principal soils of the old beach ridges. The surface soils are dark colored and rest on layers of stratified sand and gravel at depths ranging from 12 to 30 inches. In many places the gravel is 10 feet or more in thickness and is interbedded with strata of sand. These ridges provide suitable sites for farm buildings. In many places gravel is excavated from these ridges and is used for construction work in connection with buildings and roads, and for railroad ballast. A large proportion of these soils is under cultivation, rye being the most common crop.

The poorly drained soils of this group as previously mentioned are Tanberg sandy loam and Arveson sandy loam. The former occurs in areas of the Ulen and Grimstad soils, the latter in forested regions where the Poppleton soils are found. Both occupy marshy and depressed areas such as sloughs from which wild-grass hay is harvested, although some are used for pasture. Only the drier portions are cultivated and planted to grain and other crops.

Because of the wide variations in the soils, their productivity varies widely, too. Owing to their sandy nature they are not capable of producing high yields. They have a low water-holding capacity which causes plants to suffer from insufficient moisture, and the rapidity with which the surface layer dries out makes them subject to serious wind erosion. Most of them are moderately well supplied with organic matter, with the exception of those developed under forest vegetation. The other plant nutrients in general are ample with the possible exception of phosphate, applications of which in commercial form are often necessary. Lime is abundant in both the surface soil and subsoil, being more plentiful in those of the grassland region.

Mixed farming prevails in most of the area. The production of grain for sale is important but less so than in the associations with heavier soils. The production of livestock is important on many farms. Potatoes and sugar beets are grown on the more productive soils.

Carrington-Clyde Association (CC)

This association occupies an area of about one and one quarter million acres in the southeastern part of the state including most of Mower and Dodge counties and smaller parts of Fillmore, Olmsted, Rice, Goodhue, and Dakota counties. The surface ranges from nearly level to gently rolling with areas of steeper land near some of the stream valleys. Parts of the uplands are nearly level and surface drainage is frequently inadequate. In the areas where the soils are heavy the underdrainage is very slow and the soils dry out slowly in the spring, delaying seedbed preparation and seeding. Boulders in general are not numerous on or below the surface,

although in some of the swales and depressions they are so numerous that the land is not cultivated but is used for permanent pasture.

The original vegetation of most of the area consisted of prairie grasses except near some of the streams where trees occupy the bottomlands and narrow strips of the upland. The grass vegetation of the prairies produced a large quantity of fibrous roots which are mostly concentrated in the upper 12 to 14 inches of the soil. This accumulation of organic matter decays slowly and is responsible for the dark color of the soils.

The climate of this area is representative of that prevailing in southeastern Minnesota. It is characterized by a rather wide range in temperature between the extremes of winter and summer. The average annual precipitation ranges from 28 to 32 inches with the major part of it falling during the growing season, April through September. The average frost-free season of approximately 140 days provides ample time for the corn crop to mature.

The soils are derived from glacial material older than that of the Clarion-Webster association which borders it on the west. Most of the soils were developed under the influence of grass vegetation, although in places where a forest occupied the land the soils have characteristics different from those developed under a grass cover. In such places the surface soils have less organic matter and are much lighter colored. The soils are rather variable, but in general most of them have dark-colored topsoils of medium to fine texture with subsoils of similar texture. The more level lands have a deeper black topsoil and a heavier-textured subsoil through which water percolates slowly, resulting in a condition somewhat unfavorable for plant growth in seasons when the rainfall is more than normal. In some places the underlying bedrock of sandstone or limestone is exposed or is close to the surface. Frequently the glacial material is mixed with the distintegrated rock, giving rise to soils of variable composition. Within the area also are soils which are underlaid at depths ranging from 20 to 36 inches with sand or gravel. The surface soil is generally a sandy loam, though not infrequently it is a heavy loam or silt loam with a rather heavy upper subsoil overlying the sand or gravel.

The main soil types in this association are Carrington loam and Carrington silt loam, both occupying the well-drained uplands and developed from glacial till. Floyd silty clay loam is developed on the smoother areas where both surface and underdrainage are somewhat restricted, and Clyde silty clay loam occurs in the more poorly drained areas, potholes, and depressions. Hines silt loam is a fine- to medium-textured soil developed under forest vegetation and has good surface drainage. Its imperfectly drained associate is Skyberg silt loam, a soil with a rather tight, impervious subsoil. In places where the glacial material is relatively thin or where the underlying sandstone or limestone has contributed to the soil material, Rockton loam, Etter loam, and Arland sandy loam are the dominant soil types occupying the better-drained positions. Dark-colored soils situated on nearly level high benches along the streams, generally underlaid with sand or gravel, are Waukesha silt loam, Waukegan silt loam, and Dakota loam. The principal dark-colored bottomland soils, subject to frequent overflow, are Wabash silty clay loam and Cass fine sandy loam.

Practically all the fine-textured soils with slopes of sufficient gradient to provide adequate surface drainage are highly productive and are well adapted to small grains, corn, soybeans, tame grasses, and legumes. On the flatter lands surplus water must be removed, either by tile drains or open ditches or a combination of both. Suitable crop

rotations should be selected which will improve the drainage conditions prevailing on some of the wetter soils. Some of the better-drained soils are acid and require lime for sensitive legumes. Most of the imperfectly drained soils do not require lime but do respond to additions of fertilizers containing phosphate and potash.

This association is predominantly one of livestock farming, with dairying the principal enterprise. The production of hogs, beef cattle, sheep, poultry, and poultry products also is important.

Waukon-Barnes Association (WB)

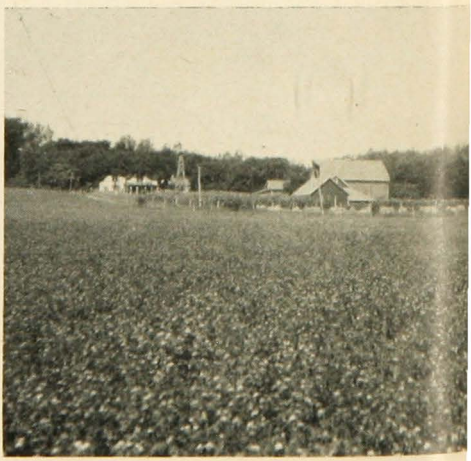
The Waukon-Barnes association occupies an area in the northwestern part of the state on the rolling uplands outside of the level basin of glacial Lake Agassiz, which borders a part of it on the west. It comprises approximately one and one-fourth million acres or about 2¼ per cent of the state. It is a transition belt between the forested section of the north central part of the state and the prairies of the Red River Valley. It carries a mixed vegetation of forest and grass. Originally the entire area was prairie and the soils were dark colored, but subsequently portions of it were invaded by the forest moving westward from the timbered region of north central Minnesota. The forest vegetation resulted in some alteration of the soils, modifying its characteristics to those which resemble a soil developed under the influence of a forest cover. This change is shown in the lesser amount of organic matter and mineral compounds in the upper layers of the soil. At the present time some of the land still remains in forest, but a large part has been cleared and put into cultivation.

The surface is gently rolling with some parts strongly rolling and even hilly. Peat bogs are common, but in most places the peat is not very deep. The soils are remarkably uniform over large areas except for differences caused by surface contour. This uniformity is attributed to the similarity of the underlying parent material from which the soils were formed. Rolling terrain, broad upland flats, swales, and wet depressions are the outstanding characteristics of the landscape. Peat bogs occupy many of the deeper depressions.

Stones on and below the surface are more or less numerous in all the soils with the exception of peat. They occur in greatest numbers on the higher elevations, though not infrequently they are abundant in some of the swales and bordering the lower-lying situations.

Drainage conditions over most of the area are generally good. The slope of the land is such that surplus water finds its way to natural drainageways, rivers, potholes, and lakes. In some places on broad upland flats where the surface is nearly level the drainage is inadequate and preparation of the land for spring seeding is often delayed. Water collects in many of the depressions and they remain wet for long periods.

FIG. 17. Well-improved farmstead shows prosperous conditions in the Carrington-Clyde area



Owing to the rolling topography with steep slope gradients, water erosion is severe on the cultivated lands, and rills and gullies have formed, particularly where intertilled crops are grown. Some damage is caused by soil drifting when the land is bare of vegetation, as in the early spring before seeding and after plowing in the fall.

The climate is similar to that prevailing in the central part of the Red River Valley. The average annual precipitation ranges from 21 to 24 inches, a large portion of which falls during the frost-free period. The growing season, or the number of days free of killing frost, varies from 120 to 130 days. These climatic conditions are favorable for the production of small grains and tame grasses, including alfalfa and sweet clover. Inasmuch as the climate is rather cool and short for the production of corn for grain, some of the early-maturing varieties are grown successfully and in most years some hard corn is harvested.

The soils are developed from limy glacial till of recent age. Nearly all have dark-colored surface soils except those altered by forest vegetation where they are grayish brown, and their content of organic matter is much less than is the case with the prairie soils of the Red River Valley. Since this area includes some true prairie soils, such as the Barnes soils of the Barnes-Parnell association, there is considerable variation in the organic matter content from one locality to another within the region. In some places, particularly near the eastern border of the area, some light-colored soils occur in association with the darker ones.

FIG. 18. These rolling lands in the Waukon-Barnes area need good soil management

The principal soil types are Waukon loam and Waukon fine sandy loam. Of secondary importance and less extensive are Barnes loam and Barnes silt loam. All occur in positions that range from gently rolling to strongly rolling with comparatively smaller areas that occupy broad, nearly level upland flats. As previously mentioned, the Waukon soils are derived from the same kind of material as that of the Barnes group but differ from them in the manner of their formation owing primarily to the forest cover which prevailed over much of the area. The surface layer of these soils is lighter-colored and thinner than the corresponding layer of the Barnes soils. A large part of the Waukon soils is under cultivation, but a substantial acreage is still in native timber.

In productivity the soils compare favorably with those of the Barnes-Parnell group. The soils dry out rather rapidly in the spring permitting early preparation and seeding of the land. Erosion, however, is more severe on the sloping soils and they need to be well managed to maintain productivity.

Agriculturally the area is well developed. A large percentage of the land is included in farms and much is cropland. Where the land is too hilly, gravelly, or stony, as it is in some places, or where the forest is too dense it is utilized as pasture. A large number of beef cattle and sheep is raised and many farmers derive income from dairying. Poultry are raised on nearly every farm.

Hayden Association (H)

This association occurs in the east-central part of the state in four separate tracts of about equal size. The areas lie north, south, and west of the Twin Cities. The combined acreage of the four tracts is a little more than 900,000 acres, which is slightly less than 1¾ per cent of the total area of the state. The soils of this association have characteristics similar to those of the Nebish-Rockwood group in that they both have developed under a forest vegetation. The soils of the Hayden association, however, occur in a region where the growing season is longer and the precipitation more abundant, and thus have a wider adaptation of crops. The two southern areas are included in what is known as the "Big Woods" area, so-called because the area was originally forested with thick stands of mixed hardwoods. The two northern tracts also bore a forest similar to that which originally covered all the northern part of the state where white pine predominated on the heavier soils.

The surface ranges from undulating to strongly rolling with many depressions, swales, and peat bogs intermingled with the higher, better-drained land. Aside from the many peat bogs, drainage conditions are generally good since there is sufficient slope to most of the upland to permit surface runoff of excess moisture to some natural drainageway, lake, or swamp. Very few of the peat bogs have been adequately drained, mostly because of high cost of tiling and in some cases to a lack of a suitable outlet. Stones are present in variable amounts at and below the surface, but seldom are they present in sufficient quantities to interfere seriously with tillage. Sheet erosion is rather serious in the more strongly rolling areas where the land has been cultivated for a long time. In many of these places a large proportion of the topsoil has been lost by erosion, some of it being deposited on the lower slopes, some in the depressions, and some carried away in the streams. Gullies have formed in many places where little attention has been paid to soil conservation practices.

The original vegetation of the area consisted of a deciduous forest, which exerted an important influence on the soils while they were developing. Forest vegetation produces an accumulation of leaf litter on the surface of the soil but supplies very little organic matter to the soil itself. Most of the tree roots are large, penetrate deeply, and are relatively few in number. As compared with grass roots, they add only a small amount of organic matter to the soil. Since the soils of this area have developed under a forest cover, the surface soils are low in organic matter and are gray or grayish-brown.

The soils are derived from glacial material rich in lime. In general, most of the parent material consists of a pebbly clay loam till with a preponderance of the finer particles, such as silt and clay. Material of a coarser texture is generally associated with the areas where the topography is hilly. In the northern areas some of the soils have developed from materials high in silt and clay deposited in ancient glacial lakes. These soils occur in nearly level or gently sloping situations where the drainage conditions range from fair to good. The subsoils, however, are rather tight and compact; water percolates through them slowly.

The soils are characterized by their moderately light-colored topsoil which is a light gray or brownish gray at the surface. They are comparatively low in organic matter and nitrogen and upon drying have a tendency to bake or form a crust on the surface. They range from sandy loams to clay loams. Those formed from the lake-laid deposits referred to above have a silt loam surface and a silty clay loam subsoil. In general, the surface soils are some-

what acid; but appreciable quantities of lime are found in the subsoil, although in places where the soils are derived from coarser-textured material, much of the lime has been removed by leaching. On some of these lighter-textured soils liming may be necessary to insure maximum production, but the need for lime is extremely variable and the soil should be tested to determine its lime requirement.

The principal soil types on the undulating and rolling uplands are Hayden loam, Hayden fine sandy loam, and Bradford loam. The latter is associated with areas where the surface is smoother, whereas the former occupy the more rolling lands. On these soils erosion is moderate to severe and gullies are beginning to develop where the land is devoted almost continuously to small grains and intertilled crops. The soils in the depressions associated with the upland soils have a darker-colored topsoil and are poorly drained. They are Bluffton loam and Bluffton silty clay loam. Thurston loam and Thurston fine sandy loam have moderately dark-colored topsoils and occur on the upland where a coating of fine-textured material ranging from 10 to 30 inches in thickness overlies loose sand and gravel. These soils are generally drouthy unless the layer of fine material is 30 inches or more in thickness. Brickton silt loam is derived from silts and clays laid down in glacial lakes.

The soils in general are productive. Corn, small grains such as oats and barley, tame hay including the common clovers, and alfalfa are the crops most commonly grown. Nearly all the soils are well adapted to alfalfa and sweet clover, since the supply of lime in the soil in most cases is adequate for their growth.

Dairying is the principal enterprise. Vegetable gardening, poultry raising, and the production of apples and small fruits are also important.

Moody Association (M)

This association is located in the southwestern part of the state, occupying most of Rock and parts of Nobles, Pipestone, and Lincoln counties. It includes slightly more than 500,000 acres, which is under one per cent of the total area of the state. The surface ranges from undulating to strongly rolling, with some rough and broken land where a hard reddish quartzite rock is exposed. In some places this rock is covered with a comparatively shallow layer of soil with frequent exposures of rock at the surface making the land unsuitable for plowing. Most of the area has a surface of rounded hills with moderate slopes separated by narrow swales and drainageways. Parts of the area are nearly level; other parts are sharply rolling or hilly.

Most of the soils of the association have adequate natural drainage, except on the nearly level upland flats and in the swales. Some of these areas are tiled, which has improved the internal drainage. However, many of the poorly drained depressions in the uplands have not been tiled and are too wet to be cropped in years of normal rainfall.

Most of the dominant soils are free from stone at and below the surface with the exception of the bedrock outcrops previously referred to. Exposures of this rock are prominent in the northern part of Rock and the southern part of Pipestone counties.

The region lies wholly within the prairie portion of Minnesota. Along some of the larger streams there is some forest growth. The native vegetation consisted of tall prairie grasses, the roots of which had a marked influence on the soils as they developed.

The climate of the region is characterized by wide ranges in temperature between winter and summer and a somewhat irregular distribution of rainfall. Generally the rainfall is sufficient to insure good to high yields of the

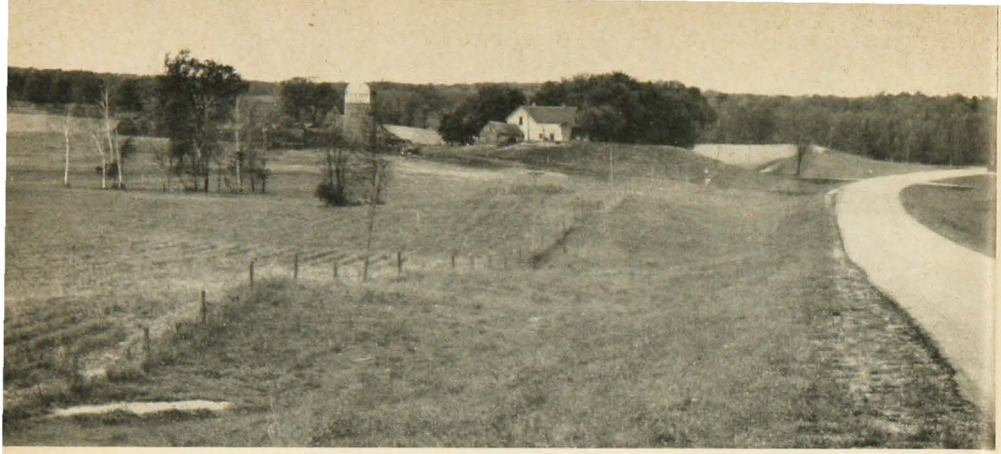


FIG. 19. Many prosperous dairy farms are located in the Hayden area

agricultural crops adapted to the area. The average frost-free season is about 140 days, which insures maturity of the corn crop. The average annual precipitation ranges from 24 to 26 inches, two thirds of which is received from April to September inclusive.

The soils are derived from loess—a fine silty material of variable thickness laid down over the surface by wind, presumably at a time when climatic conditions were very different from what they are at the present time. The thickness of the loess varies considerably, but in general it becomes thicker from east to west. Its maximum thickness may be as much as 15 or 20 feet. On some of the steep valley slopes it is often entirely absent, having been removed by erosion. The loess originally consisted of highly calcareous silts and clays with silt predominating. On most of the well-drained uplands the lime has been leached to depths ranging from 20 to 36 inches. On the crests and upper slopes of the more rolling land the lime is very close to the surface.

Most of the soils have a very dark brown or black silt loam surface with a yellowish-brown silty clay loam subsoil. In some places in the upland, sand underlies the silty material at depths ranging from 2 to 4 feet, but these areas are not very extensive. On some of the old river terraces along the streams, sand and gravel underlie the finer-textured mantle at depths ranging from 12 to 30 inches. These soils are generally drouthy, more particularly when the precipitation is below normal and unevenly distributed during the growing season. The soils in general are well supplied with organic matter and nitrogen, and lime is abundant in the subsoil. Some of the larger upland flats where the surface is nearly level have slower underdrainage and occasionally the land cannot be cultivated as early in the spring as in areas where the relief is more pronounced. Poorly drained areas and wet depressions are less numerous in this association than in those to the north and east. Losses of soil by erosion are rather severe on the more rolling land. In some places gullies have formed rendering the land difficult to cultivate.

The principal soil is Moody silt loam which occupies the well-drained uplands. This soil is developed on loessial material that is 36 inches or more in thickness. Kranzberg silt loam occurs where the loessial covering is less than 36 inches thick, beneath which is a heavy-textured glacial till. These two soils do not differ materially in their productivity. Afton silty clay loam is a wet soil occupying the depressions and bordering some of the intermittent stream channels. Alcester silt loam occurs in the swales and on the lower slopes. Most of the soil material comprising the upper part of this soil is derived from dark-colored topsoil of the higher lands which was washed down and deposited in the lower positions.

FIG. 20. The soils of the Moody area are adapted to small grains

On the rolling uplands, where sand is encountered at depths ranging from 24 to 36 inches, the soils are Flandreau silt loam and Flandreau very fine sandy loam. On the nearly level stream terraces not subject to flooding where sand and gravel underlie the fine-textured material, the soils are Fordville sandy loam and Fordville silt loam. The bottomland soil along the streams and drainageways, often subject to flooding, particularly in the spring, is Lamoure silty clay loam. These soils are often under cultivation, but there is always danger of the crops being ruined by flooding. The wetter soil of the bottomlands, very seldom cropped but occasionally used as permanent pastures, is Rauville silty clay loam. In a few places the glacial till, which everywhere underlies the silty mantle at varying depths except where bedrock outcrops, is exposed at or very near the surface. The principal soil developed from this heavy calcareous till is Vienna silty clay loam. The soils that are underlaid by bedrock at a depth of 30 inches or less are Ihlen loam and Ihlen silt loam.

All the soils of this association are well adapted to corn, small grains, and tame hays. The proportion of land devoted to tame hay is smaller than in the associations to the east, owing in part to the somewhat lower average rainfall in this part of the state. Hay crops have a tendency to exhaust the soil moisture reserves more rapidly than the small grains or intertilled crops and this is reflected in lower yields of these crops during the following year.

The heavy-textured soils of this association are as fertile as those in any other part of the state, but with the somewhat lower amount of rainfall the crop yields are somewhat lower. Seldom, however, is there a total failure of all crops because of insufficient moisture. Often the yields are just as high as in the regions farther east provided the rainfall is normal and well distributed over the growing period. Livestock and small grain production predominate in this region. A considerable proportion of the cattle is used for meat production. Many hogs are also raised.

Ontonagon Association (O)

This association occupies a relatively narrow strip extending along the north shore of Lake Superior and embraces an area of approximately 372,000 acres. It varies in width from 5 to 10 miles. The most southerly portion extends into eastern Carlton County where it reaches its maximum width. At the time of one of the glacial periods this area was a part of the bed of glacial Lake Duluth, a body of water much larger than the present Lake Superior, which was a part of glacial Lake Duluth during the closing stages of the glacial period. Glacial Lake Duluth at its highest stage was some 500 to 600 feet above the

present surface of Lake Superior, but as the ice age came to a close the lake receded to the present level of Lake Superior—602 feet.

The surface ranges from nearly level to strongly rolling with the steeper land on the slopes rising above Lake Superior. Adjacent to some of the streams that dissect the area the surface is rather rolling. The surface drainage in general is good but on the more level areas the underdrainage is somewhat restricted because of the heavy texture of the subsoil which does not permit rapid penetration of water. The soils are generally free of stones.

The original vegetation consisted of white pine and mixed hardwoods. Practically all of the original stand of white pine has been removed and a second growth of hardwoods and brush now occupies the greater part of the area. Peat bogs, mostly covered with spruce and tamarack, occur throughout.

The climate is rather severe. Winters are long and cold followed by summers with moderate to high temperatures. The extremes of temperatures which prevail in areas farther removed from Lake Superior are less noticeable near the lake because of the modifying effect of the water temperature. The average growing season ranges from 120 to 140 days with the longest period nearest the lake. The average annual precipitation ranges from 28 to 30 inches, about the average for the state.

The soils have developed from heavy red clays which were deposited in the quiet waters of the lake during its existence in glacial times. The surface soils are gray or light-grayish-brown silt loams or clays resting on compact, reddish-brown heavy sticky clay generally free from stone and gravel. The dominant soil type is Ontonagon clay loam. Other soils, excluding the peat soils, are of minor extent but are related to the Ontonagon clay loam and occur in association with it. These generally are not as heavy and have some admixture of sand and gravel in the subsoil.

Only a small proportion of the land is under cultivation. Clearing the land of stumps and brush is extremely difficult owing to the numerous large pine stumps. Only a few farms are developed and on these the cleared fields are irregular and small. Most of the cultivated land is devoted to hay crops such as the common clovers, alfalfa, and tame grasses. Dairying is the principal farm enterprise.

Waukegan-Withrow Association (WW)

This association occupies an area of approximately 321,000 acres in the east-central part of the state and includes parts of Washington, Dakota, and Goodhue counties. The area is characterized by unusual physical land features for a region so relatively small. These include rolling and hilly glacial plains pitted with swamps, deep depressions, and lakes, belts of rolling loose-textured glacial material, relatively smooth outwash plains, and terraces along the St. Croix and Mississippi rivers which border the area on the east and southeast. Outcrops of limestone and sandstone occupy some of the highest points in the southern part of the area. The smoothest areas of any considerable size lie in the northern part of Dakota County where a mantle of silty material of varying depth covers the underlying beds of sand and gravel.

Natural surface drainage is good to excellent nearly everywhere and many of the soils have good internal drainage as well because of the rather permeable nature of most of the soils. It is only in the depressions in the upland and low-lying areas along some of the streams that drainage is sluggish.

The soils are more stony in the northern parts of the area than on the smoother outwash plains, but in general most of the soils are not too stony

for farming. On some of the terraces of the St. Croix River the bedrock outcrops in scattered areas. In the gorge of this river sandstone and limestone are exposed on its steep walls. The better agricultural lands are generally free from stone.

Parts of the area were originally covered with mixed conifers and hardwoods, other parts with wild prairie grasses. Many of the peat bogs, most numerous in the northern part of the area, are covered with swamp vegetation, such as reeds, rushes, spruce, and tamarack, and shrubs of various kinds.

The climate in this area is favorable for the crops commonly grown. The average length of the growing season is approximately 150 days. The average annual precipitation of nearly 28 inches is sufficient and usually well enough distributed during the crop-growing season to sustain good crops on all but the most sandy soils.

Both wind erosion and water erosion are severe on many of the soils. Water flowing down to the valleys from the higher elevations has cut gullies into the upland and has deposited the soil thus removed in layers of sand upon many lower-lying farm lands. On many soils with more gentle slopes erosion is removing a thin sheet of surface soil from cultivated fields. In some localities where the surface soils are sandy the wind is also removing surface soil from uncovered fields.

Because of the variable character of the materials found in this region the soils have a wide range of characteristics and form an intricate pattern of small bodies of one or more soil types interlaced with larger tracts of others more uniform. Because of their complex nature, it would not be possible in the space available in this bulletin to give a full description of the various materials from which the soils are derived, but in general many of the soils are sandy, more particularly the subsoils.

The soils can be grouped into two broad categories, those with dark-colored topsoils, and those with light-colored ones. The former were originally tree-covered, the latter, grass-covered. The wooded soils have light-colored surface soils and are generally associated with areas with strong relief, whereas those that are dark at the surface lie on the smoother undulating to gently rolling plains. The surface textures of both groups range from light sandy loams to loams and silt loams and the subsoils, too, are extremely variable, in some places being sand and gravel, in others silt loams and clay loams.

In this association there are some 50 or more different soil types occurring on slopes that range from less than 1 to more than 40 per cent. No attempt will be made to describe them all but only the predominating ones will be dealt with. On the well-drained uplands where the soils are derived from unassorted glacial material, Carrington silt loam and Hampton silt loam are the two most productive soils. They have dark-colored surface soils with clay loam subsoils. Also occupying similar positions with dark-colored surface soils and with upper subsoils of a silty texture, beneath which at depths ranging from 22 to 36 inches is sand or a mixture of sand and gravel, are Waukegan silt loam, Waukesha silt loam, Bayport loam, and Langdon silt loam. These soils along with some others of less extent are distinguished from each other by the thickness of the overlying fine-textured layer. Kato silt loam and Marshan silt loam are important soils which occur in close association with them. They occupy nearly level or slightly depressed areas and are not well drained. Marshan silt loam is the more poorly drained. The dark-colored soils that are more dominantly sandy in the surface layer as well as in the subsoil are Hubbard loamy sand, Hubbard sandy loam, O'Neill sandy loam, and Sparta fine sand as well as some

others. Etter silt loam and Rockton silt loam are dark-colored fine-textured soils underlaid at depths ranging from 24 to 30 inches with sandstone and limestone respectively. Withrow gravelly sandy loam and Withrow silt loam occur in a complex pattern on the well-drained rolling uplands. The general characteristic of the Withrow soils is the presence of a layer of smooth silty material of variable thickness, lying on a thick deposit of sand and gravel. In many places the silty coating is absent and the sand and gravel are exposed at the surface. On a 10- or 20-acre tract it is not uncommon to find an equal distribution of both conditions. Whether the silty mantle once covered the entire area occupied by these soils, and has subsequently been removed by erosion, is not known, but the indications are that it did not. Judson silt loam is developed from dark-colored silty material carried down by water from the higher lands and deposited on the lower-lying slopes and in the swales. Copas sandy loam is a dark-colored soil found on the structural benches of the St. Croix and Mississippi rivers. It is a shallow soil underlaid at depths ranging from 6 to 30 inches by limestone or sandstone bedrock. Boone loamy fine sand is derived from white sandstone which is exposed in various places and is a drouthy soil.

The productive capacity of the soils of this association depends to a large extent on the lay of the land and the texture of the surface soil and subsoil as well as upon the content of organic matter in the surface layer. The soils with a gravelly subsoil at or near the surface are decidedly poor for crop use or even for hay meadows or for pastures. They are generally low in organic matter, usually acid, and very drouthy. Where the gravel layer is 30 inches or less below the surface and the overlying material is a loam or silt loam with a moderate amount of organic matter, the soils often are capable of producing moderate to high yields, provided the precipitation is normal and fairly well distributed during the growing period, a condition which generally prevails. The highest-producing soils are those of the Carrington and Hampton group and related ones. The water-retaining capacity of these soils is sufficient to sustain growth during the entire growing season, even during short periods of dry weather in midsummer. In addition to their relatively high water-holding capacity they are well supplied with plant nutrients. The sandy soils such as Hubbard loamy sand, Sparta loamy sand, and Boone loamy sand are subject to serious wind erosion. The yields on them are often seriously affected by drouth. They are generally low in organic matter and frequently are acid, requiring lime for sensitive crops, such as alfalfa and sweet clover. Some of the soils usually occupying comparatively small areas but in the aggregate comprising a considerable proportion of the association are not suitable or are poorly adapted for agricultural use because of steep slope, moderate to severe erosion, excessive drainage, irregular surface, or liability to destructive overflow.

Most of the soils are naturally well supplied with mineral nutrients with the exception of some of the most coarsely textured ones. In the soils originally wooded, nitrogen is often deficient, but the lack of it may be overcome by a good soil management program which provides for growing an inoculated legume. Some of the soils are acid and need lime. Where large numbers of livestock are kept, the manure produced and applied to the soils has helped to maintain the fertility.

The type of farming in this area is greatly diversified. Owing to its proximity to the markets of the Twin Cities many of the farmers are engaged in dairying. Vegetable gardening and the production of fruit are also important sources of income.