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THE MUCK SOILS OF MICHIGAN

Their Management for the Production of General Crops

By M. M. McCOOL and PAUL M. HARMER

AGRICULTURAL EXPERIMENT STATION

MICHIGAN STATE COLLEGE
Of Agriculture and Applied Science

SOILS SECTION

East Lansing, Michigan.

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The total area of muck soil in Michigan has been estimated by various investigators as from 2,000,000 to 4,000,000 acres. Unlike conditions in many states, where the muck soil is localized and occurs in large areas, that of Michigan is widely distributed, and, for the most part, in relatively small areas. Because of its wide distribution and the difference in extent of development, muck land varies from the unsettled, unreclaimed areas, valued at practically nothing to areas which have the highest valuation of any agricultural land in the state. The latter group owes its high value to the highly developed, intensive cropping systems practiced.

A considerable proportion of Michigan farms (Table 1) have, within their bounds, muck soil. This may occur in upland fields as "pot holes," or, in more extensive areas, as pastures, usually in a worn-out condition, as wood lots, meadows, cultivated fields and waste areas. This last group is by no means small and such areas are in many cases found near the farmstead, an "eye-sore" to passersby. Many times these waste areas are so located that they result in irregular fields and increase the problems of management. Since these areas in most cases are producing nothing, are interfering with the most economical system of farm management and are nevertheless taxed, the net result is an increase in the average cost of operating the farm.

Muck farming in Michigan is in its infancy. Of the total muck area, the proportion of reclaimed land is not more than a small percentage. The acreage of the special muck crops grown in the state, notably celery, onions, and mint, is gradually increasing, but, assuming the total muck area to be 2,000,000 acres, the porportion used at the present time for the production of these three special crops combined is less than three-fourths of one per cent. It is evident that any large increase in the proportion of the total muck area used for the growing of the special muck crops would result in a serious over production of these crops. Further, since such crops require considerable hand work, the labor situation in the state tends to prevent such increases at the present time. Instead, the development of new muck areas must be along the line of general farming, with the raising of products which are in general demand.

Crop production on muck soil is largely dependent on five different factors worthy of careful consideration by the farmer, viz.: nature of the muck, extent of drainage, cultural methods, fertilization, and crop

Table 1. Showing Percentage Muck Area, Total Muck Area, Percentage of Sections containing Muck, and Average Muck Acreage in Sections containing Muck, as calculated from Soil Survey Report (24).

Area surveyed (1)	Percentage muck of total land area	Percentage of sections containing muck	Average No. acres of muck contained in sections which contain muck	Total acreage of muck in area surveyed
Allegan Co.	9.3	57.6	100.0	49,280
Alma area (part of Gratiot Co.)	9.5	57.3	105.5	17,408
Calhoun Co.	12.5	74.6	103.5	55,616
Cass Co.	8.0	51.5	94.6	25,728
Genesee Co.	5.7	55.4	67.4	24,192
Munising area (part of Alger Co.)	8.1	41.2	125.3	21,184
Oxford area (part of Oakland Co.)	15.2	91.7	94.5	20,416
Pontiac area (part of Oakland Co.)	4.4	41.4	65.2	8,640
Owosso area (part of Shiawassee Co.)	5.3	33.7	102.1	9,088
Saginaw area (parts of Bay, Saginaw, Tuscola and Huron Cos.)	7.6	34.9	46.6	48,128
St. Joseph Co.	13.9	82.2	86.6	44,864
Wexford Co.	2.1	22.6	59.6	7,744
Berrien Co. (2)	2.8	39.5	44.1	10,196
Ingham Co. (2)	13.8	87.9	99.5	48,841
Isabella Co. (2)	4.5	55.9	51.2	16,474
Kalamazoo Co. (2)	9.2	79.2	72.4	32,983
Livingston Co. (2)	15.4	98.1	99.1	56,018
Manistee Co. (2)	6.3	28.1	143.9	22,592
Ottawa Co. (2)	5.0	23.1	137.2	18,080
Van Buren Co. (2)	8.3	67.6	76.6	32,775

(1) In some of the earlier soil surveys, small areas of meadow and swamp were mapped. Since recent investigation has shown that these areas are largely muck, they are included as muck in the above calculations.

(2) Survey of county completed but report not yet published.

adaptation. In general, the methods of soil management which are successful on upland (mineral) soil are not adaptable to muck soil. General farming on the larger muck areas of the state has not in all cases proved successful, largely because the farmers have attempted to use upland farming methods. It is for the purpose of pointing out the methods which are proving successful in muck farming, and of presenting the results of four years of experimental work on the muck soils of the state, that this bulletin is prepared.

Definition of Muck. The term "muck," as used in Michigan, refers to those soils which contain a high percentage of organic (vegetable) matter, in a well decomposed condition. Peat signifies the rawer organic soils. It is evident that there is no sharp line of demarcation. In general the agricultural practices which are suited to muck are likewise adaptable to peat soil. For that reason the term "muck" may be considered to include both mucks and peats in the discussion which follows.

THE ORIGIN OF MUCK SOIL

Muck soils vary markedly, one from another, in their several characteristics. According to the conditions which prevailed at the time of its origin, a muck may be deep or shallow, well decomposed, fibrous or woody, of the same type of material throughout or varying in type of material at different depths. Since the natural productiveness of a muck varies to some extent with the type of deposit, a consideration of the different types of muck and the factors governing their formation is undertaken at this point.

Methods of Formation. The most important factors in the formation of a muck soil are poor drainage, and a fairly high precipitation (rainfall plus snowfall) rather uniformly distributed throughout the year. Muck is formed by the accumulating growth of aquatic plants, the remains of which fall into the water below, which serves to prevent their complete decomposition, by keeping out the air necessary for the decaying process. In general a cool climate, which provides a lower rate of evaporation and a slower rate of decay, permits a more extensive accumulation of muck. For this reason, the proportion of muck land to the total swamp land has been found to be considerably lower in most of the southern than it is in the northern states.

Muck deposits are formed either by the filling in of lakes or by the building up of the muck on wet flat areas and "springy" hillsides. Examination of the profile of a filled-in lake shows that deposit generally to consist of layers of different types of material. The formation of these various layers depends on the depth of the water, only a relatively few plants being able to thrive in water more than six feet deep. As the lake is filled in by the muck and the water becomes shallow, other plants are able to come in, resulting in a change in the type of the muck formation.

Types of Muck Materials

Any one of the different layers mentioned later may be at the surface in one deposit but lacking or buried by other layers in another deposit. Furthermore, these various mucks, formed by quite different types of vegetation, may vary considerably in color, texture and productivity. In a classification of different mucks according to the conditions under which they are formed, Dachnowski (8) has placed them in four distinct groups: the aquatic (deep water), the marsh, the swamp and the bog.

Aquatic Group. The deep water type of muck, deposited in water varying from two to 15 or more feet in depth, is formed by the remains of such plants as the pond weed, water plantain and water lily, deposited in a more or less structureless condition, and mixed with the sediment brought in by streams. The result varies from a coarsely macerated to a finely divided muck, the latter often smooth to the touch and having the consistency of liver when wet. It may contain seeds and spores and sometimes considerable marl or shells. In color it varies from gray to brown or black. Usually it is more or less intermingled with roots of the slough grasses (sedge).

If the finely divided type of the deep-water muck is drained before other types of vegetation have developed muck layers above it, it may prove quite difficult to manage, although productive when properly farmed. Frequently it tends to shrink markedly on drying, sometimes forming cracks, which close only after prolonged rainfall. After continued cultivation, this type may form a very fine dust which blows badly. Occasionally rather pure deposits of this muck are found to be quite impervious, resulting in a water-logged soil for several days after heavy rains, even though ditches and tile lines are numerous.

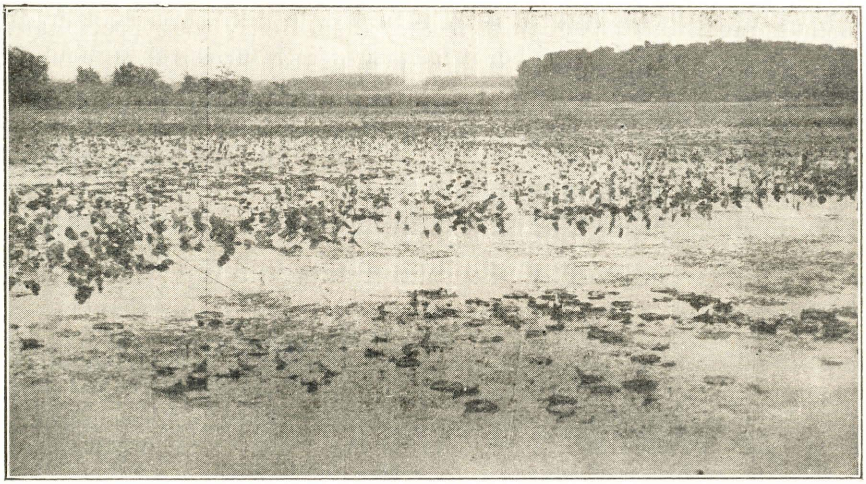

Fig. 1.—Formation of the deep-water type of muck is progressing in this lake. Note the water lilies, pond weed and other associates which thrive in water up to fifteen or more feet in depth.

If the deposit is very fine, structureless and oozelike, trouble is sometimes experienced with the tile which tend to settle out of alignment when laid in the fine material. If such a spot is encountered in tiling, the condition may be remedied by laying boards underneath the line of tile.

Marl. Frequently the deep water type of muck is somewhat mixed with and often underlain by a white or gray material known as marl. Marl is a more or less pure form of lime carbonate, deposited in large part, according to Davis (9) and others, by a few small plants of the algae family. These plants live in deep water and are able to take lime from the water and deposit it as a scale around the plant. When the plant dies, this lime becomes part of that left by preceding and succeeding generations to form the deposit of marl. Shells sometimes enter into the formation of marl, but their presence is generally only an indication that clam life (mollusks) existed in the lake at the time that the marl was forming. For the use of marl in correcting soil acidity see page 31.

Marsh Group. As the vegetative growth continues each year to build up the muck deposit, the water slowly becomes more shallow. As a result other species of plants gradually come and supplant those which were most abundant in deep water. If the water was never deep, the deep-water muck is entirely lacking and the marsh muck is the bottommost type of muck material. The plants most commonly entering into the formation of the marsh muck are the cat-tails, rushes, reeds, slough grasses (sedges) and the true grasses. These plants are usually associated in their growth to a greater or lesser extent, but in the greater part of the mucks of this type in Michigan, the sedge has played by far the most important part. In fact sedge is generally considered the most important former of muck in the state.

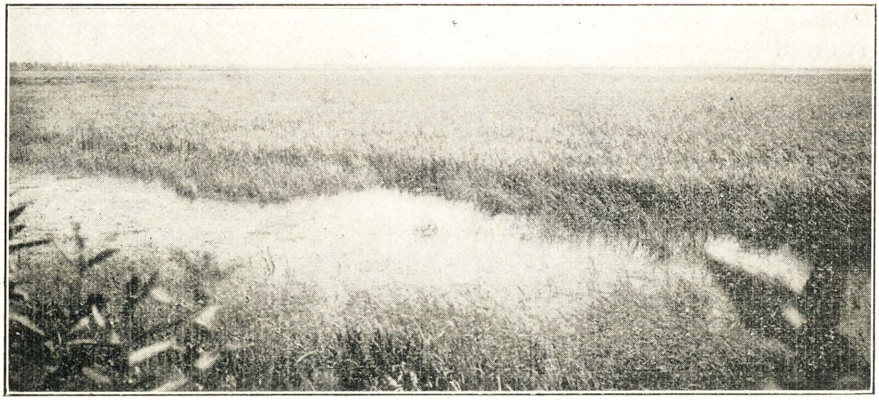

Fig. 2.—A sedge marsh, with a small area of open water in the foreground.

The structure of this muck is usually fibrous, with the leaves and roots of the sedge, rushes and reeds easily recognizable. In many deposits the surface 4 to 10 inches is rather well decomposed but, generally, the underlying material is readily identified. The color varies from light to dark brown or brownish black, the more decomposed material being the darker.

Frequently the sedge becomes an important factor in the development of muck by growing out from the edges of a lake to form a felt-like mat on the surface of the water. This mat may finally close in and entirely cover the lake surface, forming what is known as a "floating" or "quaking bog." As this mat builds up, it sinks of its own weight until it may finally rest on the muck at the bottom.

The soils of this group usually drain well when ditched or tiled and do not have the tendency to shrink and crack on drying, that is exhibited by the deep-water group. Although it is a popular opinion that this type of muck is not as productive as the forest type, this is probably largely due to the fact that its natural fertility in many cases has been largely exhausted by the removal of marsh hay before the muck is first broken.

Swamp Group. The swamp group is made of muck materials formed largely from forest litter. The forest trees commonly found on these deposits in Michigan are the tamarack, white cedar (arbor vitae), black spruce, ash, elm, maple, poplar, birch, alder, willow and occasionally others. The forest does not enter upon the muck deposit until it has been well built up, so that the ground water level is below the level of the muck surface for a considerable portion of the year. Of the different species, the tamarack is most often the first to enter the marsh, while the three cone-bearing trees, tamarack, black spruce and white cedar are able to grow under moister conditions than are the ash, elm and maple. If the cone-bearing trees do not enter, the alder or willow or both may serve as the advance guard for the forest.

Several investigators have found that the ash—elm—maple swamp represents the final product in the formation of a muck soil. The water level remains below the surface for the greater part of the year, so that decomposition of the muck practically equals the accumulation. In Michigan this type of muck deposit is largely confined to the southern portion of the state.

Fig. 3.—A forested muck. Here the forest is composed of a mixed growth with white cedar (arbor vitae) and tamarack predominating.

Bog Group. Instead of the entrance of the forest on the marsh, when its surface has been built up to or above the water level, the next type of vegetation may be the bog. The most characteristic species of plants entering into the bog formation are the shrubs: leather leaf (Cassandra), huckleberry, labrador tea, bog rosemary and cranberry, frequently associated with sphagnum moss and sometimes with sedges. In time this vegetation may be more or less replaced by a forest growth, usually tamarack and black spruce. If the original shrub vegetation was abundant and the deposit deep, the succeeding forest is generally scant and dwarfed, and represents the climax in the building up of the deposit.

This group of muck materials is by far the least fertile of the four described, and is usually low in lime (Page 28). It is generally raw and should be classed as peat. It does not compact readily when drained and, for that reason, crops grown on it may suffer from drought, unless the soil is well managed. Although the aggregate of these deposits is comparatively small in the state, they are widely scattered, usually in small deposits. This type of muck is represented in the southern part of the state by huckleberry (swamp blueberry) marshes. Improvement of drainage frequently results in the dying out of this bog vegetation and sometimes in the formation of a barren area.

The Muck Profile

In the preceding description of the four main groups of muck materials, only the most important plants entering into their formation have been named. Since the drainage conditions frequently vary in different parts of a muck area, it is evident that from one to all four of these different types of muck may comprise the surface layer in various portions of any one deposit. Although, under normal conditions, the muck profile would show the deep-water muck at the bottom of the deposit, and forest or shrub muck as the final stage, changes in the ground water level, by the damming of the natural drainage outlet, or by the burning over of the deposit, frequently result in a reversion to some of the plant species which were common to the area during the earlier stages of poorer drainage. The writers have observed as many as three distinct layers of forest material, alternating with as many of sedge muck in a muck profile. In the natural sequence of the plant species, the transition from deep-water to sedge muck is gradual and the line of demarcation in the muck profile is not definite. The transition from sedge muck to forest muck is usually, but not always, more abrupt.

Fig. 4.—A black ash and elm swamp, showing good growth of timber. Located on deep muck, this field was being used as a woodlot at the time it was photographed.

Besides the filled-in deposits, built-up deposits are formed on poorly drained flat areas, and on "springy" hillsides. These are more abundant under the lower temperatures of the northern part of the state than in the southern portion. These deposits may be of the same material throughout or they may vary with depth as do the filled-in deposits. The deep-water type of vegetation is seldom present in such deposits, but the other three—marsh, forest and bog—are rather common.

HISTORY OF MUCK LAND DEVELOPMENT

European

Records show that the so-called "Fen" method of muck cultivation was developed in Holland at least as early as the 16th century. This consisted in the spreading out of the surface material after the underlying layers had been removed for fuel, the mixing in of 4 or 5 inches of sand with the surface layer, followed by fertilization with a compost of stable manure and city refuse. Naturally this system of muck farming was limited to areas not far from cities. It is not in practice at present.

The "burning" method was developed in the seventeenth century in the outlying districts of Holland and in other parts of Europe. As it was largely used on the low-lime, less fertile mucks, the fertilization produced by burning off the surface layer did not prove of much benefit after a few yearly burnings had brought the surface down to the less fertile muck. This method is now to a considerable extent prohibited by law in Europe.

The "Rimpau" method, developed in Germany in 1862, differed from the Fen method in two particulars. By the Rimpau method the sand was applied as a layer over the muck, and cultivation confined to the sand layer. Instead of the city refuse, phosphate and potash fertilizers were used.

The fact that the Rimpau method, very successful on the high-lime mucks of southern Germany, was a failure on the low-lime mucks of northern Germany, resulted in the establishment of the Bremen Peat Experiment Station, the first peat and muck experiment station in the world. The success of this station has resulted in a number of similar experiment stations on the muck soils of other European countries.

The Fen and Rimpau methods of muck farming are now, for the most part, displaced by more recent methods. They are impractical in Michigan because of the large amount of labor required for "sanding" the soil. A modification of the Rimpau method is used in cranberry growing.

American

According to Elliot (10), the United States contains within its boundaries approximately 79,000,000 acres of swamp land, a considerable proportion of which is undoubtedly muck. About one-fifth of this acreage, most of which is muck, lies in the northern states, north of a line drawn from the southern boundary of Iowa to the center of New Jersey and east of a line passing along the Minnesota-Dakota boundary. Of the southern states, more muck is found in Florida (largely in the Everglades) than in any other. The poorly drained lands of Canada are estimated at 22,000,000 acres, most of which are east of Lake Winnipeg. A large proportion of this area is without doubt muck and peat.

Although the agricultural development of the muck lands in the United States must be considered as only begun, that in Canada is practically untouched. A considerable proportion of that which has been reclaimed is being used as meadows and pastures without any attempt at soil improvement. Only a very small fraction of the mucks of the country are being used in truck crop production. Considerable study regarding the fertilizer requirements of the muck has been carried on at several experiment stations. A brief review of that work is made later in this discussion.

Fig. 5.—A portion of a small huckleberry bog, showing shrub growth in the foreground and forest growth on the edge of the deposit.

THE MOISTURE SUPPLY

No group of soils is more exacting in its requirements for an unfailing supply of moisture for crop production than is muck soil. Frequently a report is made that a certain area is not producing satisfactory crops and that fertilizer is not improving the yields. Although other factors may be the cause of this condition, it is often a problem of moisture supply. Since different crops vary somewhat in their water requirements, it is necessary that in lowering the water level the conditions be studied closely in order that drainage satisfactory to the crops to be grown may be given.

Proper Drainage

With the exception of such crops as cranberries and huckleberries, the natural water level of a muck area is ordinarily too high for satisfactory crop growth. A majority of general farm crops and root crops produce their best yields on muck with the ground-water level during the summer months averaging around three feet below the surface, although it may be somewhat higher during the early part of the season. Hay produces well, and is in less danger of winter killing, if the water table can be maintained at about two feet below the surface without causing flooding during wet periods. Water levels in pastures should be from two to two and one half feet below the surface, to prevent the cutting up of the sod by the stock. If the muck is quite raw or fibrous, the water level should be slightly nearer the surface, while, if the muck is compact and contains considerable clay, the water level may be considerably farther below the surface than the distances just given.

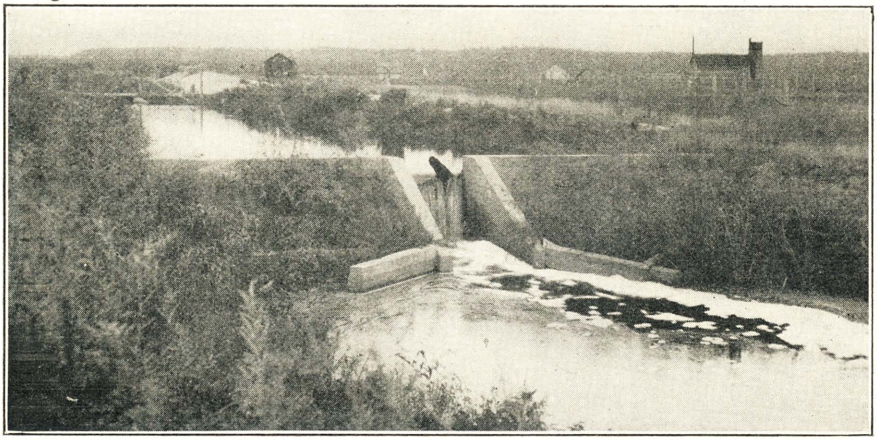

Fig. 6.—Proper drainage is essential in muck farming. The photograph was taken in an area which was excessively drained and shows the only remedy for that condition, the use of dams for holding back the water.

Most important in this connection is the need for a fairly uniform water level during the greater part of the growing season. A high water level in the spring causes a "cold" soil, resulting in delayed planting and, frequently, poor germination and slow growth. A water level which drops considerably after the root system has become established produces a droughty soil, with consequent lessened yield. On the other hand, an increase in the height of the water level, after the root system has become established and lasting several days, causes a "drowning" of the root system, resulting in the cutting off of the supply of plant nutrients and ending the growth of the crop. A crop will produce better yields with the water level permanently at a depth of two feet, than it will if the water level is at a depth of three feet for the first part of the season and then suddenly rises to a depth of one foot at the time when the crop is making its greatest growth. The need, then, is a drainage system, adequate to remove the excess water within a few hours following a heavy rain, without, at other times, inducing excessive drainage of the soil.

Excessive Drainage. Just as lack of sufficient drainage results in decreased yields, excessive drainage has a similar effect. The writers have observed areas of muck which, due to this excess, were quite barren through the year. If an over-drained muck becomes very dry, it may become extremely resistant to wetting, considerable rain being necessary to restore its normal moisture content. If this muck is one which shrinks and develops deep cracks on drying, the problem becomes still more serious. Such areas are relatively few in Michigan.

Where muck areas have been excessively drained, the unproductive condition can generally be corrected by the use of dams, placed in the outlet ditches, to raise the water level. If these dams are equipped with flood gates, the spring waters may be allowed to flow out and carry away any deposit of accumulated sediment. The gates may then be closed to a height which gives satisfactory moisture conditions in the soil areas above.

The Drainage System

The most important part of the drainage system is a satisfactory outlet, that is, one having sufficient fall. The main drain of most drainage systems is an open ditch leading into a river or lake. Generally in the drainage of Michigan muck areas, the submains and laterals, likewise are open ditches. Where tile have been used, they are proving very satisfactory when properly laid; in the saving of land area, in avoiding the cutting up of fields by ditches, in eliminating trouble with the gradual filling up that occurs in ditches, and in doing away with the ditch bank, a continual source of supply of weed seed.

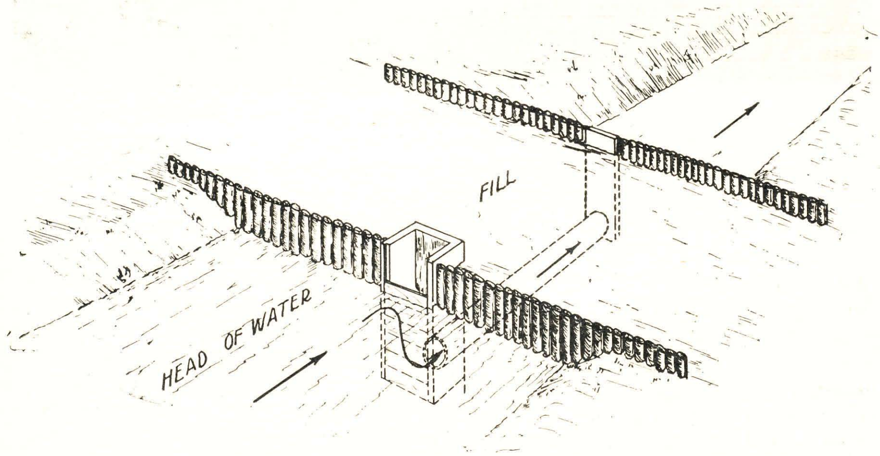

Fig. 7.—Digrammatic sketch of dam devised and constructed by Dr. O. Lloyd-Jones in co-operation with the Agricultural Engineering Dept. of this Station.* It has the advantages of being cheaper in construction than the type shown in Fig. 6 and of serving as a bridge across the ditch. The water-way leads over the flush boards into a concrete box which opens into a large tile passing under the fill. Because of seepage, a thin wall of puddled clay must be placed in the fill, extending into the banks. If the head of water is not great, it is not necessary to use the lines of piles.

*A detailed description of this type of dam under the title "Drainage Control on Muck Land" appeared in the May, 1925, number of the Michigan Experiment Station Quarterly.

Of the different kinds of tile, either glazed or unglazed clay tile have proven satisfactory on muck soils. Although practically as serviceable as glazed tile, the unglazed are generally less expensive. Investigations with concrete tile, made by the Agricultural Chemistry and Agricultural Engineering Departments, (28) lead them to recommend that they should not be used in muck soil, owing to their tendency to disintegrate when placed in some mucks. A few farmers have used box tile, made by nailing four-six-or seven-inch boards together. In some cases the box tile are reported in good condition after 20 years use.

Fig. 8.—The open ditch gradually fills in, and has to be cleaned out every few years. Its banks soon become a seed bed of obnoxious weeds and the presence of the smaller ditches is often a source of inconvenience in the management of the farm.

Distance between tile lines. The distance at which parallel lines of tile should be placed, to secure satisfactory drainage of muck land, depends on three factors, viz; amount of rainfall, type of muck and nature of underlying material. In general the greater the rainfall, the closer the lines of tile should be placed. Since the precipitation in Michigan is fairly uniform, averaging from 27 to 36 inches (23) in different parts of the state, the two last-named factors present more variable conditions for consideration in the laying of the tile lines. If the muck is of a fairly open type and is underlain by sand or gravel, at a depth which will be penetrated by the main ditches, ditches at half mile intervals may prove sufficient to give adequate drainage. If the muck is deep, or underlain with clay or marl, lines of tile or ditches at intervals of 150 to 300 feet are generally found necessary. If the muck is of a very impervious type, such as sometimes results from deep water origin, tile lines placed as close as 50 feet apart, may be required to give adequate drainage.

Depth of tile. If tile are laid soon after the mains are completed, consideration should be given to the facts that muck settles rapidly for a few years after draining, and that settling takes place between the surface of the soil and the ground water level. At the East Fen at Lincolnshire, England, drainage records show that the muck layer decreased in thickness from six to two feet in 80 years. Likewise on the University Marsh at Madison, Wisconsin, accurate measurements (11) showed a settling of the muck of three-fourths foot in five years, after tile were laid at a depth of three and one-half feet, that settling taking place above the tile. Because of this settling, it is advisable to allow the muck to lie a few years after the area has been ditched, before tile are laid. During this period pasturing will prove beneficial. When the muck has settled for a few years, tile laid at a depth of three to three and one-half feet will lower the water table to a depth satisfactory for general crops. Since proper drainage is so important on muck soil, the services of a capable drainage engineer are practically indispensable in laying out a drainage system.

Loss of Natural Vegetation with Drainage. Drainage of a muck area that is forest covered or supporting a growth of huckleberries or cranberries generally results in the dying out of some of the trees and a considerable portion or all of the huckleberry and cranberry growth. Since many of our undrained mucks are giving a fair return in their present condition, this loss and the cost of reclamation should be considered before drainage is undertaken.

PREPARATION OF THE SOIL FOR CROPPING

The amount of labor required to bring the newly drained muck into condition for cropping varies greatly, depending on the type of muck and its condition. If it is forested, the first cost is that of clearing, while, if it is grass-covered, the initial step is breaking. Although a recently burned-over area generally can be prepared for cropping with less expense than can the others, the use of fire in clearing cannot be recommended for several reasons, as indicated below.

Clearing the Muck

A large proportion of the muck soils of Michigan are forest-covered. This growth may comprise black ash and elm, tamarack, white cedar or mixed growth. If the land has been cut over or if fire has swept the area in the past, the original growth may be largely replaced by poplar. Usually the root growth is quite shallow and the clearing is not as difficult as on upland. Sometimes the layer of muck of forest origin has considerable depth, and below the living growth are buried stumps, trunks and roots of trees of former generations which slowly come to the surface. In certain areas in the state, which have been under intensive cultivation for more than 30 years, several loads per acre of roots are still being removed at the time of plowing.

After the timber has been removed, the use of a muck area as pasture, for several years before breaking, often proves desirable. This method allows the stumps and roots to decay and to work gradually to the surface where they may be more easily removed. At the same time, it gives the farmer opportunity to use his spare time in continuing the clearing of other fields. Suggestions for establishing or improving a sod on the unbroken muck are given on a subsequent page.

The Use of Fire in Clearing. In clearing off the brush from a cut-over area or in removal of the shrubs and moss from the bog deposits, a certain amount of burning of the debris is necessary. However, this should be done as early as possible in the spring while the muck is still rather damp, in order to prevent destruction of the soil. Frequently the breaking of a grass-covered deposit is likewise facilitated by burning off the vegetation. If the surface layer of the muck after breaking is very fibrous and is underlain by a more decomposed muck at a short distance below, as is occasionally the case, burning of the surface layer may be a distinct benefit. The surface of such a soil should be well disked as early in the spring as possible, and, as soon as the disked layer becomes dry enough, it can be burned without danger to the underlying layers.

In some localities fire is used for the double purpose of clearing the muck of its forest growth and of burning off a layer of the surface soil, the ash serving to fertilize the soil for several succeeding crops. This use of fire is to be discouraged for several reasons. Chief among them are:

1. Danger to neighboring fields and farmsteads.
2. Burning off of shallow deposits often leaves sand, marl, clay or hardpan exposed.
3. Decreasing depth of muck shortens life of muck deposit.
4. Surface muck is often more fertile than lower layers.
5. Lowering the level of the field lessens chances of obtaining proper drainage.

If a substratum of sand or marl is left exposed by burning, a soil of relatively low fertility is generally the result. If a tough clay is exposed, considerable labor is required in improving the soil structure, and in incorporating organic matter in the compact surface layer. Even though a foot to 18 inches of muck remains after burning, the life of this layer is relatively short.

From the very nature of the formation of a muck deposit, each generation of plant growth owes its existence to the plant food in the muck within the reach of its roots. For this reason it is frequently true that the surface layer is the most fertile. When this layer is burned, its ash, with a considerable amount of the mineral elements of plant nutrients, is left to fertilize the first crop. However, the crop is able to utilize only a small portion, and the remainder is largely washed down by rains beyond the reach of the roots, only the insoluble portions remaining. The amount of such plant food retained by the soil, varies with the nature of the muck.

Occasionally the amount of water-soluble plant nutrients held in a muck after burning is so large that it proves injurious to the crop. Such a muck is temporarily an "alkali" soil, the alkali proving especially injurious to corn. The writers have observed this condition produced in corn by the burning of approximately two feet of surface material of deep muck at Madison, Wisconsin in 1920 and of deep muck in Ingham

County in 1921. The effect of the alkali condition of the Wisconsin muck had entirely disappeared the next year, when the field was heavily manured and a good crop of ensilage corn raised. The Ingham County muck likewise produced a good crop of sugar beets in 1923. Occasionally fire can be used advantageously in correcting the acidity of a low-lime muck. This is discussed to greater extent on page 31.

The danger to a community of the use of fire in clearing or of fertilization by the burning method, cannot be overestimated. When this method is followed, every precaution should be used to guard neighboring fields, property and lives. On an open marsh the most successful method of combating a muck fire is by digging a ditch down to wet muck around the fire area and allowing it to burn itself out. If the fire is driven by a high wind, a supply of water is needed to extinguish sparks blown across the trench. Heavily rolled muck is not so likely to burn as is loose, unrolled muck.

Removing the Hummocks. Very frequently mucks, which have been long in pasture, have developed a very uneven surface, covered with innumerable hummocks. Such a surface is very difficult to break. An implement which does very good work in the reducing of these hummocks is made by taking the front bob of a bob-sled and attaching a strip of sheet steel, sharpened on the front edge, diagonally across from the bottom of one runner to the bottom of the other. After the hummocks are cut down, disking often aids in preparing the land for the plow.

Cultural Management

Breaking. The plowing of a muck for the first time can best be done with a tractor and a heavy breaking plow. A plow which turns a wide furrow (18-22 inches) and is equipped with a long mold board, usually does better work than the ordinary type. The disk plow also produces very good results in breaking muck, the claim being made that it is especially suited to muck containing tough roots which would interfere with the mold board type. If the disk plow is used it is necessary to keep the disks well sharpened.

If the muck is filled with roots, a wing or knife coulter on the mold board plow usually gives better results than are secured with the ordinary rolling coulter. If the sod is loose, and likely to push ahead of the plow, or filled with roots, a mold board plow with a very large rolling coulter generally turns the furrow in a satisfactory way. A special type of breaking plow now on the market, for use on muck land supporting a growth of brush, is able to bury the entire growth beneath the furrow.

In order to bury the heavy sod often found on muck, it is essential to break fairly deep, from six to eight inches usually being sufficient. There is thus placed on the surface a layer of muck which is generally fairly well decomposed and free from sod. The furrow should be laid as flat as possible in breaking, in order to provide a level surface, free from sods, for seed bed preparation. A special type of plow recently put on the market, has a pushing attachment which shoves the furrow slice to the right after it has been turned by the plow, leaving a wide furrow to receive the next furrow slice. In this way it is claimed that a very level plowed surface is produced.

If a new muck is to be broken up, the breaking should be done preferably during the summer previous to cropping, in order to give time for settling and decay. If the surface of the muck is free from sod and weeds, as is usually the case on burned-over areas, and sometimes on muck from which the forest growth has been removed, breaking is unnecessary. A good seed bed can be secured with less effort by the thorough use of the disk.

Plowing and disking. Muck soil is generally loose and open as compared with mineral soil and is not in need of the weathering action of the elements. For these reasons muck soils, with the possible exception of a few very compact soils high in clay content, are not in need of annual plowing, unless it is for the purpose of turning under sod or manure, or burying a weed growth or crop residues. Better yields of grain crops are usually secured if the seed bed is prepared by disking. Limited experiments indicate that root crops produce better crops on plowed muck if the muck has been heavily rolled after plowing. If the land is plowed, fall plowing on muck generally results in higher yields than does spring plowing, due apparently to the soil becoming more compact. It is desirable also because farming operations on a muck are usually late in the spring, owing to the fact that

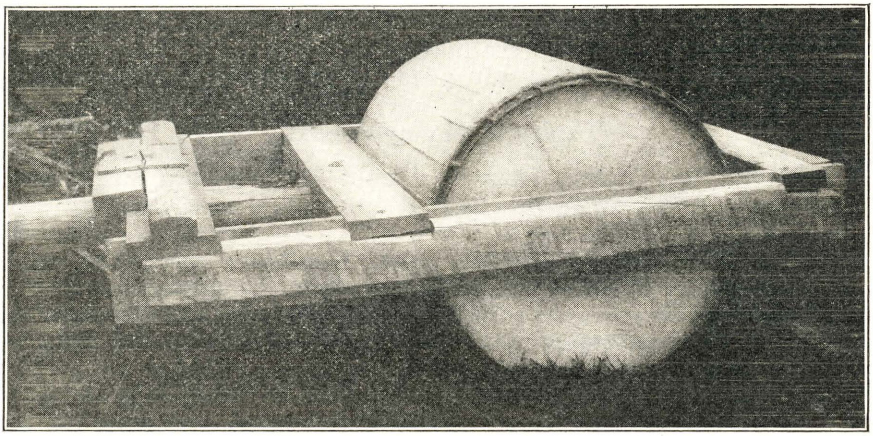

Fig. 9.—A concrete roller made by a Huron County farmer. Length 5 feet, diameter 30 inches, weight about 3500 pounds. Mower wheels were used at the ends and 4 inch boards were placed around the outside and held in place with log chains. After the concrete had hardened, the boards were removed. Three or four horses are required to handle it in the field.

muck is slow in warming up and sometimes too wet to support the weight of horses during the early season.

Rolling. In the management of muck and peat soils, with the possible exception of a few very heavy mucks, no other farm implement is as important as the roller. German, Swedish and American experiments have demonstrated that rolling of muck will produce marked increases in crop yields. The ordinary roller is not heavy enough for best results, unless it is heavily weighted. German and American investigations have shown that a roller weighing 500 to 700 pounds per linear foot is not too heavy. The Minnesota Agricultural Experiment

Station advises farmers that, in the absence of rollers, they should use the disk harrow, well weighted and with the disks set straight.

The compacting caused by heavy rolling is important for two reasons. In the undrained muck are many small spaces filled with water which upon draining become filled with air. Rolling tends to close these air spaces, thereby giving the roots of the growing crop a better opportunity for development and penetration. At the same time it allows the soil moisture from below to move more directly upward, by capillary action, to supply the plant roots with water. Although the float, used by many Michigan truck farmers, will smooth the soil, it will not produce the compaction secured by the heavy roller. Although an ordinary roller will compact the surface muck to some extent, it is equally important to compact the underlying layers.

The Bremen Peat Experiment Station, in Germany, first advocated the use of the concrete roller on muck soils. This type has been used

Fig. 10.—The muck to the left of the stake was rolled with the concrete roller while that to the right was not rolled. Note the difference in stand.

in America with success for several years. Such a roller* can be constructed at a fairly low cost by using, in so far as possible, materials from the farm. A good draft horse can pull from 12 to 20 linear inches of a 30-inch concrete roller, the amount depending somewhat on the compactness and levelness of the muck.

German investigators report that the greatest benefit is secured from rolling when the soil is moist but not very wet. As standard, they advise rolling the muck at the time that walking upon it leaves the deepest imprint. They further advise the rolling of pastures two or three times during the season and meadows in the spring and after each hay crop is removed. If the muck is poorly drained, the benefits from rolling may not be sufficiently great to pay for the extra labor.

*Detailed instructions for the construction of a concrete roller are given in the Michigan Agricultural Quarterly Bulletin, May, 1924, which may be secured without charge by addressing R. S. Shaw, Director, Agricultural Experiment Station, East Lansing, Mich.

On such a soil, heavy rolling in a wet summer, may result in reduced yields. If the muck is excessively drained, the heavy rolling may be the means of saving the crop from loss by drought. If the muck has a tendency to blow, a roller which leaves a corrugated surface on the soil allows less drifting than takes place on a smooth surface. Rolling at right angles to the direction of the prevailing winds proves most effective in checking the blowing of the muck.

Cultivation. In general, shallow cultivation gives more satisfactory results than deep cultivation. The cultivated layer of muck soil is relatively loose and, as a result, air circulates readily through it and dries it out. The cultivated row, whether it be sugar beets, potatoes, corn or mint, if cultivated deeply, loses water not only from the surface but also from the sides. This leads to drying out of the muck in the row with a consequent lessened yield. For the same reason shallow hilling of potatoes is preferable to high hilling on muck. During the drought of 1923 the advantages of shallow cultivation were especially marked.

COMPARISON OF UPLAND (MINERAL) AND MUCK SOILS

A comparison of the properties of upland (mineral) and muck soils brings out some important differences between them. Among the more important of these are differences in density, in chemical composition and in heat conductivity. These are especially important because the supply of plant nutrients in a soil depends on the first two properties. The third is important because, as Bouyoucos and McCool (4) of this station have recently explained, the occurrence of frosts on muck during the summer is due to the low conductivity of heat in that soil.

Density. Muck and peat soils are generally much less compact than the mineral soils and the material of which they are composed is much lighter in weight when dry. In general, a cubic foot of dry mineral soil weighs from 75 to 100 pounds, while the same volume of muck weighs from 15 to 30 pounds. True peat, on the other hand, varies in weight from 6 to 20 pounds per cubic foot. Even if a muck and an upland soil had the same composition, pound for pound, it is evident that much less plant nutrient would be within the reach of the roots in a muck than in a mineral soil.

Composition. Table 2 gives the chemical composition of the surface eight inches of a number of mucks, and also of two mineral soils. This is expressed in pounds of the plant nutrient constituents per acre of soil, taken to a depth of 8 inches. In all cases the nitrogen and the organic matter content of the muck soils are much higher than those of the mineral soils. The lime content also is usually higher, though in a few cases, it is decidedly lower. Phosphoric acid and potash are present in smaller amounts in the mucks. Since these are the plant nutrient elements which are most often insufficient in mineral soils, the comparison gives some idea of the relative natural fertility of these different soils.

Table 2.—Composition of Seventeen Muck Soils and Two Upland (Mineral) Soils, expressed in pounds p of 8 inches. (1)

Soil No.	Location—county	Original vegetation	Organic matter	Mineral matter (ash)	Insoluble ash (2)	Soluble ash	Degree of acidity (soiltex)
1	Ingham Co. No. 2....	Moss and huckleberry............	391,800	208,200	187,200	21,000	Very strong..
2	Kalamazoo..........	Moss and huckleberry...........	519,600	80,400	67,800	12,600	Very strong..
3	Ottawa No. 2........	Moss and huckleberry............	465,000	135,000	107,400	27,600	Very strong..
4	Missaukee No. 2.....	Sedge........................	544,800	55,200	37,800	17,400	Very strong..
5	Berrien No. 1........	Sedge........................	449,400	150,600	93,600	57,000	Strong......
6	Berrien No. 2........	Sedge........................	480,600	119,400	54,000	65,400	Medium.....
7	Ingham No. 1........	Sedge........................	460,800	139,200	58,200	81,000	Very slight..
8	Gratiot.............	Tamarack....................	486,600	113,400	35,400	78,000	Not acid....
9	Ottawa No. 1........	Tamarack....................	482,400	117,600	45,000	72,600	Very slight..
10	Calhoun.............	Tamarack....................	500,400	99,600	30,600	69,000	Very slight..
11	Lapeer No. 1........	White cedar, tamarack and ash...	409,200	190,800	83,400	107,400	Not acid....
12	Lapeer No. 2........	White cedar, tamarack and ash...	489,000	111,000	24,600	86,400	Not acid....
13	Huron..............	White cedar, tamarack and ash...	510,600	89,400	22,200	67,200	Not acid....
14	Eaton...............	Mixed, tamarack predominating...	454,800	145,200	81,600	63,600	Very slight..
15	Missaukee...........	Mixed growth..................	442,200	157,800	85,800	72,000	Medium.....
16	Washtenaw..........	Mixed growth..................	451,800	148,200	64,800	83,400	Slight.......
17	Van Buren...........	Ash and elm...................	399,600	200,400	107,400	93,000	Very slight..
18	Tuscola, clay loam....	....	95,000	1,905,000	....	....	Slight.......
19	Cass, sandy loam.....	....	32,800	1,967,200	....	....	Strong......

(1) Calculation on the basis of 600,000 pounds as the weight per acre for the surface 8-inch layer of m pounds for that of upland (mineral) soil.

(2) Determined by digestion with aqua regia.

Frostiness

It is well known that crops on muck soils are much more subject to frosts occurring during the summer than are those on mineral soils. Even if the two soils are at the same elevation or if the muck, covered with a layer of sand or clay, is compared with bare muck, a frost may injure crops on the uncovered muck during the summer, while those on the other soil will not be damaged. Bouyoucos and McCool made temperature studies on clay loam and muck placed at the same elevation, with muck cultivated, compact, and covered with sand. Their results (Table 3) indicate that heat moves more rapidly through a mineral (clay) soil than through a muck soil. During the early part of the day, the clay loam absorbed the heat more rapidly than did the muck, but by late afternoon, the muck had become nearly as warm as the mineral soil, even to a depth of six inches. On the clear, cool night which followed, heat was lost from both soils by radiation. The temperature of the surface of the cultivated muck soil dropped eight degrees more than that of the mineral soil, reaching a temperature four degrees below the freezing point of water. At a depth of six inches, however, the temperature of the mineral soil dropped five degrees more than did that of the muck soil. In other words, sufficient heat moved from below to the surface of the mineral soil to keep the surface from freezing. The muck soil was such a poor conductor that the heat below did not move up, consequently the surface layer and the air just above it were cooled to a point at which a crop would have been frosted. The compact muck soil was a better conductor of heat than was the cultivated muck, with a result that the surface temperature dropped to only one degree below freezing. Further, the muck with a light covering of sand gave an even smaller drop in temperature at the surface than did the compact muck.

The "frostiness" of a muck depends on several factors, of which the following are most important: (1) Moisture content; (2) compactness; (3) state of decomposition; (4) content of mineral matter; (5) fertilization.

Heat moves up from below to the surface more rapidly in a moist than in a dry muck. If the soil is compact, the movement of heat takes place still more readily. For that reason the heavy roller is a valuable implement in aiding the prevention of frosts. The looser the surface layer, the greater the danger of summer frosts. Frequently when a field of corn or potatoes on muck has been partly cultivated before a frost occurred, the cultivated portion has been frosted while the uncultivated part has escaped. The loose cultivated layer serves as a blanket to keep the heat in the soil so that the air just above it is not kept warm.

Ordinarily the more decomposed a muck becomes, the smaller becomes the probability of frost occurrence. For that reason, old mucks are generally not as "frosty" as those recently reclaimed. A soil fairly high in mineral matter is likewise not as subject to frosts as one that is low in these constituents. If the surface of the muck is covered with a layer of ashes, or sand or clay has been spread over it, as is done to some extent in Europe, the danger of summer frosts is much decreased.

Fertilization of the muck may prevent injury of the crop by a light frost. As an illustration: on the plots in Huron County, a frost, occurring on the night of August 20, 1922, practically killed the corn on the unfertilized plots, but only slightly damaged that on the well fertilized plots. This protection probably is due largely to the greater growth of the crop on the fertilized plots, which tends to prevent the loss of heat from the air near the ground. It may be due in part also to a greater resistance to freezing, offered by the plant juices of the fertilized crop.

Summer frosts on muck are best combatted by a selection of crops which are not easily frozen. This will be dealt with more fully under the section "Crop Adaptability" (page 70).

Table 3.—A comparison of temperatures of mineral and muck soil for the afternoon and night of October 5, 1921.

Soil	Point of measurement of temperature	Temperature in degrees Fahrenheit		
		Taken at 1 P. M.	Taken at 4 P. M.	Lowest temperature for the night following
Clay loam (compact)	Air, 1 inch above surface			34.2
	Soil at surface	55.0	57.0	36.2
	Soil at depth of 6 inches	54.1	54.0	46.5
Muck (compact)	Air, 1 inch above surface			31.8
	Soil at surface	58.0	57.0	31.0
	Soil at depth of 6 inches	51.2	53.1	50.5
Muck (cultivated)	Air, 1 inch above surface			30.5
	Soil at surface	57.0	57.0	28.0
	Soil at depth of 6 inches	51.7	53.2	51.4
Muck (compact and covered with sand)	Air, 1 inch above surface			32.8
	Soil at surface	56.0	58.0	31.8
	Soil at depth of 6 inches	51.8	54.0	49.8

EFFECT OF FERTILIZING ELEMENTS

Improvement of the fertility of any soil is accomplished by the use of manure, green manure or commercial fertilizer, together with lime when it is needed to correct a sour (acid) condition of the soil. If manure or complete commercial fertilizer is used, three important fertilizing constituents are added to the soil, viz: nitrogen (ammonia), phosphoric acid and potash. Generally, muck soil is very responsive to **proper fertilization.** Increases of 200 to 300 per cent and even more, in yields of certain crops, are not uncommon. Since selection of the necessary fertilizing constituents is so important, a brief consideration of those effects of these several constituents on plant growth, which are of especial importance on muck, is desirable.

Nitrogen. Nitrogen, applied in the form of any of the quick-acting or medium acting fertilizers, tends to produce, among others, the following effects:

1. Increased growth of tops, with lodging of grain.
2. Delayed maturity of the crop.

Even though muck soil is high in nitrogen content, these effects from application of a nitrogen-carrying fertilizer are often noticeable.

Phosphoric acid. When applied in the form of a readily available phosphate, this constituent:

1. Hastens maturity of the crop.
2. Increases growth, especially of the above ground parts.

The effect of phosphate in hastening maturity is especially important on muck soils because the maturity of crops on muck is generally delayed by the nitrogen in the soil. However, it is possible to so

Fig. 11.—This picture illustrates a condition often found on muck areas, which may be due to any one of three causes: (1) potash starvation, (2) a very acid condition of the soil, (3) an alkali condition produced by the recent burning off of a layer of muck. The first condition is generally the cause but both the others have been observed to act in a similar manner on corn on Michigan muck soils.

hasten the maturity of certain crops, by an application of phosphate without potash, that the crop matures before reaching its normal growth. This is especially noticeable on root crops, and, in our investigations, has been more evident on those mucks which did not require phosphate for increased growth of the crop.

Potash. An application of potash to crops grown on muck:

1. Increases plant growth, especially in tuber and root crops.
2. Increases sugar and starch content of tubers and roots.
3. Delays maturity of the crop.
4. Improves quality of crop.

The effect of potash in increasing all plant growth is very important to the muck farmer. Its effect on the quality of the crop has not been given sufficient consideration in the past. In delaying maturity it tends to offset to some extent the action of phosphate.

CLASSIFICATION OF MICHIGAN MUCK SOILS ACCORDING TO FERTILIZER REQUIREMENTS

For a number of years, an organized study of the needs of the muck soils of Michigan has been conducted by the Soils Department of Michigan State College. At the start of the 1922 season, the scope of this study was considerably enlarged. On the basis of the natural fertility in the soil and the fertilizer and lime requirements for general crop production, the muck soils of the state, in so far as they have been studied, may be grouped as follows:

I. Low-lime mucks. Lime, potash, phosphate and nitrate required.
II. High-lime mucks.
  1. Newly reclaimed mucks. No fertilizer requirements for from one to several years.
  2. Very shallow mucks. Potash and sometimes phosphate and nitrate required.
  3. Medium and deep mucks.
    a. Mucks requiring potash only.
    b. Mucks requiring both potash and phosphate.

EXPERIMENTAL WORK ON MUCK SOIL*

During the seasons of 1921 to 1924, inclusive, experimental work with general and special crops was conducted on 46 different muck areas. These were widely scattered but largely in the southern half of the state, due to the fact that only a relatively small proportion of muck areas in the northern half have been developed. In the succeeding pages, the results from the different mucks are grouped according to the type to which the soil belongs. Natural vegetation, distribution of the type, drainage and proper methods of fertilization are considered.

*The writers wish to state that the five sets of experimental plots conducted in 1921, were established by Ezra Levin, who was a member of the Soils department until July 1 of that year. All yields reported herein were secured by the authors, with the help of James Crum, Forest Grim and Andrew Huff, student assistants. A. G. Weidemann of the Soils department was to a considerable extent responsible for the determination of the sugar content of the sugar beets. The authors wish to take this opportunity to thank the county agents of the counties in which the experimental work was done, and the farmers on whose farms the plots were located, for their hearty co-operation in making the work a success.

In the different sets of experimental plots reported in the following pages the fertilizers used analyzed as follows:

Symbol	Fertilizer	Description of Fertilizer
P.	Acid Phosphate	16% Phosphoric acid
K.	Muriate of Potash	50% Potash
N.	Nitrate of Soda	18% Ammonia
S. A.	Sulphate of Ammonia	25% Ammonia
M.	Manure	Generally a mixture of horse and cow manure

LOW-LIME MUCKS

It has long been a popular impression among Michigan farmers that all mucks need lime. As a matter of fact, the proportion of low-lime mucks is relatively low. However, they are found widely distributed over the state, usually in fairly small areas and often not far distant from high-lime mucks. In so far as investigation has been made, all deposits in southern Michigan, which supported an abundant growth of shrubs and sphagnum moss, are very strongly acid (low-lime), while very few of the deposits originally covered with sedge, and none of those originally timbered with ash and elm and maple need lime. In central and northern Michigan the grass (sedge) mucks are more generally low in lime, while still further north the mucks supporting a growth of tamarack and black spruce (when dwarfed) likewise are generally very strongly acid. Those mucks supporting a good growth of white cedar or tamarack, in so far as they have been investigated, have not required lime.

Fig. 12.—This muck was so strongly acid that the crop was practically killed out in spots and would have been much benefited by liming on most of the field. Generally the presence of marl under the muck is considered proof that the muck is sweet. Here, however, the nearly barren area on which the man is standing was underlaid by fair quality of marl at a depth of four and one-half feet. Marl was thrown up on the ditch bank about 30 rods away.

Ingham Co. Project No. 2, 1922-1924. Experimental plots were conducted from 1922 to 1924 on a low-lime muck near Mason, Ingham County. This muck originally supported a growth of sphagnum moss and shrubs. As shown in Table 2, page 23 (Muck No. 1), this soil was very low in lime and phosphoric acid. About 35 years ago, the portion on which the plots were located was tile-drained, with the expectation of raising truck crops. Immediately after drainage was established, all vegetation died. Since that time the drained portion has been absolutely devoid of any vegetation, except around the edges, where mineral soil was washed down onto the muck and timothy has crept in.

The area for plot work was divided into three equal strips, the first of which received pulverized limestone at the rate of two tons per acre; the center strip was not limed and the third received pulverized limestone at the rate of four tons per acre. Although the limestone was applied in 1922, only shortly before the crops were planted, a marked benefit was secured. Across these strips, different fertilizer applications were made. On each limed and unlimed area, several different crops were grown, the yields of some of which are given in Table 4.*

On the various crops grown in 1922, sugar beets, sweet clover, and timothy and clover failed to appear above ground on the unlimed portion of the field, while Hungarian millet and spring rye developed the first leaf and then died. Potatoes were the only crop to persist with-

Table 4.—Crop Yields on Very Strongly Acid Muck—Ingham Co.—1922-1924.

1922

Plot No.	Fertilizer application—1922 lbs. per acre	Hungarian millet lbs. per acre (2 tons lime)	Potatoes—bu. per acre			Sugar beets lbs. per acre (4 tons lime)
			(2 tons lime)	(No lime)	(4 tons lime)	
1	No fertilizer	66.7 (1)	9.9	0.7	12.7	66.8 (1)
2	P 200 K 300 (2)	2095.9	30.5	0.6	58.1	1982.7
3	P 300 K 300	2712.5	27.0	0.5	37.6	1250.1
4	P 400 K 300 N 100	4305.4	41.9	0.2	46.1	1115.1
5	P 400 K 300	....	31.9	0.2	56.0	2135.0
6	P 400 K 200	3155.3	39.7	0.2	73.7	1380.0
7	P 400 K 0	0.0	18.8	0.2	7.1	Scant growth
8	No fertilizer (3)	Scant growth	36.9	1.9	19.1	Scant growth

1923 / 1924

Plot No.	Fertilizer application—1923-24 lbs. per acre	Hungarian millet lbs. per acre (4 tons lime)	Potatoes—bu. per acre			Rutabagas tons per acre (4 tons lime) (1924)
			(2 tons lime)	(No lime)	(4 tons lime)	
1	No fertilizer	170.1 (1)	17.6	1.8	9.1	....
2	P 300 K 300 (3 installments)	1488.8	66.7	1.8	49.1	5.3 (1)
3	P 300 K 300	1276.1	69.1	1.8	56.4	4.0
4	P 300 K 300 N 200 (3 installments)	3232.8	93.4	2.4	89.1	5.8
5	P 300 K 300 N 200	2297.0	70.3	3.0	81.2	3.1
8	No fertilizer	255.2	24.2	8.5	24.9	1.1

(1) The yield of sugar beets, Hungarian millet and rutabagas was 0.0 for all plots on the unlimed portion of the field.

(2) P—acid phosphate; K—Muriate of potash; N—Nitrate of soda.

(3) Sandy portions of plot 8 increased the yield of potatoes.

*A more detailed report of the results secured in 1922 on this very acid muck is given in the Mich. Agr'l. Expt. Sta. Quarterly, November, 1922, under the title "Liming an Acid Muck Soil." This may be secured, without charge, by addressing R. S. Shaw, Director, Agricultural Experiment Station, East Lansing, Michigan.

out lime throughout the season, the plants being very stunted and practically without root development, but each plant produced a potato about the size of a small marble. Fertilizer applications without lime produced no increase in growth and were entirely wasted.

With all crops, the four-ton application per acre of ground limestone gave better results than the two-ton application. The sugar beet crop on the portion of the field receiving the two-ton application was a very poor stand and failed to grow satisfactorily; it was finally disked out and Hungarian millet sown. With all crops, the effect of fertilization on growth was very marked, potash being especially beneficial. Phosphate alone gave no increase in growth, but nitrate applied in addition to potash and phosphate produced marked benefit with Hungarian millet, spring rye, sweet clover and timothy and clover.

In 1923, the fertilizer treatments were changed, in order to compare application of fertilizer before planting with application in installments during growth. Two plots (6 and 7) were left unfertilized. The plots were given the same fertilizer treatments in 1924 as in 1923.

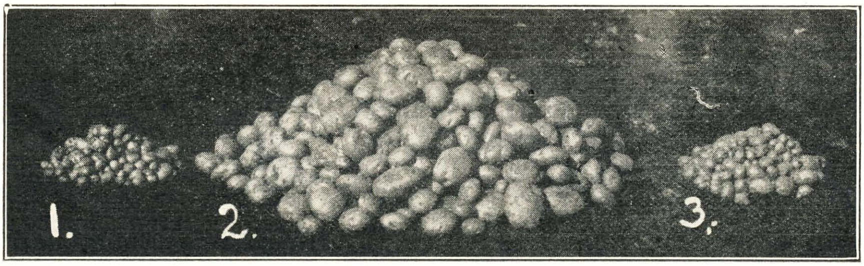

Fig. 13.—Potatoes on very acid muck. The three piles are from an equal number of hills. The first received fertilizer only, number 3 marl only and number 2 fertilizer and marl.

The yields of both Hungarian millet and potatoes in 1923 and of rutabagas in 1924 largely confirmed the results secured in 1922. Nitrate, in combination with potash and phosphate, appeared of considerably greater benefit to the potatoes than in 1922. The application of the fertilizers in three equal installments (one before planting and the others at intervals of about one month) gave marked increases of millet and rutabagas, and likewise of potatoes when nitrate was included. This is discussed further under the section "Time of Application of Fertilizers," page 53.

The yields of potatoes in 1923 on the fertilized plots receiving two tons of limestone, averaged even larger than those on the portion receiving four tons per acre. In 1924 the potato vines were killed by a frost in the early part of August so that yields were not obtained.

In 1923 the growth of Hungarian millet, on the portion of the field which had received the two-ton application of limestone in 1922, was very spotted and poor, the crop being injured by the acid condition of the soil. In 1924, the growth of millet on the portion receiving the four-ton application of limestone was likewise very spotted and poor, while the crop on the portion which received the two-ton application of limestone died shortly after coming up. The rutabagas on the unlimed portion failed to germinate; those on the portion receiving the two-ton application of limestone made a very thin stand which grew but little, and even those on the portion receiving the four-ton application gave low yields on all plots. It was thus quite evident that, little more than two years after the application of ground limestone, the soil had become too acid for all the crops which were grown, with the possible exception of potatoes.

Fertilizer Management of Low-Lime Mucks

The division between high-lime and low-lime mucks is not sharp. Whether or not a muck needs lime depends not only on the lime content of the muck but also on the crop which is to be grown. Such crops as potatoes and Hungarian millet yield well on muck that is too acid to give satisfactory crops of celery, clover and sugar beets. Most mucks which are slightly acid (Soiltex determination) have a high lime content. When lime is applied to a high-lime muck, a slight decrease in yield sometimes results. If a muck is moderately acid, it probably does not require lime, but, if it is strongly acid, the only method of determining whether or not it needs liming is by a field test.*

Correction of the acidity of muck soils can be made by the application of several different substances. The more important are ground limestone, marl, sugar beet lime, and wood ashes. If ground limestone is used for general farm crops, from two to six tons per acre are applied according to the degree of acidity. If a good quality marl, or sugar beet refuse, or wood ashes is used, from two to three cubic yards should be applied instead of each ton of limestone. If the wood ashes have not been leached, an amount of potash, approximately equivalent to that contained in 200 pounds of 50 per cent muriate of potash, and of phosphoric acid, approximately equivalent to that contained in 250 pounds of 16 per cent acid phosphate is added in each ton of ashes applied. About three-fourths as much hydrated lime is needed as of ground limestone. Heavier applications of the liming materials are necessary for some of the special muck crops on the very acid areas. The lime should be applied after plowing, preferably the summer before cropping, and thoroughly worked into the soil. If possible plowing should not be practiced for a few years after the lime application. Penetration of the lime may be hastened by disking and harrowing. In the case of exceptionally acid mucks, as for example the barren areas, it is probably advisable to plow deeply at the end of one or two years after liming and apply a second application of liming material to the upturned surface. Because of the fairly heavy applications needed on these strongly acid mucks and the relatively higher cost per ton, the use of hydrated lime cannot be recommended unless it can be secured at a very moderate price.

Occasionally a low-lime muck is underlain by a high-lime deposit at a depth of only a few feet. In such deposits, the burning off of one or two feet of the surface layer often furnishes sufficient lime in the ash, so that the crop can grow and the roots penetrate into the high-

*Before deciding to apply liming material to a muck soil, have the muck tested for acidity by sending a pint sample to the Soils Dept., M. S. C., East Lansing, Mich., or lime a small area in the field and watch results.

lime muck below. Specific recommendations of fertilizer mixtures for general crops on low-lime muck soil are given on page 65.

HIGH-LIME MUCKS

The natural supply of the mineral elements of plant nutrients in muck soil is rather limited, as shown in Table 2, the amount of potash present being very low and that of phosphoric acid generally low, while the supply of nitrogen is usually high. Any grouping of muck soils on the basis of their requirement of the three plant nutrient elements can be only temporary, since the newly reclaimed muck of today, without need of plant nutrients, may become a soil which needs only potash, within a few years, and one which needs both potash and phosphate, sometime later. For the economical use of fertilizers, however, a knowledge of the fertilizer needs of the muck at the present time is very essential.

Newly Reclaimed Mucks

Newly reclaimed mucks, if high in lime and only recently drained, seldom respond to fertilization for from one to several years. If the muck has been drained and used for pasture for a number of years, some response to fertilization may be seen immediately, some of the fertility of the soil having entered into the flesh and bone of the grazing stock. The writers have observed several muck fields, long used as meadows, with hay removed each year and nothing returned to the soil, on which the first crop grown after breaking was a failure unless properly fertilized.

Jackson Co. Project—1923. This muck area was originally an open marsh supporting a growth in which slough grasses (sedge) predominated. Wild hay had been cut and removed annually for eleven of the preceding thirteen years and probably previous to that time. The area was drained by a deep ditch in 1920; since then the yield of wild hay has decreased. The muck was very fibrous and several feet in depth.

Table 5.—Yield of Wild Hay—Jackson Co.—1923.

Plot No.	Fertilizer application (1)—lbs. per acre	Cured hay lbs. per acre
1	K 200	1522.9
2	No fertilizer	1712.0
3	P 200	2272.0
4	P 200 K 200	3613.5

(1) P—Acid phosphate; K—Muriate of potash.

Of the various fertilizer applications (Table 5) made on the wild sod, acid phosphate gave a considerable increase in yield, while muriate of potash was of no benefit when applied alone. When the two were applied together, the yield was more than twice that secured from the unfertilized muck.

Calhoun Co. Project—1921-1923. The results of experimental work conducted on a newly broken muck in Calhoun County are given in Table 6. This muck has a depth of about eight feet. The area was formerly a tamarack swamp which was burned over in 1885 and grew up to poplar and willow. This growth was again burned off in 1913. In 1919 the area was used as a pasture and in 1920 the portion used for plots was broken up. Analysis (Muck No. 10, Table 2, page 23) shows the soil to be high in lime but to contain only a moderate amount of phosphoric acid.

A slight response to fertilization was evident with the millet and potatoes and a greater response with the root crops, mangels giving the

Table 6.—Crop Yields—Calhoun County—1921-1923.

Plot No.	Fertilizer application* 1921	1921						Fertilizer application* 1922-1923	1922		1923
		Stock carrots tons per acre	Mangels tons per acre	Sugar beets tons per acre	Rape (green) tons per acre	Hungarian millet (cured hay) tons per acre	Potatoes bu. per acre		Hungarian millet tons per acre	Potatoes bu. per acre	Potatoes bu. per acre
1	No fertilizer	18.5	11.6	8.4	......	......	38.0	No fertilizer	2.6	118.3	62.1
2	L..........	19.5	19.3	8.4	12.4	4.2	13.9	P K.......	2.9	168.2	107.8
3	L P K N...	23.9	35.9	11.9	31.1	3.4	60.9	½ (P K)...	2.9	156.7	93.8
4	L P K.....	33.3	29.2	11.3	23.7	3.6	50.7	Residual....	2.8	123.6	67.3
5	L M.......	28.6	27.9	11.3	28.4	3.9	34.2	P K.......	3.0	149.5	99.2
6	M.........	28.8	29.2	11.7	23.3	3.9	50.7	Residual....	3.2	142.4	61.2
7	No fertilizer	18.8	15.6	8.4	22.5	3.6	43.7	No fertilizer	2.6	125.0	56.0
8	P..........	17.8	20.5	8.9	24.9	3.6	46.3	Residual....	2.7	113.7	64.5
9	N.........	25.8	20.5	8.9	18.3	2.4	43.7	P K.......	2.8	149.7	130.0
10	K.........	......	......	10.6	23.3	3.6	58.3	Residual....	2.8	111.7	61.5
11	No fertilizer	23.9	11.0	6.5	14.8	2.5	55.2	No fertilizer	2.6	115.9	56.3
12	P N.......	24.4	13.8	7.3	22.5	2.9	59.6	½ P.......	2.4	120.6	56.0
13	K N.......	32.3	27.1	10.9	23.3	4.3	75.4	½ K.......	2.9	125.7	79.4
14	P K.......	32.1	28.3	11.6	26.8	4.3	71.6	½ (P K)...	3.0	175.5	131.5
15	P K N.....	32.1	32.8	10.3	......	......	74.2	Residual....	3.2	....	118.1
16	No fertilizer	......	......	......	......	......	......	No fertilizer	2.7	....	65.5

*Rate of application per acre: N—nitrate of soda, 100 lbs.; P—acid phosphate, 250 lbs.; K—muriate of potash, 200 lbs.; M—manure, 12 loads; L—ground limestone, 2 tons. ½ indicates that ½ of this application was applied.

most consistent increases. Potash was needed most while lime showed no benefit.

In 1922, the original applications of fertilizers were repeated on some of the plots, one-half those amounts on others, while still others were left unfertilized, in order to observe the residual effects from the 1921 application. Since the nitrate of soda is entirely used or leached from the soil the first season after application, residual benefits must be due either to the phosphate or to the potash or both. Little residual benefit is apparent except in the case of the manure application. Fertilization with potash and phosphate paid well in the increased yield of potatoes. The plots were again planted to potatoes in 1923 and were fertilized in the same way as in 1922. The potatoes gave promise of producing a very good crop, but killing of the vines by a frost on August 21 reduced the yields below those of 1922. No residual benefits from the 1921 applications of fertilizer and manure are evident in the yields of plots 4, 6, 8 and 10. Plot 15 still gave considerable increase over the unfertilized plot. The lime applied in 1921 produced no effect on yield in 1923. As a whole the yields of 1923 showed more consistent benefit from fertilization than had been secured in the preceding two years, and it is safe to assume that in succeeding years fertilization will produce paying increases on this field at least of potatoes and root crops.

Fertilizer Management of Newly Reclaimed Mucks. Many new mucks are somewhat raw and fibrous even in the surface layers. Decomposition of this material is carried on by the action of bacteria, which may not be present in the virgin soil. These can be supplied, and decomposition hastened, by the addition of barnyard manure, a light application generally being sufficient. If the muck has been pastured, the droppings from the stock will have produced the same effect.

Fig. 14.—An experimental field on muck. Sunflowers, potatoes, sugar beets and oats and vetch are shown in the photograph. The muck was new and little benefit was evident on the strips, which were fertilized crosswise of the crops.

It has been pointed out that the natural supply of plant nutrients present in a new muck is only a temporary condition. Within a comparatively few years, barnyard manure or commercial fertilizer will be necessary to produce satisfactory crops. It is exceedingly important that the farmer know when the decrease in productivity of his soil is due to lack of fertility. A test plot, located on a portion of the field which is representative of the greater portion of the muck, is the only reliable means of determining when fertilization pays. A method of making such a test is outlined on page 68.

Very Shallow Deposits

The life of a very shallow muck soil is, comparatively speaking, short. Each year decomposition and settling continues, and some of the muck is blown away by the wind; the deposit becomes more shallow. After the substratum underlying the muck has been turned up by the plow, whether it be sand, marl or clay, the muck in a comparatively few years becomes a mineral soil. If the underlying soil is a clay loam, the disappearance of the muck need not be considered so great a loss, but, if a sand or marl is underlying, a less productive soil may be the result. Experimental work conducted on three such areas is described below.

Newaygo County Project—1921. Originally this muck was somewhat deeper than it is now; in the clearing operations, the muck was burned over until a layer of about 18 inches was left where the plots were located. The field had been under cultivation about five years; it was cropped to rye in 1919 and oats in 1920. The deposit was rather coarse and woody and was underlain by a white sand. It had never been fertilized.

The investigation was conducted with the purpose of showing the benefits from fertilization, with and without manure. Sunflowers were selected as the crop to be used as an indicator. The average yields of duplicate plots in tons per acre of green sunflowers are presented in Table 7.

Table 7.—Yield of Sunflowers—Newaygo Co.—1921.

Plot No.	Fertilizer application*—lbs. per acre	Manure 10 loads per acre	Manure 2 loads per acre	No manure	Average
		Green weight—tons per acre			
1	No fertilizer (av. 5 plots)	25.0	20.9	17.5	21.1
2	N 100	26.0	24.4	16.7	22.4
3	P 250	23.1	19.3	17.2	19.9
4	K 200	28.0	27.2	21.0	25.4
5	N 100 P 250	23.8	19.8	20.3	21.3
6	N 100 K 200	28.6	26.8	29.5	28.3
7	P 250 K 200	30.5	25.8	26.5	27.6
8	N 100 P 250 K 200	29.9	30.2	28.7	29.6
	Ave. all plots receiving nitrate (2, 5, 6, 8)	27.1	25.3	23.8	25.4
	Ave. same treatments without nitrate (1, 3, 4, 7)	26.7	23.3	20.6	23.5
	Increase due to nitrate	0.4	2.0	3.2	1.9
	Ave. all plots receiving potash (4, 6, 7, 8)	29.3	27.5	26.4	27.7
	Ave. same treatments without potash (1, 2, 3, 5)	24.5	21.1	17.9	21.2
	Increase due to potash	4.8	6.4	8.5	6.5
	Ave. all plots receiving phosphate (3, 5, 7, 8)	26.8	23.8	23.2	24.6
	Ave. same treatments without phosphate (1, 2, 4, 6)	26.9	24.8	21.2	24.3
	Increase (+) or decrease (−) due to phosphate	−0.1	−1.0	+2.0	−0.3

*N—Nitrate of soda; P—Acid phosphate; K—Muriate of potash.

The results indicate that fertilizer cannot be used in complete substitution for manure on this very shallow muck. Potash fertilizers gave good increases, while nitrate and phosphate were of distinct benefit only when combined with potash. The use of nitrate did not pay when applied on the portion of the field receiving the heavy application of manure, while phosphate appeared to be needed only when no manure was used.

Allegan County Project—1922-1924. The original vegetation on the portion of this muck area on which the plots were located was a mixed growth of timber, with elm and ash predominating. The area was drained by ditches, the drainage being somewhat excessive. In depth the soil varied from six inches to two feet, and was underlain by yellow sand, with a thin layer of clay (hardpan) sometimes present. It had been under cultivation for about 30 years. Manure had been applied every four or five years, an average application of nine loads per acre having been made.

The results from this project are presented in Table 8. Little benefit was secured from fertilization in 1922 and 1923, due, it is thought, to the fact that the crops suffered considerably from drought. Growth was limited more by water deficiency than by lack of plant nutrients. Potash appeared to be of some benefit on all crops but not sufficiently to repay its application. Nitrate produced a slight increase in the sugar beets. Manure gave about as good results as commercial fertilizer.

Fig. 15.—A very shallow muck underlaid by sand, which is brought to the surface along the dead furrow. Its life as a muck is limited to a comparatively few years. The end can be delayed by the addition of organic matter in the form of manure, green manure and litter. Keeping the land in sod also is desirable. Better a shallow muck than an unproductive sand.

In 1924, the benefits from fertilization of this muck were much more pronounced than in the preceding two years, due no doubt to the fact that the locality received sufficient rainfall, well distributed throughout the spring and early summer. Alfalfa, mangels, and potatoes gave marked increases in response to fertilization. Potash was needed most for alfalfa and mangels, while stock carrots and potatoes needed both phosphate and potash. Stock carrots gave a good yield without fertilization. Nitrogen, applied in the form of sulphate of ammonia, appeared of little benefit. Manure did not equal the commercial fertilizer in increases produced, except in the case of alfalfa.

St. Joseph County Project—1922. The growth on this muck was

Table 8.—Crop Yields—Allegan Co. Project—1922-24.

Plot No.	Fertilizer application 1922–23 lbs. per acre	1922				1923						
		Corn bu. per acre	Potatoes bu. per acre	Sugar beets crowned tons per acre	Potatoes bu. per acre	Hay—tons per acre			Barley		Oats	
						Alfalfa	Sweet clover	Timothy and clover	Grain bu. per acre	Straw tons per acre	Grain bu. per acre	Straw tons per acre
1	No fertilizer...	47.4	75.1	6.6	69.7	0.5	2.2	0.7	12.2	0.8	42.4	0.8
2	P 300 K 0*..	46.6	67.1	7.4	77.3	0.7	2.0	1.2	17.0	0.9	42.0	1.0
3	P 300 K 100...	50.6	87.5	7.9	79.7	......	......	1.3	20.4	0.9	51.8	1.2
4	P 300 K 200...	43.1	87.1	7.0	83.6	......	......	1.6	23.3	1.0	47.1	0.9
5	P 300 K 300...	54.3	89.4	8.3	85.4	......	2.6	1.6	24.8	0.9	47.7	1.0
6	P 200 K 300...	49.4	77.9	8.7	100.0	......	......	1.4	17.9	1.1	44.6	0.9
7	P 100 K 300...	42.8	73.5	10.9	83.3	......	......	1.4	16.6	0.9	37.5	0.8
8	P 0 K 300...	47.6	73.8	9.3	82.4	1.3	2.5	1.0	11.8	0.7	39.0	1.0
9	No fertilizer...	50.2	47.7	9.6	59.3	......	......	1.0	12.4	0.7	36.7	0.7
10	P 300 K 300...	50.7	64.2	9.8	75.6	......	......	1.7	20.7	0.9	40.7	0.9
11	P 300 K 300 N 100..........	49.8	67.1	10.3	77.4	......	......	1.3	13.8	0.9	41.3	1.2
12	Manure 12 loads (1922)......	51.0	68.1	8.4	52.9	......	......	1.9	16.5	0.9	35.8	0.8
13	Manure 6 (1922) K 100.......	39.9	68.4	7.8	56.9	......	......	1.8	13.4	0.9	30.3	0.8
14	No fertilizer...	47.7	63.3	7.4	63.3	0.7	2.5	1.0	12.3	0.9	37.0	0.8

1924

Plot No.	Fertilizer application—1924 lbs. per acre	Alfalfa—tons per acre			Stock carrots tons per acre	Mangels tons per acre	Potatoes	
		First cutting	Second cutting	Total crop			Bu. per acre	% Marketable
1	No fertilizer.............	1.4	0.6	2.0	13.7	3.0	104.4	85.5
2	P 300 K 0.............	1.7	0.8	2.5	14.9	2.9	108.7	76.1
3	P 300 K 100............	1.5	0.8	2.3	14.6	9.2	203.8	91.5
4	P 300 K 200............	1.8	1.0	2.8	16.7	13.7	186.4	91.9
5	P 300 K 300............	2.1	1.2	3.3	15.9	15.6	225.4	92.7
6	P 200 K 300............	1.8	1.2	3.0	18.4	16.3	215.2	94.3
7	P 100 K 300............	1.9	1.4	3.3	16.5	15.7	189.4	96.6
8	P 0 K 300............	2.0	1.3	3.3	14.9	16.1	148.3	89.8
9	No fertilizer.............	1.7	0.9	2.6	12.1	3.6	110.8	87.7
10	P 300 K 300............	1.9	1.2	3.1	18.1	16.9	228.2	96.8
11	P 300 K 300 S. A. 100....	2.0	1.4	3.4	21.0	13.6	195.1	98.9
12	Manure 12 loads (1922)...	2.2	1.1	3.3	15.4	3.7	113.0	92.4
13	Manure 6 (1922) P 100 K 100...............	2.6	1.0	3.6	20.9	10.7	146.9	94.6
14	No fertilizer.............	1.7	1.0	2.7	17.3	4.6	112.3	75.7

*P—Acid phosphate; K—Muriate of potash; N—Nitrate of soda; S. A—Sulphate of Ammonia.

originally marsh grass. The area was drained by a dredge ditch in 1917. It was first broken up about six years ago and several crops had been successfully grown with the aid of barnyard manure. The muck on the plots was well decomposed and varied from one and one-half to two and one-half feet in depth.

The crop yields (Table 9) from this muck show a good response to potash, and in the cases of rye and potatoes, to phosphate also. Nitrate appears of no benefit except to sugar beets. Manure does not give as good results as were secured from commercial fertilizer.

Table 9.—Crop Yields—St. Joseph Co. Project—1922.

Plot No.	Fertilizer application—lbs. per acre	Spring rye; straw; and grain tons per acre	Potatoes bu. per acre	Sugar beets, crowned tons per acre
1	No fertilizer	1.2	113.9	5.2
2	P 300 K 0*	1.2	119.5	6.7
3	P 300 K 100	2.1	159.7	7.9
4	P 300 K 200	2.3	205.5	9.7
5	P 300 K 300	2.2	185.4	10.2
6	P 200 K 300	2.1	168.1	8.6
7	P 100 K 300	1.8	160.8	9.3
8	P 0 K 300	1.5	158.6	11.6
9	No fertilizer	1.0	106.1	11.8
10	P 300 K 300	1.9	201.8	11.4
11	P 300 K 300 N 100	1.8	174.2	13.3
12	Manure 12 loads	1.4	135.7	9.8
13	Manure 6 K 100	2.1	182.0	12.8
14	No fertilizer	1.5	117.2	9.2
15	Marl 2 tons	1.1	137.3	8.3

*P—Acid phosphate; K—Muriate of potash; N—Nitrate of soda.

Fertilizer Management of Very Shallow Mucks. The results of experimental work, as well as the practices found best suited to **very shallow mucks** by successful muck farmers, point to the need of maintaining the supply of organic matter in the soil. The use of farm manure, coupled with the growing of crops for green manure appears to be the best solution in the maintenance of fertility on this type of muck. As was mentioned before, this is more important on very shallow mucks underlain by sand or marl. Of the crops proving satisfactory as green manure on muck soil, biennial sweet clover, alsike clover, winter rye, oats and soybeans give good results, while the use of cabbage, mangels and turnips as green manure has been reported to the writers by muck farmers as having produced increased crop yields. The clovers and soybeans have the advantage of increasing the nitrogen, as well as the organic matter content, in the soil.

Although the green manure can be used to a large extent as a substitute for barnyard manure in increasing the organic matter content of muck soil, it should be remembered that the potash and phosphoric acid content of the green manure has come out of the soil, so that in turning it under, no permanent increase in the content of the mineral constituents has been made. Commercial fertilizers containing potash and also phosphate and nitrate, if needed, should be added. If barnyard manure is applied in the rotation, phosphate and nitrate are unnecessary in many cases. The addition of straw and of cornstalks has been found beneficial on this type of muck, by decreasing the blowing of the soil.

If the very shallow muck is underlain by heavy loam or clay, the need for potash may gradually disappear and little or no fertilizer, besides barnyard manure, be required. To some extent this appears to be true also of some very shallow mucks underlain by sand, a substratum of white or gray sand generally containing less plant food than one of yellow sand. Specific recommendations of fertilizer mixtures for general crops on shallow muck are given on page 65.

Mucks Which Need Potash Only

Many Michigan mucks need only a potash fertilizer. If increased yields result from phosphate applications, they are usually not sufficient to pay for the fertilizer. Some mucks appear to require only potash for certain crops and both potash and phosphate for others. In many mucks, yields decrease when phosphate is applied without potash, apparently because, as previously explained (page 26), of the effect of the phosphate in hastening maturity. Usually a very marked response to potash fertilization is secured, if a muck has been long under cultivation.

Berrien County Project—1921 and 1923. This deposit is to a rather large extent of slough grass (sedge) origin, with considerable very fine material of deep-water origin intermingled. The surface layer is finely divided, well decomposed and black. The muck is six to seven feet in depth and underlain by sand. The soil is very impervious, water standing in pools for some time after a rain, even at short distances from a ditch. The field had been cropped for a number of years; the crop of cabbage grown in 1920 having been a failure. The composition of the surface layer, given under Muck No. 5 (Table 2, page 23), shows it to be strongly acid, even though it contains considerable lime. It is only moderately high in content of organic matter and of phosphoric acid.

The results with the Berrien County muck (Table 10) indicate that

Table 10.—Crop Yields—Berrien County Muck—1921-1923.

Plot No.	Fertilizer application lbs. per acre	Corn: Ears bu. per acre	Corn: Stover tons per acre	Sunflowers green wt. tons per acre	Stock carrots tons per acre	Sugar beets crowned tons per acre	Mangels
1	N 100*..............	9.4	0.6	8.5	5.5	0.7	0.01
2	P 250................	7.2	0.6	9.0	5.8	0.2	0.00
3	K 200................	60.2	1.6	25.4	22.5	2.9	1.9
4	No fertilizer..........	13.8	0.8	11.2	6.1	0.6	0.1
5	N 100 P 250..........	13.9	0.8	9.6	5.4	0.5	0.01
6	N 100 K 200..........	51.2	1.4	25.6	25.4	2.2	2.9
7	P 250 K 200..........	56.5	1.6	23.2	18.0	1.8	2.3
8	No fertilizer..........	9.0	0.8	8.5	5.9	0.4	0.03
9	N 100 P 250 K 200....	71.3	1.9	23.5	22.7	2.6	2.7
10	M 12 loads...........	46.4	1.5	22.7	8.2	2.0	0.2
11	No fertilizer..........	19.6	0.7	9.8	4.2	0.3	0.02
Average unfertilized plots..		14.1	0.8	9.8	5.4	0.4	0.05

Plot No.	Fertilizer application—1923—lbs per acre.	Hungarian millet Cured hay tons per acre
1	No fertilizer........	0.9
2	P 0 K 300*........	2.0
3	P 100 K 300........	2.5
4	P 300 K 300........	2.7
5	P 300 K 200........	2.3
6	P 300 K 100........	1.8
7	P 300 K 0........	0.9
8	No fertilizer........	1.1
9	P 300 K 300 N 100........	2.3

*P—Acid phosphate; K—Muriate of potash; N—Nitrate of soda; M—Manure.

potash was needed greatly for crop production, while nitrate was beneficial with some crops. The only crop which phosphate appeared to benefit at all was corn, this benefit appearing only when the phosphate was applied in a complete fertilizer (plot 9). The very low yields of sugar beets on all plots was due apparently either to poor drainage or to the strongly acid condition of the soil. Stock carrots, which tolerate more acid conditions and more moisture than beets, produced well although grown next to the sugar beets on the plots.

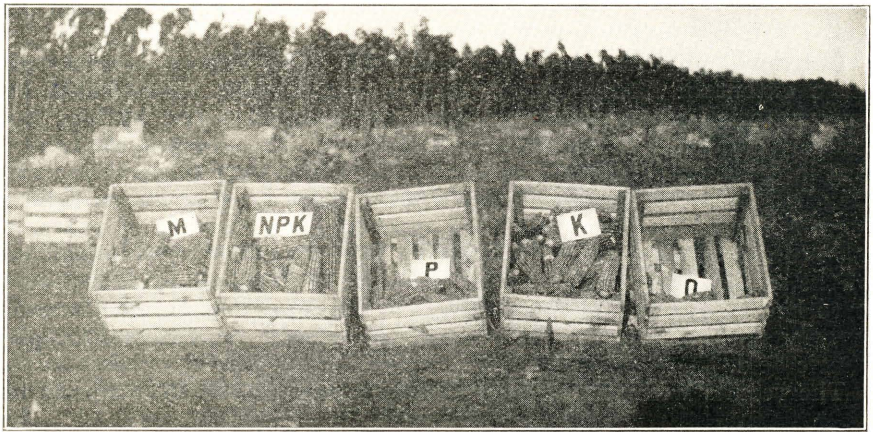

Fig. 16.—Corn on muck. From left to right, fertilized with: 1, manure; 2, complete fertilizer; 3, acid phosphate; 4, muriate of potash; 5, no fertilizer. The greatest profit was secured on this field from the application of potash alone.

The very heavy rainfall of the spring of 1922 prevented continued investigation on this muck. In the spring of 1923 a new set of plots was laid out in a field adjacent to that in which the 1921 plots were located. Lime was applied to one half of all plots, hydrated lime being used at the rate of one ton per acre. Potatoes, sugar beets, cabbage and Hungarian millet were grown. During the early part of the summer, the crops showed marked benefit from fertilization, both potash and phosphate appearing to be needed. Of the four crops, only sugar beets appeared to be benefited by the lime application. Heavy and continued rains, which began in August, resulted in crop failure of all except the Hungarian millet, which was harvested before the rains began. Differing from the results secured in 1921, the yields of millet (Table 10) increased when phosphate was applied with potash.

Lapeer County Project No. 1—1921-1922. The original vegetation on this muck was a mixture of ash, white cedar and tamarack. It was first drained in 1888, cleared in 1890 and broken up. For about twelve years after breaking, good crops are reported to have been secured without fertilization, yields of 50 bushels of corn and of oats and two tons of timothy per acre being obtained. After that the yields decreased and crop failures were common. The muck varied from two to four feet in depth where the plots were located and the surface layer was relatively high in mineral matter, lime and phosphoric acid, as indicated in Table 2 (Muck No. 11, page 23). Drainage was hardly satisfactory, the water level averaging about two feet below the surface.

The crop yields are given in Table 11. Both nitrate and phosphate were of little benefit and this was secured only when they were used with potash. Potash produced very large increases in the yield of all crops. Stock carrots was the only crop to yield well without fertilization. Although manure produced large crop increases, they were in no case as great as those secured with commercial fertilizer.

In 1922, a new set of plots was established in the field adjoining that of 1921. Here the muck was four feet or more in depth. Owing to continued rains it was impossible to get the crops in until late and, throughout the summer, the muck was very wet. As a result, the yields (Table 11) were rather low. In this case, also, lack of potash proved to be the chief limiting factor in crop production, although phosphate gave considerable benefit on two of the three crops, when it was applied with potash. Nitrate appeared unnecessary.

Table 11.—Crop Yields—Lapeer Co. Muck No. 1—1921-1922.

1921

Plot No.	Fertilizer application lbs. per acre	Corn: Ears bu. per acre	Corn: Stover tons per acre	Potatoes bu. per acre	Mangels tons per acre	Stock carrots tons per acre	Sugar beets, crowned tons per acre
1	N 100 (2)	5.9	0.5	66.1	12.2	14.1	2.5
2	P 250	16.4	1.0	59.2	3.5	14.1	2.1
3	K 200	7.7	2.3	147.7	(1) 15.7	22.3	8.2
4	No fertilizer	9.7	0.7	49.4	5.6	16.3	2.3
5	N 100 P 250	11.3	0.8	55.9	9.3	21.4	3.0
6	N 100 K 200	68.6	1.9	110.0	27.3	24.9	11.1
7	P 250 K 200	71.8	2.9	126.0	20.1	29.2	9.4
8	N 100 P 250 K 200	67.5	2.4	133.2	24.1	29.1	10.8
9	M 12 loads	55.4	1.5	103.8	16.7	26.7	10.3

1922

Plot No.	Fertilizer application—lbs. per acre	Hungarian millet dry hay tons per acre	Potatoes bu. per acre	Sugar beets crowned tons per acre
1	No fertilizer	0.04	14.8	0.9
2	P 0 K 300 (2)	1.0	59.8	6.9
3	P 100 K 300	1.4	101.6	6.6
4	P 200 K 300	1.6	105.2	6.9
5	P 300 K 300 (3)	1.1	94.4	6.3
6	P 300 K 200	1.8	99.1	4.3
7	P 300 K 100	1.2	73.1	4.1
8	P 300 K 0	0.1	24.7	2.7
9	No fertilizer	0.1	25.2	2.9
10	P 300 K 300	1.3	56.6	4.5
11	P 300 K 300 N 100	1.4	63.7	6.3
12	No fertilizer	0.1	24.9	1.7

(1) Poor stand of mangels on plot 3.

(2) N—Nitrate of soda; P—Acid phosphate; K—Muriate of potash; M—Manure.

(3) This plot was quite soddy, which probably accounts for the slight decrease in yields as compared with plots 4 and 6.

Eaton County Project—1922-1924. This muck area was originally timbered with a mixed growth, tamarack predominating. The part on which the plots were located was three feet or more in depth. The surface layer was rather well decomposed and fairly high in lime content (Muck No. 14, Table 2, page 23). The phosphoric acid content was fairly low. The field was first broken up several years ago but, because of poor drainage, it was allowed to lie idle. In 1919, the level of the lake into which the area drained, was lowered about five feet, permitting better drainage. The muck was broken up in the spring of 1920, fertilized with 200 pounds per acre of acid phosphate and planted to corn. Due to the newness of the land, a good yield resulted. In 1921, the field was fertilized with 200 pounds of a 1-8-4 mixture and planted to sugar beets. A hard freeze, during early growth, damaged the beets in part of the field but where they were uninjured, the crop was good.

Table 12 gives the average crop yields from duplicate plots for 1922. With the exception of potatoes, phosphate was of no benefit to the crops. As was stated previously, fertilizers applied the two preceding years were high in phosphate, the residual effect from which probably rendered the phosphate applied in 1922 less needed than would otherwise have been the case. Nitrate appeared to increase the yield of potatoes but had little effect on the other crops. This effect of nitrate on potato yields is not ordinarily secured.

The same applications of fertilizer were again made on these plots in the spring of 1923. The yields of the several crops (Table 12) largely confirm the conclusions drawn from the crops of the previous year. Phosphate appeared of slightly greater benefit; while nitrate gave little or no increase. The yields of potatoes secured from the different rates of application of potash would indicate that the maximum application of 300 pounds per acre of muriate of potash was not

Table 12.—Crop Yields—Eaton Co. Project—1922-1924.

1922

Plot No.	Fertilizer application—1922 lbs. per acre	Hungarian millet and soybeans, cured hay tons per acre	Sugar beets (crowned) tons per acre	Potatoes	
				Bu. per acre	Percentage marketable
1	No fertilizer	1.3	2.5	55.0	68.1
2	P 300 K 0*	1.7	2.7	53.8	77.3
3	P 300 K 100	2.3	3.9	133.0	89.0
4	P 300 K 200	3.2	5.2	210.3	97.6
5	P 300 K 300	3.4	6.0	225.2	96.5
6	P 200 K 300	3.6	5.5	215.0	95.5
7	P 100 K 300	3.2	6.5	220.8	94.6
8	P 0 K 300	3.6	6.1	185.1	96.5
9	No fertilizer	1.9	2.4	56.1	62.5
10	P 300 K 300	3.8	6.2	258.5	95.7
11	P 300 K 300 N 100	3.0	6.5	294.8	95.9
12	Manure 12 loads	3.3	5.0	235.7	90.5
13	Manure 6 loads K 100	3.1	4.5	220.5	95.5
14	No fertilizer	1.9	1.8	69.0	....

*P—Acid phosphate; K—Muriate of potash; N—Nitrate of soda.

Table 12. (Cont.)—Crop Yields—Eaton Co. Project—1922-1924.

1923

Plot No.	Fertilizer application—1923 lbs. per acre	Cured hay—tons per acre					Grain				Potatoes	
		Sweet clover	Timothy and clover	Alfalfa			Oats		Barley		Total yield bu. per acre	Percentage marketable
				1st cutting	2nd cutting	Total yield	Grain bu. per acre	Straw tons per acre	Grain bu. per acre	Straw tons per acre		
1	No fertilizer.	1.6	0.8	1.2	0.8	2.0	31.3	1.4	9.5	0.8	101.0	81.2
2	P 300 K 0*	1.5	0.8	1.5	1.3	2.8	29.1	0.9	7.0	0.8	69.5	55.7
3	P 300 K 100.	2.4	1.6	2.0	1.8	3.8	48.8	1.5	26.7	1.7	237.3	89.2
4	P 300 K 200.	2.7	1.8	2.3	1.4	3.7	53.3	2.0	30.4	2.1	295.1	97.8
5	P 300 K 300.	2.7	1.7	2.1	1.7	3.8	53.1	2.1	31.8	2.2	350.1	97.3
6	P 200 K 300.	2.7	1.6	2.1	1.7	3.8	52.2	1.8	35.3	2.3	301.4	97.9
7	P 100 K 300.	2.5	1.7	1.9	1.3	3.2	53.0	1.9	29.5	2.0	294.6	98.7
8	P 0 K 300.	2.3	1.5	1.9	1.2	3.1	55.2	1.5	32.5	1.8	262.7	97.1
9	No fertilizer.	1.2	1.0	1.4	1.0	2.4	40.1	1.3	13.1	1.0	123.4	82.9
10	P 300 K 300.	2.5	1.7	......	1.5	......	63.2	2.3	29.6	1.8	308.5	98.1
11	P 300 K 300 N 100....	2.6	1.6	......	1.6	......	57.4	2.3	33.2	2.4	351.5	97.1
12	Manure 12 loads (1922)..	2.0	1.5	......	0.9	......	54.6	2.0	33.8	1.9	139.5	91.1
13	Manure 6 (1922) K 100	1.9	1.6	......	0.8	......	57.5	2.1	30.3	1.7	180.9	97.8
14	No fertilizer.	1.0	1.0	......	0.8	......	36.7	1.4	18.4	1.1	89.9	78.6

1924

Plot No.	Fertilizer application—1924 lbs. per acre	Timothy tons per acre	Alfalfa—tons per acre			Potatoes	
			First cutting	Second cutting	Total crop	Bu. per acre	Percentage marketable
1	No fertilizer......................	0.9	1.0	0.4	1.4	94.2	76.3
2	P 300 K 0*......................	1.0	1.2	0.5	1.7	114.8	84.0
3	P 300 K 100......................	2.0	1.7	1.0	2.7	316.2	93.6
4	P 300 K 200......................	2.4	1.9	1.1	3.0	384.2	96.0
5	P 300 K 300......................	2.7	2.1	1.3	3.4	447.2	96.7
6	P 200 K 300......................	2.0	1.9	1.3	3.2	437.2	95.6
7	P 100 K 300......................	2.0	1.8	1.1	2.9	353.6	96.4
8	P 0 K 300......................	1.3	1.3	0.8	2.1	293.2	95.9
9	No fertilizer......................	1.1	1.1	0.7	1.8	145.5	84.1
10	P 300 K 300......................	2.3	1.7	1.2	2.9	401.4	94.2
11	P 300 K 300 S. A. 100............	2.4	1.9	1.2	3.1	392.9	92.7
12	Manure 12 loads (1922)............	1.6	1.5	0.6	2.1	178.4	86.8
13	Manure 6 (1922) K 100............	1.7	1.3	0.5	1.8	220.3	91.6
14	No fertilizer......................	1.0	1.0	0.4	1.4	97.7	71.6

*P—Acid phosphate; K—Muriate of potash; S. A.—Sulphate of ammonia; N—Nitrate of soda.

sufficient. The manure application of 1922 did not produce as much effect as commercial fertilizer on the crops of 1923, except in the grain crops. In the case of the first cutting of alfalfa, the plots 10 to 14, inclusive, were so weedy that the stand was considered a failure and no yields were secured. After the removal of the weeds, a good yield of clean alfalfa hay was secured in the second cutting.

In 1924 the same applications of fertilizer were again made on all plots. The yields of timothy, alfalfa and potatoes again showed marked response to both phosphate and potash, the heaviest applications producing the highest yields. With the potato crop, the yields indicate that 300 pounds per acre of acid phosphate is sufficient but that higher yields might have been secured with a still heavier application of muriate of potash. Nitrogen applied in the form of sulphate of ammonia was of little or no benefit to any of the crops. The manure application of 1922 still produced an increase in crop yields but the increases did not equal those produced by commercial fertilizers.

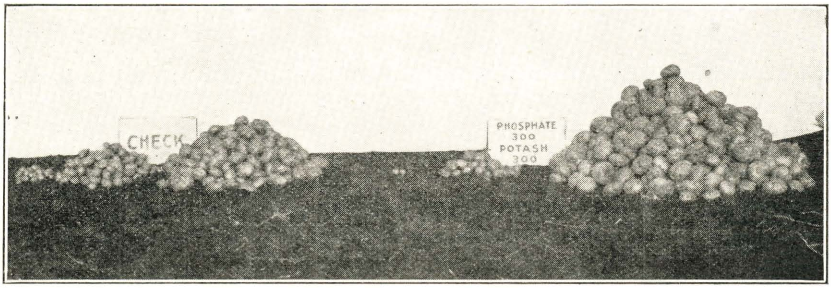

Fig. 17.—Potatoes on muck. Those at the left were not fertilized while those at the right were fertilized with 300 pounds per acre each of 16% acid phosphate and 50% muriate of potash (equivalent to an 0-8-25 mixture). Note the effect of fertilization on the proportion of grade 1, grade 2 and cull potatoes. Yield of grade 1 potatoes; unfertilized, 85 bushels; fertilized, 340 bushels per acre.

High-Lime Mucks Needing Both Potash and Phosphate

Schoolcraft County Project—1923*. These plots were established on the Seney Swamp, an extensive muck area covering approximately 15 townships. Mr. Jeffery states that "Forty-three years ago, this region was so badly burned that the tamarack timber was destroyed, either directly, or by subsequent fires burning over the fallen timber. A grass vegetation succeeded, and this in turn has been destroyed by fires, which have occurred largely since the area was drained with open ditches about 12 years ago. The upper six inches of the soil in the vicinity of the plots was quite open, but the subsoil below that depth was inclined to be gummy or waxy in consistency."

The muck varied in depth from six inches to ten or more feet in different places in the area. That in the vicinity of the plots was two and one-half to three feet in depth. This portion was lightly burned over in 1919. Drainage was secured by one ditch 30 rods east and by another 60 rods south of the plots. The field had never been plowed, cropped or fertilized previous to the establishment of the plots. According to measurements made by Mr. Jeffery, the water table in the vicinity of the plots was at a depth of about 18 inches during the early part of the growing season, with a gradual lowering to two feet by June 22 and a variation in depth between two and three feet during July and August.

*This project was conducted in co-operation with, and the success of the project is due to Jos. A. Jeffery, Agricultural Development Agent of the D., S. S. & A. R. R. Co., who had charge of the plots. Mr. Jeffery was formerly professor in the Soils Department at Michigan State College.

The land on which the plots were established was not plowed but the seed bed was prepared by a thorough disking. The oats were rolled with a heavy roller when they appeared, about two weeks after planting.

The yields from the various plots (Table 13) showed marked benefit from the application of fertilizer. Potash appeared to be needed most

Table 13.—Yield of Oats—Schoolcraft Co.—1923.

Plot No.	Fertilizer application—lbs. per acre	Grain bu. per acre	Straw tons per acre
1	No fertilizer	28.3	1.8
2	P 0 K 300*	56.2	2.2
3	P 100 K 300	66.1	2.4
4	P 200 K 300	66.7	2.4
5	P 300 K 300	56.4	2.1
6	P 300 K 200	56.1	1.8
7	P 300 K 100	51.3	1.9
8	P 300 K 0	26.8	1.3
9	No fertilizer	26.5	1.1
10	P 300 K 300	44.6	1.7
11	P 300 K 300 N 100	59.4	2.1
12	Manure 12 tons	39.0	2.3
13	Manure 6 K 100	55.3	1.9
14	No fertilizer	15.9	0.7

*P—Acid phosphate; K—Muriate of potash; N—Nitrate of soda.

but phosphate seemed slightly beneficial on some plots. Nitrate probably was of no benefit. Manure alone did not produce the increase secured by commercial fertilizer but half the application of manure plus 100 pounds of muriate of potash per acre gave practically as good results as heavier applications of potash.

Gratiot County Muck—1922-1923. The forest vegetation, which originally covered this muck area, was largely tamarack. It was cleared off several years ago and the field on which the plots were located was broken in 1920. The field was burned over very slightly in 1917. No satisfactory crops had been produced previous to the plot work. The muck was very loose and only fairly well decomposed. Analysis (Table 2, muck No. 8, page 23) shows the surface layer to be rather low in mineral matter but fairly high in lime. At a depth of three feet the soil is underlain by sand or sandy clay.

The yields secured from this muck in 1922 (Table 13A) indicate that, although the soil is fairly new, both phosphate and potash are needed. This is most evident in the yields of sugar beets from the various plots. Nitrate gave little benefit but, as is often the case on a new muck, manure produced very good results.

The plots were fertilized in 1923 in the same manner as in 1922, with the exception of the manure application on plots 12 and 13, which were not repeated. With sweet clover and timothy and clover, considerable benefit resulted from fertilization, particularly with potash. The manure and manure-potash applications produced nearly as high yields as did the fertilizer combinations.

Ingham County Project No. 1—1922-1923. These plots are located two miles north of the College on what is known as Chandler's Marsh.

Table 13A.—Crop Yields—Gratiot Co. Muck—1922 and 1923.

Plot No.	Fertilizer application—lbs. per acre	1922			1923		
		Hubam clover dry hay tons per acre	Potatoes bushels per acre	Sugar beets crowned tons per acre	Cured hay tons per acre		
					Sweet clover	Timothy and clover	Alfalfa
1	No fertilizer	1.8	94.5	(2) 4.1	1.7	1.3	0.8
2	P 0 K 300 (1)	2.3	126.8	11.1	2.4	2.2	0.9
3	P 100 K 300	2.7	124.2	12.7	2.2	2.4	0.9
4	P 200 K 300	2.3	111.3	14.8	2.0	2.5	1.1
5	P 300 K 300	2.7	133.3	11.8	2.1	2.6	1.0
6	P 300 K 200	2.4	132.0	12.4	1.7	2.5	0.9
7	P 300 K 100	2.2	155.3	10.7	2.2	2.2	1.1
8	P 300 K 0	2.6	99.6	7.6	1.6	1.4	0.9
9	No fertilizer	2.5	122.9	8.0	1.5	1.4	0.9
10	P 300 K 300	2.4	....	14.3	....	1.7	....
11	P 300 K 300 N 100	2.1	134.8	14.9	....	1.4	....
12	Manure 12 (1922)	2.0	134.6	11.6	1.8	2.3	0.9
13	Manure 6 (1922) K 100	2.3	134.6	11.5	2.1	2.2	0.9
14	No fertilizer	2.1	....	8.7	....	....	....

(1) P—Acid phosphate; K—Muriate of potash; N—Nitrate of soda.
(2) Sugar beets on plot 1 injured by cattle.

The original vegetation was largely slough grass (sedge) with a scattered growth of trees. The area was drained in 1916, and the muck is fairly well decomposed and about 6 feet deep. Analysis of the surface layer (Muck No. 7, Table 2, page 23) shows the soil to be well supplied with lime but to contain only a moderate amount of phosphoric acid. The field was pastured for several years until 1918, when it was broken up. Corn was raised for the next two years, the first crop being frozen to the ground in July, while the second escaped until the first part of September and produced a fair crop. Sugar beets grown on the field in 1920 and 1921 yielded rather poorly.

Table 14.—Crop Yields—Ingham Co. Project No. 1—1922-1924.

1922

Plot No.	Fertilizer application—1922 lbs. per acre*	Hungarian millet cured hay tons per acre	Sunflowers green wt. tons per acre	Stock carrots tons per	Turnips tons per acre	Sugar beets crowned tons per acre
1	No fertilizer	0.6	23.2	10.0	4.6	2.7
2	P 0 K 300	1.4	26.5	11.3	12.5	4.5
3	P 100 K 300	1.2	24.2	15.3	15.3	5.4
4	P 200 K 300	1.3	23.9	14.9	14.1	6.2
5	P 300 K 300	1.3	27.8	14.4	15.1	7.1
6	P 300 K 200	1.2	24.4	13.6	13.0	6.2
7	P 300 K 100	1.0	24.7	12.2	9.8	5.4
8	P 300 K 0	0.4	17.7	7.7	5.6	3.0
9	No fertilizer	0.5	20.4	7.2	6.7	2.7
10	P 300 K 300	1.4	28.6	10.9	15.9	6.8
11	P 300 K 300 N 100	1.4	23.4	13.7	15.4	7.1
12	Manure 12 loads	1.5	30.6	13.3	14.8	7.4
13	No fertilizer	0.9	22.5	7.2	8.0	3.2

*P—Acid phosphate; K—Muriate of potash; N—Nitrate of soda.

Table 14.—(Cont.) Crop Yields—Ingham Co. Project No. 1—1922-1924.

1923

Plot No.	Fertilizer application—1923 lbs. per acre	Cured hay—tons per acre: Sweet clover	Cured hay—tons per acre: Timothy and clover	Cured hay—tons per acre: Alfalfa	Stock carrots tons per acre	Sugar beets tons per acre	Potatoes bu. per acre
1	No fertilizer	1.0	0.9	0.5	....	3.3	40.2
2	P 0 K 300*	2.5	1.5	1.1	17.6	5.9	84.7
3	P 100 K 300	2.4	1.5	1.0	18.1	7.2	90.4
4	P 200 K 300	2.4	1.2	0.7	19.9	6.6	99.5
5	P 300 K 300	2.5	0.9	0.8	19.3	5.2	94.7
6	P 300 K 200	2.3	....	0.8	19.6	5.5	88.5
7	P 300 K 100	2.0	....	0.8	17.5	5.0	76.5
8	P 300 K 0	1.2	0.7	0.9	12.4	3.4	27.3
9	No fertilizer	1.2	0.7	0.6	11.3	2.8	26.8
10	P 300 K 300	2.2	1.1	0.9	18.1	6.9	99.0
11	P 300 K 300 N 100	2.5	1.0	0.7	19.7	8.2	93.3
12	Manure 12 loads (1922)	2.4	1.3	1.0	16.0	6.6	50.2
13	No fertilizer	....	....	....	12.6	3.3	36.4

1924

Plot No.	Fertilizer application—1924 lbs. per acre	Cured hay—tons per acre: Timothy and clover	Cured hay—tons per acre: Alfalfa: 1st cutting	Cured hay—tons per acre: Alfalfa: 2nd cutting	Cured hay—tons per acre: Alfalfa: Total yield	Mangels tons per acre	Stock carrots tons per acre	Rutabagas tons per acre	Sugar beets crowned tons per acre	Potatoes: Bu. per acre	Potatoes: Per cent marketable
1	No fertilizer	1.1	......	......	......	7.9	6.3	7.6	3.6	88.0	89.9
2	P 0 K 300*	3.1	1.2	1.1	2.3	20.2	7.9	22.6	10.0	124.3	93.5
3	P 100 K 300	3.2	1.5	1.2	2.7	23.3	7.4	27.1	12.1	124.3	94.8
4	P 200 K 300	2.8	1.4	1.2	2.6	21.0	10.8	23.7	12.6	208.2	96.9
5	P 300 K 300	3.3	1.3	1.3	2.6	21.8	9.2	26.2	13.2	242.9	99.3
6	P 300 K 200	3.5	1.5	1.3	2.8	18.1	9.5	25.8	11.6	214.7	97.7
7	P 300 K 100	3.8	1.7	1.3	3.0	11.1	8.1	22.5	11.6	151.7	95.2
8	P 300 K 0	2.1	1.3	0.9	2.2	6.4	5.7	7.3	5.3	79.1	69.4
9	No fertilizer	2.5	1.4	1.1	2.5	8.8	4.4	11.7	4.0	92.0	79.8
10	P 300 K 300	......	......	1.5	......	18.5	9.3	20.7	11.7	160.6	96.5
11	P 300 K 300 S. A. 100	......	2.2	1.5	3.7	23.0	9.6	23.0	13.6	226.8	97.8
12	Manure 12 loads (1922)	......	2.0	1.2	3.2	14.8	5.5	19.1	10.7	75.9	80.8
13	No fertlizer	......	......	0.9	......	6.3	6.6	16.0	3.0	66.2	73.2

*P—Acid phosphate; K—Muriate of potash; S. A.—Sulphate of ammonia; N—Nitrate of soda.

Experimental plots were established in the spring of 1922. Fertilizers, as indicated in Table 14, were applied to the plots in 1922 and again in 1923 and 1924 but no manure was applied during the latter years. Although planting was rather late in 1922, good yields were secured from the fertilized plots. Though the results from the sunflowers, millet and other hay crops indicate that potash is the fertilizing constituent most seriously lacking, the results with the root crops indicate that phosphate also is needed. Nitrate produced little or no increase in yield. The manure application brought about very good increases in all crops, both in 1922 and 1923, with the exception of potatoes in the latter year.

In 1924, the large increases produced by commercial fertilizers were again evident, very good yields being secured with all the crops grown. Because of the very wet condition of the muck in the early part of the season, and the differences in drainage of the plots, the yields from the various plots are not in all cases proportional to the amount of fertilizer applied. Both phosphate and potash were necessary for good yields, while nitrogen appeared slightly beneficial in some cases. With the exception of the hay crop, the manure application of 1922 did not produce the increases in yield secured with commercial fertilizer.

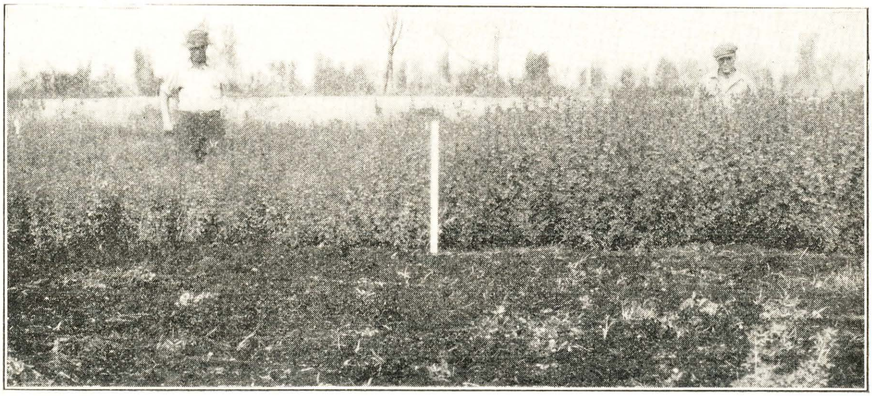

Fig. 18.—Sweet clover on muck. Left—unfertilized—yield per acre 1.3 tons. Right—fertilized with 300 pounds each of acid phosphate and muriate of potash—yield 2.6 tons.

Huron County Project—1922-1924. The forest which grew on this deposit was a mixed growth of swamp pine, white cedar, tamarack and ash. This swamp has an area of approximately 750 acres. The portion on which the plots were located was cleared about 25 years ago, but was allowed to grow up to brush without any attempt at farming having been made. It was drained by a large ditch about eight years ago and cleared and burned over slightly the following year. The field on which the plots were located was broken up and, in successive years, cropped to corn, oats, seeded to timothy and alsike, hay, corn and timothy and alsike, without a nurse crop. From the first, poor yields prevailed. In the spring of 1922, six years after the first breaking, the field was used for experimental plots.

The muck on this field was fairly well decomposed, but very loose. Analysis (Muck No. 13, Table 2, page 23) shows it to be rather low in mineral matter and phosphoric acid, but relatively high in lime. The soil was from four to six feet deep where the plots were located, and underlain by an impure marl. The water level generally was between three and four feet below the surface.

The experimental plots on this area were laid out in two sets of seven each, plots 8 to 14 being nearer the ditch and better drained than plots 1 to 7. The yields of several crops (Table 15) grown on the plots in 1922 and 1923, plainly indicate the marked need of both potash and phosphate on this soil. Phosphate was more important for the above-ground and potash for the below-ground crops but the combin-

Table 15.—Crop Yields—Huron Co. Project—1922-1924.

Plot No.	Fertilizer application—1922–23 lbs. per acre	1922 Sweet clover cured hay tons per acre	1922 Spring rye bu. per acre	1922 Sugar beets tons per acre	1922 Potatoes bu. per acre	1923 Cured hay tons per acre: Sweet clover	1923 Cured hay tons per acre: Timothy and clover	1923 Oats: Grain bu. per acre	1923 Oats: Straw tons per acre	1923 Turnips tons per acre	1923 Potatoes bu. per acre
1	P 0 K 300 (1)	1.3	5.4	7.9	81.6	0.2	1.3	5.1	2.1	21.3	124.8
2	P 100 K 300	2.7	9.3	9.3	94.4	0.9	2.0	7.9	1.8	27.4	185.1
3	P 200 K 300	4.0	12.8	8.3	118.3	1.8	2.2	13.8	1.7	23.4	182.2
4	P 300 K 300	3.3	14.2	8.7	110.3	1.6	2.6	(3)1.8	2.9	19.2	150.6
5	No fertilizer	1.2	2.9	4.2	72.0	0.3	1.5	5.8	2.6	15.1	70.4
6	Manure 12 loads (1922)	3.8	7.8	7.6	104.0	0.9	1.6	7.7	2.7	22.8	119.6
7	Manure 6 (1922) K 100 (2)	2.0	6.6	8.2	81.6	1.3	2.4	20.1	1.9	16.8	103.4
8	No fertilizer	1.4	4.7	3.5	32.0	0.4	0.8	13.2	1.2	6.9	52.6
9	P 300 K 0	2.6	7.4	3.9	51.2	0.5	1.7	4.3	1.6	7.1	45.7
10	P 300 K 100	2.5	9.7	5.8	88.0	1.3	2.1	40.4	2.7	20.5	116.5
11	P 300 K 200	3.4	8.8	7.8	94.4	1.3	2.3	46.9	2.3	26.2	149.1
12	P 300 K 300	3.1	10.5	10.7	78.4	1.7	2.7	46.3	2.5	28.7	139.4
13	P 300 K 300 N 100	3.4	8.9	10.4	80.0	2.2	2.7	48.3	2.7	21.4	131.9
14	No fertilizer	1.0	4.3	5.4	67.2	0.4	1.4	......	......	......	.....

1924

Plot No.	Fertilizer application—1924 lbs. per acre	Cured hay tons per acre: Mixed timothy, alsike and sweet clover	Cured hay tons per acre: Timothy	Grain, Oats: Grain Bu. per acre	Grain, Oats: Straw tons per acre	Grain, Barley: Grain bu. per acre	Grain, Barley: Straw tons per acre
1	P 0 K 300 (1)	0.7	0.4	11.0	0.9	18.7	1.2
2	P 100 K 300	1.7	1.5	17.8	2.0	15.2	1.4
3	P 200 K 300	1.6	2.5	32.8	2.4	25.9	1.8
4	P 300 K 300	1.5	2.2	30.9	3.0	(4)	....
5	No fertilizer	0.6	0.4	13.1	1.1	....	....
6	Manure 12 loads (1922)	0.8	0.6	7.5	1.1	....	....
7	Manure 6 (1922) P 100 K 100	1.8	1.9	29.8	1.8	....	....
8	No fertilizer	0.4	0.3	13.9	1.0	6.2	0.6
9	P 300 K 0	1.3	1.1	16.6	1.4	(4) 1.3	0.5
10	P 300 K 100	2.2	1.8	34.1	2.2	4.9	1.3
11	P 300 K 200	2.6	1.9	44.7	2.2	5.0	1.6
12	P 300 K 300	2.8	2.1	56.1	2.5	20.7	1.7
13	P 300 K 300 S. A. 100	2.7	2.4	38.3	2.8	23.3	1.9
14	No fertilizer	0.8	0.5	....	....	5.4	0.8

(1) P—Acid phosphate; K—Muriate of potash; N—Nitrate of soda; S. A.—Sulphate of ammonia.

(2) Plot No. 7 received also acid phosphate at the rate of 100 pounds per acre in Spring of 1923.

(3) The oats on plot 4 in 1923 were very badly lodged.

(4) Plots 4 to 7 and 9 to 11 inclusive were badly blighted, due to injury by a light frost.

ation of the two was most beneficial; a fairly heavy application of both fertilizers gave the best results. Nitrate was of little or no benefit. Manure produced marked increases in yield but not as great as were secured by the fertilizer combination. Plots 1 and 14 contained some small "burn outs" which in some cases increased the yields of the crops.

The results secured in 1924 show, even more than those secured in the two preceding years, the marked need of both phosphate and potash on this soil. In amounts, the 300 pound application of muriate of potash gave higher yields than smaller applications, while the 200 pound application of acid phosphate appeared to be ample for the crops grown. The manure application of 1922 had little effect on the yields of 1924, but the combination of manure, phosphate and potash gave very good results. Nitrogen, applied as sulphate of ammonia, produced little or no effect. The barley on plots 4, 5, 6, 7, 9, 10 and 11 was injured by a light frost, the crop on the first four being a complete failure.

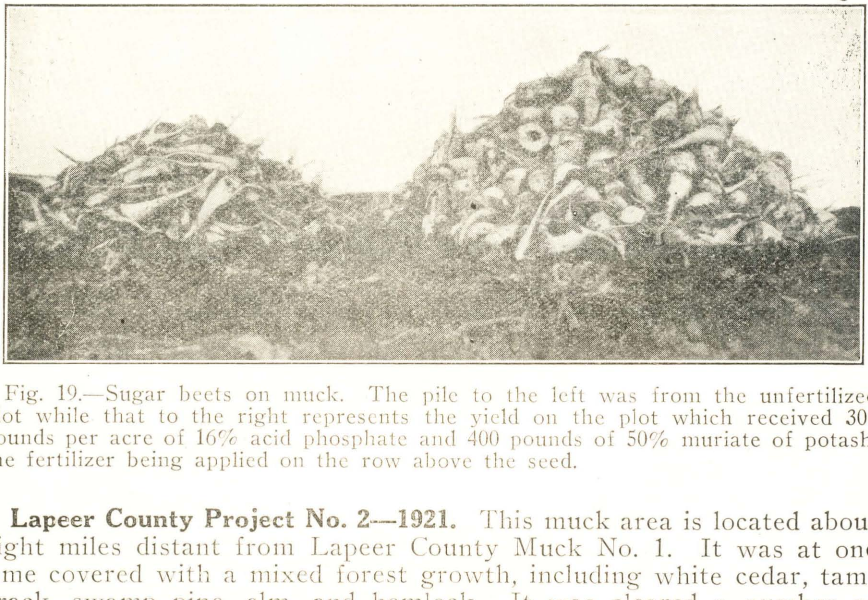

Fig. 19.—Sugar beets on muck. The pile to the left was from the unfertilized plot while that to the right represents the yield on the plot which received 300 pounds per acre of 16% acid phosphate and 400 pounds of 50% muriate of potash, the fertilizer being applied on the row above the seed.

Lapeer County Project No. 2—1921. This muck area is located about eight miles distant from Lapeer County Muck No. 1. It was at one time covered with a mixed forest growth, including white cedar, tamarack, swamp pine, elm, and hemlock. It was cleared a number of years ago and had been pastured to a considerable extent. Drainage was not adequate for good crops until about seven years ago when a large ditch was dug through the marsh. The muck was approximately eight feet deep and underlain by sand. Analysis (Muck No. 12, Table 2, page 23) showed this soil to be relatively very hibh in lime.

The response of this muck to fertilization (Table 16) was very marked, phosphate being considerably more important than potash for most crops. This fertilizer need was manifested in a much more abundant growth of weeds, where phosphate and potash were applied, and in the greater growth of June grass pasture, potash producing a 200 per cent and potash and phosphate a 600 per cent increase in growth over the unfertilized muck. Of the crops grown, corn and sugar beets responded most to potash, while phosphate was more important in increasing the yields of sweet clover. Manure failed to equal fertilizer in increases produced, except in sugar beets, where it produced the high-

Table 16.—Crop Yields—Lapeer Co. Project No. 2—1921.

Plot No.	Fertilizer application	Corn		Sweet clover dry hay tons per acre	Sugar beets crowned tons per acre
		Ears bu. per acre	Stover tons per acre		
1	N*	5.3	0.9	0.8	7.0
2	P	12.8	1.1	1.4	7.7
3	K	15.4	1.9	0.8	8.3
4	No fertilizer	7.2	1.3	0.5	5.9
5	N P	17.6	1.5	1.7	7.3
6	N K	16.0	1.3	0.7	5.6
7	P K	34.7	1.4	2.0	7.5
8	N P K	32.5	1.6	2.5	8.7
9	M	14.9	1.5	1.0	10.4

*N—Nitrate of soda; P—Acid phosphate; K—Muriate of potash.

est yield of any plot. The yields of corn on all plots were much decreased by an abundant weed growth.

Fertilizer Management of Deep Mucks. Within comparatively recent years the opinion has been widely held among the farmers of the state that manure is the only satisfactory fertilizer on muck soil. There has been also a widespread opinion that continued use of commercial fertilizers results in an accumulation of substances in the soil which are injurious to crops. The facts do not warrant such conclu-

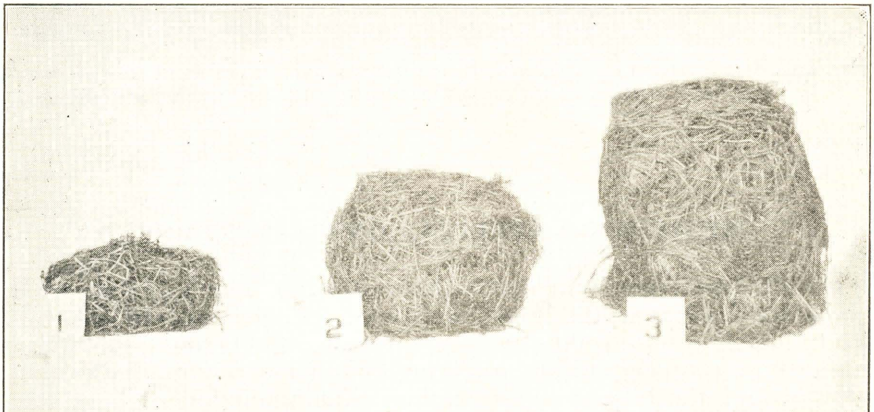

Fig. 20.—Effect of fertilization on June grass pasture. Crop cut from equal areas. No. 1 received no fertilizer; No. 2, muriate of potash 200 pounds per acre; No. 3, acid phosphate 250 and muriate of potash 200 pounds per acre. Phosphate was more important than potash for most crops on this muck but both were needed.

sions. A number of muck farmers, who have been unable to secure manure, report the continued use of commercial fertilizers for from 10 to 15 years, with no poorer and, in some cases, better crop yields at the end of the period than at the beginning. Some of these farmers (celery growers) have used from 1,000 to 2,000 pounds of fertilizer per acre per year. It appears then, that—at least to a considerable extent—the use of manure on the deeper mucks may be discontinued and commercial fertilizer used instead. The use of green manure every few years, as a supplement to the commercial fertilizer, is no doubt worth while, especially on the heavier types of muck. Specific recommendations of fertilizers for general crops on mucks requiring potash and phosphoric acid are given in page 65.

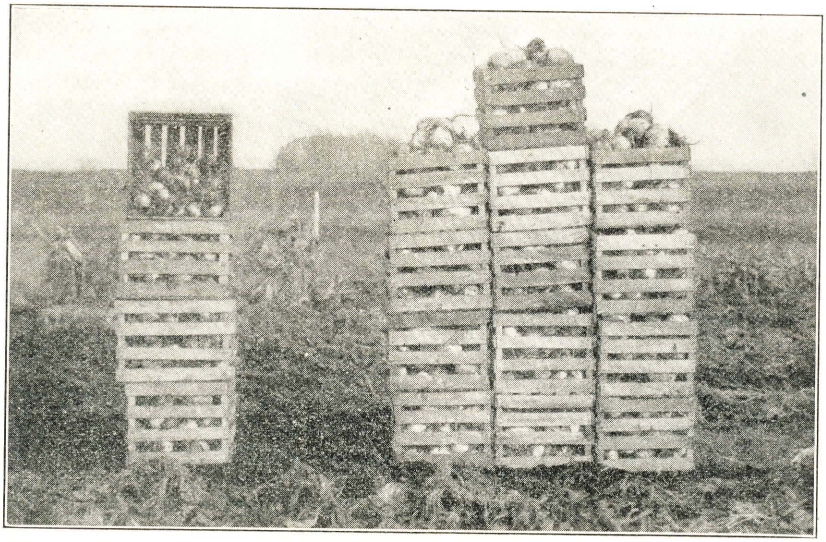

Fig. 21.—Turnips on muck. The plot represented by the crates at the left was not fertilized while that at the right received potash and phosphate.

METHOD OF APPLICATION OF FERTILIZER

On all experimental projects, the results of which are reported in the preceding pages, the fertilizers were applied broadcast and worked into the soil with a spike-tooth or spring-tooth harrow. For the purpose of determining whether a row application might produce better results than the broadcast application, experimental work was started in the spring of 1923, using potatoes and sugar beets as the cultivated crops. The average from two projects are given in Table 17. In the row applications, the fertilizer was applied on the surface above the row and then raked into the soil. The sugar beets on the Ingham County plots were planted late, which probably accounts for the rather low yields.

It is very evident that the row application on sugar beets was the better when the 200 and 400 pound applications of muriate of potash were made. When only 100 pounds, together with 300 pounds of acid phosphate was applied, the phosphate appeared to mature the beets sooner when applied on the row than when applied broadcast.

This probably accounts for the lower yield of plot 6 as compared with plot 5.

Experimental work now being conducted on sugar beets, the results of which are not yet available for publication, indicates that the heavy supplies of potash necessary for good yields on muck soil should not all be applied in the row mixed with the seed, since germination or growth is injured apparently by the concentration of the fertilizer salts.

Table 17.—Showing Effect of Row Application of Fertilizer on Yield of Beets and Potatoes.

Plot No.	Fertilizer application lbs. per acre	Sugar beets—tons per acre				Potatoes bu per acre Ingham Co.
		Clinton county		Ingham county		
		Roots	Tops	Roots	Tops	
1	P 300 K 400 (Broadcast)*	10.6	12.1	7.5	9.1	112.0
2	P 300 K 400 (on row)	12.2	12.8	8.1	10.3	138.1
3	P 300 K 200 (broadcast)	7.4	7.1	6.5	7.2	106.5
4	P 300 K 200 (on row)	8.2	6.9	6.5	6.6	114.4
5	P 300 K 100 (broadcast)	7.2	6.4	4.7	4.6	84.0
6	P 300 K 100 (on row)	5.9	4.7	4.3	4.8	109.4
7	P 300 K 0	3.8	3.1	3.1	3.8	66.4

*P—Acid phosphate; K—Muriate of potash.

Fertilization of the potato plots gave with all three applications of potash, higher yields from the row than from the broadcast application. Unfortunately the crop was frosted before it had matured; this no doubt decreased yields to a considerable extent.

TIME OF APPLICATION OF FERTILIZER

In a study of the effect of time of application of fertilizer on the yields of several crops, on high-lime muck, the average results from two projects with sugar beets and one with potatoes, presented in Table 18, were secured in 1923. These results indicate that a given amount of fertilizer applied before planting (plot 3) will give higher yields than the same amount supplied in two (plot 2) or three (plot 1) applications at intervals during growth. Higher yields resulted where the whole amount was applied before planting than where it was put on in a single application at some later time. This is not in accord with the results secured with Hungarian millet and potatoes on the Ingham County low-lime muck in 1923 (Table 4) where the installment application gave the best results. The difference in the two types of muck may explain the difference in the results secured. Because root growth is limited to the limed layer of the very acid, low-lime muck, all fertilizer leached below the limed layer is lost to the plant. With a probably lower fixation of the potash in the low-

Table 18.—Effect of Time of Application of Fertilizer on Yields of Sugar Beets and Potatoes.

Plot No.	Fertilizer application lbs. per acre	Sugar beets—tons per acre				Potatoes bu. per acre Ingham County
		Clinton county		Ingham county		
		Roots	Tops	Roots	Tops	
1	P 300 K 200 (1) (K 100) (2) (K 100) (3)	9.5	11.4	7.1	9.5	86.2
2	P 300 K 200 (K 200) (2)	9.8	11.6	7.2	8.8	112.2
3	P 300 K 400	11.4	12.8	7.5	9.1	112.0
4	P 300 K 400 (applied after blocking)	11.0	11.7	4.9	7.0	75.9
5	P 300 K 400 (applied 1 month later)	7.4	8.9	4.7	6.7	66.8
6	No fertilizer	4.6	4.3	3.6	3.2	66.4

(1) P—Acid phosphate; K—Muriate of potash.

(2) (K 100)—Potash applied approximately one month after planting.

(3) (K 100)—Potash applied approximately two months after planting.

lime than in the high-lime muck, the crop on the low-lime muck may suffer for lack of mineral plant nutrients during the later stages of growth, unless more is applied. In the high-lime muck, with its deeper zone of feeding, and its greater retention of fertilizers, the plant has time to mature while the plant nutrients are within reach of the roots. However, the results secured are to a considerable extent dependent on the season and from one season's work should be considered as suggestive rather than conclusive.

Fig. 22.—This corn was planted on May 20. It was in a badly stunted condition on July 8, at which time the plot represented by the right hand shock and pile was fertilized with potash.

It is evident from the results secured that even a late application of fertilizer is better than none at all. This fact has been made use of by the Minnesota Station in its recommendations to farmers on new muck land who start in with a grain crop. It advises the establishment in the grain field of plots receiving potash, and potash and phosphate. If the muck land is in need of fertilization, it is evident in increased growth on the plots within a few weeks, at which time an application of the needed fertilizer is made to the entire field and a possible crop failure averted.

A very striking illustration of the effect of a late application of fertilizer in preventing a failure of the crop was brought out during the season of 1923. The writers were asked to examine a field of corn which had been planted May 20 on what had been an old pasture. Portions of the field contained corn which was short, stunted and very yellow. Plots were established and fertilizer applied on this corn on July 8, seven weeks after planting. Another portion of the field had been manured at the rate of eight loads per acre before plowing, and the corn here looked very good. Plots were established also on this portion of the field. The results are given in Table 19.

Table 19.—Effect of Late Application of Fertilizer on Corn Yield.

Fertilizer application—lbs. per acre	Stunted corn not manured		Good corn manured 8 loads per acre
	Ears bu. per acre	Stover tons per acre	Ears bu. per acre
K 250*	43.4	1.89	92.9
No fertilizer	13.2	0.26	56.2
N 200 K 250	40.6	1.40	....

*K—Muriate of potash; N—Nitrate of soda.

Although potash produced a very marked improvement in the stunted corn, the yield of the crop which had never had a set-back was more than twice as great. Nitrate was not necessary. It would be interesting to know what the yield would have been on this field if the potash had been applied at the time of planting.

OTHER BENEFITS FROM FERTILIZATION

Stand. In many cases, if one part of a field is fertilized and another unfertilized, there is a difference in the "stand" of a crop in favor of the fertilized portion. This is noticeable particularly with some of the root crops, with grain and with grass and clover seedings. This appears to be due, not so much to the effect of fertilization on germination, but rather to the fertilized plants being more sturdy and developing faster, so that they are able to withstand hardships and diseases to which the weak unfertilized plants succumb. Table 20 shows the relative number of stools on some oat plots and the relative number of plants of several root crops. In general potash is the most important of the various fertilizer constituents in its effect on stand. Often the stand on the phosphoric acid plot is poorer than on the unfertilized plots.

Fig. 23.—Effect of fertilization on quality. Phosphate applied to the plot shown in the upper photograph increased the yield slightly over that from the unfertilized muck, but the increase was due largely to June grass. On the plot shown in the lower photograph, the application of phosphate and potash produced a marked increase of clean timothy.

Quality. Proper fertilization not only increases yields but it also improves the quality of most crops grown on muck soils. The writers have been told by several farmers that hay from their fertilized muck "had more heart in it" than that from unfertilized soil. If a part of a worn-out muck pasture is fertilized, it can be seen readily that the stock prefer to graze on the fertilized portion.

For a number of years, the opinion has been held that beets grown on muck soil are low in sugar content. This fact has led sugar com-

Table 20.—Relative Stand on Plots Receiving Different Fertilizer Applications, When the Stand on the Unfertilized Plots is Taken as 100.

Fertilizer application	Sugar beets Ingham Co., 1922	Oats Schoolcraft Co., 1923	Table beets Ingham Co., 1922	Mangels 1924	Stock carrots 1924	Rutabagas 1924
Average unfertilized plots....	100	100	100	100	100	100
K*..........................	179	111	192	111	114	104
P...........................	86	124	87	83	105	73
P K.........................	132	125	167	113	114	106
P K N.......................	151	135	187	115	109	92
Manure......................	135	137	192	117	109	96

*K—Muriate of potash; P—Acid phosphate; N—Nitrate of soda.

panies in some section to withhold encouragement of beet growing on muck soil. A laboratory study to determine the effect of fertilization on the quality of sugar beets has proved that the sugar content, as

Table 21.—Effect of Fertilization on Sugar Content and Yield of Sugar Beets.

Plot No.	Fertilizer application lbs. per acre	1921							
		Calhoun county		Berrien county		Lapeer Co. No. 1		Lapeer Co. No. 2	
		Percent sugar	Beets tons per acre	Percent sugar	Beets tons per acre	Percent sugar	Beets tons per acre	Percent sugar	Beets tons per acre
1	No fertilizer......................	13.8	7.4	13.8	0.5	10.8	2.3	14.4	5.9
2	N 100*...........................	12.2	8.9	14.2	0.7	12.3	2.5	15.1	7.0
3	P 250............................	12.4	8.9	10.0	0.2	12.9	2.1	14.2	7.7
4	K 200............................	13.4	10.6	16.7	2.9	14.1	8.2	15.5	8.3
5	P 250 N 100......................	12.8	7.3	11.8	0.5	11.2	3.0	14.4	7.3
6	K 200 N 100......................	12.9	10.9	16.4	2.2	15.8	11.1	14.9	5.6
7	P 250 K 200......................	14.4	11.6	14.2	1.8	15.9	9.4	14.2	7.5
8	P 250 K 200 N 100................	14.0	10.3	15.5	2.6	16.2	10.8	13.3	8.7
9	Manure 12........................	14.3	11.7	13.0	2.0	14.8	10.3	15.3	10.4

Plot No.	Fertilizer application lbs. per acre	1922													
		Gratiot county		Ingham Co. No. 1		Lapeer Co. No.1		Huron county		Eaton county		St. Joseph Co.		Allegan county	
		Percent sugar	Beets tons per acre	Percent sugar	Beets tons per acre	Percent sugar	Beets tons per acre	Percent sugar	Beets tons per acre	Percent sugar	Beets tons per acre	Percent sugar	Beets tons per acre	Percent sugar	Beets tons per acre
1	No fertilizer..........	12.3	4.1	11.9	3.3	12.7	0.9	13.5	4.2	11.1	2.4	15.0	11.8	17.4	9.6
2	P 0 K 300*.........	14.5	11.1	16.4	5.9	16.4	6.9	13.8	7.9	12.9	6.1	14.6	11.6	17.8	9.3
3	P 100 K 300..........	16.5	12.7	14.9	7.2	16.2	6.6	14.8	9.3	13.3	6.5	15.4	9.3	18.0	10.9
4	P 200 K 300..........	17.4	14.8	15.7	6.6	16.1	6.9	13.4	8.3	12.7	5.5	14.7	8.6	17.9	8.7
5	P 300 K 300..........	16.3	11.8	14.4	5.2	16.0	6.3	13.8	8.7	11.3	6.0	16.1	10.2	18.2	8.3
6	P 300 K 200..........	....	12.4	15.2	5.5	16.9	4.3	14.5	7.8	....	5.2	16.5	9.7	19.2	7.0
7	P 300 K 100..........	15.7	10.7	13.6	5.0	16.1	4.1	13.0	5.8	11.1	3.9	16.1	7.9	18.2	7.0
8	P 300 K 0..........	14.9	7.6	12.5	3.4	16.3	2.7	13.0	3.9	10.5	2.7	16.5	6.7	18.5	7.4
9	No fertilizer..........	14.8	8.0	13.5	2.8	16.4	2.9	13.0	3.5	11.2	2.5	15.7	5.2	18.8	6.6
10	P 300 K 300..........	16.5	14.3	15.1	6.9	15.6	4.5	14.4	10.7	12.3	6.2	16.8	11.4	19.3	9.8
11	P 300 K 300 N 100....	16.4	14.9	14.3	8.2	17.2	6.3	14.5	10.4	12.5	6.5	16.1	13.3	18.3	10.3
12	Manure 12...........	14.7	11.6	....	6.6	....	....	13.8	7.6	12.8	5.0	15.2	9.8	18.5	8.8
13	Manure 6 K 100......	14.7	11.5	....	....	....	....	13.5	8.2	12.9	4.5	15.6	12.8	18.0	7.8
14	No fertilizer..........	15.1	8.7	13.8	3.3	13.2	1.7	14.2	5.4	10.7	1.8	15.0	9.2	17.3	7.4

*P—Acid phosphate; K—Muriate of potash; N—Nitrate of soda.

well as the yield, is often increased when certain fertilizers are applied. The results for 1921 and 1922 are given in Table 21. The very shallow muck of the Allegan County project gave a sugar beet with a very high sugar content, with no evidence of effect of fertilizers on quality. Likewise the sugar content of the beets from the newly-reclaimed Calhoun County muck was not influenced by fertilization. On most of the other areas, however, sugar content has been markedly increased by fertilization, usually by potash, but on those mucks where phosphate was needed to increase yield, it likewise increased the sugar content. Phosphate alone appeared in some cases not to increase the sugar content and in others actually to decrease it. This probably is due to the fact that in the cool weather at the end of the growing season, a considerable increase in the sugar content of beets takes place. When phosphate hastens maturity, this last increase of sugar is not secured, with a result that the beets may be lower in percentage of sugar than those on the unfertilized soil. The conclusion is warranted that, with an application of fertilizer high in potash and not containing more phosphate than is necessary for maximum crop production, a beet having satisfactory sugar content can be produced on muck soil.

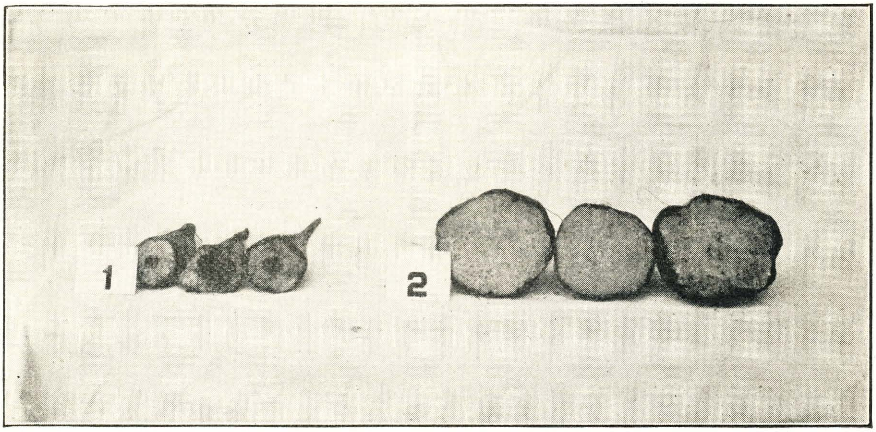

Fig. 24.—The effect of fertilizer both in increasing quantity and in improving quality of the sugar beet crop is clearly shown in these cross sections. No. 1, no fertilizer, No. 2, potash.

Limited study on stock carrots, turnips, and other root crops, has indicated that, like that of sugar beets though to a lesser extent, their sugar content is increased by proper fertilization.

In some localities, a certain prejudice has arisen against "muck-grown" potatoes, largely due to the lack of flavor, poor cooking qualities and small size of potatoes grown on "worn-out" muck soil. Investigations at this station, as well as those from other stations, show that potatoes grown on properly fertilized muck, are of fine quality in every respect; the same fertilizers that are necessary to increase the yield also improve the quality. The quality may be lowered, as well as the yield decreased if the vines are killed by a frost occurring considerably before the time of maturity.

RATE OF APPLICATION OF COMMERCIAL FERTILIZERS

Recommendations made by Other Stations. In those sections of America, where the soils have been formed under climatic conditions somewhat similar to those of Michigan, statements have been made by several experiment stations regarding the fertilizer requirements of their muck soils. Illinois (17), Indiana (5 and 22), Minnesota (1), New York (26), Oregon (20), Wisconsin (27) and Ontario (13) report the need of potash on many of their muck soils, while all, with the exception of Illinois, give evidence that some of their mucks are in need of phosphate also. With the exception of Illinois, New York, and Ontario, all of these report that some of their muck soils are low in lime; these mucks require phosphate and potash as well as a lime application. Minnesota alone advises the application of nitrate on the low-lime mucks, for all crops with the exception of inoculated legumes. Minnesota (2) reports a class of mucks, not found in any other state or country, which requires phosphate only, the addition of potash with the phosphate producing no increase over phosphate alone. Ohio (7) states that some of the mucks of that state need fertilization while others do not. Iowa (25) reports their shallow mucks not to need fertilization, while their deep mucks are considered of no agricultural importance.

Robinson (21), reporting in 1914 on the fertilizer requirements of Michigan's muck soils, stated: "Potash and phosphoric acid are the mineral fertilizing elements which give the best returns, while barnyard manure also causes a large crop increase in most cases. Except on distinctly acid deposits, lime does not as a rule give good results."

Very little has been published in America, regarding the results of any systematic experimental study made to determine what applications of phosphate and of potash should be made on muck soils, to secure the greatest return for the money invested in fertilizer. Alway (1, p. 130) recommends for the high-lime mucks of Minnesota an initial application equivalent to 400 pounds of 50 per cent muriate of potash and also 400 pounds of 16 per cent acid phosphate per acre when it is needed. For low-lime mucks he advocates the same amounts of potash and phosphate with 200 pounds of nitrate of soda. To supply lime he advises the application of two and one-half tons of ground limestone per acre. With regard to these fertilizer applications he says: "In order to be sure of getting maximum yields, the application of twice as much phosphate, potash, and nitrate (as the amounts given above) is advised; but the smaller amounts will as well answer the question as to the chemical requirements and at the same time better indicate what returns may be expected with quantities more likely to prove economical for ordinary farm crops."

Whitson (27) advises the muck farmers of Wisconsin as follows: "When applied broadcast, from 300 to 400 pounds of acid phosphate and 150 pounds of muriate of potash are the quantities best to use for all staple crops, such as hay, grain or corn." For sugar beets, he states that "these amounts should be increased from 50 to 100 per cent."

Considerable work along this line has been done in Germany, Austria and Sweden, the results of which have been ably reviewed by Alway (1). Excerpts from his statement follow.

"Bersch, who for many years was in charge of much of the *muck* soil investigation in Austria and who is the author of the best text book (3) on the subject, states in the last edition of this book that, on all low-lime bogs, both phosphate and potash, in addition to lime, must be used, as well as usually nitrogen, while potash is necessary on all high-lime *mucks* and phosphate on most of them (page 42)." The rates of application recommended by Bersch (3), expressed in terms of ground limestone, 16 per cent acid phosphate, 50 per cent muriate of potash and nitrate of soda (18 per cent ammonia), are presented in Table 22, together with the crop recommendations, for the first four years after reclamation.

"The Swedish station has found that commercial fertilizers alone do not suffice to maintain maximum yields, and for that reason recommends, in addition to the necessary amount of commercial fertilizers an occasional light application of stable manure, in order to provide bacteria to decay.

"As the initial phosphate application, Von Feilitzen (Sweden) recommends an amount of fertilizer equivalent to from 425 to 850 pounds of acid phosphate per acre, decreasing this from year to year until there is supplied each season the equivalent of the amount removed in an average crop, which will vary from about 100 to 250 pounds of 16 per cent acid phosphate. As the phosphate does not leach out, a liberal reserve is thus left in the soil at all times.

"Potash, on the other hand, leaches out to a great extent, and, if supplied in larger amounts than the crops need it may be largely lost. Therefore the potash salts are applied according to the amount removed in the crop, viz: from 150 to 450 pounds of 40 per cent potash salts per acre." (1, page 44). This is the equivalent of 120 to 360 pounds of 50 per cent potash salts.

"Fleischer (director of the Bremen Peat Experiment Station for 36 years) warns against omitting the annual application of fertilizer. The quantities which he recommends agree with those given in Table 22. The application of phosphate indicated is for those bogs on which the *muck* carries not more than 0.50 per cent of phosphoric acid. As a simple method of estimating the amounts of the fertilizers required by a hay field after the first three years, he assumes that every ton of well-cured hay taken from the field removes 40 pounds of actual potash and 13 pounds of phosphoric acid. Thus three tons of hay per acre would remove the equivalent of 240 pounds of 50 per cent potash and 250 pounds of 16 per cent acid phosphate. For pastures, much smaller applications than these may be made because so much of both the phosphate and the potash is returned to the soil in the excrement. At Bremen less than 50 pounds of potash (equivalent to 100 pounds of 50 per cent muriate of potash) and 30 pounds of phosphoric acid (equivalent to 188 pounds of 16 per cent acid phosphate) per acre each year have been found necessary for the maintenance of the productivity of pastures (1 page 42)."

The initial application of phosphate recommended by the German and Austrian investigators (Table 22) seems exceptionally high, as

Table 22.—Rates of Application of Fertilizers per acre recommended for German and Austrian Muck Soils, calculated in terms of ground limestone, acid phosphate (16 per cent phosphoric acid), muriate of potash (50 per cent potash) and nitrate of soda (18 per cent ammonia).

Fertilizer	High-lime muck	Low-lime muck
First year of cultivation	Potatoes	Potatoes
Ground limestone	None	3200 to 6250
16 percent acid phosphate	687 to 1125	1125 to 1687
50 percent muriate of potash	220 to 360	360 to 540
15 percent nitrate of soda	None	300 to 467
Second year	Meadow	Potatoes
16 percent phosphate	344 to 437	687 to 1000
50 percent muriate of potash	220 to 250	220 to 250
15 percent nitrate of soda	None	200 to 367
Third year	Meadow	Winter rye
16 percent acid phosphate	156 to 344	687 to 781
50 percent muriate of potash	110 to 140	180 to 220
15 percent nitrate of soda	None	267 to 367
Fourth year	Meadow	Oats or meadow
Ground limestone	None	1250
16 percent acid phosphate	Replacement*	Replacement*
50 per cent muriate of potash	Replacement*	Replacement*
15 percent nitrate of soda	None	267 to 367

*Sufficient fertilizer should be added here to replace that removed in the crop of the previous year (See Table 23).

does the second year application for the high-lime and the second and third year applications for the low-lime mucks. It is certain that the initial applications recommended are considerably higher than appears necessary on Michigan mucks, as judged by the results reported in the preceding pages.

The German recommendations state that, after the first three years of fertilization as recommended, a "replacement" application should be made each year, equivalent in amount of plant food to that removed by the preceding crop. Table 23 presents the average amounts of phosphoric acid and potash (16) removed by several different crops, which are suited to muck soil. These amounts are calculated as the quantities removed per acre by good yields of the different crops, and the amounts of the standard 16 per cent acid phosphate and 50 per cent muriate of potash required to replace the quantities removed by the crop are computed. Averages are struck for the hay crops, root crops and grain crops.

Recommendations for Michigan Muck Soils. Since most muck soils are, or in a relatively few years become, very low in potash and generally in phosphoric acid, it is important that the amounts removed by

Table 23.—Phosphoric Acid and Potash removed by various Muck Crops and the amounts of Acid Phosphate and Muriate of Potash required to replace the loss.

Crop	Yield per acre		Plant food removed		Standard fertilizers equivalent of plant food removed	
	Bu.	Tons	Phos-phoric acid	Potash	Acid phosphate (16 %phos-phoric acid)	Muriate of potash (50% potash)
Grain Crops						
Rye—						
Grain	30	....	12.3	9.6	76.9	19.2
Straw	....	2	11.2	31.6	70.0	63.2
Total crop	....	....	23.5	41.2	146.9	82.4
Oats—						
Grain	60	....	15.6	10.7	97.5	21.4
Straw	....	2½	10.5	75.0	65.6	150.0
Total crop	....	....	26.1	85.7	163.1	171.4
Barley—						
Grain	40	....	16.3	14.2	101.9	28.4
Straw	....	2	7.2	48.0	45.0	96.0
Total crop	....	....	23.5	62.2	146.9	124.4
Average grain crops	....	....	24.4	63.1	152.3	126.1
Hay Crops—						
White Sweet Clover	....	3	39.6	75.6	247.5	151.2
Timothy and Clover	....	3	28.2	114.0	176.3	228.0
Alsike Clover	....	3	42.0	104.4	262.5	208.8
Alfalfa	....	3	33.6	133.8	210.0	267.6
Oat and Pea	....	3	39.6	98.4	247.5	196.8
Hungarian Millet	....	3	21.6	129.0	135.0	258.0
Average hay crops	....	....	34.1	109.2	213.1	218.4
Root Crops—						
Sugar Beets—						
Tops	....	10	20.0	128.0	125.0	256.0
Roots	....	12	19.2	76.8	120.0	153.6
Total crop	....	....	39.2	204.8	245.0	409.6
Turnips—						
Tops	....	6	18.0	62.4	112.5	124.8
Roots	....	20	52.0	116.0	325.0	232.0
Total crop	....	....	70.0	178.4	437.5	356.8
Average root crops	....	....	54.6	191.6	341.2	383.2
Miscellaneous Crops—						
Potatoes	300	....	21.6	95.4	135.0	190.8
Peas—						
Grain	25	....	12.6	15.2	78.8	30.4
Straw	....	1½	10.5	29.7	65.6	59.4
Total crop	....	....	23.1	44.9	144.4	89.8
Corn—						
Grain	60	....	23.2	13.4	145.0	26.8
Stover	....	2½	22.5	64.5	140.6	129.0
Total crop	....	....	45.7	77.9	285.6	155.8
Rape—green	....	20	44.0	156.0	275.0	312.0
Oat and pea silage—green	....	15	51.0	210.0	318.7	420.0

the crop grown be carefully considered, in deciding on the fertilizer application for the succeeding year. The amounts given in Table 23 are high, because good yields were assumed in making the calculations. If the yield of a crop is one-half or two-thirds that given in the table,

Fig. 25.—Sugar beets on muck. A uniform amount of phosphoric acid was applied to all four plots shown above. In order from top to bottom, the plots received muriate of potash at the rates of none, 100, 200 and 400 pounds per acre respectively. Photographed August 10, 1924.

a correspondingly smaller amount of fertilizer is necessary to replace that removed by the crop. When the tops of the root crops, straw from the grain crops or manure is returned to the soil, the application of fertilizer for the crop following may likewise be decreased.

Reports by several investigators, and experiments in Michigan, indicate that, although phosphoric acid, applied in a fertilizer on high-lime muck is largely held in the soil, with little lost in the draining water, a considerable portion of the potash not removed by the crop, is leached away. The amount thus lost varies with the season and with the type of muck. If the summer and fall following an application, is relatively dry, considerable "residual benefit" from the potash left in the soil, will appear in the crop yield of the succeeding year. The amount of fixation in a low-lime muck is apparently somewhat less than on a high-lime deposit, both phosphoric acid and potash being lost to a considerable extent. It is evident then, that more fertilizer should be applied than the amount required by the plant and more on the low-lime than on the high-lime muck soil. For the same reason, it appears desirable that the heavier applications, needed by those crops in the rotation, which require large amounts of phosphate and potash, should be applied before, rather than following, the crops in question.

Four seasons experiments, reported on the preceding pages, constituting a systematic study of the fertilizer requirements of different crops, indicate that, on Michigan muck soils that have been cropped a few years, an initial and annual application of 200 to 300 pounds of 50 per cent muriate of potash and, as needed, of 200 to 300 pounds of 16 per cent acid phosphate, is sufficient for good yields of most farm crops. This is not much in excess of the plant nutrients removed by a normal crop, except in the case of the grain crops, and is not sufficient to maintain fertility when high yields of root crops are secured, if the tops are removed from the field.

Inasmuch as the fertilizer requirement depends not only on the crop to be grown but also on the nature of the muck itself, Table 24 is presented, giving formulas of fertilizer mixtures adapted to the various types of muck, as well as the range in application for the several crops. Since all of the high-lime muck soils do not show need of phosphoric acid, several recommendations are made for each crop. When muriate of potash (50 or 60 per cent) is applied alone, about one-half the application recommended for the mixed fertilizers, should be made. If an 0-8-32 mixture is used, approximately two thirds as much should be applied as of the 0-8-24 mixture. If the muck is shallow, or if it has been fertilized for the past several years, or heavy fertilized for the crop of the preceding year, less fertilizer is needed than if the opposite is true. If the muck is excessively drained, so that the factor limiting crop production is supply of moisture rather than of plant nutrients, the application which would give best returns on the investment may be somewhat lower than the minimum recommendation.

Table 24.—Fertilizer Mixtures and Rates of Application recommended for Various General Crops on Michigan Muck Soils.

Crop	Fertilizer formula			Range in annual application of mixed fertilizers lbs. per acre (If muriate of potash is applied about half the application recommended below should be made)
	High-lime muck		Low-lime muck (strongly acid in reaction) Ground limestone or marl should be applied previous to fertilization	
	Deep and medium mucks	Very shallow muck — Manure or green manure in rotation*		
Rye	0-12-12 0-8-24 Muriate of potash	0-12-12 0-8-24	2-8-16	200-300
Oats Barley	0-8-24 0-8-32 Muriate of potash	0-12-12 0-8-24	2-8-16	200-400
Corn Sunflowers	0-8-24 0-8-32 Muriate of potash	0-12-12 0-8-24	2-8-16 3-8-24	300-500
Sugar beets	0-8-24 0-8-32 Muriate of potash	0-8-24	Crop not adapted to very acid muck	400-800
Turnips Rutabagas Stock carrots Mangels	0-8-24 0-8-32 Muriate of potash	0-8-24	2-8-16 3-8-24	250-500
Peas	0-12-12 0-8-24	0-12-12	Crop not adapted to very acid muck	300-600
Potatoes	0-8-24 0-8-32	0-8-24	2-8-16 3-8-24	400-800
Sweet clover Timothy and alsike Hungarian millet	0-8-24 0-8-32 Muriate of potash	0-12-12 0-8-24	2-8-16 3-8-24	250-400
Pasture	0-8-24 0-8-32 Muriate of potash	0-12-12 0-8-24	2-8-16	100-300

*If no manure, green manure or litter is added to the very shallow muck during the rotation, a complete fertilizer containing about 2 per cent of nitrogen (ammonia) may give better results than one containing no nitrogen.

THE HOME MIXING OF FERTILIZERS

Home mixing of fertilizers is important to the muck farmer for two reasons: first, because many times he is unable to obtain from his dealer the mixture adapted to his soil, and second, because his system of farming may not keep him busy during the winter and home mixing will pay him well for his time. The implements needed are found on every farm: a solid floor, a shovel and a tamper.

As each sack of fertilizer is emptied, it is best to spread it very shallow and, if any lumps are present, to break them with the tamper. One fertilizer for the mixture is usually emptied, tamped and shoveled into a broad flat pile, then the second is tamped if necessary and spread evenly over the first, and so on. When all fertilizers are added, the pile is shovelled by starting at one end and throwing it into another pile. This is repeated until the mixture appears uniform and without streaks in it. It can then be sacked and stored until used. If it is kept in a dry place, any lumps which form can be broken readily. Any filler that may be used should be dry. Sifted sand or sifted muck may be used, or the filler may be left out and a correspondingly smaller proportion of the fertilizer applied per acre.

Table 25.—Showing Amounts of Unmixed Fertilizers required to make 1,000 pounds of Mixed Fertilizer.

Formula of mixed fertilizers desired	Nitrogen (ammonia) use one of the fertilizers below		Phosphoric acid, use one of the fertilizers below				Potash, use one of the fertilizers below	
							Muriate or sulphate of potash	
Use the amount opposite the formula desired, from one carrier of each of the 3 fertilizing constituents*	Nitrate of soda (18% ammonia)	Sulphate of ammonia (25% ammonia)	Acid phosphate (16% phosphoric acid)	Acid phosphate (20% phosphoric acid)	Treble super-phosphate (45% phosphoric acid)	Bone meal (28% phosphoric acid)	(50% potash)	(60% potash)
0–12–12	0	0	750	600	267	429	240	200
0– 8–24	0	0	500	400	178	286	480	400
0– 8–32	0	0	....	400	178	286	640	533
2– 8–10	111	80	500	400	178	286	200	167
2– 8–16	111	80	500	400	178	286	320	267
3– 8–24	167	120	....	400	178	286	480	400

*If a filler is to be used the amount of filler is equal to 1,000 pounds minus the sum of the amounts of the different fertilizers used.

Table 25 shows the amounts of the different unmixed carriers of the three fertilizing constituents—nitrogen, phosphoric acid and potash—needed in the making up of 1,000 pounds of mixed fertilizer having the composition of any of the several formulas adapted to muck soil. Only two sources of nitrogen are recommended because most other less available nitrogenous fertilizers are too slow in their action to be suitable on muck soil. The use of the nitrate in preference to sulphate of ammonia is recommended for a mixed fertilizer for strongly acid muck.

In making up a fertilizer having the composition 3-8-24, it is possible to select unmixed materials, the necessary total of which is more than

1,000 pounds. In other words the concentration could not be obtained. In that case a correspondingly heavier application per acre should be made.

Very frequently, muck farmers who already have purchased a mixed fertilizer desire to improve the composition of the mixture. As a guide for this murpose Table 26 is presented. Such a mixture would, of course, cost more per ton than one made up entirely from the unmixed fertilizers, since the cost of the first mixing must be included. However, with a mixture of the wrong composition on hand, it is generally well worth the increased expense to add the constituents necessary for the improvement of the mixture rather than to use a mixture which is not adapted to the soil or the crop.

Table 26.—Showing Amounts of Unmixed Fertilizers required to be added to a Mixed Fertilizer of one Formula to produce a Mixture more suitable to the Muck Crop to be grown.

Formula of mixed fertilizer desired	Formula of mixed fertilizer on hand	Number of pounds required to make 1000 pounds of fertilizer desired				
		Mixed fertilizer on hand	Nitrate of soda (18% ammonia)	Acid phosphate (16% phosphoric acid)	Muriate of potash (50% potash)	Filler
0-8-24	0-12-12	667	0	0	320	13
0-8-24	0-12- 6	667	0	0	400	*
0-8-32	0-12-12	667	0	0	480	*
2-8-16	0-12-12	667	111	0	160	62
2-8-16	2-12- 2	667	37	0	292	4
2-8-16	3-12- 4	667	0	0	266	67
2-8-16	3- 8- 6	667	0	167	240	*
2-8-16	0-12- 6	667	111	0	240	*
2-8-16	0- 8-24	667	111	167	0	55
3-8-24	0-12-12	667	167	0	320	*
3-8-24	2-12- 2	667	93	0	454	*
3-8-24	2- 8-16	1,000	56	0	160	*

*The total weight of these mixtures is slightly greater than 1,000 pounds but contains the same amounts of the fertilizing constituents as 1,000 pounds of the mixture desired. Consequently a proportionately greater application per acre should be made.

Maintaining the Fertility of the Farm Which Contains Both Upland Soil and Muck

A large proportion of the muck farmers of Michigan have farms which are in part made up of upland (mineral) soil. As was shown in Table 2, the mineral soils in general are low in nitrogen and organic matter and often in phosphoric acid. Recommendations made by the Soils Department of the Michigan State College (19) show that the fertility of these soils may be improved by the proper use of manure and acid phosphate. On the other hand, muck soil is high in nitrogen and organic matter and its fertility can be improved chiefly by the application of potash fertilizer, with phosphate when needed. Feeding the crops from both soils, and applying the manure to the mineral soil, improves the mineral soil, which needs more nitrogen and organic matter. This is done at the expense of the muck soil, which is not injured by the loss. As has been already mentioned, this statement does not hold true in the case of very shallow mucks.

The Field Test Plot For Determination of Fertilizer Needs

If a muck area is newly reclaimed, the need for fertilization may develop gradually or it may appear very suddenly in the form of a crop failure immediately after reclamation or following a series of years of good crops. If the muck has been cropped for several years, the fertilizer need may be immediate, either potash alone or both potash and phosphate being required. Since a field test is the only reliable means of determining the soil's requirements, a set of fertilizer test plots, established on the muck as illustrated in the diagram, is well worth while. In locating such a set of plots, a portion of the field, which has been uniformly treated in the past, should be selected with the plots placed well away from fence rows and at right angles to the nearest ditch or tile line.

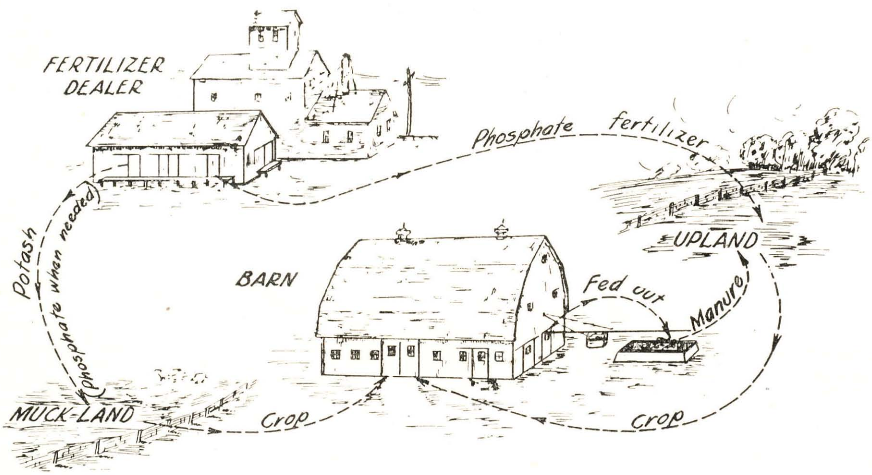

Fig. 26.—Maintenance of fertility of the soil on the farm which is composed of both mineral (upland) soil and muck. Increase the nitrogen and organic matter content of the upland soil by applying the manure from the muck crop to the upland, and maintain the fertility of the muck by the use of commercial fertilizer.

If the muck is new, a set of plots established with permanent stakes at the corners and continued until a response to fertilization is secured, will show definitely when fertilizer can be economically applied. An annual application at the rate of 200 pounds each of 16 per cent acid phosphate and 50 per cent muriate of potash (20 pounds of each on the one-tenth acre plots) is suggested, until a response to fertilization is secured. If the muck has been under cultivation for several years, without heavy applications of manure or the addition of fertilizers, a set of plots continued for a single year will generally give the desired information.

The fertilizer may be applied to the small plots best by broadcasting. The corners of the plot can be established with stakes, and the edges of the plot defined by walking from stake to stake and dragging one foot. If more than one fertilizer is to be applied, they may be weighed out and well mixed. In order to get a uniform spread, the fertilizer may be mixed with 4 or 5 times its volume of slightly moist muck. The mixture is then applied in a manner similar to the sowing of grain by hand, the application being made at a time when the wind is not strong.

If a cultivated crop is to be grown, and the rows will cross the fertilizer plots, it is advisable to leave an alley of 4 feet between the fertilizer treatments, to eliminate the effect of fertilizer dragged from one plot to the next by the cultivating implements. More than one crop can be grown on the plots, the different crop (oats, sugar beets and sweet clover are suggested) being sown crosswise of the plots. If it is necessary to simplify the plots, the phosphate plot may be omitted, and the unfertilized plot placed between the potash and potash-phosphate plots.

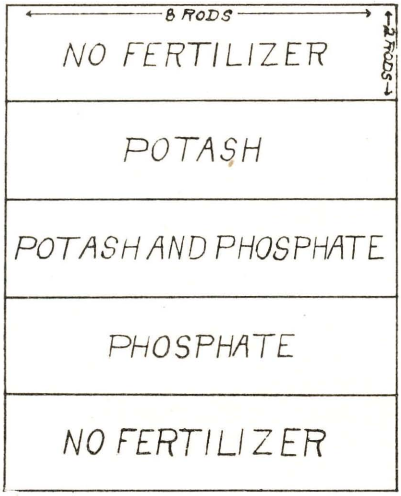

Fig. 27.—Suggestive outline of test plots for the determination of the fertilizer requirement.

It is by all means desirable, if possible, to weigh the yield of the crop from each plot, since the eye is often unable to distinguish in the field, an increase in yield considerably more than sufficient to pay for the fertilizer applied. A Huron County muck farmer, who was applying potash for sugar beets, in a field adjoining one on which a new set of plots were being established, was induced by the writers to apply a sack of acid phosphate, in addition to the potash, on a strip down the center of his field. During growth, the farmer considered the phosphate wasted and it was only at the harvest of the beets that he concluded to stake off equal areas and keep the weights separate as they were hauled to the loading station. He was surprised to find that the yield, where both potash and phosphate were applied, was just twice that secured with potash alone.

With some crops, notably grain, results are difficult to secure from small plots. Here it may be possible to establish half acre or acre plots, harvesting and threshing with the standard size machines. Fairly long plots are to be preferred, since they bring the different treatments closer together than if the plots are short and wide.

CROP ADAPTABILITY

Practically all crops can be grown successfully on well-decomposed muck soil, if the factors limiting production—fertility, water supply and climate—are taken into consideration. Although the soil may be fertilized and satisfactorily drained, it is economically not practicable to prevent occasional summer frosts on a majority of Michigan muck areas. For this reason the selection of those crops, which are able to withstand considerable frost, is to be strongly recommended for our muck soils.

Hay. This crop is one of the most dependable that can be grown on muck soil. With proper soil management, good yields of fine quality can be raised. White sweet clover, sown without a nurse crop, generally produces a good crop on muck the same year it is sown, and two crops the second year, if the first is cut high. Timothy also produces well and is able to thrive with less fertilizer than is needed by the legumes. Hungarian millet is an annual which gives a good yield and may be sown as late as July 1. It is occasionally injured by hard summer frosts. Sudan grass gives a heavy yield but has a tendency to produce a coarse hay when grown on muck. Soybeans have been tried with success but are likely to be injured by summer frosts.

Of the mixed seedings, timothy and alsike clover (sown one part of timothy to two parts of alsike) is probably most popular, while a mixture of timothy, alsike, and medium red (June) clover (sown equal parts) is proving successful with some muck farmers. If the land is very wet or very acid, redtop may well be included in the mixture; otherwise it is better omitted, since it tends to crowd out the other grasses. A mixture of timothy, alsike, brome grass and sweet clover produces a good yield of hay of good quality.

Alfalfa is giving very satisfactory results on a number of mucks in the southern part of the state. Its cultivation on any muck area should be begun in an experimental way until it is determined that drainage conditions are satisfactory. The crop requires a well drained soil which is not subject to overflow. It is admirably suited as a crop on ditch banks, since it is a perennial and also tends to crowd out the weed growth which is generally abundant in that location.

Seedings of clover, alfalfa or grasses on muck land can be made successfully in the spring, either with or without a nurse crop. Rye, barley or oats, ranking in the order named, are generally preferred for this purpose. If sown without a nurse crop, a stand is usually more certain. If a cutting of sweet clover is expected the same season, no nurse crop should be used.

Although fertilization of the new seeding usually results in a more uniform and vigorous growth, it often also results in a much greater growth of weeds. Unless these weeds are kept mowed, with the mower sickle set high, the seeding may be smothered and a poorer stand secured than if no fertilizer is used.

Pasture. The popular idea of a muck pasture is one that produces a coarse grass of poor quality, on which the grazing cattle are always in a "run-down" condition. This is due to the fact that the muck pasture has been much neglected in the past, and, when the muck has become so worn out that it fails to produce other crops, it is usually seeded down and pastured. When it is properly drained, fertilized and seeded, a pasture of very good quality can be secured, unless the muck is very acid.

June grass (Kentucky Blue Grass) is the most popular native pasture grass on the mucks of southern Michigan. Of the seedings, timothy and alsike has proven very satisfactory, while white sweet clover is reported to have given excellent results. A mixture of timothy alsike and sweet clover (equal parts) is reported also to produce a very good pasture. It is essential in the maintenance of a good sod, that it be neither pastured until firm in the spring, nor too closely during the summer.

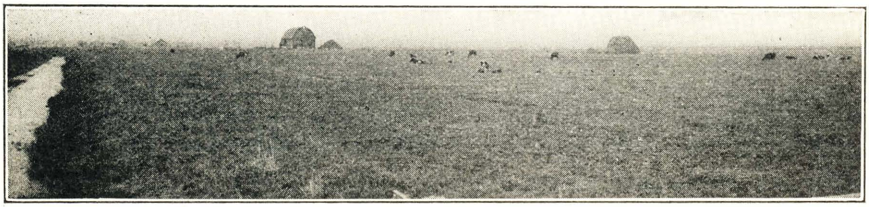

Fig. 28.—Muck pasture. A tame seeding on muck gives an abundant growth of good quality grass if properly drained and fertilized.

Frequently the expense of removing stumps and roots, or the cost of breaking, prevents the final reclamation of a muck area. The experiences of several muck farmers, as well as experiments being conducted, show that such areas, if they are not strongly acid, may be much improved for pasture, without breaking, by the seeding of a grass and clover mixture. Timothy and alsike is most commonly used for this purpose. One report from northern Michigan states that very successful results were secured from the use of white sweet clover in this way. A mixture of all three might also be used with good results. If a number of crops of hay have been removed, a light application of fertilizer may markedly increase the growth of grass.

Grain. Grain farming on muck has not proven entirely successful for two reasons: one, that the grains are slightly susceptible to summer frosts, and the other, that the tendency of grain to lodge when grown on muck often results in crop failure. Where summer frosts are not frequent, successful results can be secured by fertilization with potash and phosphate which tends to decrease the lodging. In general winter rye, oats and barley rank in the order named in their adaptability to mucks. Winter wheat cannot be generally recommended although some farmers are reporting good results with it. Early maturing, stiff-strawed varieties usually give the best yields. Ordinarily, seeding of the spring grains as soon as the muck is in good shape is preferable to late seedings. Both oats and barley do better while the weather is cool, and if sown late are often choked with weed growth. Further they are usually injured by frost less during early growth than late in the season.

Three varieties of oats which have given very satisfactory results in our fertilizer experiments on muck are Gopher 674, Iowar and Iowa 103. All of these varieties are shorter, stiffer-strawed, and earlier maturing than are the varieties ordinarily grown on Michigan soils and for those reasons are especially adapted to muck soil. Wisconsin Pedigree barley has given the best results in our fertilizer trials.

Buckwheat and flax have been very successfully grown in some localities. Buckwheat is somewhat susceptible and flax very sensitive to frosts. The Minnesota Station (1) reports that they have found flax "able to do without fertilization better than other crops" but state that the failure of this crop on burned muck for the first season after burning is a common experience in that state.

Corn is one of the best crops that can be grown on muck where frost is not a factor, but it is very sensitive. It is one of the best indicators of a decided lack of potash in the soil, a dwarfed or weak leaning stalk, of a sickly yellow color, with no ear or with shrunken kernels on a "nubbin" ear, being a very sure sign of "potash hunger," if drainage is proper and the soil is not strongly acid. An early maturing variety should be selected for the muck field.

Root Crops. Muck soil is ideal for the production of root crops. Sugar beets, stock carrots, turnips, mangels, and similar roots, give very good yields and make excellent fall and winter feed for stock. Yields of 8 to 14 tons per acre of sugar beets and of 20 to 30 tons of the other roots mentioned are not uncommon, when they are fertilized. Root crops can withstand considerable freezing, although they are sometimes injured by a hard freeze during early growth. Stock carrots produce good yields on mucks which are too acid to produce satisfactory results with sugar beets or mangels. They do not require as heavy fertilization as the other root crops but the crop of the following year should be well fertilized.

Fairly early planting of sugar beets, stock carrots and mangels generally results in the best yields on muck, but a June planting of turnips is better for winter feeding. On finely decomposed mucks, it is advisable to cultivate as soon as the rows can be seen, if a smooth surface has been established by rolling, since the wind may injure the crop by blowing away the muck.

Results secured from the growing of sugar beets as a cash crop promises to make it one of the most important crops on muck soil. A good return is secured from the roots, without a great loss of plant food, if the tops are returned immediately to the soil. However, in the majority of cases observed, beet growers have allowed the tops to rot in small piles in the field, which results in the leaching out of a considerable portion of the potash into a very small area of soil. Since potash is the most important fertilizing constituent on muck soil, this loss certainly should be by all means avoided. Feeding of the tops in the fall or as silage (see a subsequent page) will pay well for the additional fertilizer to compensate their removal. Feeding in the field usually results in considerable waste.

An additional advantage in growing sugar beets is that the clean cultivation involved results in the destruction of weeds, frequently a very important factor on muck soils. As a means of controlling leaf spot (commonly called blight), the most serious disease of sugar beets in Michigan, it is stated (6) that sugar beets should not be grown two years in succession on the same field.

Fig. 29.—Two examples of mismanagement of muck soil. These piles of sugar beet tops were not spread in the fall after topping. Instead they were disked in as shown in the photograph and the field was sown to oats and seeded down. The oats gave no evidence of the presence of the piles, but, after harvest, the location of every pile was evident in a much greater growth of the seeding. The white lumps are part of a fairly heavy application of lime from a sugar beet factory, hauled five miles and applied to a muck that didn't need it.

Potatoes. Potatoes are strongly recommended as a muck crop by European and American investigators. They prove very satisfactory on mucks which are not subject to summer frosts. When they are not frosted, a very good yield can be expected on a well fertilized muck, but when the vines are frozen back in July or August a much decreased yield is generally the result.

In variety tests, conducted co-operatively by C. E. Cormany of the Farm Crops Section and the writers in 1922, Early Ohio produced the best yield among several of the early varieties, while the Russet Rural (Petoskey) was the best of several later varieties. Russet Rural showed considerably the greatest response to fertilization. A late variety planted fairly early generally gives better yields than an early variety, on muck soil. Russet Rural has the disadvantage of being slightly darker than some of the white varieties, when grown on muck.

Beans. Although this is an important crop in Michigan, it cannot be recommended for our muck soils. This is because the crop is very easily injured by frosts, throughout its growth. On muck areas which are protected from frost by their nearness to a lake or by a high content of mineral matter in the soil, they make a very satisfactory crop, but on a large majority of the mucks they must be considered as not adapted to the soil.

Peas. Peas, considering either the varieties used for canning or the field varieties, are well suited to muck land, especially because of their marked resistance to frost. Very little experimental work has been done with this crop on muck, but the results secured indicate the need of early planting for best results. A fertilizer mixture containing more phosphoric acid than is used with most muck crops gives the best results in this case. When they are combined with oats, a good quality of hay or silage can be produced.

Silage Crops. Besides the mixture of oats and peas, three other crops grown on muck soils should be considered from the standpoint of their suitability for silage, viz.: corn, sunflowers, and sugar beets.

Fig. 30.—A portion of the field shown in Fig. 29, showing the effect of the sugar beet top piles on the second crop of the hay three years later. The clover is practically gone except where the sugar beet top piles were located, where the growth is largely clover, of a good color and a much better growth than elsewhere.

Sugar beet tops, which term includes both tops and crowns, as they are cut from the roots when the crop is sent to the factory, are used for silage with excellent results in the sugar beet sections of the western States (Idaho, Utah, Colorado and Montana). In a report (18) of a study made by the U. S. Dept. of Agriculture of the value of beet-top silage, the following statement appears: "Most beet growers estimate that beet-top silage has a value about 1/3 to 1/2 that of alfalfa hay. The silage is well suited for the dairyman or for the feeder of beef cattle and sheep. When beet-top silage is feed for the production of beef or mutton, the hay requirements may be reduced 50 per cent; furthermore, the warm succulent silage seems to stimulate the appetite of the animals, causing them to consume and utilize larger quantities of feed." Caution is urged against the inclusion of sand in the silage, a factor which need not be considered with muck beets.

Though the tonnage of beet tops on mineral soil averages about one-half that of the roots, those grown on well fertilized muck generally approximately equal the roots in weight. The yields of tops from several high-lime mucks for the season of 1921 and 1922, are presented in Table 27 and the yields from two fields in 1923, in Tables 17 and 18. The lowest yield was secured in Eaton County, where they were grown on muck that had grown beets the year before and the yield of tops was greatly decreased by a severe attack of leaf spot, which killed the leaves as fast as they developed. The beets on the Allegan County project grew on a very shallow muck, while those in the Lapeer County were planted very late. It is evident from the experience of beet farmers on high-lime muck that an 8-ton yield of tops can be expected, if the beets are well fertilized with a mixture containing a high percentage of potash. In ensiling, western growers add straw to take up the excess moisture from the beet tops and in that way the quantity of silage is somewhat increased. A Clinton County grower reports very good results from the feeding of beet top silage to his dairy cattle. As he puts the beets through the ensilage cutter, he adds an equal quantity of corn stover, from which the ears have been removed.

Table 27.—Effect of Fertilization on Yield of Sugar Beet Tops in Different Muck Areas.

Average of plots	Tons per acre of sugar beet tops—1921			Average of plots	Tons per acre of sugar beet tops—1922					
Fertilizer application—1921 lbs. per acre	Lapeer Co. No. 2	Berrien Co.	Lapeer Co. No. 1	Fertilizer application—1922 lbs. per acre	Allegan Co.	St. Joseph Co.	Lapeer Co. No. 1	Eaton Co.	Ingham Co. No. 1	Huron Co.
Unfertilized......	8.4	1.3	6.4	Unfertilized......	6.8	13.2	3.6	2.2	3.4	6.9
K 200...........	10.2	5.1	10.2	K 300...........	7.9	17.2	10.3	4.7	6.4	8.2
P 250 K 200.....	12.1	4.2	9.9	P 300 K 300.....	7.2	18.2	6.2	4.4	10.0	11.5
P 250...........	13.7	0.9	4.7	P 300...........	6.4	10.9	4.2	2.1	5.3	6.5
P 250 K 200 N 100	13.6	4.1	10.5	P 300 K 300 N 100	9.1	19.8	6.9	5.4	11.8	11.1
Manure 10 loads..	12.1	3.2	9.9	Manure 12 loads..	7.9	13.7	......	4.0	8.7	9.7

A comparison of corn silage and sunflower silage has been made at several different experiment stations with very conflicting results. In general, the conclusion has been in favor of corn silage where it can be raised. However, sunflower silage has proven satisfactory in some parts of northern Michigan, northern Minnesota and Canada. Sunflowers have advantages in that they are not easily frosted and that their yield is at least 50 per cent greater than that of corn. Sunflowers are more difficult to harvest and the silage is sometimes not readily eaten by stock. Nevertheless, reports from a number of muck farmers indicate that sunflowers have a place, when grown for silage on the frosty mucks of the state. They require less cultivation than corn, as their abundant foliage prevents weed growth. The writers have observed, on some of the experimental fields, that Canada thistles were numerous in the corn plots but there were practically none in the sunflower plots adjacent.

Fig. 31.—Effect of crop on weed growth on muck. The crop above was sunflowers, the stubble showing in the picture. Note the absence of weed growth. The lower picture shows corn stubble. A corn bundle is just visible in the weeds in the center of the picture, but the stubble is entirely hidden by weeds. The two pictures were taken in adjoining strips in the same field, which were plowed, fitted and cultivated in the same manner.

General Crop Rotation on Muck Soil. The general crops which can be grown successfully on muck are best suited to a system of farming which includes dairying or livestock raising. A 5-year rotation which fits into such a system of farming is: first year, grain seeded down; second year, hay; third year, pasture; fourth year, potatoes, corn, sunflowers or a root crop; fifth year, sugar beets. If the muck is rather subject to summer frosts, the potatoes and corn should be omitted. Instead the pasture may be continued for two years, broken up in late summer and well worked to kill grass, then planted to sugar beets the fifth year.

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