Organic Soils (Histosols) Formation, Distribution, Physical and Chemical Properties and Management for Crop Production
Michigan State University Agricultural Experiment Station and Cooperative Extension Service
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FARM SCIENCE

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ORGANIC SOILS (HISTOSOLS)

Formation, Distribution, Physical and Chemical Properties and Management For Crop Production

(Upper left) a recent drainage ditch located on the Michigan Muck Experimental Farm near Bath. (Upper right) celery field located near Hamilton, Michigan. (Lower left) harvesting peat for sale in Quebec Province, Canada. (Lower right) harvesting head lettuce near Pahokee, Florida.

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FORMATION

Histosol, one of 10 soil orders, is the nomenclature used by scientists to identify organic soils. They were formed under water or in very poorly drained areas. Agriculturists usually describe the soil as peat if undeveloped or fibrous in texture and muck when well decomposed after tillage. Some other common names for organic soil deposits include marsh, turf, bog, fen, moor, mire and muskeg.

Organic soils are found in all parts of the world and total about 845 million acres (342 million hectares). Most deposits are found in wet, cool areas of Canada, U.S.S.R., Finland, Sweden and Alaska. The total in the U.S.A. is about 52 million acres of which 27 million are located in Alaska.

The process of Histosol formation because of water-logging conditions is called "paludification." The major environmental factors that affect organic soil accumulation and the physical-chemical properties include:

1. Water source and balance
2. Mineral content of the water
3. Climate
4. Parent vegetative cover
5. Management after drainage

Water Source

Many soil specialists combine the effects of water source and its mineral content to describe the formation of three major types of organic soils, Moore and Bellamy (139), however, separate the effects of water source. They list the three as Group A, B and C.

Group A - Rheophilous[1] - The water source for this group of soils is derived from the surrounding land. Within Group A are four subtypes which describe the water flow as continuous, or intermittent in combination with flowing over or beneath the organic soil. The mineral in this group is predominately calcium bicarbonate. Many writers describe this group as eutrophic organic soils.

Group B - Transitional - This organic soil develops when the waters are derived from seepage. The dominate ions in the water are calcium and sǔlfate. The mineral subsoil may supply a limited amount of plant nutrients if the peat layer is shallow. This group is also called mesotrophic organic soils.

Group C - Ombrophilous[2] - These soils obtain their water only from precipitation. The water lacks the basic cations, Ca (calcium), Mg (magnesium) and K (potassium). They are also called oligotrophic organic soils.

Effect of Minerals in the Water

As already noted, water source affects the ground water mineral content. This difference in minerals markedly affects the kind of plant species that grow on the organic soils. Weber (204) described the three major categories as eutrophic (rich in lime), mesotrophic (intermediate) and oligotrophic (poor in lime) peats. Water samples from eutrophic deposits averaged about 50 ppm (parts per million) basic cations Ca, Mg, K and Na, while oligotrophic peats contained only about 5 ppm.

Wilde (205) investigated the chemical properties of the ground waters for several Wisconsin Histosols. The pH, specific conductance (in mhos) and the redox potential (in millivolts) for waters collected from moss peat were 4.2, 7.9 and -255;, for a wood peat, 6.1, 22 and -49 and for a sedge peat 7.0, 68 and +52, respectively.

Under eutrophic conditions if the climate is favorable, there is an abundant growth of plants. Under oligotrophic conditions only mosses, lichens, acid tolerant grasses and

[1]Rheophilous means "loving the flow"

[2]Ombrophilous means "loving the rain"

shrubs grow. In the tropic, however, oligotrophic peats are often covered with dense forests (214). Many organic soils will show all three stages of development, a eutrophic plant residue in the lower profile, then mesotrophic and finally oligotrophic residue in the upper horizon when the mineral supply became limited.

Botanical Sources of Organic Soils

Peat bogs in their natural setting can exhibit large numbers of contrasting flora (Figure 1). Dachnowski (36) reports over 300 plant species found in the Lake States. These species include those submerged and floating in water, growing along the shoreline and on the bog surface. The sequence for the latter is usually meadow, heath, shrub and finally forest association. The chemical composition of both the organic and the inorganic fraction, water level and pH greatly influence the plant associations. Differences in plant cover change the organic soil characteristics which in turn influences our present day utilization of the soil.

Dachnowski describes the general pattern of organic soil developments as first plankton growth in the water and chara, hornwort (Ceratophyllum demersum) and others in the deep water and pond weeds (Potamogeton sp.) and water lilies (Nymphaea) in shallow water. After a period of accumulation the conditions become favorable for the growth of sedges, reeds and grasses. These give way to heath cover and finally are displaced by shrubs and forests. In general, such a succession of plants occurs around lakes with deep water.

Bellamy's (12) model illustrates five possible stages of development in a peat formation for shallow lakes or glacial drainage depressions. In Stage 1, a water flow occurs over all of the depression. It promotes the production and

Figure 1. Some contrasting organic soil formations in Michigan.

Figure 2. A sphagnum peat profile in Ireland. Note layering effect caused by changes in the environment, also the lower material is much more humified.

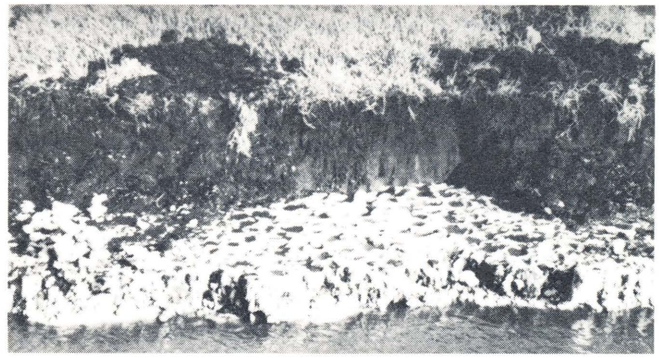


Figure 3. The Pahokee muck profile over the limestone rock. Note pitting of the limestone. Depth of soil now is only about 4 feet.

deposition of algae, pond weeds and other limnic sediments. After sufficient organic residue accumulation, reeds, sedges and other plants grow which retard flow.

In Stage 2, the depression is subject to complete overflow only during periods of excessive runoff. At Stage 3, the peat accumulation has diverted the outside water away from the deposit. The water source is then only seepage and precipitation. At Stage 4, large areas of the peat surface are unaffected by moving water. At this stage, the growing conditions are favorable only for plants that tolerate low mineral supply and high acidity (Figure 2).

At Stage 5, the peat accumulation develops a perched water table and the water source is only precipitation. Conditions are identical to those described earlier as "Group C" peats. The ground water is probably less than 2 ppm calcium. At this stage, the deposits are called raised peats (Hochmoor in German) because the middle of the deposit has a higher elevation than the edges (convex shape). The depressed margin is known as the lagg. The raised surface is due to the greater rate of organic matter accumulation. In contrast, the peats on the edges contain more minerals and oxygen, decay faster, and are more humified and are darker in color.

Limnic Peats

As already mentioned, aquatic plants are the first peat formers. Finney et al (57) studied a number of peatlands in Minnesota and found the thickness of limnic materials ranged from one foot to over nine feet. Three major components make up the limnic sediments—coprogenous earth, marl and diatomaceous earth.

In the Great Lakes area, coprogenous earth and marl are the dominate limnic materials. Coprogenous earth includes materials described by European workers as "dy," "gyttja" and "sapropel" (108). Limnic peats are often called sedimentary peats. On drying they often show thin, flat sheet characteristics.

Coprogenous materials consist of a mixture of pollen, algae, wind blown and water transported mineral, and plant residue material. Marl consists mostly of calcium carbonate derived from deposits on Chara, from shell fragments, and from precipitation of calcium from bicarbonate saturated solutions.

Limnic peats are sometimes called "allochthonous peats" because the organic sediments usually have been transported. In contrast, autochthonous peats are derived from plants growing on the site. Some limnic peats contain high amounts of microscopic diatom remains. When burned, the ash is high in silica and usually is creamy-white in color.

Telmatic Peats

After an accumulation of limnic residue and/or water cover is shallow, semiaquatic plants grow and produce telmatic peats. If the water is rich in lime (Ca, Mg) then the environmental conditions favor the growth of phragmites, sedges, cattails, sawgrass and herbs (Figure 3). If the water is poor in lime, then cottongrass, carex sedges, cranberries, and sphagnum mosses are the primary plant association.

Terrestic Peats

These peats are formed above the water table. Under eutrophic conditions, the plant associates include sedges, grasses, herbs, shrubs and trees. Under oligotrophic conditions, the primary plants are likely to be cottongrass, leather leaf, mosses, blueberries, sedges and/or pines.

Numerous botanists and geologists have published papers on the ecological and botanical makeup of organic soils. Of special mention is the work of Cohen and associates (32) now at the University of South Carolina, Department of Geology. They have developed procedures for taking microtome sections of peat for microscopic analysis. By comparing these with microtome sections of growing plants, it is possible to determine the types and proportions of the botanical constituents in peats.

Many general terms are used to describe organic soil. Generally, for crop production purposes, they can be grouped into two major categories—high lime or low lime. Names of some opposite types based upon soil acidity are:

Low Lime pH 4.5 or below	High Lime above pH 4.5
Peats	Fens
Bogs	Marshes
Raised Peats	Depressional peats
Oligotrophic	Eutrophic
Ombrogenous	Soligenous
Lime poor	Lime rich
High moor	Low moor
Hochmoor	Niedermoor
Moss	Reed-sedge
Heath	Sedge-forest
Upland	Local
Blanket	Basin
Dysic*	Euic*

See section on family, page 6.

CLASSIFICATION OF ORGANIC SOILS

During the past 25 years, the classification of organic soils has undergone major revisions. Less emphasis has been placed on botanical origin and more on morphological characteristics and on testing procedures which can easily be used in the field. Soil scientists (56, 132, 176) have introduced a classification that includes:

1. Order All soils of the world fit into one of ten orders. Histosols cover those that describe organic soils. (Histos is a Greek word meaning tissue.) A Histosol must contain a minimum of 12% organic carbon when the mineral portion contains no clay and 18% carbon if the soil has 60% or more clay. These carbon values are equivalent to 20 and 30% organic matter, respectively.

In addition, the following profile descriptions are included:

a. A depth of 60 cm or more if 75% of the volume is fibric sphagnum or moss or if the bulk density is less than 0.1 g/cc.

b. A depth of 40 cm if the organic soil material is saturated with water for long periods (6 months) or is artificially drained, and the organic material has a bulk density of 0.1 g/cc or more.

c. A depth of 10 cm or less above a lithic (rock) or paralithic contact, provided the thickness of the organic soil material is more than twice that of the mineral material above the contact.

d. Any depth if the organic material rests on fragmental material (gravel, stones, or cobbles) in which the interstices are filled or partly filled with organic materials or rests on a lithic or paralithic contact.

2. Suborder This division differentiates Histosols by their degree of decomposition in the 30 to 90 cm subsurface layer into saprists, hemists and fibrists. In addition, a fourth division—folists—describes organic soils which consist of leaf litter and wood fragments resting on rock or gravel. Saprists are soils that show by volume less than 17% fiber when rubbed, hemists 17 to 75% and fibrists over 75%. Fibers are described as the peat residue which will not wash through a 100 mesh sieve (0.15 mm opening), and contain recognizable cellular tissue of the parent plant.

3. Great Group This division separates out Histosols by soil temperature regimes—cryo, boro, medi, and tropo—as illustrated in Table 1. This group also separates out the peats that carry sulfidic materials. These peats are sometimes called acid-sulfate Histosols.

4. Subgroups Each great group is divided into three divisions—one is designated as: 1) typic for typical profile, 2) intergrades and 3) extragrades.

The intergrades recognized are:

(1) Fibric - mostly fibrous peat

(2) Hemic - mostly partly-decomposed peat

(3) Sapric - predominately decomposed organic soil

(4) Fluvaquentic - two or more thin layers of mineral soil.

The extragrades total five and include those that do not fit into the typic or intergrades. These are:

(1) Terric - peats with a mineral soil layer or layers

(2) Limnic - limnic layers

(3) Pergelic - permafrost layer

(4) Lithic - presence of rocks

(5) Hydric - open water

5. Family Within each subgroup, Histosols are separated into families based upon soil properties that are important in soil management. These include mineral subsoil texture, presence of iron, kind of limnic material, depth of peat, soil reaction (pH) and soil temperature class. Modifiers to indicate reaction are:

Euic - The pH of undried samples is 4.5 or more in 0.01 M $CaCl_2$ for some part of the organic materials in the control section.

Table 1. Great groups of Histosols.

Great Group	Soil Temperature Regime	Temperature Classes
Cryosaprists Cryohemists Cryofibrists Cryofolists Sphagnofibrists	Mean annual soil temperature of less than 8° C; and 1) are frozen in some layer within control section; or 2) have an oceanic climate with no frost below 5 cm.	Frigid Isofrigid
Borosaprists Borohemists Borofibrists Borofolists Sphagnofibrists	Mean annual soil temperature that is less than 8° C.	Frigid
Medisaprists Medihemists Medifibrists	Mean annual soil temperature that is greater than 8° C.	Mesic Thermic Hyperthermic
Troposaprists Tropohemists Tropofibrists Tropofolists	Mean annual soil temperature of 8° C or more and less than 5° C difference between mean summer and winter soil temperatures	Isomesic Isothermic Isohyperthermic
Sulfihemists Sulfohemists	No restrictions on climate.	

Dysic - The pH is less than 4.5 in 0.01 M $CaCl_2$ in all parts of the organic materials in the control section.

6. Series Within the family group there are soil units with narrow but observable differences. Each unit is designated as a soil series. In the U.S. there are about 100 series listed for organic soils. The name of the soil series has no pedogenic significance but may represent some geographic location where the soil was first described (for example, Houghton, Napoleon, Pahokee). Some of the major properties that make for a series unit are pH, temperature class, depth, and the mineral soil texture within and/or below the organic soil layer.

Table 2 shows examples of the taxonomy for just 10 Histosols to illustrate the various divisional descriptions.

Age and Rate of Peat Accumulation

Peat accumulation started eons ago when plants grew in swampy areas. With time, and from pressure of overlying sediments, the plant residue changed from complex organic compounds to less complex materials. This process, called "coalification," proceeds from plant residues to form peat, to lignite (brown coal), to bituminous coal and, with heat, to anthracite coal. During these changes the carbon content increases from 40% in plant residue to about 90% in anthracite.

Peat forming processes probably reached their peak during the carboniferous period when the world temperature was milder, land surfaces flatter and the atmosphere richer in carbon dioxide. In North America, this period corresponds to the Mississipian and Pennsylvanian period. The low mineral soil contamination in the ancient deposits would indicate extensive marshland and little sediments in the run-off water.

Our present day deposits are largely the results of glaciation which wiped out previous surface deposits and then formed pot holes, lakes and glacial river valleys (Figure 4). Calculations based on radiocarbon 14 (^{14}C) studies show that the ice started to recede from Lower Michigan about 15,000 years B.P. (before the present) and was completed in Upper Michigan about 9,500 B.P. Thus, the age of surface peats located in Michigan does not exceed this time limit.

Studies at Belle Glade, Florida indicate peat formation in the Upper Everglades began about 4,400 years B.P. (131). It took about 800 years to produce 8 cm of basal marly-muck. Then, about 3,500 to 4,000 B.P., plant growth and peat production increased rapidly because of environmental changes. By the year 1914, the peat had a thickness of about 3.65 m. for an average accumulation of 8.4 cm/100 years (3.3 inches). In terms of volume, the production was about 8.4 m^3/ha/yr. Assuming a bulk

Table 2. Some examples of Histosol classification (176).

Suborder	Great Order	Sub Group	Family	Series (Location)
Saprist	Medisaprists	Terric Medisaprists	Euic Mesic	Adrain (Great Lakes)
Saprist	Medisaprists	Limnic Medisaprists	Marly Euic Mesic	Edwards (Great Lakes)
Saprist	Troposaprists	Terric Troposaprists	Clayey Kaolinitic Dysic Isomesic	Alakai (Hawaii)
Hemists	Borohemists	Typic Borohemists	Dysic Mesic	Spaulding (Great Lakes)
Hemists	Borohemists	Hydric Borohemists	Dysic	Tahquamenon (Great Lakes)
Hemist	Medihemists	Lithic Medihemists	Euic Hyperthermic	Pahokee (Florida)
Hemists	Sulfihemists	Typic Sulfihemists	Euic Thermic	Handsboro (Mississippi)
Fibrists	Borofibrists	Typic Borofibrists	Dysic	Vassalboro (Maine)
Fibrists	Sphagnofibrist	Pergelic Sphagnofibrists	Dysic	Lemeta (Alaska)
Fibrists	Cryofibrists	Fluvaquentic Cryofibrists	Dysic	Staney (Alaska)

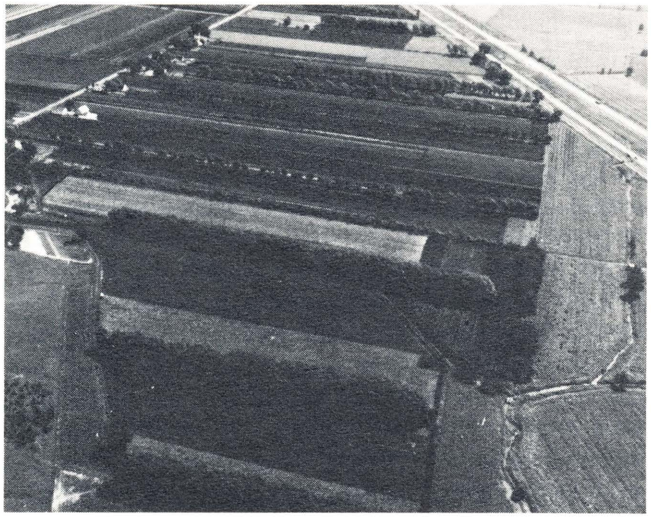


Figure 4. An aerial view of the mucklands in the Hudsonville, MI area. This valley was formerly the Grand River bed during the late glacial epoch. Similar formations are located near the cities of Imlay City, Decatur, South Bend and others in the Great Lakes area.

density of 0.15 g/cc, the production averaged about 1260 kg/ha/yr (1120 lb/acre).

In the unglaciated area of S.W. Wisconsin, Davis (40) calculated the annual rate of accumulation was 6.8 cm/100 years for a deposit that started 4,400 B.P. Einarsson (51) reports that the rate of peat accumulation in Iceland averages about 3.9 cm/100 for the past 1,000 years. However, during the 2,500 to 4,000 B.P. period, the rate was only about 1.8 cm.

Others have found it required 5,600 years to form a 4.3 m deposit in Japan, 6,700 years for 2.4 m in So. Africa, 11,000 years for 6 m in Michigan and 1,700 years for 2.3 m in Florida. Dawson (47), reviewing a number of studies, concluded that in most situations it required 600 to 2,400 years to accumulate 1 m of peat and the average was about 1,500 years.

In Southern Finland, Tolonen (189) found that peat accumulation ranged from 250 to 430 kg/ha/yr where the primary plant growth was estimated to be 4200 kg/ha. In another study (190) he reports less than 20% of the annually produced phytomass remains stored in deep peat layers.

Peats are nature's record of past climates and flora. Extensive studies have been made by biologists, paleontologists and others on peat deposits. The procedure now commonly used to determine age is to measure the radiocarbon content (119). In addition, age can be estimated by volcanic ash layers (162), pollen analyses, varved clay studies and archaeological markers.

Studies by Von Post (197) and many others in Europe make it possible to relate climatic changes by a study of the pollen grains preserved in the peat. (One gram of peat usually contains over 50,000 pollen grains.) It was possible to relate age by comparing the pollen in peat with those in varved clays. (Varves are sediment layers found in old or existing lake beds. Age can be determined as one counts rings in a tree trunk.) The first evidence of alder pollen in the peat profile is often used as a bench mark. Age for this layer was estimated at 9,000 B.P. Later radiocarbon determinations substantiated the date.

The distribution pattern for pollen in Figure 5 illustrates how climatic changes affect peat composition and the surrounding plant cover. The "Grenzhorizont" is often cited as a reference point, where dark-humified peat is overlain by light colored sphagnum moss—a description first designated by Weber (203). More recent studies, however, indicate that a number of light peat layers over dark colored layers can be found in the bogs of Central Europe where age can differ by 1000 years (167).

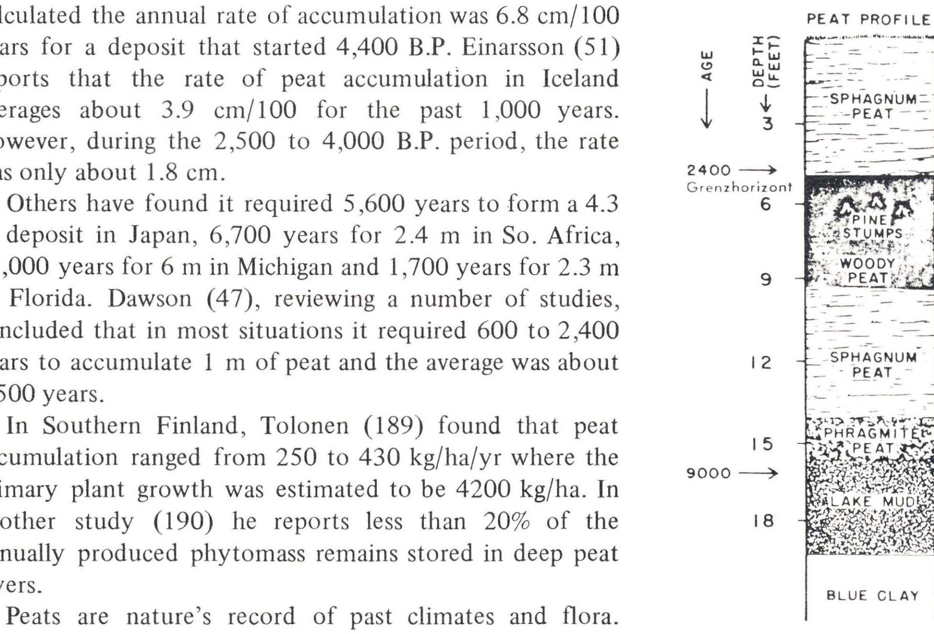
Stages of Climatic Succession

In Europe, major climatic succession has been determined by pollen anlysis. (Ages indicated are estimates reported by Hammond (79) and Godwin (71):

1. Late glacial period. (Pollen Zone I, II and III)

This period was characterized by presence of late glaciers, with wide meadows (Tundra) and sporadic clumps

PERCENT POLLEN COUNT



WILLOW	BIRCH	PINE	ALDER	LINDEN OAK ELM	SPRUCE
0	10	56	3	0	31
0	20	42	8	2	28
0	33	43	8	5	11
0	25	53	12	8	2
0	28	43	15	11	1
0	32	40	18	9	0
0	30	41	19	10	0
0	34	30	16	20	1
0	31	40	13	16	0
1	49	37	10	3	0
6	62	32	0	0	0
4	68	28	0	0	0

Figure 5. Stratification found in a peat soil in Sweden because of climatic changes. The top sphagnum peat was formed during the sub-Atlantic period; the woody peat during the sub-boreal period; the lower sphagnum peat during the Atlantic period; the area down to zero alder count was formed during the boreal period. Most peats show a gradual change in botanical makeup in the zone between the Atlantic and sub-boreal. Figures at right show the percentage pollen distribution for various layers. Data in part from Von Post (197).

of willow, pine and birch trees. Age - 10,000 to 12,000 years.

2. Pre-boreal or birch-pine period. (Pollen Zone IV)

Thick stands of pine and birch were present and a few heat loving trees appeared. Age - 9,000 to 10,000 years.

3. Boreal period. (Dry and warm) (Pollen Zone V, VIa, b, c)

In this period, post-glacial heat increased and resulted in drying of the bogs which then became partly covered with forests, chiefly hazel, birch and pine. Age - 7,000 to 9,000 years.

4. Atlantic period. (Wet and warm) (Pollen Zone VIIa)

In addition to pine, alder and oak and in some areas a mixed stand of oak–elm and linden was established on the highlands. The young sphagnum bog groups began to appear. The Atlantic period extended from 5,000 to 7,000 B.P.

5. Sub-boreal period. (Warm but rather dry) (Pollen Zone VIIb)

Pine, oak, elm, linden and alder were present in some bogs. Oak, ash, beech and linden predominated in the highlands of Denmark. The period lasted about 2,500 years. The frequent separation of European sphagnum peats into the upper layers and woody peats in the lower dark to brown layers correspond to a climatic change following this period. Age - 2,500 to 5,000 B.P.

6. Sub-Atlantic forest period. (Increasing wetness and falling temperature) (Pollen Zone VIII)

Spruce and pine increased and oak, elm and beech retreated. Man appeared on the scene accompanied by an increase in meadows and farms replacing the forests. In the last 100 years there has been a warming trend. Age - 2,500 to the present.

North American peats show similar trends in climatic changes as in Europe, but not in the type of peat. In Europe many species of the Tertiary flora were eliminated during the Pleistocene glaciations because the Alps prevented the retreat of flora southward. In this same period in North America, flora retreated south to southeast. The preboreal period was characterized by a pine maximum followed by a pine decline and a rise in hardwoods. Later the tree species–maximum of beech and in places hemlock –indicated a higher humidity. This corresponded to the Atlantic period in Europe.

In North America, the warmer drier period that followed was characterized by oak and oak-hickory forests. According to Potzger and Courtemanche (153), forests extended about 350 miles north of the present line in Canada. Finally, the increase in spruce in northern areas, correlated with a return to higher humidities, corresponded to the sub-Atlantic period in Europe. Pollen studies on Ohio peats indicate the forest sequence as: first, spruce and fir; second, pine and birch; third, beech; fourth, oak and hickory; and fifth, oak and beech (152).

Crane (34), and Zumberge and Potzger (208) determined the radiocarbon age of a 30 inch deposit of peat buried under dune sand found near South Haven, Michigan. The age was 7,925 years for peat near the base. Pollen studies showed that this peat layer was formed during the waning phases of the spruce-fir period. Peat sampled seven inches from the base gave a high pine pollen count and showed an age of 6,300 years. Peat from near the top of the 30 inch deposit was believed to mark the time just before the present Lake Michigan dune activity. Pollen deposited at this point probably first preceded the xerothermic period of oak, pine and broadleaved forest of the South Haven latitude. The radiocarbon age was 4,000 years.

Distribution of Organic Soils

Organic soils may be found in practically any climatic zone. Bramryd (23) estimated Histosols covered 4% of the land in Europe, 11% in Asia, 0.6% in North America, 0.13% in South America, 0.18% in Africa and 0.04% in Australia. The average annual accumulation was estimated at 0.7 mm per deposit and totaled about 2.1 x 10^{11} kilograms of organic carbon. There are about 32 million hectares in the tropics (213) and extensive areas in subarctic regions.

The world's peat resources have been compiled by several authors. Usually the amounts reported are the exploitable reserves for fuel and horticultural sales. They underestimate total areas classified as Histosols. For example, Histosols in the U.S.S.R. are estimated to exceed 166 million hectares (112). Data in Table 3 reports some estimates presented at International Peat Congresses, by Moore and Bellamy (139) and by Driessen (211). Data in Table 4 reports acreages in the U.S. totaling about 51,825,000 acres (20,989,000 hectares).

Chemical Composition

The chemical composition of organic soils is largely determined by the plant associations (Figure 6), the stage

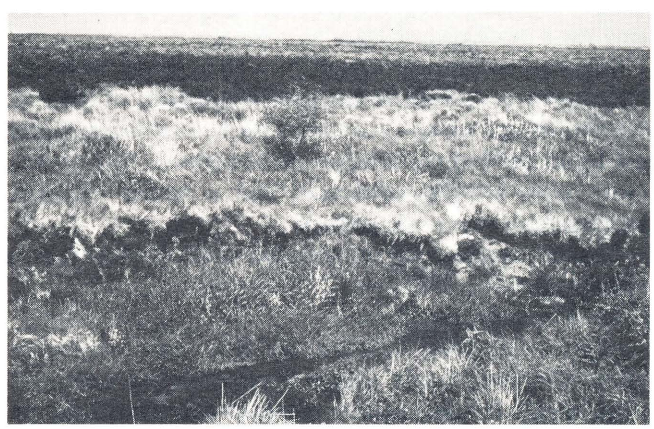


Figure 6. Native raised peat bog in Ireland. Note the changes in botanical cover as one departs from the drainage stream–first sedge (Carex) then heather (Calluna) and finally Eriophorum-Sphagnum plants. (Bog of Allen, Co. Kildare).

Table 3. The world's organic soils resources (hectares).

USSR	150,000,000
Canada	112,000,000
USA	21,000,000
Finland	10,000,000
Sumatra	9,700,000
Sweden	7,000,000
Kalimantan	6,265,000
China	3,500,000
Norway	3,000,000
Venezuela	3,000,000
Sarawak, Brunei	1,650,000
United Kingdom	1,582,000
Argentina	1,500,000
Poland	1,500,000
Vietnam	1,500,000
West Germany	1,129,000
Brazil	1,000,000
Iceland	1,000,000
Zairie	1,000,000
Eire	970,000
Malaya	800,000
Guianas	500,000
Papua	500,000
East Germany	489,000
Columbia	350,000
Cuba	200,000
Japan	200,000
Thailand	200,000
New Zealand	166,000
Hungary	100,000
Netherlands	100,000
Denmark	60,000
France	60,000
Italy	60,000
Czechoslovakia	33,000
Austria	22,000
Romania	6,000
Israel	5,000
Others	500,000
Total	342,647,000

of decomposition and the mineral content of the water associated with the formation of the deposit. In certain cases, the sedimentary material brought in by water and wind has a modifying effect.

Organic compounds primarily of plant origin make up 20 to more than 98% of the total dry weight of the soil. Included in this category are cellulose, hemicellulose, lignin and lignin derivatives, nitrogenous complexes, fats, waxes, resins, water-soluble substances, and a variety of other compounds of minor importance.

Organic compounds in organic soils (Table 5) are separated into five fractions:

1. Water-soluble substances.

Organic materials soluble in cold and hot water (polysaccharides, simple sugars, traces of amino acids, and water-soluble tannins) usually comprise less than 5% of the dry weight, although they may constitute as much as 10%. Due to leaching the content of this fraction is higher in fresh plant materials than the soil formed from them.

2. Ether and alcohol soluble substances.

Ether extracts from plant materials contain fatty acids, wax-like compounds, resins, and nitrogenous fats. Alcohol extracts consist of waxes, tannins, certain pigments, alkaloids and soluble carbohydrates. Sphagnum peats may contain up to 15% soluble carbohydrates. The percentage in sedge and reed peats is 5% or less. As the age of the deposit increases, the amount of this fraction generally increases.

3. Cellulose and hemicellulose.

This fraction accounts for 5 to 40% of the dry weight of organic soils. These compounds are easily decomposed by soil organisms and their content in the original plants is higher than in the peat. Woody sedge peats are generally low in this fraction whereas those derived from sphagnum may be as high as 40%. Reducing sugars are obtained by extracting the residual sample with 2% hydrochloric acid at 100°C for five hours under a reflux condenser. The extractable sugar times 0.9 is considered as the amount of hemicellulose.

4. Lignin and lignin derivatives.

This fraction is considered as the residue remaining after hydrolysis with strong sulfuric acid. The total dry material, minus the ash and protein, multiplied by a suitable conversion factor, represents the lignin content. Many sphagnum peats contain 20 to 30% lignin. Sedge, forest, heath and sawgrass peats may consist of 50% lignin. In general, the lignin content increases with the greater degrees of decomposition. Lignin is fairly resistant to microbial

Table 4. Acreage of organic soils in the United States(a).

Midwest Region	Acres	South Region	Acres
Illinois	104,000	Alabama	115,000
Indiana	375,000	Florida	3,000,000
Iowa	118,000	Georgia	430,000
Michigan	4,530,000	Louisiana	1,800,000
Minnesota	6,377,000	Mississippi	75,000
Missouri	4,000	North Carolina	1,200,000
Nebraska	1,000	South Carolina	75,000
North Dakota	1,000	Texas	10,000
Wisconsin	2,831,000		
TOTAL	14,341,000	TOTAL	6,705,000

Northeast Region	Acres	West Region	Acres
Connecticut	100,000	Alaska	27,000,000
Delaware	4,000	California	166,000
Maine	772,000	Colorado	10,000
Maryland	22,000	Hawaii	486,000
Massachusetts	347,000	Idaho	14,000
New Hampshire	151,000	Montana	110,000
New Jersey	113,000	Nevada	2,000
New York	648,000	Oregon	67,000
Ohio	122,000	Utah	4,000
Pennsylvania	39,000	Washington	200,000
Rhode Island	24,000	Wyoming	5,000
Vermont	60,000		
Virginia	312,000		
West Virginia	1,000		
TOTAL	2,715,000	TOTAL	28,064,000
		TOTAL U.S.A.	51,825,000

(a)Acreage of organic soils obtained from Regional Technical Service Center and compiled by William E. McKinzie, Assistant Principal Soil Correlator, Midwest Region, Soil Conservation Service.

Table 5. Principal constituents of organic matter of various peats.(a)

Type and location of peat	Depth (in.)	Reaction pH	Total Organic Matter	Water Soluble	Ether and Alcohol Soluble	Hemi-cellulose	Cellulose	Lignin humus Complex	Total N
			percent						
Sphagnum	2-4	3.8	95.5	8.6	7.2	25.2	13.1	17.9	0.6
Orono, Main	8-12	3.8	95.7	5.2	7.8	24.1	17.1	18.0	0.8
Heath	0-3	4.0	92.8	4.9	7.4	10.8	5.3	49.3	6.9
Beaufort, North Carolina	3-9	3.5	97.7	3.4	9.1	8.0	4.9	55.7	1.7
Saw-grass	0-4	5.3	91.5	4.1	2.2	11.8	3.6	43.5	3.9
Belle Glade, Florida	32	6.3	93.3	2.1	2.3	4.4	2.2	60.1	3.5
Woody sedge	0-6	4.6	89.2	8.9	9.2	8.1	2.7	35.6	3.0
Monroe, Washington	10-16	4.5	93.5	5.9	7.7	7.0	3.2	38.2	3.3
Sedimentary	15-30	6.2	53.4	6.1	3.5	3.6	1.1	39.6	3.9
Miami, Canal Lock, Florida	42-48	5.9	89.7	2.9	2.2	4.2	1.7	46.1	3.5

(a)Data from Feustel and Byers (58) based on 100 parts of organic matter.

action and the lignin content of the soil is higher than that of the plants from which it was derived. On the basis of methoxyl content, many reed and sedge soils have more lignin in the surface layer than at lower depths. In many raised bogs the reverse of this situation has been reported.

5. Nitrogenous constituents.

The nitrogen in organic soils is practically all in the organic forms, although small quantities of nitrate are usually present in well-drained soil. Measurable amounts of ammonia may be detected when water tables are high. Approximately 65 to 75% (198) of the total organic nitrogen is considered proteinaceous in nature.

The analyses of two deposits in Southern Quebec Province showed some striking differences in the nitrogen fractions (178). A Ste Clothilde profile ranged from 45 to 50% amino acid-N, 4 to 6% hexosamine-N, 8 to 12% NH_4-N, and 20 to 24% acid insoluble-N. A Farnham profile showed 38 to 43% amino acid-N, 9 to 11% hexosamine-N, 11 to 15% NH_4-N and 20 to 29% acid insoluble-N.

Analyses of nine Histosols in Wisconsin (94) showed an average of 36% of the hydrolyzable N was amino acid-N, 6.6% hexosamine-N, and 14.6% NH_4-N—25.7% was not identified. The nonhydrolyzable-N was 17.2% of the total soil N.

The nitrogen content of peat varies between 0.3 to nearly 4%. Peats developed from reeds, sedges and various trees are generally two to four times higher in nitrogen than those from sphagnum mosses and Eriophorum sedges. These latter have 1 to 1.5% nitrogen in the plant tissue but their peat residue contain less than 1%. For the Everglades, the opposite effect occurs—sawgrass plants contain only about 1% nitrogen but their peat residues contain about 3%.

The degree of humification has a great influence on the chemical composition of peats. Data in Figure 7 illustrate the changes found for some sphagnum peats in Finland (93).

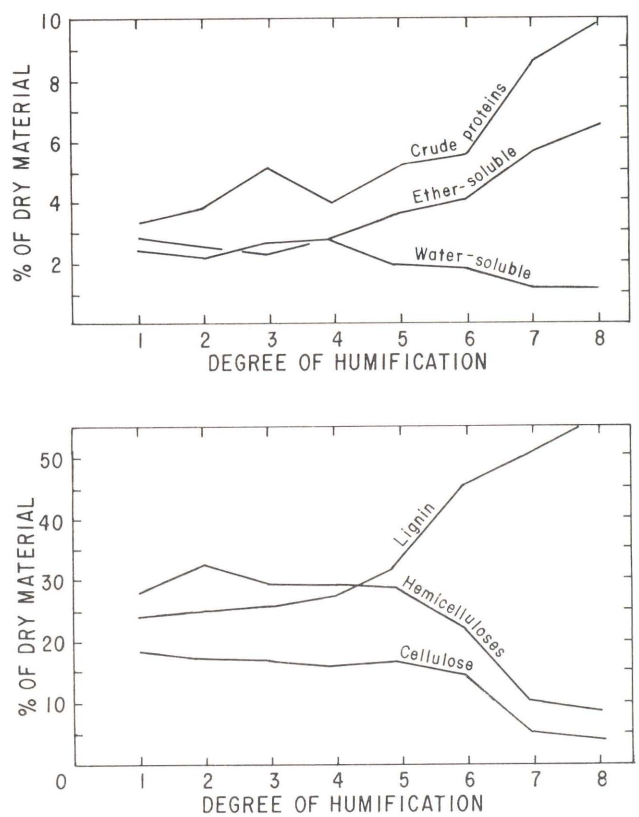


Figure 7. Influence of humification on the organic composition of Sphagnum peat. Source - Finnish peatlands and their utilization (93). For humification values, see Table 14.

Humic Acid

Data in Table 5 do not report the humic acid amounts. This fraction is the organic matter which is soluble in 1.0% NaOH and insoluble in acid solutions. Humic acids are mostly aromatic in structure, that is, they are closed ring compounds but may contain some aliphatic compounds. Humic substances are microbial decomposition products formed from carbohydrates, hemicellulose and lignins.

Generally, plants low in lignin (such as sphagnum mosses) produce peats that contain 5 to 20% humic acid. Reed, sedge and woody peats contain 25 to 50% humic acids. Analyses made on some Minnesota bogs showed 17% humic acid in moss peat, 34% in herbaceous-woody peat and 41% for a herbaceous-moss peat (151). Rakovskii et al (159) report phragmite peats contain 40 to 55% humic acid; forest peat, 30 to 40% and sphagnum 15 to 30%.

The humic acid, fluvic acid and humin contents of four Everglades soils are reported in Table 6. Note that the Torry Series, which contain some clay, had the highest humic acid content.

The humic acid content of peat is of some interest in crop production because humic acid is considered to be an active auxin. Researchers have demonstrated the benefits to plant growth when used in nutrient cultures and soils low in organic matter. In most field trials, however, the addition of humic acid products has not improved crop production because sufficient amounts are already present in the soil (183).

Fractionation Schemes

Interest in peats as a source of energy and chemicals has increased greatly because of higher petroleum costs. The method of Waksman and Stevens (202) has given information about peat composition similar to that shown in Table 5. For industrial uses Passer et al (151) have developed the procedure shown in Figure 8. More recently, Lucas at Penn. State (120) has proposed procedures where one can isolate various fractions from the original sample.

Data in Table 7 show the ranges for the various fractions where a number of samples were analyzed from three peat deposits in Minnesota.

Elemental Composition of Organic Soils

The range in percentage elemental composition for organic soils is presented in Table 8. A wide variation in mineral composition occurs between different peats and in horizons within a deposit (6). The principal constituent of the ash is either silicon or calcium. The silicon usually comes from wind-blown minerals or washed-in sediments. In areas such as the Everglades, the silicon content can test less than 0.3%. The data in Table 9 report some specific analyses of the ash.

In some deposits, the calcium content is high. When amounts exceed about 5% of the organic fraction, then free calcium carbonate or marl is generally present. Calcium and magnesium exist in acid organic soils largely in the ionic form strongly adsorbed onto the colloidal organic particles. Alkaline water, marl, shells and ash resulting from burning can account for a high calcium and magnesium content.

Table 6. Organic fraction distribution for Florida Histosols.

Series	Depth cm	Ash Content	Humin	Humic Acid	Fulvic Acid
		% of total	% of Organic Fraction		
Monteverde	0-13	12	75	13	11
Least decomposed	13-36	10	68	15	17
	36-81	6	86	11	3
Pahokee	9-18	15	57	7	36
Intermediate decomposed	18-86	13	67	12	21
Okeelanta	0-21	46	59	22	19
Decomposed sandy muck	21-66	15	70	12	17
Torry	0-21	67	55	38	7
Decomposed muck with clay	21-53	71	36	55	10
	53-109	14	65	20	15

Data by Zelazny and Carlisle (207).

Table 7. Some ranges in the major organic constituents found in Minnesota peats.

Type of Peat	Bitumens	Humic Acids	Humins	Holo-Cellulose	A-Cellulose
	Organic Fraction				
	% of composition				
Moss	5-9	10-17	23-43	30-58	9-36
Herbaceous Moss	9-14	10-41	28-56	30-52	8-18
Herbaceous	8-11	12-34	31-58	22-33	8-12
Herbaceous Wood	6-10	12-26	39-56	25-33	6-10
Highly Decomposed	8-9	21-39	27-50	26-29	7-11
Limnic(a) (aquatic)	5.7	10	37	47	17

(a)One location. Data by Passer et al (151).

Table 8. Approximate ranges and average in percentages of some elements occurring in undeveloped organic soils.

Element		Percent range (oven dried)	% Typical Average: Eutropic Peats (lime rich)	% Typical Average: Oligotropic Peats (lime poor)
Aluminum	Al	0.01 - 5.0	0.5	0.1
Barium	Ba	0.0006 - 0.3	0.005	
Boron	B	0.00001 - 0.1	0.01	0.0001
Calcium	Ca	0.01 - 6.0	2.0	0.3
Carbon	C	12.0 - 60.0	48.0	52.0
Chlorine	Cl	0.001 - 5.0	0.10	0.01
Cobalt	Co	- 0.0003	0.0001	0.00003
Copper(a)	Cu	0.0003 - 0.01	0.001	0.0005
Hydrogen	H	2.0 - 6.0	5.0	5.2
Iron(b)	Fe	0.02 - 3.0	0.5	0.1
Lead	Pb	0.00 - 0.04	0.005	0.001
Magnesium	Mg	0.01 - 1.5	0.3	0.06
Manganese	Mn	0.0001 - 0.08	0.02	0.003
Molybdenum	Mo	0.00001 - 0.005	0.001	0.0001
Nickel	Ni	0.0001 - 0.03	0.001	0.0005
Nitrogen	N	0.3 - 4.0	2.5	1.0
Oxygen	O	30.0 - 40.0	32.0	35.0
Phosphorus	P	0.01 - 0.5	0.07	0.04
Potassium	K	0.001 - 0.8	0.1	0.04
Silicon	Si	0.1 - 30.0	5.0	0.5
Sodium	Na	0.02 - 5.0	0.05	0.01
Sulfur	S	0.004 - 4.0	0.5	0.1
Zinc(c)	Zn	0.001 - 0.4	0.05	0.005

(a)Cupriferous bogs in Canada contained nearly 0.3% total Cu (22).
(b)Samples with bog iron present could contain more than reported in this estimate.
(c)6.7% of zinc has been reported present in New York soils containing toxic amounts of zinc (180).

Table 9. Chemical composition of ash in several types of peat.

Type of Peat	Location State	Depth inches	Ash in dry Peat %	Si	Fe	Al	Ti	P	Ca	Mg	S	C	Na	K	Mn
				Inorganic Constituents of the Ash (%)											
Sphagnum	Maine	8-12	2.29	15.0	2.9	6.1	0.3	2.0	17.3	5.9	4.0	1.3	0.8	1.1	0.11
Sphagnum	Maine	8-12	1.55	29.3	3.9	5.9	0.3	3.4	9.0	12.4	5.4	0.3	0.7	1.4	0.05
Heath	N. Carolina	3-9	2.33	21.7	3.2	5.3	0.3	1.4	7.2	8.1	5.9	0.2	1.0	1.1	0.01
Sedimentary	N. Carolina	24-30	6.74	33.8	1.5	5.3	0.7	0.2	4.5	2.5	3.1	--	0.4	0.2	Tr
White cedar forest	N. Carolina	36-42	27.05	36.3	2.2	7.4	0.8	0.2	0.9	0.4	0.7	0.2	0.2	0.5	0.01
Saw-grass	Florida	4-6	6.67	4.6	1.5	0.4	0.2	0.7	31.3	4.4	5.1	7.0	0.2	0.4	0.05
Saw-grass	Florida	94-96	17.82	20.9	2.2	4.3	1.0	0.2	15.4	3.5	2.9	2.5	0.3	0.4	---
Sedimentary	Florida	42-48	10.27	16.8	5.1	3.9	0.4	0.7	15.9	3.5	7.7	1.6	0.4	0.3	0.02
Woody sedge	Washington	0-6	10.28	16.1	19.7	6.0	0.3	1.7	8.5	1.4	3.0	0.3	--	0.7	0.62
Herbaceous sedge	Washington	10-16	6.51	8.3	17.4	8.1	0.3	1.7	15.5	1.2	5.1	1.2	0.6	0.4	0.62

Calculated from data by Fuestel and Byers (58).

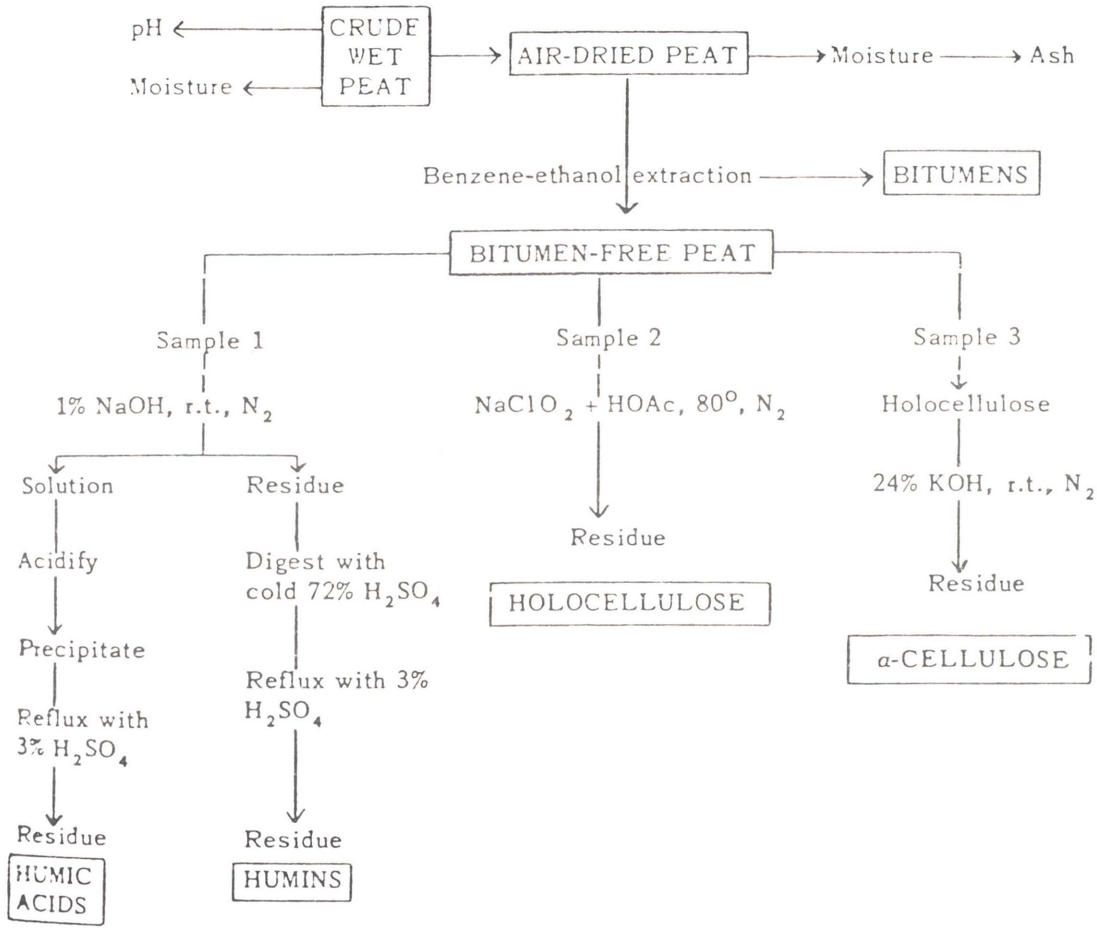


Figure 8. The University of Minnesota peat analysis scheme by Passer et al (151).

"ITCHY" MUCK

These soils were described by Dachnowski-Stokes (36a) as mostly limited to the aquatic mucks found in the Kankakee River Valley in the Great Lakes area. In dry weather the fine soil particles are easily blown about by wind and can cause irritation to the skin of man and animals. The problem is particularly noticeable in areas along the edges of fields where the soils are sandy mucks.

The irritation is due to the presence of the remains of sharp-pointed spicules of fresh water sponges. Farm workers show marked differences in tolerance or sensitivity to these spicules. (The writer was very allergic.) After many years of tillage, the itch feature lessens as the spicules become weathered. Less tillage and the use of enclosed tractor cabs help decrease exposure to such soils.

MOISTURE RELATIONSHIPS

A knowledge about moisture retention is especially important in the management of organic soils. The capacity can be markedly different and is related to the degree of decomposition, the botanical source and the mineral soil content. Another important factor in moisture retention is the height of the soil above a free water surface.

There is a great deal of confusion about moisture retention values as expressed on a percent by volume, percent of the oven-dry weight or as the percent of the wet weight. Soil scientists usually express the soil moisture content on an oven-dry basis. If the weight of water is equal to the weight of the soil, the moisture content is 100%. Practically all organic soils collected from the field hold more water than the weight of the solid fraction.

The percent moisture content of peat offered for sale is generally expressed on the "as received" basis. Thus a soil containing 100% moisture when expressed on the dry weight basis contains 50% moisture on the "wet basis." Unless understood, reporting moisture contents on the wet weight basis distorts values. For example, at 85% water, the solid content is 15%, but the same soil at 70% moisture would have 30% solids.

Data in Table 10 illustrate the relationship between the amount of solids and water at various moisture contents. Note the marked differences in the amount of water for each 10% reduction in moisture content.

Table 10. Water and dry solid content of saturated peat as the wet weight moisture is reduced from 90 to 0% moisture.(a)

Wet Weight Basis	Dry Weight Basis	Weight of water eliminated of each 10% reduction	Cumulative quantities of water eliminated	Weight of peat after each 10% water loss	Quantity of water	Quantity of solid matter
		lbs.	lbs.	lbs.	lbs.	lbs.
90	900	---	---	2,000	1,800	200
80	400	1,000	1,000	1,000	800	200
70	233	333	1,333	667	467	200
60	150	167	1,500	500	300	200
50	100	100	1,600	400	200	200
40	67	67	1,667	333	133	200
30	43	48	1,714	286	86	200
20	25	36	1,750	250	50	200
10	11	28	1,778	222	22	200
0	0	22	1,800	200	0	200

(a)One ton (2000 lbs) of saturated peat (90% water - 1800 lbs) 10% dry solids (200 lbs) will have a volume of about 31 cu. feet and a bulk density of 0.10 g/cc (6.4 lb peat/cu. ft).

Source: Davis, C. A. (42).

When working with drainage problems, the volume of water is generally the concern. It is related to water content, bulk density, air voids, suction tension and hydraulic conductivity. Data in Figure 9 illustrate some of these differences. Note that well decomposed peat contained about 85% moisture at saturation, and 72% at 0.1 bar of suction. Sphagnum peat with about 90% moisture at saturation had only about 31% by volume at 0.1 bar. The explanation for the difference is the sphagnum peat had large pores, whereas the decomposed peat had mostly small pores.

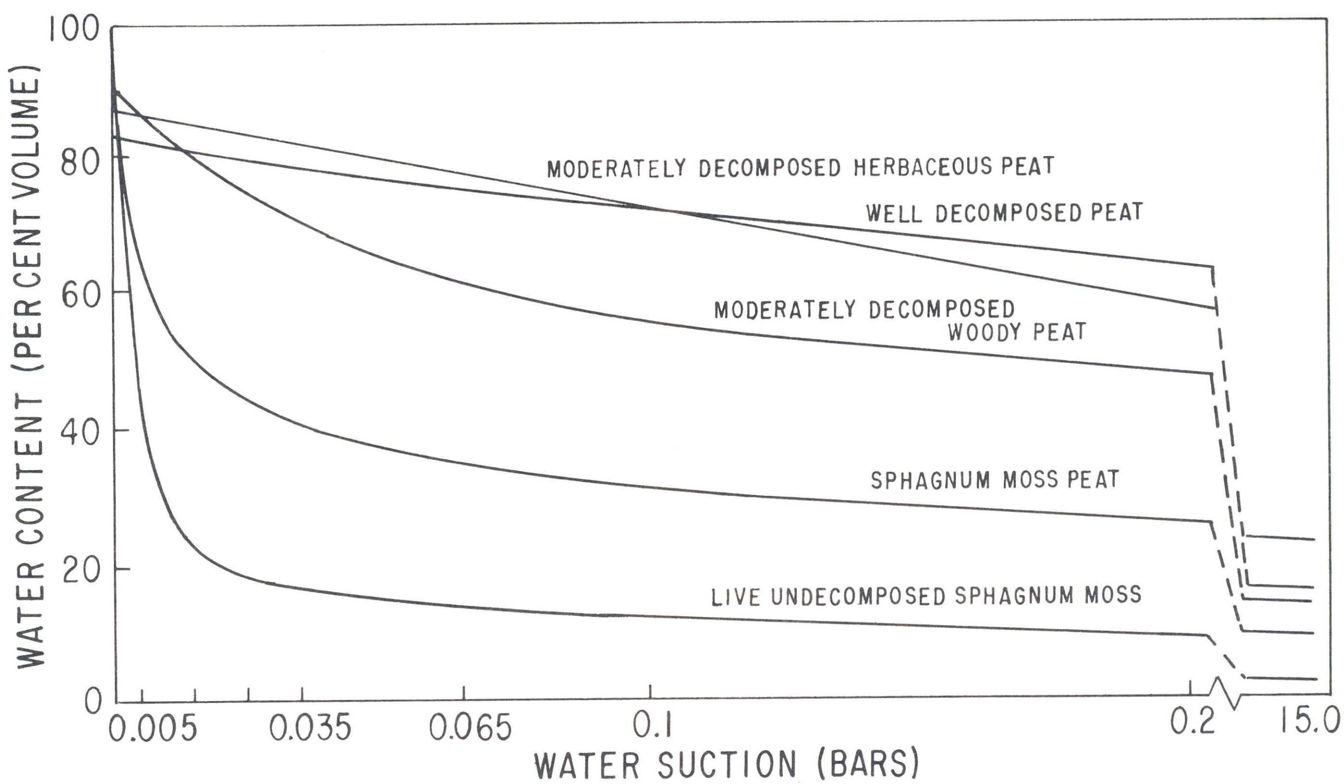


Figure 9. Water retention curves for several northern Minnesota peat materials. Data by D. H. Boelter (19).

It is more appropriate to compare soil water on a volume basis (especially when considering plant requirements or water removal) than to compare moisture retention on a dry weight basis. Data in Table 11 illustrates how a sphagnum peat with a water holding capacity of 1400% held only 50.5% water on a volume basis. The decomposed reed-sedge peat had a much lower water holding capacity, but on a volume basis contained 69% moisture.

Moisture retention by soils is generally characterized by determining the water content at various suctions or pressures. Units used may be bars, atmospheres and/or pF values. Bars and atmosphere units are similar—one atmosphere is equivalent to 1.013 bar. One atmosphere is the suction that can be obtained by a column of water 1033 cm in height (34 feet). Some reports cite suction on a pF scale, which is the logarithm for the height of water in centimeters. Thus, a pF of 3 indicates a suction of 1,000 cm of water.

Most current reports express moisture as bars. A retention of moisture at 0.01 bar suction is similar to the water content at saturation, 0.33 bar suction to field capacity and 15 bars to the wilting point.

Table 11. Some air-water content at field moisture capacity (peats).

	White Sphagnum	Peat Type Reed-sedge	Decomposed Reed-sedge
Volume weight as			
received weight	43 g/l	340 g/l	486 g/l
dry weight	36 g/l	116 g/l	152 g/l
Air volume			
oven-dry peat	97.4%	91.7%	89.2%
as received	96.7%	69.3%	56 %
wet peat*	47 %	26 %	20 %
Water-holding capacity(a)			
Volume basis	50.5%	66 %	69 %
Weight basis			
as received	1,170%	193%	142%
oven-dry peat	1,400%	570%	454%

*(a)Based upon 12 cm of water tension. All calculations assume that peat has a specific gravity of 1.4 (123).

Water Holding Capacity

The quantity of water held by a soil is a function of the height above the water surface. The American Society for Testing and Materials (ASTM) describes a procedure that measures moisture held by a column of soil that is 22 cm in height (9). The Finnish scientists use a 100 cm^2 tube opening that is able to hold 10 ±0.5 cm column of peat (154). The tube and soil are immersed in water until they reach constant weight. For dry peats, this may require several days. The tube is then placed in an upright position for two hours to allow the excess water to drain.

In some procedures, the soil is placed in metal containers 5 x 5 x 2 cm in size that have a metal screen on the bottom. After complete saturation, the container is placed in a Bell jar and the soil allowed to drain. Water holding capacity values are much greater by this procedure than the ASTM or the Finnish method. The latter methods, however, give more realistic values for greenhouse grown plants.

The weight (W) difference between the wet and the oven-dry soil at 105°C is the moisture held. Thus, W (wet) – W (dry) x 100/W(dry) = Water Holding Capacity on a dry weight basis.

Some typical values for various Histosols are:

Sphagnum peat	1000-2000%
Reed-sedge peat	500- 700%
Wood-sedge peat	300- 400%
Well decomposed peat	200- 250%
Cultivated Histosols	100- 250%

These holding capacity values show marked differences. However, when organic soils are compared on a volume basis, the differences are less. For example, as reported in Table 12, a liter of saturated sphagnum peat held 930 ml of water and the peat humus 780 ml.

Field Capacity

The amount of water held against gravity after the soil has been completely wetted is called Field Capacity. In the field this takes one or two days. The value cannot be precisely determined because there is no equilibrium point. For this reason, scientists characterize the moisture retention by determining moisture content at various suction or pressures. Those that approximate field capacity are:

a. 0.33 bar suction
b. 0.3 atmosphere
c. pF 2.2 (Suction equivalent to 346 cm column of water)

Wilting Point

The soil moisture at the permanent wilting point ranges from about 25 to 100% (oven dry basis) for the various types of organic soils. This point approximates the moisture content at 15 bars or pF 4.2 suction.

Peat is often used to increase the moisture holding capacity of mineral soils. The available water, however, generally is not improved because of the increase in the wilting point and a decrease in volume weight (59). Data in Table 13 report some moisture retention values for virgin peats near saturation (0.1 bar) and the permanent wilting point.

Available Water

This value is the difference between the quantity of water retained at field capacity and at the permanent wilting point. For cultivated mucklands the available water is about 700,000 pounds per acre-foot. In actual field situations, the quantity of available water for optimum

Table 12. Dry weight and water content of saturated peats.

Peat Weight g/l(a)	Water Content g/l(a)	Total Weight g/l(a)	Water Content % wet basis	Water Content % dry basis	Peat Types
88	930	1,018	91	970	Sphagnum
160	890	1,050	85	554	Fibrous reed-sedge
240	835	1,075	78	346	Decomposed reed-sedge
320	780	1,100	71	242	Peat humus

(a)g/l indicates grams per liter (g/dm^3).

growth is much less. Puustjarvi (154) suggests the lower limit for greenhouse crops should be about 1 bar rather than 15 bars suction. For field crops, productivity decreases markedly as the amount of available water falls below 30% of the total available water. The tension at this moisture content is about 5 bars.

Hygroscopic Coefficient

This moisture value is the amount held at 98% relative humidity. Values from 8 to 15% have been reported for organic soils.

Rewetting

Organic soils with low bulk densities cannot be rewetted to their original maximum water holding capacity after air drying. Dyal (49) reported irreversible changes were small for sphagnum peats but marked for vascular and hypnaceous peats. Feustel and Byers (58) found the water holding capacity was decreased from 40 to 75% for U.S. peats. Maas (125) obtained complete rewetting if the soil had high bulk densities (e.g. 0.42 g/cc). Peat material, however, from the 45-60 cm depth that had a bulk density of 0.17 g/cc would only recover 45% of its original volume.

Several ideas are offered to explain the cause of irreversible wetting. Puustjarvi and Robertson (157) believe the acid, humified peats exhibit the greatest resistance because of their carboxyl (C-COOH) and phenolic hydroxyl (-OH) groups, and high lignin contents. Sphagnum peats, because they are low in lignins, rewet fairly readily.

Table 13. Moisture retention for several unprocessed peats. (Oven dry basis).

Origin	% Ash	% Moisture Retention 0.1 bar	15 bar
Iowa	12.8	411	75
S. Carolina	3.3	330	93
Georgia	3.4	898	96
Florida	3.2	670	88
Florida	5.9	739	92
Minnesota(a)			
Wood peat		400	102
Herbaceous		461	102
Well decomposed		275	113

Data by R. S. Dyal, F. J. Hermann and R. J. Ferretti (50).
(a)Calculations from data by Boelter (18).

Rewetting resistance has also been explained as due to adsorbed air films and iron coating around the humate particles (30).

A major concern in the development of the Histosols of Eastern North Carolina was the marked irreversible wetting properties. The problem soils are sometimes described as "coffee ground mucks" because of their hard coal-like granular structure when dried (215).

In the Fens of England, some describe the organic soil layer directly above the mineral subsoil as "drummy peat." This layer is high in colloidal humus, iron and sulfur derived from aquatic plants and is difficult to rewet.

Wind blown muck that collects in the fence rows and ditches can be very difficult to rewet. A farmer in Michigan encountered serious rewetting problems and drought stress in crops when he chisel plowed his field for several years. The muck showed high iron content and was fairly acid. Conventional mold board plowing improved the moisture retention properties.

Rewetting properties of organic soils can be improved by liming above pH 5.5, exposing the soil to freezing and thawing, and plowing down the dry surface soil. Peats used in soil mixes can be treated with some acceptable wetting agent so as to speed up the rewetting process.

Permeability

The rate of movement of water through the soil is dependent on the character of the organic components and particularly the pore sizes. Permeability rates are reported as distance per unit of time. Laboratory measurements are usually expressed in seconds. For field conditions, rates per hour or day make it easier to relate to rainfall and applied water.

In general fibrous peat and cropped surface mucks have a moderate rate of water movement. Decomposed and herbaceous peats often show low values. Rates less than 0.36 cm per hour are considered too slow for general agricultural development (20).

Measured infiltration rates for a Michigan Houghton muck at 0-7.5, 22-30 and 45-52 cm depths were 30, 18 and 9 cm/hr., respectively. Compacting the surface layer reduced the rate to 1.2 cm. Laboratory studies on some Holland Marsh mucks in Ontario (92) showed hydraulic conductivity values of 22, 18 and 4 cm/hr. for sample depths of 0-15, 15-30 and 30-45 cm, respectively.

Florida soils were found to have hydraulic conductivity values of 67 cm/hr for Montverde, 49 for Pahokee, 29 for Okeelanta and 37 cm for Torry mucks (207). These rates were obtained for the top 12 to 21 cm depth. With increases in depth, the rates were slightly less. Some herbaceous peats in Minnesota were found to have some extremely low rates - 0.02 cm/hr. (20).

Horizontal hydraulic conductivity rates can be faster than the vertical if the profile has a humified subsoil layer. Boelter (17) determined there was no significant difference between the two values for any one particular peat type. Clayton, et al (31) however, concluded water movement in the Everglades Histosols was greater vertically and related this difference to the orientation of the sawgrass roots which were generally in a vertical position.

Swelling and Shrinking

Organic soils shrink upon drying and swell upon re-wetting. Shrinkage calculated as a percent of the original volume may vary between 90% for aquatic peats, 40% for fibrous peats and about 20% for Houghton muck. Maas (125) reported the lower the bulk density and the more gelatinous the organic particles, the greater the shrinkage. Shrinkage could be as high as 87% in volume for an aquatic peat.

Irwin (92) determined the shrinkage and water loss for a number of sites at the Holland Marsh in Ontario and found the change in volume was 98% of the volume of the water loss for samples taken from the 31 to 37 cm depth. Van Dijk and Boekel (194) reported that for every gram of water evaporated, the volume decreased about one cc. However, when the moisture content fell below 27%, the shrinkage was greater than the volume loss of water.

Sphagnum peats do not exhibit high shrinkage except if they are extremely dry. Ekman and Sundgren (52) reported such peat, whether air or artificially dried, showed marked increases in shrinkage when the moisture content was 30% or lower on the wet weight basis. In this range, there are large changes in the cellular structure of sphagnum peat.

For Florida deposits, moss and most fibrous, matted sedge peats were found to shrink the least and sedimentary plastic mucks shrink the most. Everglades saw-grass material shrank to about 20 to 25% of its original volume when air dried, Loxahatchee semi-aquatic mucks to 10-15%, woody Gandy mucks to 30-50% and mangrove mucks to about 40-50% (45).

Chemical soil tests made by volume measure should consider these shrinkage differences. The curve presented in Figure 10 is the weight relationship to moisture content for some soil samples submitted to the Florida Soil Testing Laboratory. Assuming a potassium test of 200 lb/acre was obtained for a moisture content of 40%, this same sample soil would test about 240 pounds at 20% moisture and 170 pounds at 80% moisture if volume measures were used.

Bulk Density

Bulk density depends on the amount of compaction, botanical makeup of the organic soil, mineral content and particularly the moisture content at the time of sampling. Lynn et al (124) report bulk densities range from 0.05 to 0.15 g/cc for the fibric and most of the hemic Histosols. For sapric material, the range was wider; but densities greater than 0.25 g were limited to organic soils with less than 7% rubbed fiber of which most were from cultivated surface soil.

Irwin (92) found there was generally an increase in bulk density with an increase in ash content. Organic soils with 5% ash averaged about 0.08 g/cc in bulk density and soils with 30% ash averaged about 0.22 g/cc. This difference reflected the degree of decomposition after tillage. The mean value for the surface layer at the Holland Marsh, Ontario, was 0.18 g/cc. The bulk density value usually decreased with depth and had a mean value of 0.10 g/cc for the subsoil.

Florida Histosols were found to range from 0.26 to 0.73 g/cc for the upper layers and 0.08 to 0.16 g/cc for the lower deposits (207). The Pahokee mucks around the Agricultural Research and Education Center, Belle Glade, test about 0.35 g/cc in the top 15 cm layer and 0.18 g/cc for the 45-60 cm depth.

Jongedyk and associates (101) reported the bulk density of the plow layer varied from 0.30 to 0.45 g/cc for an

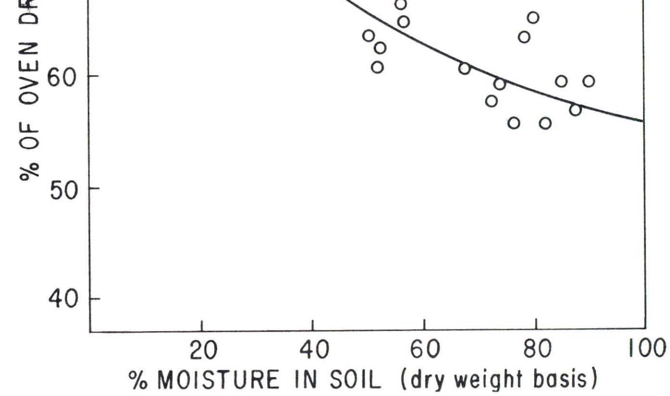


Figure 10. The percentage amount of oven dry soil when 10 cc of moist soil was compared with 10 cc of oven dry soil – (a typical range for samples submitted to the Belle Glade Testing Laboratory).

Indiana muck. Water table levels changed the subsoil values. For a water table of 40 cm, the bulk densities at the 22, 38 and 52 cm depths were 0.32, 0.17 and 0.14 g/cc, respectively. When the water table was maintained at 96 cm, the corresponding values were 0.30, 0.18 and 0.17 g/cc, respectively.

Cultivated Houghton muck at the Michigan Experimental Farm has a bulk density of about 0.30 g/cc in the plow layer and 0.15 g/cc for subsoil samples. Based upon these values, the upper 15 cm of soil contains 450,000 kg/ha of solids (407,000 lb/6 inch acre) and 225,000 kg/15 cm/ha in the subsoil.

Densification which includes dehydration and compaction is the major factor accounting for bulk density differences. Developers of peat for sale especially need to recognize the great loss by volume when peat is air-dried.

CATION EXCHANGE CAPACITY (CEC)

The exchange capacity is a chemical measure which describes the ability of a soil to hold positive charged ions called cations. The major elements are H, K, Na, Ca, Mg and Al which are adsorbed on the surface soil particles when they have unneutralized negative charges. Organic matter upon decomposition produces organic acids, lignin and many other products which can exhibit exchange properties (169).

The major unit contributing to CEC is the carboxyl (R-C-O-O-H) radical. Others include phenolic, enolic and quinonic hydroxyls, and heterocyclic nitrogen structures. Dawson (46) estimated that for some organic soils the carboxyl groups accounted for 54% of the CEC, phenolic and enolic hydroxyl groups 35%, and imide-N groups 10%.

CEC values are usually expressed as me/100 g (milliequivalents per 100 grams) or as me/100 cc. The CEC value for organic soils is highly pH dependent. When the hydrogen ion remains tightly associated (fixed) with the functional group, as found in acid soils, it does not exhibit exchange properties. However, if the soil pH increases, the H ion on the hydroxyl group becomes more active and increases the CEC value. This increase is a major factor accounting for the high buffering capacity of slightly acid and alkaline soils.

Calculations by Helling, Chesters and Corey (85) for the CEC of organic matter in a mineral soil show 73 me/100 g at pH 3.5, 127 at pH 5.0, 131 at pH 6.0, 163 at pH 7.0 and 215 at pH 8.0. Other researchers report similar differences. Because it is a function of pH, the CEC value must be reported for some particular pH. For agricultural purposes, pH 6.0 would be a realistic point. Scientists, however, generally report CEC values at pH 7.0 or 8.0.

The carboxyl group acts as a weak colloidal acid on organic matter. Thus, many describe the complex as an acidoid regardless whether the complex is soluble or insoluble in alkali. The two cations, H and Ca, occupy most of the exchange sites (48). Their organic complexes are often called H - Ca humates. Others may refer to them as H - Ca mucks or peats.

Bloom and McBride (14) believe the ion activity follows the mass action exchange model, $pH = pK - n \log \frac{1-a}{a}$. In this model the pK and n are empirical constants and "a" is the degree of H-humate dissociation. The pK constant for a Ca system was estimated to be about 3.5 and the "n" constant 2.6. Estimates on dissociation constants are about 4.5×10^{-4} for sphagnum, 5.6×10^{-5} for sedge peats and 5.0×10^{-5} for woody peats (155). The weak colloidal acid properties of organic fractions also contribute greatly to the buffering properties of soils.

The exchangeable cations are sometimes divided into acidic cations (H and Al) and basic cations (Ca, Mg, K and Na). The proportion of the total CEC in the basic form is often expressed as the percent base saturation. For example, a muck soil is 55% base saturated if the soil contains 110 me of exchangeable basic cations and has a CEC of 200 me/100 g. The percent base saturation has a direct relationship to the pH of the soil. Calcium, because it is the predominate exchangeable basic cation, is normally used to compare pH's at various base saturation percentages. Mehlich (133) obtained pH's of 3.7, 4.5, 5.5, 6.4, 7.0, and 7.5 at calcium saturation percentages of 0, 20, 40, 60, 80 and 100, respectively.

Organic soils can show some marked differences in percent base saturation for a particular pH. These differences are caused by the kind and the amount of pH dependent organic materials, differences in the dissociation constants of the humates and the amount of other cations—particularly the amount of exchangeable Al. Evans and Kamprath (55) illustrated the important role of Al in an acid organic soil. Even though lime had been added at three times the neutralizing requirement for the exchangeable H, the soil still had a pH of less than 5.0 because 16% of the CEC was exchangeable Al.

Sphagnum peats usually have much lower pH values than sedge peats for a given base saturation percentage. For example, Lee et al (115) obtained a 50% base saturation at pH 5.0, which is about 0.5 pH unit lower than most muck soils.

Some typical percent base saturations reported are 78% at pH 6.2 for a Florida Pahokee muck and 71% at pH 5.8 for Okeelanta muck (207). A Michigan Rifle peat showed base saturation percentages of 13, 25, 40 and 53 at pH's of 3.8, 4.4, 5.0 and 5.8, respectively (74). Some CEC values reported for Histosols measured at pH 7.0 are:

Organic Soil	Profile Zone	CEC me/100 g	Location
Adrian Muck	Aa 4	190	Wisconsin (175)
Carlisle Muck	Aa 5	200	Wisconsin (175)
Dawson Peat	Aa 1	200	Wisconsin (175)
Houghton Muck	Aa 2	120	Wisconsin (175)
Montverde Muck	13-36 cm	127	Florida (207)
Pahokee Muck	0-18 cm	208	Florida (207)
Okeelanta Muck	21-66 cm	188	Florida (207)
Frydrychowo Muck	M - 2	182	Poland (147)
Tupola-Blonie Muck	M - 2	176	Poland (147)
Moss Peat		140	Finland (155)
Sedge Peat		70	Finland (155)
Woody Peat		100	Finland (155)

In general, fibric Histosols show CEC values of about 100 me/100 g and saprist Histosols 200 me/100 g.

Users of organic soils for agricultural purposes usually prefer information and recommendations based upon **volume** rather than on a **weight basis.** The differences for the two systems can readily be shown in the following example.

Soil	Cation Exchange Capacity Weight Basis me/100 g	Cation Exchange Capacity Volume Basis me/100 cc
Loam soil	12	14
Sphagnum peat	100	8
Woody peat	90	14
Muck	200	60

On a volume basis, about the same amount of lime is required for the loam soil as the woody peat to make a similar change in the percentage calcium saturation. Muck soils, however, require about four times more lime than the loam soil or the wood peat.

DEGREE OF DECOMPOSITION

Two systems are generally employed to describe the degree of decomposition. One method differentiates Histosols as fibrists, hemists or saprists–see page 6. The second system is the ten point system of Von Post (196). It is used mostly by commercial users of peat. A value of H-1 represents undecomposed peat and H-10 as complete decomposed. The system is best used for fresh sphagnum peats and is less applicable to other types, particularly if the peats have been dried.

To make a rating, a small quantity of fresh peat is squeezed in the palm of the hand. The color of the water extract and the amount of fiber remaining in the hand are indicators of the degree of decomposition. A microscope can be used to help make an estimation. Categories H-1 to H-3 are considered undecomposed, H-4 to H-6 are partly decomposed and H-7 to H-10 are highly decomposed. A brief description of the scale is reported in Table 14.

MICROORGANISMS

Many kinds of microorganisms are found in organic soils. They play an important role in type, color, rate of decomposition and in the formation of nitrates, sulfides, and other compounds. As stated by Waksman (199), microorganisms can contribute three distinct parts in the chemical transformation leading to soil development and decomposition. They are:

1. Microorganisms active during the first stages of decomposition of the plant residues. Certain groups, largely fungi and actinomyces on the soil surface and bacteria below the surface, bring about the decomposition of cellulose, hemicellulose and some of the proteins.

2. Microorganisms active in the various horizons of the peat profile long after the initial stages of decomposition have passed. The organisms active at this stage are facultative and obligative anaerobic bacteria that live without benefit of air containing oxygen. They produce pockets of gas rich in hydrogen, methane, and sulfides. These products are derived from cellulose, proteins and other complexes.

3. Microorganisms active in the decomposition of the soil after the organic soil is drained and air is admitted. These are fungi, aerobic bacteria and actinomyces which decompose fairly resistant organic complexes such as lignins. They are responsible for biological oxidation of organic matter which results in subsidence of the soil. The end products of complete organic matter decomposition

Table 14. The Von Post Decomposition Scale of Peats.

Degree of decomposition	Nature of squeezed water	Amount of peat extruded between fingers	Nature of residue
H-1	Clear, colorless	None	Unaltered fibrous
H-2	Almost clear	None	Almost unaltered
H-3	Slight brown	None	Remains easily identifiable
H-4	Turbid, brown	None	Remains identifiable
H-5	Strongly turbid with some peat	Very little	Most of remains difficult to identify
H-6	Muddy	About 1/3	Most remains not identifiable
H-7	Very muddy	About 1/2	Few remains identifiable
H-8	Thick mud, little free water	About 2/3	Very few remains identifiable
H-9	No free water	Almost all	No identifiable remains
H-10	No free water	All	Completely amorphous

include carbon dioxide, water, nitrates, sulfates and minerals.

Waksman and Stevens (202) reported that in high-lime peats, the number of aerobic bacteria diminished with depth. Counts on soils sampled at the one and four foot depths showed 350,000 and 100,000 organisms per gram, respectively, in a New Jersey soil; and 32,000,000 and 1,600,000 organisms per gram, respectively, in a Florida soil.

The types of microorganisms found in low-lime Maine peats (sphagnum) contained mostly acid resistant anaerobic bacteria. Counts at a pH of 3.7 to 4.2 showed from 100,000 to 750,000 organisms per gram. Contrary to general expectations, the number of microorganisms increased with depth. The counts were 100,000 near the surface and nearly 2,000,000 at the 8 foot depth.

Most of the organisms found in this sphagnum peat were gas, alcohol and butyric acid producers. Nitrifying and cellulose decomposing bacteria were not found. The nitrogen fixing bacteria (azotobacter) were also reported to be absent. Studies in New York (206), however, report the presence of azotobacter in soils that varied in reaction from pH 3.6 to pH 7.6.

Tate (185) studied microbial activity of several horizons in the profile, the plant cover, and the seasonal changes for Pahokee mucks in Florida. He found the activity in the upper 10 cm remained fairly constant from May to October but decreased to about 50% in January. At the 60 to 70 cm depth, activity dropped 90%. Little difference was found in activity where the cover was sugar cane, St. Augustine grass or fallow.

The total carbon evolved from the different horizons of the soil decreased with depth. However, if one corrected for bulk density differences, the rate of subsidence was similar throughout the soil profile above the water table. The data in Table 15 show the activity and the subsidence rate.

A valuable product of organic matter decomposition is the production of nitrate-nitrogen. The rate of production depends upon the soil moisture, temperature, aeration, acidity and the total nitrogen content. Waksman and Purvis (200, 201), in laboratory studies, obtained little decomposition near moisture saturation (84% moisture). The greatest rate of nitrification took place between a moisture content of 53 and 71% (moist weight basis). When the moisture dropped much below 50%, nitrate release rapidly decreased.

Table 15. Relative carbon evolution and subsidence rate at different soil depths.(a)

Depth cm	Bulk Density Estimate g/cm^3	Bacteria count/cm^3	Yearly Carbon Evolution kg/ha(1)	Subsidence cm/yr
0 - 10	0.36	8.5×10^5	3,200	1.0
30 - 40	0.20	5.4×10^5	2,260	1.3
60 - 70	0.15	2.8×10^4	1,590	0.8

(a)Evolution from an acetate substrate. Data by Tate (185).

Table 16. Amounts of soluble organic-N and inorganic-N after incubation at 30°C for six months (94).

	Length of Incubation Period			
	0	1 month	3 months	6 months
		pH		
Aerated	5.8	5.7	5.6	5.5
Waterlogged	5.8	6.0	6.1	6.9
		Soluble organic-N ppm		
Aerated	--	8	12	3
Waterlogged	--	55	34	41
		NH_4-N ppm		
Aerated	12	28	53	26
Waterlogged	12	230	144	42
		$NO_3^- + NO_2^-$-N ppm		
Aerated	44	248	346	390
Waterlogged	44	28	14	0

A succession of wet and dry cycles generally increases the mineralization of organic matter compared to the amount released when a constant moisture level is maintained. Terry (209) reported that wet/dry cycles of 28 days increased the mineralized nitrogen by 39% for a Florida Pahokee muck.

In a field study, where a Pahokee muck was flooded in June, the NO_3^--N dropped from 50 ug N/g (ppm) to 12 within three days (210). This concentration was maintained until the field was drained in mid-July. At no time did the NO_3^--N level fall below 4 ug/g. Ammonium-N increased from a preflood amount of 4 ug/g to about 20 during the flooding. In an adjacent field, where soil and climate conditions were similar, rice on flooded plots showed less than 10% increase in the grain yield when topdressed with urea-N.

In a laboratory study on nine selected Histosols, Wisconsin scientists reported marked changes in pH, soluble organic-N and inorganic-N when aerated and waterlogged soils were compared. Data in Table 16 report the averages. Note the differences in pH and in the forms of N.

Turk (191) showed that the nitrifying capacity of two acid soils (pH 4.3 and 3.4) was increased about fourfold by liming. A third soil (pH 3.4), for some unexplainable reason, did not show an increase. Studies on tropical acid soils show marked crop response to N fertilizer (214).

Field studies in Canada on 40 acid soils, pH 4.0 to 5.6 showed liming increased the available soil N by 15 to 42 kg/ha in the first year, but by only 7 to 10 kg in the third year (146). Thus, the researchers concluded that soil acidity did not greatly restrict mineralization of organic N and the effect of liming is mostly temporary. Furthermore, the nitrification rate was not found to be statistically related to base saturation or to the soluble Fe, Al or Mn. The writer, however, has often observed N deficiency in crops grown on acid soils that test below pH 4.8.

Soil temperature has a great influence on microbial activity. Unpublished data on Houghton muck showed that in an eight-week incubation period 31 ug/g of nitrate-N was produced at 5°C and 136 ug/g at 22°C.

As one might expect, the total nitrogen content of a soil has an important bearing upon the rate of nitrate release. Soils with low ash and less than 1.5% total nitrogen have an unfavorable carbon-nitrogen ratio. Thus, soil micro-organisms are likely to utilize (for metabolic functions) the nitrates as fast as they are formed. Puustjarvi (156) concluded that the critical C/N ratio is about 30 to 1; that is, values over 30 would give rise to nitrogen stress. Peats, however, that contain high amounts of easily decomposable organic matter require a lower C/N ratio because of nitrogen immobilization by microorganisms.

Fumigants are often used to control nematodes and certain soil borne diseases. Some fumigants used are dichloropropene, methyl bromide, methyl isothiocyanate and chloropicrin. Fumigation and steam sterilization results in marked changes in the proportion of various soil microorganisms. Nitrifying bacteria are destroyed to a greater extent than the ammonifiers. The result is an accumulation of ammonia in the soil.

The data in Figure 11 show typical effects of fumigants on nitrate and ammonia formation. Note that it took about three weeks after fumigation before nitrates started to increase. The experiment was carried out under rather ideal temperature conditions. Farmers who fumigate in the fall or spring observe a much longer lag period because of cool temperature.

Fields fumigated in October in Michigan have been found to contain over 100 pounds per acre of ammonia-N and practically no nitrate in early June. Celery and potatoes are adversely affected by such high ammonia-N levels. Farmers who fumigate should thoroughly aerate the soil about two weeks after treatment. Nitrate fertilizers are often preferred to ammonia fertilizers for early spring-planted crops on fumigated land.

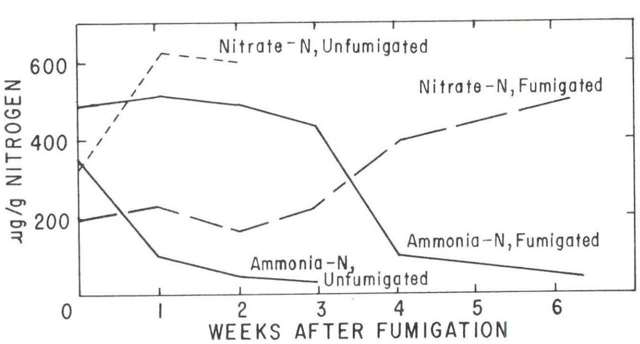


Figure 11. The effect of methyl bromide fumigation on the ammonia and nitrate-nitrogen levels in muck soil fertilized with ammonium sulfate (100 pounds of nitrogen per acre). (Data from Thiegs, 188).

For additional information about microbial activity in drained organic soils, we recommend the review by Tate (186).

WATER CONTROL

Organic soils are formed under conditions of poor drainage. Two opposing forces, 1) the provision of adequate drainage for optimum crop yields, and 2) the maintenance of as high a water table as practicable to prolong the life of the soil, operate in the agricultural utilization of these soils. The services of a qualified drainage engineer are desirable in formulating and executing an adequate drainage plan. The plan should include provisions for necessary drainage requirements, attention to springs and seepage areas, and practical means of water-level control. If the fields are not utilized, they should be kept wet and preserved until needed.

A drainage project may be financed entirely by private capital or as a public program, wherein taxes are levied on areas served by a particular drain. The problems of integrating drainage requirements of farmers operating mineral soil farms and those farming the lower lying organic soils are sometimes difficult to solve. Parties contemplating drainage improvements should familiarize themselves with existing drainage laws.

If necessary, to obtain a right-of-way across adjoining properties, an easement providing for maintenance of the drain should be made a matter of public record. To further complicate drainage problems the main drain may not have sufficient carrying capacity and may require expensive improvements.

Outlet

A suitable means of water disposal is essential for the success of any drainage project. The outlet may be either an existing river or stream or a constructed drainage ditch. Occasionally, large diameter tiles are installed for this purpose, thus reducing the loss of land area for crop production. However, if rapid removal of surface water is an important factor, an open drainage ditch may be preferable to main tile installation (Figure 12).

A system of levees, dams and discharge pumps may be needed to provide adequate outlet facilities.

Sufficient slope to the sides of the drain should be provided (for stable banks). The ability of a drain to withstand "caving-in" of the sides depends on the type of the organic material. Narrow ditches for laterals with perpendicular sides 3 to 4 feet deep are satisfactory in fibric herbaceous peat, but sedimentary or aquatic organic materials are generally unstable.

Frequent cleanouts of surface drains are advisable to maintain carrying capacity and unobstructed flow. Drains in heavy mineral soils require less maintenance than those in organic soil areas. The possibility of chemical weed control should not be overlooked in drain maintenance work.

Figure 12. An open drainage ditch in fibrous peat. Note the position of the corrugated steel pipe. These were extensions from plastic field tile.

Ditchbank Protection

A ditch may completely fill in with soil as a result of one wind storm. Maintenance costs are increased and serious losses may occur from an impaired drainage system. Grass planted on the ditch bank in 15 to 20 foot strips provides protection from this hazard.

Grass for this purpose should be winter hardy, low growing, and maintain itself to the water's edge; but should not persist under water. The grass should possess an extensive root system capable of holding the soil. It should also maintain a green succulent growth during the season to reduce the danger of fire hazard resulting from the accumulation of mature herbage. Redtop (*Agrostis alba*), chewings fescue (*Festuca ruba*) and rough-stalked meadow grass (*Poa trivialis*) are suitable grasses under Michigan conditions.

Plastic Tile

The major innovation in drainage during the last two decades is the use of corrugated plastic tubing (Figure 13). Plastic tile can be installed faster than clay tile, there is less weight to handle and they do not become misaligned because of uneven settling. In some areas, however, there may still be a cost advantage to using clay tile.

Plastic drains are better, in many cases, than open ditches as they can be used to remove excess water and can also be used for sub-irrigation. They should be placed at least 50 inches deep in newly developed soils to allow for

Figure 13. An experimental plastic tubing being placed in the Everglades. Much of the Everglades soils are now too shallow for either mole or plastic drains.

the initial subsidence. It is often advisable to delay tiling for four or five years while the initial settling takes place through use of ditches spaced 100 to 200 feet apart. Tiling during the dry season such as late summer and early fall will usually result in better installation.

Spacing

A spacing of 30 to 100 feet between drain lines is suggested depending upon the permeability of the particular site, the rainfall and the cropping system. A colloidal layer of peat in the profile can greatly impede drainage, and closer spacing of lines will be necessary. A 30-foot spacing may be inadequate in some locations with impermeable subsoil.

Observations of water level wells spaced at 6-foot intervals between tile lines will demonstrate the character of a draw down curve between the lines, and will serve as a practical indication of the adequacy of the spacing of the laterals. These water level wells can be made out of six foot lengths of four inch diameter down-spout. A collar placed 12 inches from the top of the well will act as a stabilizer.

Size - Capacity

Plastic tubing used for mucklands usually has a diameter of four inches. Clay tile is usually six inches. The drainage system should provide sufficient capacity to remove a minimum of one inch of water in 24 hours for general crops and two inches for vegetable crops sensitive to excess water. The grade should have at least 1.5 inches fall per 100 feet. Plastic tubing needs to have about 0.5 to 0.7-inch diameter holes and clay tile 0.5-inch spacing.

If the holes or slits are too small or the tile spacing too close, they can easily become sealed with organic and iron (Ochre) sediments. The drains should be covered as soon as possible with 6 to 12 inches of partially decomposed or fibrous muck. Where serious sedimentation problems may occur such as in fine sands or colloidal muck, it is advisable to use marsh hay, straw, corn cobs or fiberglass sleeves.

Surface Inlets

Surface inlets in drains are often hazardous because they allow sediments and trash to get into the system (Figure 14). These inlets are used where depressions occur in the field and where the infiltration rate is slow. They are especially needed for high value crops which are sensitive to excess water. If surface inlets are installed, use galvanized or asphalt coated metal pipe. They can be capped at the top and openings cut on the side which have grates to screen out trash and animals.

Where major installations are planned, the inlets should include sediment wells or traps. Inlets should always be higher than the surface to prevent soil erosion. They should be well marked in the field with flags or some other marker to prevent damage to farm equipment or to the inlets.

Outlet Protection

The outlet of the tile line into the open ditch should be adequately protected. A section of metal (16 gauge, corrugated metal or equivalent) galvanized or asphalt coated pipe should be used. The tile and the outlet opening is fitted with a 2-inch spaced grating of rods for protection against rodents. This pipe should be placed on a steeper grade than the tile.

The length of the pipe depends upon the character of the soil. A 12-foot length is usually sufficient for mineral soils. If the lateral lines connect up with one discharge main, only one outlet needs to be serviced. Manufactured connections are recommended for joining the laterals to the main line. The end of the outlet may be fitted with a gate to prevent water from backing up into the lines during times of high water.

Metal junction boxes (Figure 15), which also serve as a silt trap, can be divided in the center by boards placed in channel iron slots for partial water level control. The inlet to this junction box should be of bell-joint tile or sealed plastic tile that extends far enough back so the pressure of the water does not cut around the box.

Roots in Tile Lines

Water-loving trees such as willows should be kept 50 feet from the tile line because of possible stoppage by roots. If it is necessary to run a line under a willow windbreak, a sealed plastic or metal pipe should be used.

Iron and Organic Sediments in Drains

Ochre and organic sediments may accumulate in drainage lines and either diminish or completely block the flow of water. Also the inflow capacity can be affected when the tile joints or holes in the plastic drains become sealed. Hundal and Taylor (90) investigated the problems of clogged drains in the Willard Marsh area of Ohio and found two main types of sediments—either black organic or a mixture of organic and reddish-brown ochrous sediments (Figure 16). The ochrous material contained 10 to 23% iron

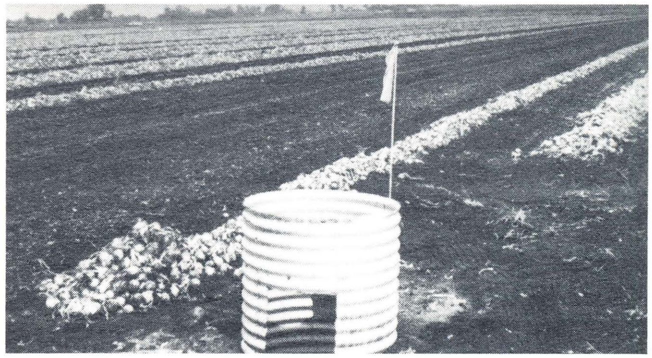


Figure 14. An effective catch basin designed to remove surface water. It is advisable to cap the pipe and to add grates to the side opening to screen out trash and animals.

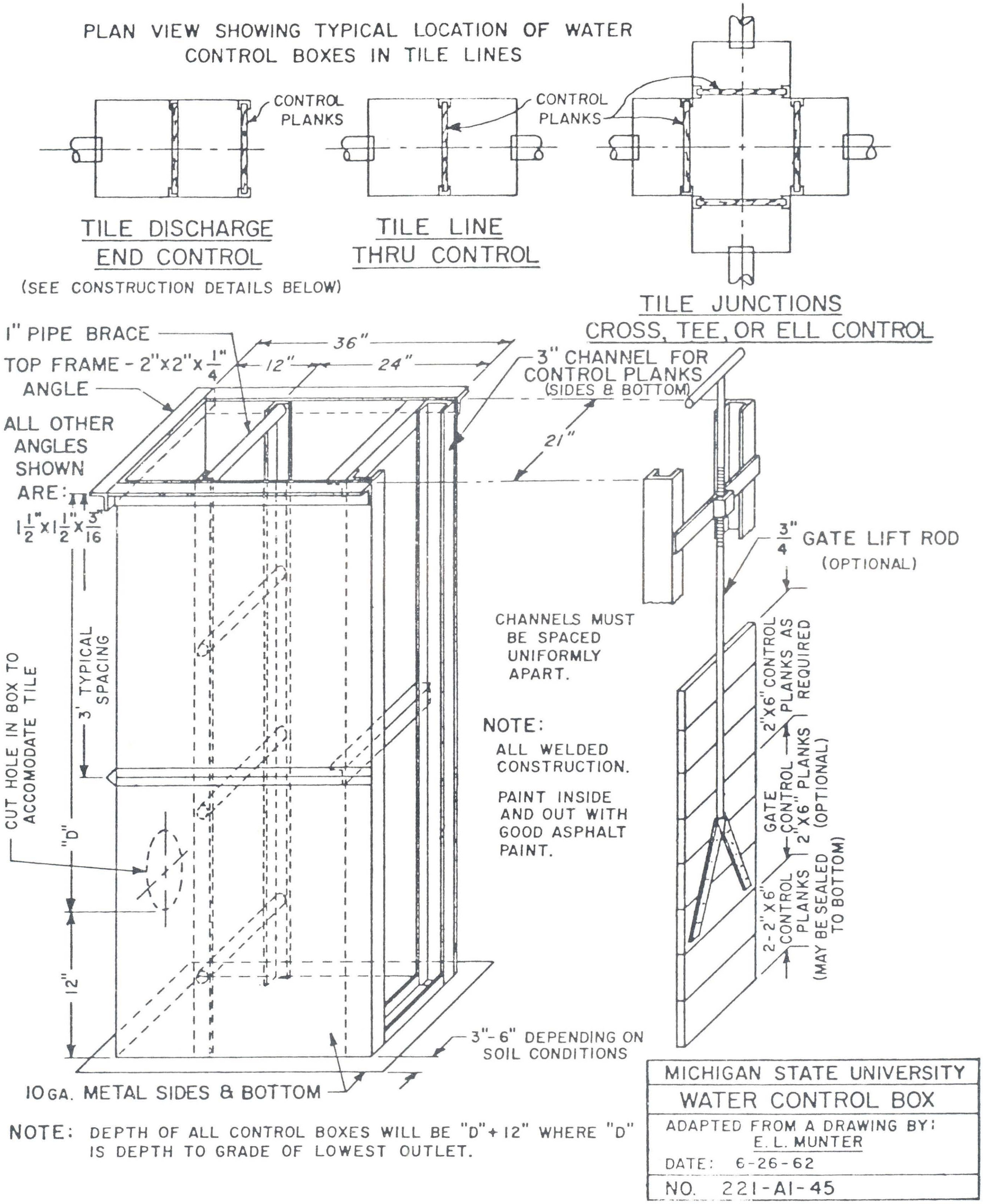


Figure 15. Water table control box in tile line.

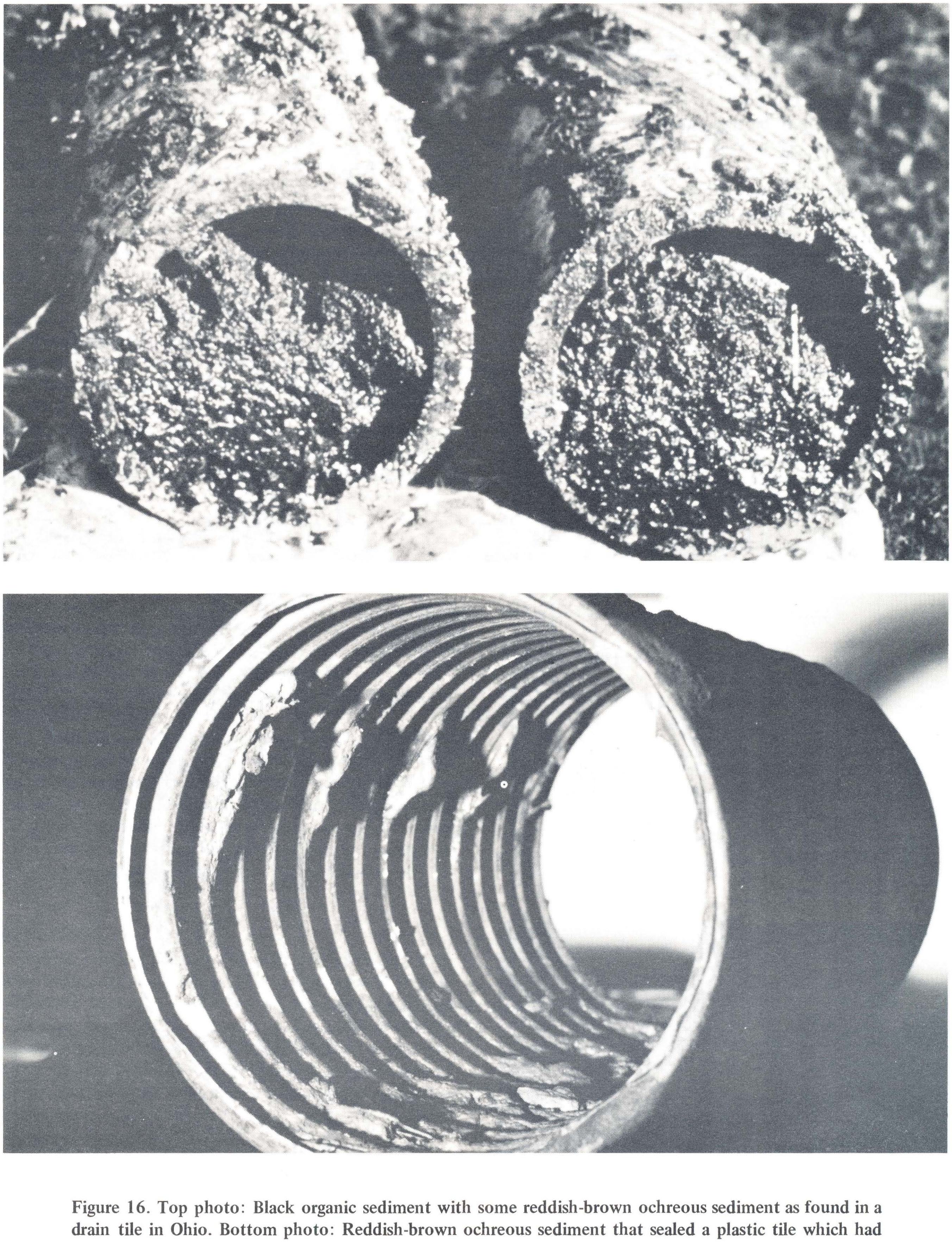


Figure 16. Top photo: Black organic sediment with some reddish-brown ochreous sediment as found in a drain tile in Ohio. Bottom photo: Reddish-brown ochreous sediment that sealed a plastic tile which had narrow slit openings. Photo courtesy of G. S. Taylor, Ohio State University.

on a dry weight basis from problem fields that contained about 2% total iron in the soil.

There is a difference of opinion whether plastic drains accumulate more sediments than clay tile. Most drain specialists believe there is no significant difference. Plastic drains, however, are usually smaller in diameter than clay tile. They present more problems if the slit openings used for mineral soil are installed.

The mechanism of ochre formation in drains is due to the absence of oxygen in excessively wet soil. This condition favors the activity of anaerobic organisms such as those that reduce ferric iron to ferrous iron. The latter is much more soluble and mobile. Deposition of iron then takes place when it picks up oxygen in the drains. The microorganisms involved with the reduction of iron belong to the Gallionella, Sphaerotilus and Metallagenium genera (95).

No practical management methods are known which prevent the formation of ochre in drains. Mechanical flushing of the drains with high pressure fitting nozzles can be used (90). Submerging both the tile and the outlet completely in water will greatly limit the activity of the bacteria. After a period of submersion, the system should be drained rapidly to help flush out the sediments.

Mole Drains

Limited use has been made of mole drains in the Great Lakes Area, but it is customary in the Florida Everglades (84). Mole drains are also sometimes used in lowering the water levels to expedite the removal of peat for commercial purposes. The equipment consists of a mole or metal bullet six inches in diameter to which a metal ball, with a slightly larger diameter than the bullet, may be attached by a short length of chain. The ball tends to compress the sides of the trench and thus prolong its life.

A vented shank is recommended to eliminate the suction created by the travel of the mole through the soil. The surface of the land should be level so the mole drain can be kept parallel to the surface. A rolling coulter of sufficient diameter to extend to the bottom of the trench, placed ahead of the mole, will facilitate the moling operation.

At least 30 inches of soil are needed above the mole drain to prevent it from collapsing under the weight of the farm machinery. The length of time a mole drain works effectively depends upon the character of the material through which the drain passes. Drains in finely divided material soon close up and become ineffective. Annual moling may be needed under these conditions.

Water Level Control

The height of the ground water level influences crop production and affects the rate of subsidence. Thus, the water level should be at sufficient depth to obtain optimum crop yields, and yet allow for the least amount of subsidence. Maintenance of a static water level in an area is affected by a number of factors:

1. Amount of Available Water

The ratio of water surface to land surface and the character of the underlying substratum influences the amount of ground water available for water level control. In the Great Lakes region the situation varies greatly with each area. In some areas it is not possible to maintain a high water table because of pervious subsoils.

The Everglades of Florida lend themselves to water table management because of small elevation differences, high hydraulic conductivity and large quantities of available water. The main source of water is that in Lake Okeechobee. It is moved to the farms by an extensive system of canals which are also used for drainage. Almost all subirrigation is by seepage from field ditches (98, 174).

2. Crop Tolerance

The tolerance of a crop to ground water level varies greatly with species (Figure 17). Generally, those grown on organic soils show far less damage from over-draining than too high of a water table. Growers also frequently maintain water tables lower than the suggested minimum to allow for a margin of safety in the event of heavy rains.

A number of studies have been made in the U.S., England and other countries to determine the highest possible water table without causing crop damage. Data in Table 17 present the minimum depth of water suggested for different crops.

3. Cultural Considerations

At water levels above 24 inches, tractors and harvesting equipment are easily bogged down. In many situations, it is advisable to maintain the water table below 30 inches at harvest time. Animals grazing on high water table pasture land can cause excessive turf damage.

In spring, when fields are open to wind erosion or frost is likely, it is helpful to maintain the water table at 12 to 16 inches. Once the crop is well established, lower the water table to the desired level.

The amount of rainfall during the season is an important consideration. If substantial amounts of rain are likely, it would be advisable to lower water tables below the 36 inch level.

Figure 17. Forked roots on sugar beets caused by high water table. Excess subsoil acidity can also cause forked roots.

Table 17. Minimum depth to water suggested for maximum yields and quality of several crops grown on organic soils.

Crop	Florida(a)	Indiana(b)	Minnesota(c)
		Depth in inches	
Beans	18 - 24	–	18
Beets (red)	– – –	28	–
Cabbage	18 - 24	26	24
Carrots	– – –	26	–
Celery	18	24	18
Corn	24 - 30	30	24
Lettuce	30 - 36	–	30
Mint	– – –	30	–
Onions	18 - 24	30	36
Potatoes	18 - 24	26	24
Parsley	14 - 16	–	–
Radish	14 - 16	–	18
Pasture-sod	12 - 20	18	–
Sugar case	24 - 30	–	–

(a)University of Florida Bul. 801 (174).
(b)Purdue Univ. Agr. Exp. Sta. S.C. 366 (53)
(c)Minn. Agr. Exp. Sta. Bul. 330 (165).

Plant-nutrient requirements vary with drainage (Figure 18). Nitrogen application will compensate, in part, for yield reductions in a high water table situation. The extent of this compensation depends upon the crop and the amount of rainfall. Results from Indiana (54) show that a corn yield of 147 bu/acre was obtained from plots with a 16 inch water table when 80 lb N/acre were applied sidedress. Plots without the nitrogen sidedressing yielded 98 bu/acre. Where the water table was maintained at 30 inches or more, the corn yields were 147 bu/acre with or without nitrogen sidedressing.

Phosphorus and potassium fertilizer requirements are usually greater with a high water table because of restricted root development. Likewise, micronutrient disorders in crops, especially manganese and zinc, are more likely to occur with a high water table.

Adverse Moisture

In spite of well drained conditions, excessive rainfall and/or flooding is a common hazard facing the muckland farmer. The flooding can be caused by overloaded streams because of runoff from the surrounding highlands. It can be a local, state or even a national issue. Examples are the Kankakee River Valley in Indiana, the Portage Drain in Jackson County, Michigan, the Wallkill River Basin in Orange County, New York, and many of the muck deposits in Wisconsin.

Most muckland crops are adversely affected when rainfall exceeds three inches in 24 hours. When such conditions occur, the farm manager has to make speedy decisions regarding pumping, diking, and temporary ditches. Once the water is off the field, additional fertilizer, especially nitrogen, may be advisable.

It is not easy to predict the amount of damage to crops following wet, soggy soil conditions. Crop maturity, temperature, aeration and the duration of the soggy condition are all interrelated factors.

Root crops such as potatoes and carrots are particularly sensitive. Onions often show severe loss of roots, develop tip burn on the leaves and serious neck rot diseases and bulb stains. Head lettuce, after head development, can be a complete crop failure because of bottom rot (*Rhizoctonia* disease). Cultivated crops that are more tolerant of temporary wet conditions are immature beans, corn, celery and mint.

Measures for Water Control

Control measures include the use of dams, levees, sub-irrigation through tile lines, pumps and irrigation wells (Figures 19, 20, 21).

Dams can serve two purposes: 1) if installed in conjunction with adequate systems of levees, they can prevent flood waters from backing up over the protected area; 2) they assist in maintenance of a controlled ground water level program. Reinforced concrete, interlocking steel piling, planks or corrugated steel culverts are some of the materials used in construction of dams (Figures 19, 20).

A steel plate with channel iron for holding flash boards in place, and welded to the end of the culvert, acts as a gate in maintaining water levels. Steel gates controlled by a

A. Water maintained at 16 to 18 inches

B. Water maintained at 30 to 36 inch level.

Figure 18. Effects of water table on growth of potatoes and corn. Purdue Univ. (83).

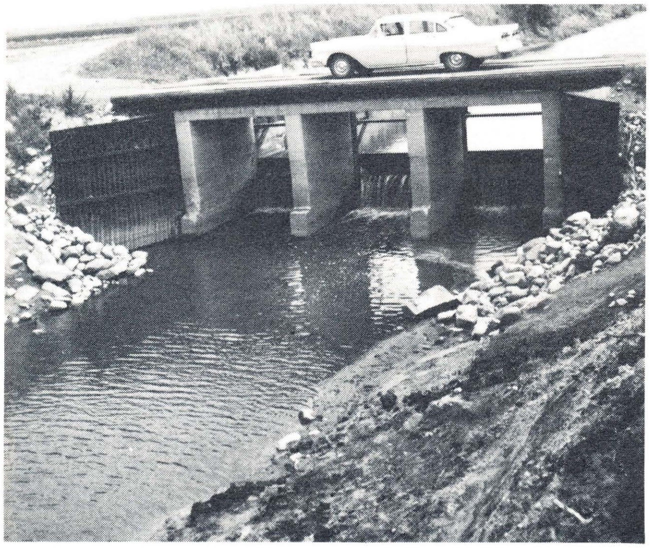


Figure 19. A well constructed dam in a public drain. Because of possible adverse reactions by others, such a structure often has limited use.

winch are sometimes installed at the end of dams to provide for water table control. Whenever possible the dams should be located in stable mineral soil. Used interlocking steel piling can often be purchased from salvage operations for use in construction.

Failure to extend the supporting buttress walls far enough into the banks of organic soil may result in seepage damage and in final washing out or bypassing of the structure. Dams that impound water should have the approval of the county or state authorities. Some dams have been washed out because of faulty construction. Once a dam is built it needs regular inspection.

Levees or dikes should be constructed of stable mineral soil materials, but be careful not to overload the bank (Figure 22). When completed they can serve as roadways. Muskrat activity in dikes, if not controlled, can result in serious damage.

Propeller and centrifugal pumps are commonly used in water level control and drainage projects. These pumps are either gasoline, diesel or electric powered. Electric pumps are often equipped with automatic float controls.

Source of Water for Maintaining Water Levels

For a controlled water level installation to function satisfactorily, a source of water is necessary to replenish the supply during the dry part of the growing season. A stream that maintains an adequate flow throughout the season is a common source of water, both for sub and overhead irrigation. In a few areas water from flowing wells is available. Maintenance of a water table from a deep well is a costly procedure. A deep well pump with a 600 gallon/min. capacity would have to operate continuously 24 hours a day for 15 days in order to pump an acre-foot of water for a 40-acre area.

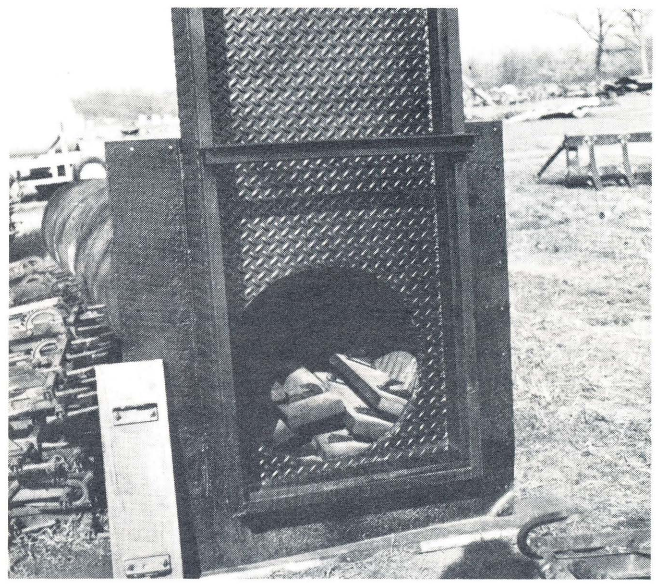
Irrigation

Irrigation gives a good start to small seedlings and transplanted crops, may increase crop yields, reduces wind erosion, decreases frost damage and prevents the burning-off of young plants during extreme heat. Water can also lessen heat dormancy of lettuce seed when the temperature exceeds 85°F. From 0.5 to 2 inches of water, depending on the soil moisture, is usually applied at one time. Unnecessary applications of irrigation water, however, can result in reduced yields.

Two types of irrigation are in general use on organic soil:

1. Sub-irrigation

This is accomplished by backing water up through the tile line or drainage ditches by means of dams and levees to raise the water level in the soil. If this method is to work satisfactorily, a source of water is necessary for maintenance of the desired level. One advantage of this system is its relatively low cost. Its success depends on the permeability of the soil and the levelness of the fields. Water levels



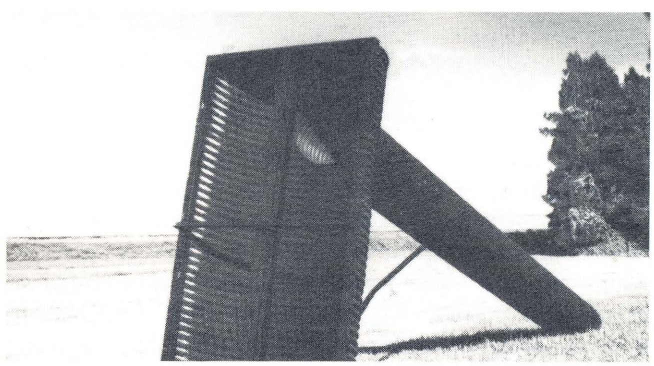


Figure 20. Two similar culvert designs used in open drain outlets that can be used for water control. Roadways are often constructed over the culverts after installation.

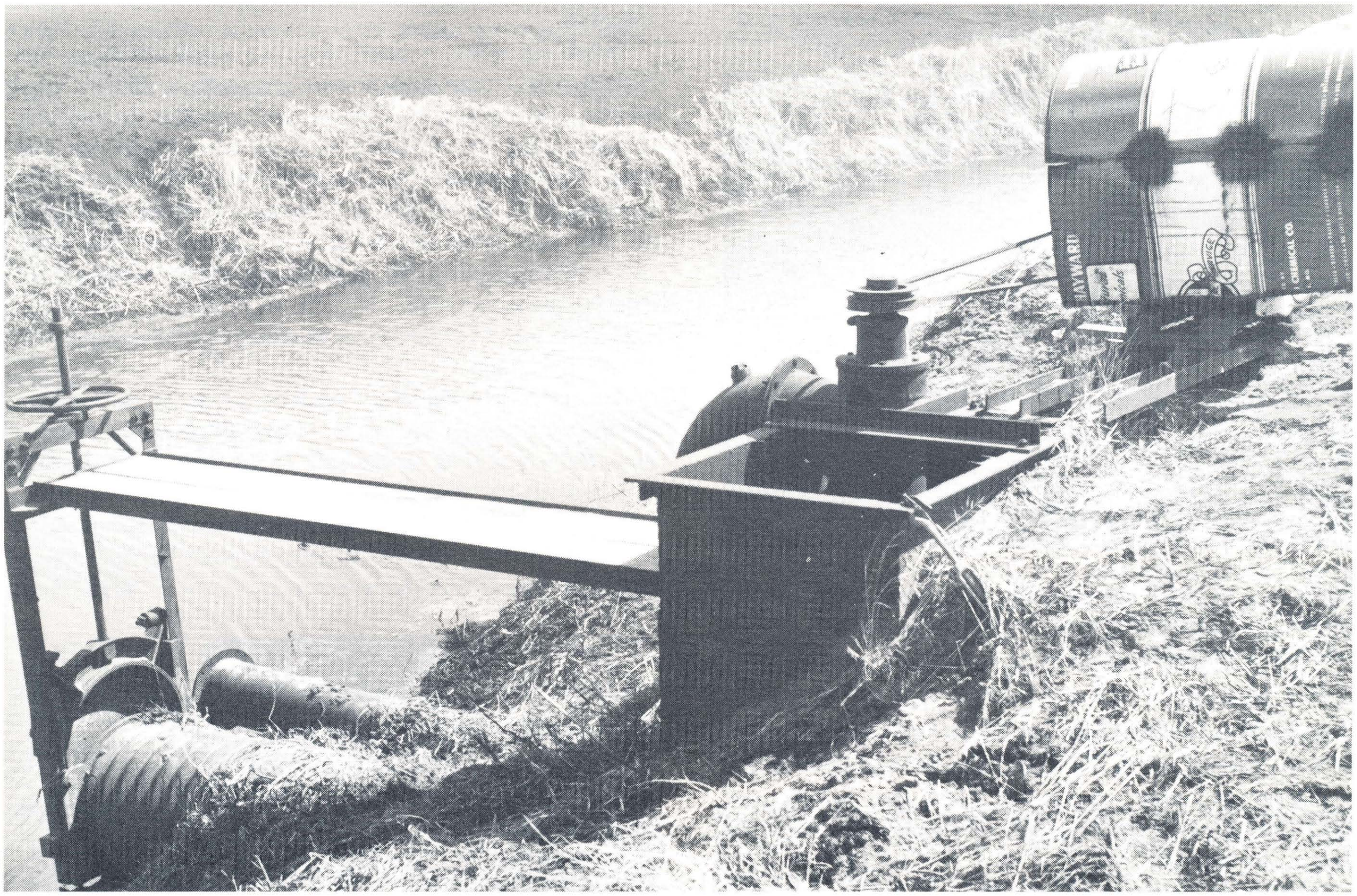


Figure 21. A combination pumping and water intake system used in water control.

Figure 22. Excessive weight of dredged material caused this serious splitting of the bank. Too much spoil weight can also cause splitting and uplifting in the bottom of the drain.

should be checked at various points in the field to determine the difference in heights between the field and the surrounding drainage ditch.

With sub-irrigation, the grower should watch the condition of the crop and should not maintain the water level too close to the surface so as to cause root damage. The advantages of sub-irrigation over sprinkler irrigation are that alkaline drainage water is not applied to the surface, less possible spread of plant disease, fewer weed problems and less interference with tillage operations.

2. Overhead Irrigation

This system is commonly used in intensively farmed areas. It is especially needed where sub-irrigation is not feasible, as on uneven fields, where there are restrictions on control dams, and on pervious subsoils. Portable aluminum alloy pipe equipped with either small or large guntype sprinklers is used. Water can be pumped from streams, ponds or deep wells. The cost of pumping from a drainage ditch or pond is usually less than pumping from a deep well. The turbine type of pump used with deep wells is usually more expensive than the centrifugal pump installations used adjacent to surface sources of water.

There are a number of different overhead systems used in irrigation including the conventional quick coupling pipe equipped with rotary sprinkler heads, the solid set system equipped with either fixed or quick coupling sprinklers, the sequencing type of solid set, the side-roll mechanized lateral and the traveling (self-propelled) giant sprinklers. Each system has its merits and handicaps.

Factors to consider are equipment and labor costs, ease of handling, damage to crops, water distribution patterns and field puddling. The trend in recent years has been away from the quick coupling systems because of the high labor costs. The solid set and the sequencing types use smaller diameter lateral pipes which greatly reduces weight. The pipe, however, is usually left in place for the duration of the season. Thus, investment costs are high.

The solid-set systems are preferred when light-rapid watering is needed to help prevent frost, wind and burnoff damage to crops. Some growers prefer solid-set systems with quick coupling sprinklers, which reduces equipment costs and allows for more flexibility in the amount of water applied at each site.

Side-roll mechanized irrigation systems are used for low growing crops such as potatoes, mint and beans. The equipment is moved by wheels spaced about 50 feet apart. The units are generally 1,300 to 2,600 feet in length. The pipe serves as an axle to turn the wheel. Side roll systems tend to cause excessive ponding in some areas when the pipes are drained. Equipment is advanced by small air-cooled engines located in the middle of the unit. Recent innovations have made it possible to start these power units from the end of the field.

The traveler system has a large sprinkler on a trailer. It is coupled to the main pipe by a four to six inch flexible hose. Engine or hydraulic power is used to wind up a cable to slowly move the sprinkler across the field. The cable is anchored at one end of the field. The rate of water application is high and this can cause damage to small plants. Because of wide strips—usually 330 feet—the pattern of water distribution is poor under windy weather conditions.

Long span pivot irrigation systems have become common in many areas. Unfortunately, they are not suitable for mucklands because of serious flotation problems when the wheel tracks become wet and deep.

Water Quality

Water used for sprinkler irrigation has been known to introduce plant diseases, nematodes and mineral problems. Water with conductivity readings of less than one millimhos/cm (640 ppm of salt) is generally satisfactory for most crops. When leaching from rainfall occurs, water up to two millimhos/cm can be used for short periods, but not for salt sensitive crops.

Some well waters carry high amounts of iron which stain irrigation equipment and plant foliage but crop damage is usually negligible. The use of large amounts of water high in iron increases the need for manganese and phosphorus fertilizer. Continued use of water high in lime can increase soil pH. One acre inch of water containing 200 ppm of calcium will add the equivalent of 112 pounds of calcium carbonate.

Plant diseases and nematodes have been introduced where the water source is from stagnate streams and ponds. Onions and corn have been known to develop bacterial infection (Erwinia spp.) when contaminated water gets lodged in the neck or the whorl of the plants. Leak (*Pythium debaryanum*) problems in potatoes have also been associated with questionable water sources. One should be particularly cautious of water that has come in contact with cull or washed vegetables.

DEVELOPMENT OF ORGANIC SOILS FOR AGRICULTURAL PURPOSES

Several factors should be evaluated before the reclamation of an organic soil for agricultural purposes is initiated. These factors include: 1) the pH of the various horizons of the profile, 2) the depth of the deposit, 3) the character of the underlying material in shallow soils, 4) the practicality of the establishment of a suitable water control system, 5) the cost of clearing and draining, and 6) the tentative cropping system. Table 41 reports penalty numbers for different physical features.

An adequate soil sampling procedure in the evaluation of any location is essential. If the vegetation is uniform, samples obtained from a line running diagonally through the area may provide dependable information. The distance between sampling locations and the sampling depths in profile should be governed by the variability of the deposit. For a uniform area, an interval between sample locations of 300 feet is suggested. It is also advisable to check acidity at one foot intervals within the profile to a four foot depth. Areas indicating any marked changes in vegetation or elevation should be separately sampled.

The depth of the deposit and the nature of the underlying material are important factors in determining the length of life of the deposit, the establishment of adequate water control measures and, to some extent, the crop adaptation. Allowable development costs are, in part, dependent on the value of the crops that can be grown on the area.

Clearing

Drainage of the marsh or bog may be the first step in the clearing operation (so heavy equipment can be supported). Removal of trees, stumps, and roots, preferably with a bulldozer, is the next operation. In clearing a timbered area, the bulldozer operator should be protected from falling trees by a steel cab. Clearing and draining organic soils not intended for immediate agricultural use should not be undertaken because of the increase in rate of decomposition and the increased fire hazard.

Shrub growth and small trees up to two to three inches in diameter can be turned under with a breaking plow if the tractor is equipped with a bulldozer (which helps to push over the cover ahead of the plow). The plow should be capable of turning a furrow slice 18 to 22 inches wide and 12 to 15 inches deep and be equipped with a large diameter (24 to 30 inches) rolling coulter to facilitate the breaking operation. The furrow slice should be laid as flat as possible to provide a level surface for subsequent tillage operations.

Figure 22a. Excessive amounts of buried roots and stumps can prove too costly to clear the land for cultivated crops. Drainage, liming and seeding to pastureland is advisable. Photo courtesy J. P. Lilly, North Carolina State University.

Repeated diskings with a heavy set of double disks (18 inch diameter) will aid in preparing a suitable seedbed for a crop the following spring. A land leveler can be used to smooth the surface. It is usually not advisable to plow for two to three years after the first breaking in order to give the plant growth which was turned under a chance to decompose.

In areas where roots are prevalent, it will be necessary to pick roots off the area annually for a number of years. In some situations, as in eastern North Carolina, excessive amounts of roots can greatly hinder tillage and can prove too costly to develop (Figure 22a). The cost of clearing an acre of wood land may exceed 30 times the cost for a grass covered area.

On raw decomposed organic soils the use of a heavy roller weighing about 600 pounds per linear foot is sometimes desirable. The compaction caused by the heavy rolling improves the capillary action of the soil and thus improves the soil moisture relations. It also serves as an aid in frost prevention because moisture will come to the surface more easily. **The roller should not be used on finely divided organic soils that have a slow infiltration rate.**

Subsidence

The agricultural utilization of organic soils is accompanied by subsidence, the lowering of surface elevation (Figures 23a, 23b, 23c). The rate of subsidence is influenced by several factors, including: 1) biological oxidation, 2) height of water table, 3) character of the organic material, 4) compaction, 5) burning, 6) wind erosion, 7) water erosion, 8) shrinkage and dehydration, 9) geological subsidence and 10) cropping system. Sometimes the terminology "densification" is used which includes compaction, desiccation and loss of the buoyant force of ground water (182). In addition to soil losses, subsidence adversely affects drainage. Outlets may have to be deepened and in many cases the installation of discharge pumps is necessary.

One of the oldest records of subsidence refers to a location in the Fens of Great Britain (142)[3]. A graduated iron column was sunk in Holme Fen in 1848 which had an initial depth of 5.4 m to underlying clays. In 1870 a loss of elevation of 2.3 m had occurred. In 1879 pumps were installed to improve drainage. This resulted in a further drop of 7.5 cm in one year. By 1913 the loss in elevation amounted to 3.0 m. By 1951 the lowering had amounted to 3.4 m (11.2 feet).

In another study (160), measurements of the decline in peat depth between 1941 and 1971 for 14 sites in East Anglia, England showed higher subsidence (wasteage) since 1955 than before. The mean value for subsidence rate over the entire period was 1.37 cm/yr. (0.55 inches).

When an organic soil is developed for crop production, conditions are more favorable for oxidation by aerobic microflora. Normally microorganism activity and decomposition rates are greater in the upper 10 cm of soil. However, as shown in Table 15, the subsidence rate at the 60 to 70 cm depth of drained muck was about the same at the 0 to 10 cm depth because of differences in bulk density.

Largely because of biological oxidation losses, it is estimated that by the year 2,000 there will be only about 13% of the Everglades remaining that will be deeper than

[3]For interesting reading about drainage, subsidence, agriculture and health, see "The Drainage of the Fens" by H. C. Darby (37). Some citations: "In 1665 the silt region of Marshland, North Wisbeck and Holland (England) was about five or six feet lower than the peat-fen behind : Today the position is reversed, the silt is about ten feet higher."

"The moory soil, the watery atmosphere with damp unhealthy moisture chills the air, thick stinking fogs and noxious vapours fall, ague and coughs are epidemical. Here every face presented to our view looks of a pallid or a sallow hue."

"Because of the ague the residents indulged in brandy drinking and took opium pills. Despite statistics of longevity many people were fearful of entering the fens of Cambridgeshire lest the **Marsh Miasma** should shorten their lives" – – There was considerable discussion as to what caused the plague–humid atmosphere, decaying vegetable matter or bad drinking water." (We now know the dreaded **Marsh Miasma was malaria**).

Much the same was reported by the author's grandfather who farmed in the Kankakee River Valley (Indiana)–an area famous for deer and water fowl hunting. A section in **History of Warren, Benton, Jasper and Newton Counties** (87) vividly describes the situation of frontier life and tries to explain the cause of ague: "The clearing-off of the timber or the breaking up of prairie sod involved the rapid decay of large quantities of vegetable matter, gave rise to the inevitable **Miasma** which wrought its sure work upon the system. Such sickness was generally confined to the last of the summer and fall.

"It was commonly remarked that when the bloom of the resin weed and other yellow flowers appeared, it was time to look for the plague. Physicians were very few and often so far situated that it took a day's ride to reach them. Boneset, Culver's physic roots and a long list of teas and herb decoctions were found in every cabin.

"For newcomers who had hitherto possessed a fresh complexion, after coming here (Jasper County) wore the pale, sallow complexion of semi-invalids. It got to be very much the custom for each family to prepare–in late summer–for the inevitable attack, arranging matters so that they could care for themselves, it being no infrequent thing for a whole family to be confined to the bed at the same time."

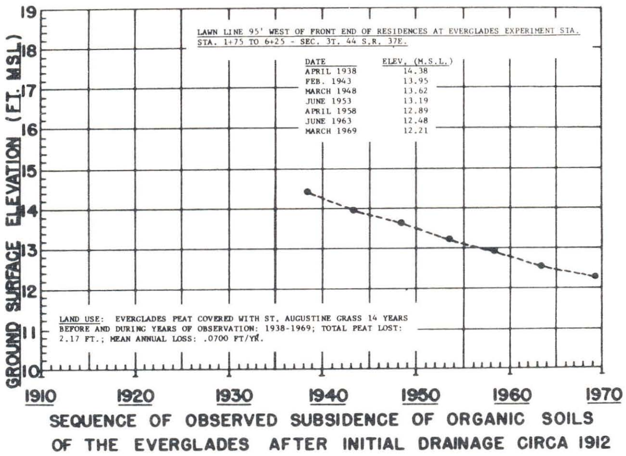


Figure 23a. Measured elevation values of a pasture land for the period of 1938 to 1969.

Figure 23b. Homes built with footings in bedrock. Initially in the '30s these homes had only two or three steps. Picture taken in 1980.

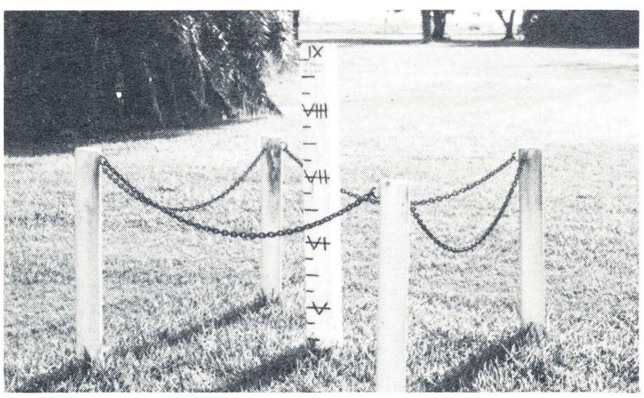


Figure 23c. Subsidence bench mark at the Everglades Station. In 1924 the depth of the soil was slightly over 9 feet. In 1980, the depth was 4 feet.

Figure 23. Subsidence of soils at the Everglades Research Center.

36 inches. A 1978 report indicates the predictions made in 1951 (174) and shown in Table 18 are nearly on target.

The rate of subsidence is closely related to the height of the water table. A study in Indiana showed annual subsidence rates of 1.1, 1.8 and 3.0 cm where water tables of 42, 68 and 98 cm, respectively were maintained (100). In Minnesota, subsidence of 15 cm and 60 cm were obtained over a five year period with water levels of 30 and 135 cm, respectively (165). Under climatic conditions of the Florida Everglades, the annual soil loss for water tables of 30, 60 and 90 cm resulted in subsidence rates of 1.6, 3.6 and 5.7 cm per year, respectively (98, 174).

Thus, if the depth of the soil above the water table is doubled, the rate of subsidence is doubled. Also note the rate in Florida is twice that for the Great Lakes area. Another Florida study has shown that the subsidence rate for both vegetable fields and pasture land were similar but was about 30% less for sugarcane land (173).

Canadian workers have investigated various alternatives for retarding the subsidence rate. Laboratory studies (7, 126) have shown that residual Cu (copper) fertilizer curtails the decomposition due to the inactivation (by the Cu) of certain extra cellular accumulative and degradative soil enzymes. A muck sample rich in Cu (2,922 ppm) lost carbon through aerobic soil respiration at half the rate of a muck sample containing 1,159 ppm Cu. Similarly, the rate loss for a hemic peat containing 797 ppm Cu was half that of a peat sample with 408 ppm Cu.

Such effects of Cu need to be studied under field conditions to determine possible toxic effects on field crops. Many fields, especially those with a long history of celery, contain substantial amounts of Cu. Studies should be initiated to determine the effects of such Cu levels on crop yield and quality in addition to the subsidence rate.

Wind erosion has been one of the predominant causes of subsidence. Losses from wind erosion may be over 3 cm of soil during a severe storm. Control measures play a vital part in the limiting of such soil losses. Water erosion is usually not an important causal factor of subsidence except following severe storms (Figure 24). Occasionally, plowed furrows are actually floated away during flood conditions, and peat deposits are lost through wave action.

Compaction by machinery accounts for some of the subsidence that occurs in cultivated fields. When the groundwater level is lowered the buoyant force of water is

Table 18. Measured and predicted depths for the 700,000 acres of Florida Everglades Histosols. (174)

Year	Depth (inches) 0 to 12	12 to 36	36 to 60	Over 60
	Percent of Total			
1912	0	1	3	96
1925	1	3	8	88
1940	1	7	7	85
1960	4	12	28	55
1980	17	28	41	14
2000	45	42	9	4

lost in the upper layers. The deeper layers then have to carry an increase in weight of about 1 g/cc per cm (62 lb/cu ft) of groundwater drawdown.

In the Netherlands, where ditch water levels of about 25 cm were lowered to 70 cm, the soil subsided six to ten cm in six years (170). Of this amount, 65% was charged to shrinkage and oxidation and 35% to compaction of the soil below the groundwater. Once compaction has taken place because of drainage, and by farm machinery, its effect on subsidence is minor.

Shrinkage because of dehydration accounts for most of the excessive subsidence obtained during the first few years following drainage and cultivation. The change in soil bulk density before and after drainage gives a good estimate on the amount of shrinkage.

A systems model was designed by Browder and Volk (26) which simulates the interaction of climatologic and biologic factors in the biological oxidation of organic soils. It was designed to test different management alternatives which might slow the rate of subsidence. The three major factors considered in the model are temperature, water table height and organic composition.

Loss By Fire

Prior to 1950, fires probably accounted for most of the loss of organic soils in the U.S. These fires were both deliberate and accidental. Some of the deliberate fires were attempts to answer excess soil acidity, low nutrient levels and greater frost problems. Pasture and marsh hay lands were often burned to destroy old plant residues and unwanted brush.

The accidental fires were more common in pioneer times because the top organic soil was more fibrous in texture. Other factors include smaller fields, more grassland and the custom of spring burning. Rail locomotives and early model farm tractors also contributed to fires. Modern fire fighting equipment and cultural practices have greatly reduced the losses.

Fires not only increase subsidence but they can also leave fields extremely rough, which increases drainage and land leveling costs. Fires can expose undesirable subsoils such as droughty sands, gravel, marl or sticky blue clay. Burning causes marked variability in the soil pH within a field. Fires that took place over 50 years ago are still known to cause patches of manganese deficiency in crops. These

Figure 24. Soil erosion by water can be serious even though the field appears fairly level. Losses are particularly severe during heavy rains or during the spring thaws.

localized patches can easily be overlooked in routine soil sampling (Figure 25).

Controlling a fire is extremely difficult, especially if accompanied by high winds. Digging a ditch around the fire and down to the wet soil, which allows the fire to burn itself out, is one method of control. Compaction by heavy tractors and the use of double disks or heavy rollers are the most effective measures.

The application of water by a high-pressure sprayer or from water wagons is satisfactory if the fire is small. The addition of a detergent or wetting agent in the water increases the effectiveness of the water. If available, sprinkler irrigation pipe can be run to the vicinity of the fire and can supply large amounts of water.

Burnt out areas, espécailly near the fire, are difficult to rewet. Fires can also easily smolder in protected areas or pockets; even through a severe winter. Thus, make several follow-up inspections to make certain the fire has been extinguished.

SOIL REACTION AND LIMING

Six ranges in soil reaction are suggested as characteristic of organic soils and reflect possible differences in management: pH 2.7 to 4.0, intensely acid; 4.0 to 4.5, very strongly acid; 4.5 to 5.2, strongly acid; 5.2 to 6.5, medium acid to slightly acid; 6.5 to 7.5, nearly neutral to mildly alkaline; greater than 7.5, alkaline or calcareous.

The range in pH of most organic soils measured in water is between 3.7 and 7.8. Higher tests have been reported due to the presence of soluble sodium salts. The acidity of organic soils is accounted for by the presence of organic compounds, exchangeable hydrogen and aluminum, iron sulfide and other sulfur minerals.

The intensely acid layers found in certain organic soils are believed to have formed under conditions reported for acid sulfate soils (16, 60, 212). These soils, which exceed 25 million acres in the world, are found mostly in tropical and semitropical brackish coastal areas. They are associated with plants such as reeds (phragmites), cord grass (*Spartina laterniflora*), papyrus and certain mangrove species which can accumulate sulfur.

The acid sulfate organic soils found in the Great Lakes area and in northern Europe are associated with the coprogenous earth sediments. These are aquatic residues of algae, diatoms and possibly iron-oxidizing bacteria (*Gallionella, Sphaerotilus*).

In the Great Lakes area, the acid sulfate soils are usually small and scattered areas within a deposit. Because of the high iron content, they appear to be associated with old seepage areas or may have developed along the sides of former streams. They are normally located in a one to four inch layer near or on the bottom of the peat profile. In marly areas, the streaks may be found in or just above the marl.

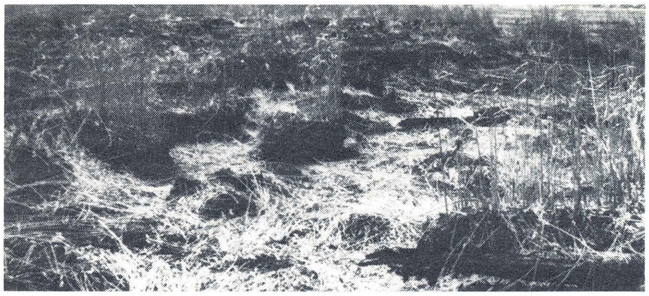


Figure 25. Soil loss after a severe muck fire. The burnt areas often show high iron content and require liberal rates of Mn and P.

Extensive acreages of the acid sulfate soils are found in the Fens of England and are in a layer directly above the mineral subsoil. When encountered in crop production, they are called "drummy" peat and are difficult to rewet after drying. The line marking the boundary between the drummy soil and the subsoil is often undulating, which gives a variable patchwork effect on plant growth.

In its natural water-logged state, the pH of the acid sulfate soil can be nearly neutral in reaction. However, upon drainage and exposure to air, the sulfur and sulfides oxidize rapidly to form crystals of Jarosite $KFe_3(SO_4)_2(OH)_6$, Copiapite $Fe^{+2}Fe_4(SO_4)_6(OH)_2 \cdot 20\ H_2O$ and Melanterite ($FeSO_4 \cdot 7H_2O$). Sparkling crystals of calcium sulfate are common and can range in size up to 0.2 mm in diameter and 2 mm in length.

The acid sulfate areas are normally reddish in color because of the high iron products. They often fill old root channels to form hollow cylinders after decomposition of the root fragments. Some typical acid sulfate Histosols are shown in Figures 26 and 27.

Alkaline conditions are due to several factors, the most important of which are: 1) burning (the ash from burning one foot of organic soil may raise the pH more than one unit), 2) flooding or irrigating with alkaline water, 3) presence of limestone, marl or shells, 4) overliming, 5) calcareous dust or washings from roads and ditch banks.

The occurrence of extremes in reaction of adjoining layers of organic soils may be due to burning, or flooding with high limewater. In some cases, the plow layer may still require lime even though marl is present at a 50 cm depth. In general, the percentage of organic soils in the U.S.A. which require lime for agriculture crops is relatively small.

Use of Lime Materials

For the Great Lakes area, an application of lime is generally recommended for most crops—except blueberries or cranberries—when the pH of the organic soil is 5.2 or below. In some cases, the percent of total or exchangeable calcium in the soil is a better measure of lime requirement than is pH.

Results from Germany and Sweden indicated that a lime-sufficient soil should contain a minimum of 1.8%

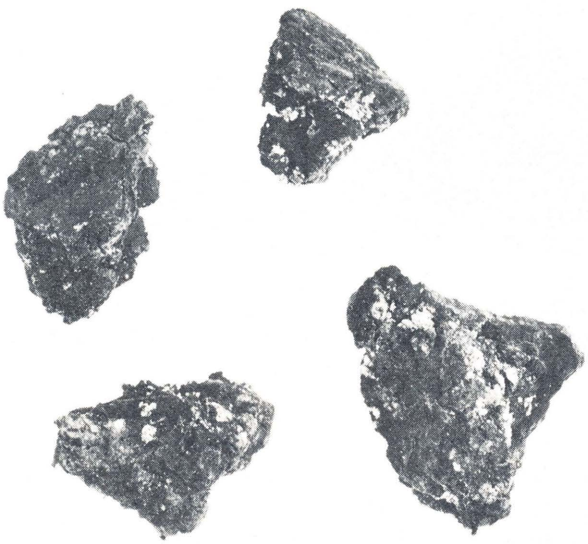


Figure 26. Clods of unproductive acid sulfate Histosol. The pH is often below 3.5. The soil usually shows reddish-brown iron streaks around old plant fibers, yellow colored iron mineral deposits and sparkling white crystals of calcium sulfate. After drainage the sulfides oxidize to form sulfates. High rates of limestone are required to make these areas productive. (See Figure 27.)

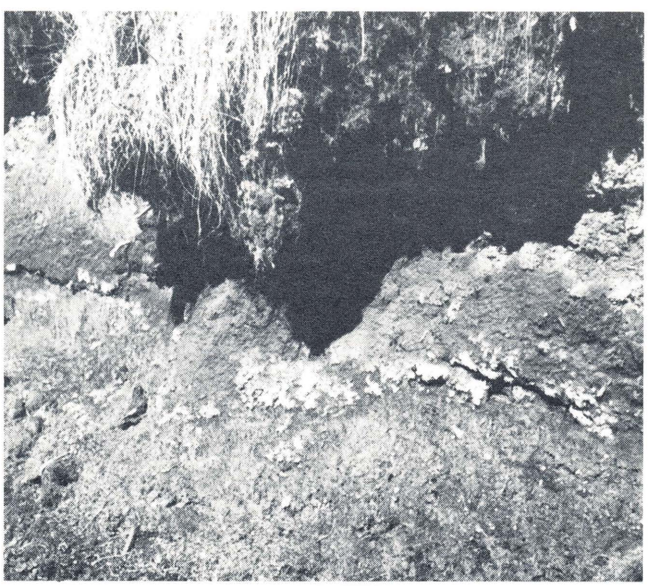


Figure 27. An organic soil profile exposed by an open ditch showing an intensely acid layer (pH 2.8). The acid layer is the dark horizontal streak containing white salts located about one meter below the soil surface. Notice the normal grass cover which would not be possible if the acid streak was near the surface.

calcium total dry weight. Nygard (145) placed a value between 0.5 and 0.9% calcium as the critical point between lime-sufficient and lime-deficient Minnesota soils regardless of pH. No response to lime was obtained from red clover over a 15 year period for one location that had a pH of 4.1 and 0.8% calcium.

Swedish advisors prefer total Ca content of a soil rather than a pH measurement as an indicator of lime needs. Limestone is recommended if the Ca content is less than 3,600 kg/20 cm hectare, advised for responsive crops if the content is 3,600 to 5,000 kg, and no lime is recommended if Ca exceeds 5,000 kg.

Field studies at North Carolina obtained the best corn and soybeans at about pH 4.6 to 5.0 (55, 135). Advisors in New York State recommend liming above pH 5.5 if the organic soils contain substantial extractable iron and aluminum (47). Shickluna and Davis (171) grew good onions on soils that tested as low as pH 4.3, but not at pH 3.7. Similar results were found when alfalfa was grown (Figures 28, 29). The writer compared the soil pH levels from various parts of a problem celery field and found the critical pH was 5.3 (Figure 30).

It is quite apparent that several factors modify the critical pH for good plant growth, including crop sensitivity to active Ca content. In general, for organic soils low in Fe and Al and derived from sphagnum, the suggested minimum pH is 4.5, for wood-sedge soils, the minimum is about 4.8. For others the pH should be 5.2 to 5.6 depending upon the sesquioxide content. Liming to pH 6.0 or higher as recommended for mineral soils is a serious mistake because of added costs and the reduced availability of Mn, Zn, B and P (122). The chart in Figure 31 illustrates how pH affects the availability of plant nutrients.

Materials and Rate of Application

Finely ground agricultural limestone, marl and water treatment lime are products used to correct soil acidity. The amount required per unit change of pH varies for different soils. For example, Shickluna and Davis (171) limed two organic soils that had essentially the same initial pH. The addition of 12 tons per acre changed one soil from pH 3.6 to 5.6 but for the other soil the change was from 3.7 to 7.0.

The cation exchange capacity based upon a volume measure, such as CEC/100 cc, is a major chemical property related to lime needs. Other factors to consider are the mineral soil content, hydrogen dissociation constant of the humus, kind and amount of pH dependent functional groups and the amount of exchangeable Al (see page 19). When mixed six inches deep, about 700 pounds of limestone for peaty soils and 1,000 pounds per acre for muck soils are needed to raise the soil pH 0.1 unit.

Limestone is classified as calcitic ($CaCO_3$), dolomitic ($CaCO_3 \cdot MgCO_3$) or a mixture of the two. Calcitic limestone is faster acting in the soil and is easier to grind. Crushed marl is a good liming material but it usually tests

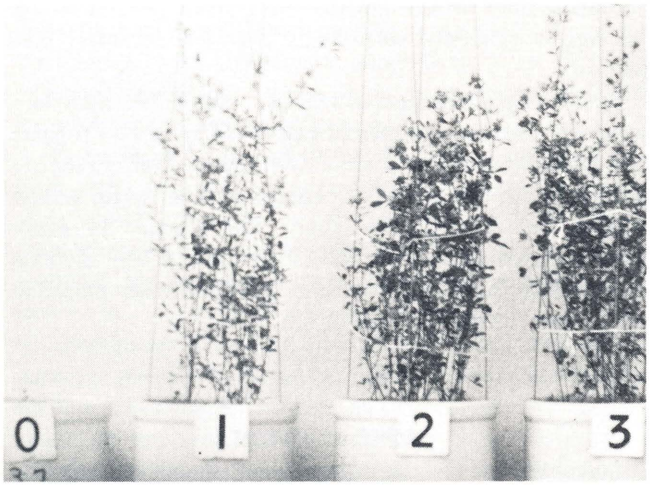


Figure 28. Alfalfa failed to grow in soil with 14 m.e./100 g of exchangeable calcium at pH 3.7. 0 - no lime; 1 - 2 tons per acre, pH 4.2; 2 - 6 tons per acre, pH 5.0; 3 - 10 tons per acre, pH 7.0. Lime source was precipitated calcium carbonate.

low in magnesium. Organic soils that test less than 200 lb/acre (6 inch depth) of Mg should be limed with some dolomite.

Limestone particles are easily coated with iron minerals and soil humates which interfere with the liming reaction. For this reason, most of the limestone should be ground to pass through a 100 mesh sieve. Maintenance applications may be needed every five to ten years; however, have the soil tested before liming.

Maintenance treatments are not as common as for mineral soils because upon biological oxidation of the humus the Ca and Mg accumulates; which partly compensates for the leaching and crop removal losses. When peaty soils are farmed the soils decompose, bulk density increases and the percentage of base saturation (on a volume basis) decreases. This change normally increases soil acidity and the soil may require liming.

Many soil testing laboratories use buffer solutions to help estimate lime requirement. Some of the methods are not suitable for organic soils. Mehlich (134) developed a suitable test using a pH 6.6 buffer which contained triethanolamine, acetic acid, ammonium chloride, barium chloride and sodium glycerophosphate. Liming was recommended if soil in the buffer tested less than pH 5.5.

Method of Application

Limestone should be applied at least ten inches deep for most field crops. Deep-rooting, acid sensitive crops such as sugar beets and carrots should be limed at least 15 inches deep. Grasslands growing where moisture supply is adequate should be limed about six inches deep. In western Ireland, good clover and grass grew where only 2,500 pounds of limestone per acre were applied to the top three inches (149).

Figure 29. An organic soil having 26 m.e./100 exchangeable Ca grew nearly normal alfalfa. 0 - no lime, pH 4.3; 1 - 2 tons per acre, pH 5.0; 2 - 6 tons per acre, pH 5.8; 3 - 10 tons per acre, pH 7.0. The unlimed soil required nitrogen fertilizer because the N fixing bacteria were inactive.

Lime applied to organic soils has very little lateral or horizontal movement; thus, it is important to obtain good mixing. This can be accomplished by several diskings or by a rotavator. Where deep mixing is needed, apply about one-half of the lime and surface mix before plowing and then apply the other half after plowing. This split application permits the use of calcitic limestone for the one treatment and dolomite for the other.

Sulfur

There are situations when acidity needs to be increased to improve phosphorus, manganese, boron and zinc availability. Sulfur is the common material used to counteract the calcareous conditions. The alkalinity may be caused by

Figure 30. Poor celery plants caused by excess soil acidity. The critical pH was found to be pH 5.3. No doubt, high salts caused by liberal rates of fertilizer accentuated the acidity.

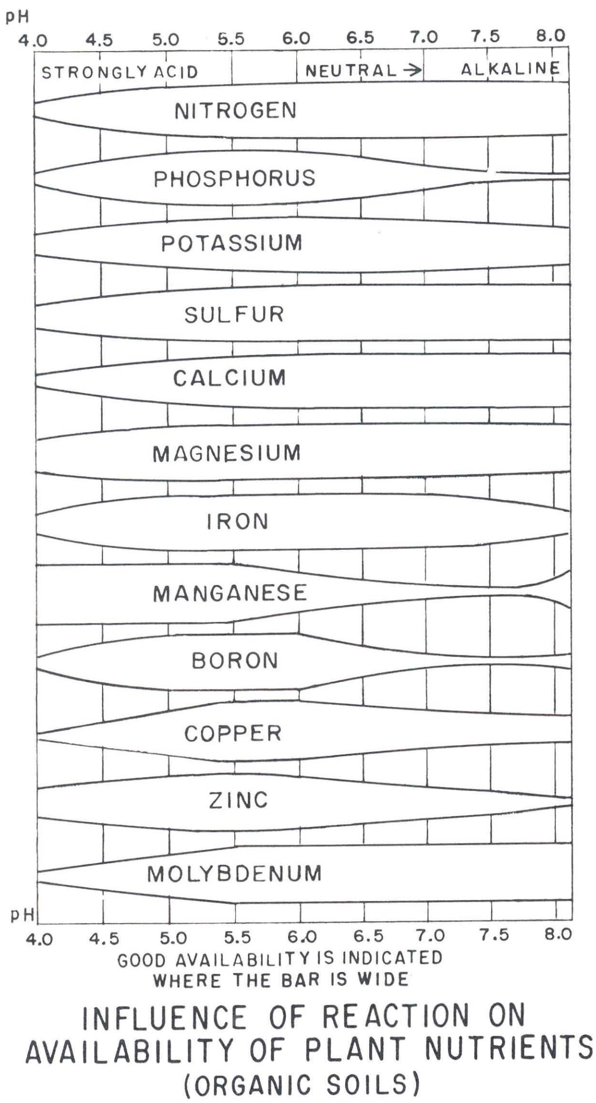


Figure 31. Influence of reaction on availability of plant nutrients. (Organic soils)

floodwaters, marly materials from spoil banks or the increase in calcium resulting from organic matter decomposition.

An application of 1,000 pounds of sulfur per acre will lower the top six inches of soil about 0.4 pH units. Soils that contain marl or extensive amounts of free limestone require large amounts of sulfur. It would not be feasible to treat such soils with sulfur because of expense. Carrots, sugar beets, mint, parsnips and cabbage can be grown on calcareous soils providing ample manganese fertilizer is used.

Agricultural grade sulfur at the rate of 500 pounds per acre is recommended for sugar cane in Florida when the pH is 6.5 or greater. To reduce costs, this sulfur is applied with other fertilizer in the furrow when the crop is planted. This placement only affects the pH for a small portion of the soil but is generally sufficiently effective for crop production.

Acid-loving plants such as azaleas, blueberries, rhododendrons and certain ornamental plants are grown on organic soils. Elemental sulfur, aluminum sulfate or iron sulfate can be used to increase acidity. Coarse or granular sulfur is slow reacting but is easier to apply and handle. In many situations acid forming fertilizers are used to help increase acidity. Such fertilizer is particularly helpful when placed in a band near the seed or plant.

FROST CONTROL

Susceptibility to frost injury is an important factor in determining the adaptability of any crop to organic soil. Frost damage to crops is more likely to occur on organic soils than on mineral soils. A difference of 10°F between air temperatures over organic soils and surrounding mineral soils frequently occurs. Three factors are important causes of frost occurrence: 1) rapid loss of heat from the soil surface by radiation, 2) poor conduction, and 3) the settling of cold air in low lying areas.

Under climatic conditions existing in the vicinity of East Lansing, Michigan, frosts may occur any month of the year. A temperature of 18°F at the surface of the soil was recorded at the Michigan State University Muck Experimental Farm in late June. Frost damage is most likely on cool, clear nights with low humidity when conditions are most favorable for heat loss by radiation.

Methods of Control

Frost hazards may be reduced by 1) irrigation, 2) mechanical stirring of the air, 3) presence of a body of water, 4) improvement of air drainage, 5) heavy fertilization with potash, 6) sanding or claying, 7) close spacing of crops, 8) selection of frost-hardy crops, and 9) cultural methods.

1. **Irrigation.** A dry surface acts as an insulator, reduces the rate of heat conductance and thus increases the frost hazard. Water applied either by overhead methods or sub-irrigation increases the rate of heat conductance and the total mass weight. When water freezes, the heat released amounts to over 33 million B.T.U. per acre inch of water. Sprinkling foliage with water further reduces frost damage because of this factor.

Unfortunately two or three successive nights of freezing temperatures often occur. Application of excess quantities of water by sprinklers can waterlog the soil and cause crop damage. Flooding with water is used as a frost control method in cranberry production. In this case, an effective water control system is necessary.

2. **Mechanical stirring of air.** Under conditions of high radiation and low wind velocity, the air temperature 20 feet above the soil is higher than at the surface. If this situation is present, stirring the air by mechanical means helps to

prevent frost by mixing air layers. Stirring the air can cause deposition of dew which may give sufficient protection to the crop to withstand temperature drops 2 to 3°F below freezing. Mechanical stirring of the air can be accomplished by power driven fans or helicopters.

3. **Presence of bodies of water.** Protection afforded by a lake, river, or pond makes it possible to grow many crops that would otherwise be severely damaged by frost if planted away from the area influenced by the water. This accounts for successful crop production in several areas located in a relatively cool temperature zone.

4. **Air drainage.** Good air drainage will help to reduce frost hazards. Avoid windbreaks or other barriers that are not needed. Cold air is heavier than warm air and tends to collect in low areas thus accentuating their frosty nature. Air drainage is of special significance in the selection of a location for blueberry production because of the serious reduction in yield from frost injury to the branches and fruit buds.

5. **Heavy fertilization.** Heavy applications of potash reduce frost hazards to crops. This effect is more noticeable in fall than in the spring. From a practical point of view, however, it is not recommended that plants be overfertilized with potassium to prevent frost damage.

6. **Sanding or claying.** Applying sand or clay over the soil surface reduces the danger of frost. However, high costs limit this practice for general use in the United States.

7. **Close spacing of crops.** A decrease in frost hazard accompanies closer spacing of crops. This effect is particularly noticeable in fields of potatoes and corn. However, spacings inconsistent with optimum yields for the purpose of reducing the danger of frost are not recommended.

8. **Selection of frost hardy crops.** The selection of frost tolerant crops is one of the most practical means to prevent losses from frost. Susceptible crops, such as corn and potatoes, should be early maturing varieties. These crops should be planted early even at risk of spring frost. Crops shown in Table 19 are classified according to their tolerance to freezing temperatures.

Table 19. Degree of frost tolerance by crops commonly grown in Michigan (43).

Hardy	Medium Hardy	Fairly Susceptible	Easily Dam'g.
Canary grass	Barley	Asparagus	Bean
Parsnip	Cabbage	Blueberry	Cucumber
Rutabagas	Carrot	Corn	Pepper
Rye	Cauliflower	Lettuce	Squash
Salsify	Celery	Parsley	Strawberry fruit
Spinach	Clover	Peppermint	Sudan grass
Timothy	Oats	Potato	Soybean
Turnip	Onion	Radish	
Brome grass	Pea	Spearmint	
	Sugar beet		
	Table beet		
	Wheat		

9. **Cultural methods.** Loose, dry soils are more subject to frost than moist soils. Practices that will reduce frost damage are: 1) roll or cultipack, especially if the soil is peaty in texture; 2) fall plow rather than spring plow; 3) use herbicides instead of cultivations to control weeds; 4) minimum tillage after adequate compaction; 5) refrain from plowing up too much peaty subsoil; 6) do not till when weather conditions appear favorable for frost and 7) cover plants such as mint and potatoes with soil during the period of frost danger with disk hillers mounted on tractors. The soil is later removed by a light drag or by workers using leaf rakes.

PLANT BURNOFF

Because muck soils are black in color and poor conductors of heat, the surface can become too hot for small plants. The damage often called burnoff can occur when air temperatures exceed 86°F (30°C), the humidity is low, the sunlight is intense and the soil is loose and finely divided.

The best cultural program to help prevent burnoff is to keep the soil moist and firm. Do not let close spaced grain windbreaks become too high as they hinder air circulation (Figure 32). Over tillage causes a fine surface mulch which can increase burnoff. The seeding equipment illustrated in Figure 38 makes a firm, raised seedbed which aids in capillary moisture movement and good air circulation. One should be prepared to sprinkle irrigate when soil and weather conditions appear unfavorable.

Experimental field tests were carried out by the writer to see if white colored, four-inch strips over the seed row could help prevent burnoff. The products tested were spray grade lime, white quartz sand and gypsum. Although not too conclusive, the treatment did appear to reduce burnoff. Following a light rain, the gypsum treatment was the only one which maintained the white colored strip.

Figure 32. Burn off of onion seedling in front of small grain was severe. Better air movement saved onions on the opposite side.

WIND EROSION CONTROL

Severe losses can result from wind damage. In addition to the soil loss and resultant lowering of elevation, many crops are either totally destroyed or seriously injured during the early part of the growing season. Losses of one inch of soil and complete filling in of a drainage ditch from one storm have been observed. Fields left smooth after floating or light harrowing are especially prone to wind erosion. The great loss of soil is partially responsible for the "Nomad" type of farming in several of the organic soil areas (Figures 33, 34).

Injury to the growing crop may result from soil removal by exposing the seeds or roots; or from the abrasive action of the soil particles on the young plants. It is nearly impossible to completely prevent wind erosion on organic soils during severe wind storms.

Methods of Control

The following practices can be used to reduce wind erosion losses and damage to crops (163):

1. **Using irrigation water to keep soil moist.** Moist soils are not easily blown. Apply water from solid set systems before the surface soil dries and before the wind blows. Other systems are not well suited for this purpose.

Some producers regularly monitor the National Oceanic and Atmospheric Administration (NOAA) weather radio and when wind velocities are predicted to exceed 15 miles per hour, solid set irrigation systems are activated.

2. **Regulating water table height.** The ideal water control system on organic soil permits a progressive and controlled lowering of the water table in the growing season. Maintain a high water table until just before spring field operations. Where possible, lower water tables in the same sequence that fields are worked.

3. **Tree windbreaks.** This long-time wind control method has not been used extensively in recent years. Hardy evergreen trees on farm boundaries provide maximum year-round protection while the deciduous trees lose some effectiveness in the fall after their leaves drop.

Windbreaks should generally be two rows planted at right angles to the prevailing winds. Protecting from wind is effective over an area about ten times the tree height. Exercise care in choosing a species because some trees are better suited than others on specific soils. Also, roots can clog drainage tiles if the wrong species is planted.

While trees effectively reduce wind erosion, some vegetable producers report that in calm weather, especially with irrigation, they increase crop disease problems because vegetation dries slower. Also, with reduced air movement, frost and burnoff hazards increase when the soil surface is dry.

4. **Shrub windbreaks.** Using shrubs, such as spirea, instead of trees is appealing to some vegetable producers because they need less land surface. The protected areas are not as wide and more windbreaks are required.

5. **Small grains.** Small grains are planted in single or double rows and sometimes in drill widths (Figures 35, 36). Spring-planted small grains are much less effective than fall-planted. Some farmers have made special cutting devices to retard growth and cultivators to destroy the grain rows once the danger of wind erosion passes.

On some farms, the entire field is planted to rye and strips are left when plowing in the spring. The width of the strip for vegetable production is carefully measured to accommodate tillage, planting and harvesting equipment. Rye strips should be seven or more feet wide, while the cultivated strips vary depending on the wind erodibility. Most soils require widths less than 70 feet.

Where rye is left for seed, match the width of the strip with the width of the combine cutterbar. Some farmers use strips of fall planted rye and single rows of spring-seeded small grain between each vegetable row. This is relatively effective when used in combination with other soil conservation practices.

6. **Long, narrow fields perpendicular to prevailing winds.** Use this method in conjunction with other conservation practices. It is not a perfect solution because on occasion the wind blows at 90° from the direction of prevailing winds. In addition, tillage, planting and harvest directions in long, narrow fields are regulated by field shape.

Figure 33. A sandy muck left smooth is vulnerable to serious wind erosion. Corrective measures need to be adopted.

Figure 34. Wind blown soil can cause a number of adverse effects–one is the filling in of drainage ditches.

Figure 35. Small grain plantings in fall or early spring before drilling the vegetable crop can reduce the wind erosion hazard.

Figure 36. Preemergence band spraying over mint row allowed oats on left to grow. Shortly the mint plants will have sufficient size to ward off wind erosion of the soil.

7. **Tillage directions at right angles to prevailing winds.** Most tillage implements create ridges which, when the wind blows at right angles, reduce soil movement by **saltation** (a movement where soil particles bounce one or two feet into the air and then back to hit the soil's surface) and by **surface creep**. This method is relatively ineffective when the wind blows at high velocities for extended periods.

8. **Ridging.** Ridging is an important consideration since fields with a smooth surface are easily eroded. Maximum protection occurs when the surface soil is ridged with tillage, planting and cultivating equipment perpendicular to prevailing winds. Ridges are easily leveled off by wind and are effective for only short periods unless they are rebuilt.

Seedbeds that are about three feet wide with seven-inch trenches are helpful for both wind erosion and excess water. These beds are formed during seeding and then lightly watered (Figures 37, 38).

9. **Strip-cropping perpendicular to prevailing winds.** Alternate strips of equal width of vegetable crops with small grains or corn. Maximum width is determined by kind of crop and size of tillage, planting and harvesting equipment.

10. **Primary tillage immediately before planting.** The best moisture level for tillage is also the best for planting; so ideally, tillage and planting should be done in the same operation or on the same day. Organic soils dry rapidly after tillage and erosion potentials increase.

11. **Spring minimum tillage methods.** Minimum tillage is the least tillage necessary for rapid seed germination, a good stand and high yields. Where root crops are grown on organic soils, the definition is expanded to include the production of well-shaped roots. Minimum tillage is important on organic soils containing relatively large amounts of mineral materials, especially marl. The larger the soil aggregate, the more it weighs and the less likely it will be moved by the wind. Residues from previous crops are effective if present in sufficient quantity.

12. **No-till methods.** No-till planting in a full stand of fall-planted rye represents a theoretically wind-proof environment. Unfortunately, details of planter design and approved herbicides have not been worked out. Methods for obtaining rapid seed germination, uniform stands and root shape and sizes need to be researched. Uniform planting depth of small-seeded crops and adequate seed-soil contact, even where rotary strip tillage was used, have been difficult to obtain. Nevertheless, this method of wind erosion control looks promising and may be used extensively for many crops.

13. **Single sweep shovel on cultivator.** A single sweep shovel produces excellent weed control between the rows while producing relatively large soil aggregates not easily moved by wind. In addition, small ridges form to effectively reduce wind action.

14. **Fall-planted cover crops.** Fall planted cover crops protect the soil during the critical winter and spring months. Rye, ryegrass, wheat, oats, barley and buckwheat have all been effective, providing that good fall growth is obtained. For crops that freeze during the winter, such as oats, residues retard soil drying in the spring by reducing evaporation rates. Incorporating cover crops into organic soil increases the fiber content and reduces wind erosion losses. Both cover and green manure crops improve aeration and soil structure when incorporated into older, finely divided organic soils. This is important in root crop production.

15. **Snow fences.** After planting a crop, some producers still use snow fences to protect the soil. These effectively reduce wind velocities, but labor and material are expensive. In the past when fields were small, crates and burlap fences set in the field served as similar control methods.

Figure 37. Combination ridger and seeder often used in lettuce production. See Figure 38 for a large commercial unit.

PLOWING

Organic soils are generally loose and open and require less power to plow than a similar volume of mineral soil. Muck can be too loose, especially if dry. Under such conditions it will push rather than make a partial inversion pattern. Wet sticky soils will cause problems when using certain moldboard plows. The angle of the moldboard and the finish of the steel can affect scouring. Some farmers obtain better results using a slatted moldboard which increases soil pressure on the steel surface. Teflon covered moldboard has also been used with limited success.

Trashy fields with corn stalks or straw can be a problem. Plowing deeper and using bigger plows–18 inches or larger–will be helpful. Chopping and rolling the trash a few days before plowing is advisable.

Some farmers have plowed to a depth of 20 to 30 inches to bury weed seeds, problem soils and soil borne diseases such as verticillium wilt and onion smut. Generally, the disadvantages of the practice outweigh the benefits because of excessive costs, the possibility of turning up sticky aquatic muck, roots, marl, sands; and possibly damaging the drainage system.

In Europe deep plowing is practiced to extend the productive period of shallow Histosols. Usually the soil is turned on its edge rather than making a complete inversion. Such soils then have the characteristics of a peaty sand, or sandy muck or other designation depending upon the subsoil texture.

English researchers (29) have been testing a three prong tool bar on a tractor which was capable of working the soil to a depth of 50 inches. Each prong had a 45° angle and a blade tapering from 18 inches wide at the bottom to 12 inches wide at the top. These blades enabled the subsoil to be scooped up and then to gradually spill off as the subsoil worked its way to the surface.

CULTIVATION

An organic soil is cultivated for three reasons 1) weed control, 2) drying out wet soils, and 3) improving aeration of the soil with resultant increase in nitrate formation. If the soil is in a waterlogged condition, the use of a hook-type cultivator will loosen and aerate the soil and improve plant-growth.

Several types of cultivating equipment are used, varying from the sweep-type shovels to the rotary-type knives protected by hoods. Rotary hoes, finger weeders or rubber tooth drags will control small weeds in potatoes, mint, corn and similar crops. The weeder can be used in a potato field when the plants are 12 to 14 inches high if the tractor speed is reduced so injury to the plants is minimized.

Root pruning caused by deep cultivation should generally be avoided. However, if it is necessary to aerate the soil after a heavy rain, the sacrifice of a few roots may be overcome by the advantage gained by the deep cultivation. It is impossible to give any strict procedure to follow and a good grower will recognize the needs of his particular crop and cultivate accordingly.

GREEN MANURE AND COVER CROPS

Green manure and cover crops are important for many reasons:

1. Reduce leaching of residual plant nutrients and, when incorporated into the soil, release plant nutrients for subsequent crop utilization.
2. Prevent soil loss by wind erosion.
3. Improve soil structure of the older, finely decomposed muck soils.
4. Act as a partial weed control measure after a crop has been harvested.

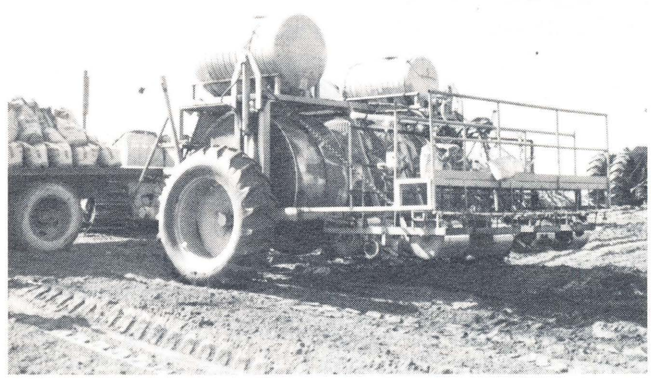


Figure 38. A combination 4 bed ridger, fertilizer placement applicator, lettuce drill and herbicide applicator. The fertilizer is applied ahead of the roller in 3 to 5 inch bands either as liquid or dry material. Furrow openers spaced three feet apart are in front of the roller to help divide the beds. The wedges on the rollers help press and form the beds. Such land preparation leaves a firm seed bed, reduces wind erosion and plant burn off and reduces bottom rot disease in lettuce. Equipment developed by Harold Gatzke of Wisconsin and now used by many lettuce growers.

The most important value of green manure crops on newly developed soil is wind erosion control. The preferred stage of maturity to incorporate the cover crop into the soil depends somewhat on the length of time the land has been farmed. For the older areas, it may be advantageous to plow under more mature materials for a longer lasting effect on soil aeration.

The opinion is sometimes expressed that a green manure crop on recently developed soils hastens decomposition of the soil and thus increases the rate of subsidence. Studies from Ohio, however, indicate that green organic matter added to organic soil increases the amount of residual carbon (184).

Winter rye is an excellent green manure crop for the Lake States. The seed is inexpensive, can be seeded late in the fall and is winter-hardy. Other suitable cover crops are oats, barley, sorghums, Sudan grass and soybeans. Corn, planted thickly in seven-inch rows after early harvested crops, is a popular cover crop with some growers. Florida growers sometimes plant a flooded cover crop such as rice.

PLANT NUTRIENT REQUIREMENTS OF CROPS

Organic soils, especially in their native state, are quite deficient in several essential plant-nutrients. As the organic matter accumulated, it resulted in a marked dilution of the mineral nutrients. The deficiencies are particularly high for raised bogs which depend upon fall-out from air-borne sediments and rainwater. Data reported in Table 8 illustrates some typical mineral compositions. The need for plant-nutrients, commonly called fertilizers, involves the interaction of a number of factors. For each particular situation, these factors need to be appraised.

Nitrogen (N)

Organic soils range from less than 0.5 to over 3.5% total N. It exists largely as a constituent of the organic matter—see page 11. Following decomposition by soil microorganisms, nitrogen is released in inorganic forms. The final state for aerated soils is nitrate—N $(NO_3)^-$, but the ammonium ion $(NH_4)^+$ is an intermediate product which can be used by plants. The ammonium N is preferred by certain acid tolerant plants such as blueberries and by plants that grow naturally in waterlogged soils.

The total N content, temperature, moisture, aeration and extreme acidity affect the activity of soil organisms resulting in a variable supply of available N. The carbon-nitrogen ratio (C/N) of the soil is an important variable in the available N supply. Sphagnum-dominated organic soils have a C/N of about 55, reed-sedge 25, Everglades muck 18 and well-humified low ash mucks about 15. Since the C/N ratio in bacteria ranges from 8 to 12, organic soils with broad C/N ratios are not likely to accumulate inorganic N. Puustjarvi of Finland (156) found that even after three years of cropping in the greenhouse, sphagnum peats rarely exceeded 1.0% total N.

Effects of temperature and aeration upon N release were discussed previously on page 22. Because cool temperatures retard nitrification, winter vegetables grown in Southern Florida often need supplemental N fertilizer even though the soil contains about 3% N. For the same reason, many crops grown in the Great Lakes area and Canada need N fertilizer in the spring months but seldom in July and August.

Water table levels modify the amount of N released because it affects the root zone, aeration and soil temperature. Trials in Indiana showed a great need of N fertilizer when the water table was maintained at 16 to 20 inches but little or none was needed when the level was below 32 inches (Table 20).

Acidity affects the N release but only when lime is needed. Two factors—less nitrification and poor root development—account for the need. Canadian studies (146), however, point out that liming acid soils only increased the available N supply 7 to 10 lb/A/year.

Excessive rains can result in N deficiency. This situation was noted in South Florida in October 1979 on vegetables following 18 inches of rainfall in September. Periods of soggy soil conditions bring on rapid denitrification of the available N and cause extensive loss of roots, so supplemental N fertilizer is usually needed to help in the recovery of plant growth.

At times, excessive amounts of N are produced and can stimulate vegetative growth at the expense of tuber and root development; such as in potatoes and sugar beets. This can result in reduced yields and low starch content. Some crops such as beet roots, celery, radish and spinach can accumulate fairly high levels of nitrate—N, but levels in vegetables for the fresh market in 1970 were not much different from 1907 reports (128). Minotti (138) reports that, for table beets, high available N levels produce an undesirably high amount of glutamine at the expense of sugar. Dry, hot weather conditions which retard plant growth can result in excess nitrates in plant tissue.

Production of nitrate-N in the Everglades muck is substantial under certain conditions. The problem of nitrate accumulation in certain forages during cloudy winter days has been the concern of cattlemen since it can result in the death of animals. Ryegrass and oats were found to accumulate quantities greater than 4% nitrate-N on a dry weight basis (102, 106).

Table 20. Average percent increase in yield to sidedressing nitrogen at different water table levels.

Crop	Year in Test	Water Table Level		
		16 inch	24 inch	32 inch
		% Yield Increase		
Corn	7	43	6	2
Potatoes	4	67	9	4
Onions	5	23	3	2
Peppermint	5	10	6	3

Data by Harris et al (83).

On some of the organic soils of Central Wisconsin cows will abort when turned out on weedy, native pastures in late spring or early summer (105). Stinging nettles, elder berry, boneset, goldenrod and ragweed seem to be the chief offenders. The nitrates are changed to nitrites in the cow's stomach which changes the hemoglobin of the blood to methemoglobin. This causes a lack of oxygen and the fetus will die. If large quantities of nitrates are eaten the cow may die.

No definite recommendation as to time or rate of N application will fit all conditions. From 0 to 200 pounds of N per acre may be required during a cropping season. Because of loss, fall application of nitrogen fertilizers—including anhydrous ammonia—is not recommended for the following spring or summer crops. Experiences at the Michigan State University Muck Experimental Farm, which is a well drained Houghton muck, indicate that most early planted crops respond to 50 pounds of N per acre applied in the spring. The degree of response varies with the season. However, in no case has a reduction in yield of any crop been noted from the use of this amount of N.

Some crops such as onions, celery, head lettuce and corn tolerate high levels of available N. Where needed, early application of N-fertilizer can hasten maturity of onions. Harmer (80) found that in field trials in 1925-26, onions receiving no N fertilizer showed 13% immature onions but those receiving 50 lb N/A averaged 4.4% immature onions.

Unpublished field trials by the writer during the 1947-51 period in Indiana showed that onions often needed 150 lb N/A for early uniform maturity. Storage trials on bulbs receiving up to 300 lb of N/A showed no adverse effect on quality. Trials at the Michigan Muck Experimental Farm during the 1953-56 period showed little yield increase from N fertilizer in 1953 and 1954. However, in 1955 and 1956, 100 pounds of N per acre increased yields an average of 67 cwt/acre (243 vs 310 cwt/A).

Regardless of the yield differences, the application of nitrogen before June 1 matured the bulbs earlier and evener. Extension publications by Indiana, New York and Michigan all recommend 100 to 150 pounds of N/A. Such rates do not support the report (161) that nitrates in the soil depresses the yield of northern grown onions. Excess nitrates, however, can result in a salinity problem which will reduce yields.

Data in Table 21 illustrate the mobility and the amount of residual nitrogen after three years of cropping.

Phosphorus (P)

Virgin Histosols contain from 0.01 to over 0.3% P. Crops growing in those soils low in ash and over 0.2% are not likely to respond to P fertilizer. However, most organic soils contain less than 0.1% P and need P fertilizer for good crop production. From 30 to 85% of the total P in virgin organic soils is in the organic form (198) and has to be mineralized before it can be utilized by plants.

Three forms of organic P (phospholipids, nucleic acid and inositol phosphates) have been suggested as the major components of organic soils (217). Upon addition of mineral P fertilizers and a buildup of soil minerals because of organic matter decay the total P content becomes a poor indicator of available P.

Data in Table 22 illustrates the response of crops to P and K fertilizer on plots that had received the same treatment for ten years.

Table 21. A - Residual NO_3-N soil tests for a Houghton Muck sampled at various depths in mid-May 1971 after fertilization and growing head lettuce and spinach in 1969 and 1970.
B - N soil tests for the same "A" plots in mid-July after fertilizing in mid-May and growing a crop of spinach (Mich. State Univ. Exp. Farm, 1971).

N(a) applied	Soil Depth (Inches) 0 - 6	6 - 12	12 - 18	18 - 24	Total
lb/acre	Lb NO_3 - N/A (Residual)				
A					
0	16	13	11	10	50
80	20	17	15	14	66
160	26	24	24	20	94
320	24	24	21	20	89
B	Mid-July tests after cropping				
0	43	26	16	15	100
80	71	37	24	17	149
160	138	68	45	40	291
320	168	98	58	55	379

(a)NH_4NO_3 fertilizer applied annually 1969-1971.

Table 22. Effect of phosphate-potash fertilizer on yield of crops grown on Houghton muck. (Mich. Muck Expt. Farm). (43).

P_2O_5 - K_2O Lbs/A	Crop: Corn Bu/A	Soybeans Bu/A	Snap beans Cwt/A	Sugarbeets Tons/A	Peppermint Oil Lbs/A
0 - 0	11	13	16	3.6	11.0
100 - 50	96	29	158	12.1	29.5
50 - 50	98	31	157	11.3	23.5
50 - 100	105	32	170	15.6	27.1
50 - 150	107	32	176	18.4	26.2
0 - 150	77	23	14	16.3	11.0
100 - 0	12	10	61	3.3	11.1
Years in test	(4)	(6)	(1)	(2)	(5)
	Potatoes Bu/A	**Carrots Ton/A**	**Cucumbers Cwt/A**	**Sugarbeets Tons/A**	**Cabbage Tons/A**
0 - 0	89	10.7	33	5.2	1.1
200 - 100	376	24.1	457	18.3	24.1
100 - 100	391	24.3	437	18.1	22.4
100 - 200	459	26.7	516	21.3	24.1
100 - 300	482	27.1	583	23.2	24.4
200 - 0	88	9.0	157	6.4	1.3
0 - 300	299	20.7	95	9.7	2.5
Years in test	(7)	(5)	(1)	(2)	(4)

Table 23. The effect of liming an acid organic soil on the yield and phosphorus content of Sudan grass and the percent of phosphorus derived from fertilizer.(a)

Tons lime per acre	Soil pH	Yield Grams per pot 0	Yield 50 lb P_2O_5/A	Yield 200 lb P_2O_5/A	Percent phosphorus in plant 0	50 lb P_2O_5/A	200 lb P_2O_5/A	Percent Phosphorus derived from fertilizer 50 lb	200 lb
0	4.4	11.0	9.6	12.9	0.21	0.27	0.48	48.2	88.5
1½	4.9	13.1	13.1	13.2	0.21	0.26	0.42	38.5	89.3
3	5.3	9.8	13.5	15.7	0.22	0.22	0.39	36.4	83.4
6	5.8	9.1	11.1	12.8	0.26	0.26	0.36	35.0	79.2
9	6.4	11.3	11.2	12.5	0.21	0.21	0.31	26.2	76.8
12	6.8	9.2	10.6	11.7	0.19	0.19	0.25	28.9	64.0
16	7.2	8.3	10.3	12.5	0.13	0.13	0.27	30.8	57.4

(a)Plants sampled four weeks after seeding. Data from Lawton and Davis (114).

Sorption and Fixation of P

Phosphorus fertilizer applied to the soil changes rapidly into many different compounds of low to extremely low solubility. This loss of solubility is often called fixation. Many of the same chemical reactions which occur in mineral soils also take place in organic soils. The degree of reaction for Histosols, however, is quite variable and is related to the Fe, Al, Ca contents and the kind and amount of inorganic soils. Low ash, oligotrophic organic soils have essentially no P sorption and fixation. Using tracer technics, Lawton and Davis (114) found liming depressed the recovery of P for a Rifle peat (Table 23).

The effect of pH levels on leachable P is illustrated in Figure 39 for an Okeechobee muck (Florida) low in Fe and Al (121). The maximum P concentration of the leachate at pH 4.9 was 30 ppm but at pH 7.0 the concentration was 10 ppm. A similar test on a Pahokee muck that contained about ten times more Fe and Al showed less than 2.8 ppm P in the leachate at pH 6.2. This Pahokee muck was typical on the land under cultivation for over 20 years.

Because the sesquioxides (Fe and Al) and the inorganic soil fraction increase with long tillage, they greatly reduce the P solubility and mobility. Studies in Indiana showed that a low ash virgin muck at pH 5.0 adsorbed less than 0.2 mg P/g of soil, but one that was drained and farmed for over 15 years absorbed 16 mg P (113). Shickluna et al (172) using ^{32}P leached water through 30 cm columns of Houghton muck obtained 24,000 counts per minute for a virgin soil, 2,200 counts for a soil that had been fertilized and cultivated three years, and only 900 counts for a soil well fertilized and cultivated for 25 years.

Time is an important factor in the degree of P fixation. The data in Table 24 are typical for soil test changes. Note that tests from treated areas were decreased about one-half over the untreated when the 30 day and the 210 day samplings are compared. The data in this table also shows little mobility of P into the 15 to 30 cm depth. Similar chemical changes with time have been reported for mineral soils (88) because of the formation of less soluble Ca, Fe, and Al compounds.

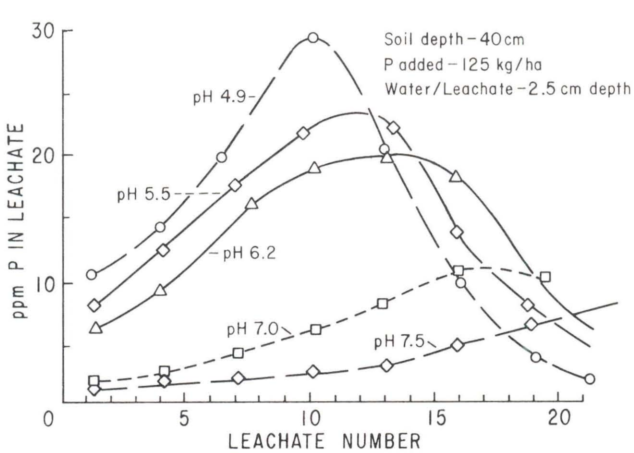


Figure 39. The effect of pH levels on the leachable P obtained from an Okeechobee muck.

Table 24. Phosphorus soil test 30 and 210 days after surface application of triple superphosphate to fallow Pahokee Muck (121).

Depth inches	Sample period	P Treatment Lb/A 0	150	300
	Site A - pH 6.0 (not flooded) Water soluble P lb/A (a)			
0 - 2	30(b)	4	19	36
	210(c)	5	9	14
2 - 6	30	4	4	6
	210	5	9	15
6 - 12	30	4	4	4
	210	5	5	6
	Site B - pH 7.2 (flooded 50th to 90th day)			
0 - 2	30	2	15	29
	210	6	12	17
2 - 6	30	3	4	4
	210	7	9	11
6 - 12	30	4	5	4
	210	8	8	9

(a)Water soluble P in 1-25 soil-water extract. (2.0 g air dried soil plus 50 ml water).
(b)Total rainfall - 6.8 inches
(c)Total rainfall - 48 inches

Where organic soils contain substantial amounts of inorganic clays and sesquioxides, the availability and the properties of P are similar to inorganic soils. It has been shown that P moves to the plant roots by diffusion (11,117). In culture solution studies, P as low as 0.03 ppm was found to be adequate for some plants if continuously supplied (8). Highly responsive crops such as head lettuce may require levels of about 0.3 ppm P (143).

Such seemingly low levels are only possible when the soil contains adequate amounts of highly buffered products to maintain the soil solution P. Acid organic soil, low in ash and sesquioxides, have very low capacity to adsorb P and require high concentrations of soil solution P to compensate for the low levels of buffered P compounds (63, 64).

The writer compared the P in saturated extracts of Everglade mucks with the 1 to 25 soil-water procedures used by the Belle Glade Laboratory (61). The content of P for both extracts was found to be similar for nearly neutral and alkaline soils. However, as the soil acidity increased, the P in the saturated extracts increased appreciably.

For good plant growth the P content in saturated organic soil extracts needed to be about ten times higher than the levels suggested by Nishimoto and associates (143) for mineral soils. When the organic soil was below pH 5.5 and low in ash, the P concentration in saturated soil extracts had to be even higher to obtain nearly maximum crop yield.

Daughtrey and associates (38, 39) at North Carolina showed that soil solution P values proposed for mineral soils are not adequate for organic soils. They report that some organic soils gave as much as 20 lb. of P per acre in the first extraction using 0.01 $\underline{M}$ $CaCl_2$ but were found to be poor suppliers of P for crop production. It was also shown that the amounts of P released by inorganic soils high in organic matter are quite small but tend to increase with successive water extractions. By the twelfth extraction the values for both the organic and inorganic soils were nearly the same.

Because organic soils differ greatly in adsorption and fixation of P, these chemical properties have to be considered when interpreting soil test results, when using organic soil for waste disposal sites and when using peats for various horticultural soil mixes.

Potassium (K)

Potassium is the nutrient most needed for crop production on organic soils. Plant requirements range from less than 100 lb/A for low biomass crops such as radish to about 500 pounds for high tonnage crops such as celery and sugar cane.

Potassium is required for a number of physiological processes. If K stress occurs the plants exhibit reduced activity for a number of enzymes, an accumulation of amino acids and soluble carbohydrates, reduced oxidative phosphorylation and retarded utilization of respiratory substances. A deficiency can affect crop yields, quality, color, strength of stalk, disease resistance and tolerance to cold and drought stress.

Plants deficient in K exhibit some rather distinct symptoms. These first appear on the margin of older mature leaves as an interveinal chlorosis. The chlorosis changes from light yellow to brown in color, the plant cells then die and leaf edges turn ragged.

Soil Potassium

The total K content in mineral soils usually ranges from 0.5 to 2.0%. The range in organic soils is about one-tenth that found in mineral soils. When calculated on a volume basis, the K is often less than 500 lb/6 inch acre for organic soils as compared to about 30,000 pounds in a loam soil. This low value on organic soils accounts for the need for large quantities of K fertilizer for crops. Typical crop responses are shown in Table 22. Other properties of K noted in organic soils are:

A. Potassium in organic matter does not revert to non-exchangeable forms but can revert in most mineral soils. Thus, for any given soil test level, mineral soils are more buffered against K change because of crop removal.

B. Even though organic soils have high cation exchange capacity values, they weakly hold the monovalent cations such as K^+, Na^+ and NH_4^+. This was shown by Baligar and associates (10) who compared the percentages of the cations in the soil solution with those on the exchange sites. For a Pahokee muck the soil solution values were 35% Na, 14% K, 25% Ca and 21% Mg. The exchange sites, however, showed 4% Na, 2% K, 69% Ca and 24% Mg. It was calculated that about 22% of the total available K was in the soil solution (at saturation) for both fertilized and unfertilized mucks.

In a laboratory study, bentonite clays were found to hold exchangeable K about twice as tenaciously as organic colloids (99). Corn growing for a limited period recovered 67% of the K from a peat soil and only 47% from the bentonite where both soils had the same amount of available K.

C. Although the K in organic soils is held less firmly than in mineral clays, more is needed for crop production. Several factors possibly account for this need. One reason is higher K levels are needed to counter balance the high amounts of exchangeable Ca and Mg. The second factor is the low buffer properties of K in organic soils compared to mineral soil. Potassium, like phosphorus, moves to plant roots by diffusion (11). This mechanism appears to be more efficient in mineral soils. A third factor is that in routine soil testing the volume measure contains more dry soil than a similar volume under field conditions. This difference is due to shrinkage upon drying.

The writer compared the amount of K found in the saturated soil extract with the total extractable K using $\underline{N}$ ammonium acetate. When field conditions had been fairly dry, the available K found in the saturated extract ranged from 15 to 21% of the ammonium acetate amounts. However, when tests were made on soil samples collected following leaching rains, the saturated soil solution K ranged only from 5 to 9% of the total available K. A similar comparison for loam soils normally shows less than 3% of available K in the saturated extract.

A number of leaching and mobility studies have been made on organic soils. Because of the weak bonding of K to the exchange sites, leaching is greater than in most mineral soils. Summer flooding is a common practice on vegetable lands in Florida. Data in Table 25 illustrate the mobility of K with and without flooding. Mobility was slight without flooding but flooding caused high mobility into the 6 to 24 inch depth.

Mobility can be marked for organic soils in the Lake States area, especially when one compares fall soil sampling with spring sampling. In some years the loss is less than 10% and in others it can exceed 50%. Data in Table 26 illustrate the changes for the upper seven inches for some long time fertility plots located on the Michigan Muck Experimental Farm.

Note that the soil tests for plots receiving 50 and 125 lb K_2O/A tested similar to the check plot. The 250 and 500 lb K_2O treatment increased the soil tests and appeared to approach a steady-state value after three years of treatment. However, in 1969 the tests showed marked losses and reflected the effects of a very wet June in 1968 followed by above normal rainfall in early 1969.

Some soil testing agencies and fertilizer suppliers have advocated high soil tests such as 1,000 lb K/A because of the high soil exchange capacity for organic soils. The field trials conducted at the Ohio Experimental Farm, Celeryville, illustrate what high K rates might do to the yield of onions and to the yearly soil tests (Table 27).

In this experiment the onions were not responsive to K application. Rates above 578 lb K/A caused reduced yields. The similarity between the fall 1964 tests and the fall 1965 tests suggests a steady-state condition. It appears that K mobility is much greater when high rates of K are applied to soils that test high in K.

From a practical viewpoint, no attempt should be made to build up the K soil test and then expect it to remain high for several years in areas of high rainfall. Fertilizer recommendations based upon soil tests need to be modified to correct for leaching following heavy rainfall or flooding conditions.

Table 25. Potassium soil test 30 and 120 days after surface application of KCl to fallow Pahokee muck.

Depth inches	Sample period	K Treatment Lb/A 0	180	450
	Site A - Not flooded Soil Test K Lb/acre(a)			
0 - 6	30(b)	104	166	222
	120(c)	99	167	220
6 - 12	30	23	31	34
	120	30	38	48
12 - 18	30	5	6	5
	120	12	13	13
	Site B - flooded 50th to 90th day			
		0	270	540
0 - 6	30	45	129	282
	120	37	76	109
6 - 12	30	35	37	39
	120	37	85	156
12 - 18	30	30	30	34
	120	38	72	86
18 - 24	30	23	25	26
	120	40	57	91

(a)Extractable K - 10 cc of air dry soil in 25 ml of 0.5*N* acetic acid
(b)Total rainfall - 6.8 inches
(c)Total rainfall - 27 inches

Calcium (Ca) and Magnesium (Mg)

The behavior of Ca and Mg in organic soils is similar. Carbonates of both elements are considered as liming material. The average Ca content is about 2.0% in eutrophic Histosols and 0.3% in oligotrophic soils. The Mg content is about 0.30% and 0.06%, respectively. Calcium deficiency in crops is not likely to occur if the total Ca exceeds 0.5% regardless of soil pH. However, high levels of monovalent cations such as K, Na and/or NH_4 can induce Ca and Mg deficiency in celery and other plants (70, 96). Soils where available Mg exceeds Ca can also induce Ca deficiency in crops.

Allaway (1), in a study with soybeans, found that

Table 26. Yearly variability in soil tests for K(a) (0-7 inch depth).

Annual Treatment K_2O lb/A/yr	Potato 1964	Potato 1965	Year and Crop: Onions 1966	Carrots 1967	Head Lettuce 1968	Mint 1969
	K Soil Test - Lb/A					
0	55	54	65	49	64	45
50	60	62	82	77	52	43
125	64	85	98	81	103	47
250	124	176	247	214	208	109
500	224	336	640	565	660	263

(a)Trials started in 1963. Soil samples collected in April prior to annual K application. Trials on Houghton muck, Mich. State Univ. Muck Exp. Farm. All plots received 200 pounds of P_2O_5 per acre annually.

Table 27. The effect of potassium application on the yield of onions and on the soil tests.

Treatment lb K/A/yr	Onion Yield lb/plot 1964	1965	K Soil Tests - Lb/A Spring(a) 1964	Fall 1964	Spring(a) 1965	Fall 1965
0	557	589	244	297	214	294
168	558	658	323	500	392	506
528	565	576	494	1101	771	1088
986	541	538	633	1335	1192	1512
1155	486	480	690	1448	1385	1500

Data calculated from results reported in Mimeograph Series No. 321 (1966) Ohio Horticulture Department.
(a)Soils sampled prior to fertilizer application.

replaceable Ca from various colloids was in the order of peat>kaolinite>illite and bentonite. The divalent cations, however, are held tighter than the monovalent cations.

The Ca-Mg ratio is often compared to determine the boundary in raised bogs where the soil has risen above the influence of ground water and where it relies only on rainwater. Soils from the latter show narrow ratios. Some located near oceanic waters often show more Mg than Ca (127). Eutrophic organic soils have an average Ca-Mg ratio of about 6 to 1. Those that contain marl may exceed a 20 to 1 ratio if the totals are compared. Even with such wide ratios in marly soils, the writer has not observed Mg deficiency in field crops providing K levels were not excessive.

Van Lierop et al (195), in a greenhouse study with onions, were not able to obtain an upper critical Ca/Mg ratio when the extractable soil nutrient ratio was as high as 16. Yields, however, decreased rapidly when the ratio was less than 0.5. In this study 1 g of soil was extracted with 30 ml of 0.05 N HC1 + 0.025 N H_2SO_4 solution. Trials by Grennan et al (74) showed the use of magnesium carbonate for an acid Rifle peat was not as effective as calcium carbonate for corn and beans but gave similar benefits for oats, barley and alfalfa.

Biochemical oxidation of organic soils changes the mineral composition of the plow area. Assuming no loss by leaching, Ca and Mg content should about double in the plow layer in ten years. Chemical tests do show an increase but soil pH values may change only slightly. This is because of a compensating factor—as peats humify, their cation exchange capacity value increases.

Sulfur (S)

Organic soils contain from low to over 3.0% S, which is mostly in the organic form. The eutrophic deposits average nearly 0.6% and oligotrophic soils about 0.1%. The edges of depressional deposits, the aquatic mucks and the marine deposits are particularly rich in sulfur. The organic soils in Ohio were found to range from 0.2 to 4.6% S (36). Florida Everglades Histosols show a range from 0.2 to 4.2% S (45).

Casagrande and Siefert (28) reported the total S for a marine mangrove located in Florida ranged from 2.0% S near the top to about 6.0% S at a depth of 12 feet. Organic soils from two fresh water sites in the Okefenokee swamp contained 0.18 and 0.19% S. The Houghton muck at the Michigan Muck Experimental Farm contains about 0.2% S in the top eight inch layer and 0.3% S in the subsoil.

Except possibly for some inland raised bogs, the S content of Histosols is more than adequate for crop production. The S in precipitation and in the air are also used by plants. Cressman (35) found that at the Michigan Muck Experimental Farm, precipitation added about 10 kg S/ha annually and atmospheric adsorption by plants was about 16 mg/100 cm^2. Peats used for potting soil may need supplemental S for plant production. Sulfate fertilizers are sometimes used rather than chlorides to reduce the soluble salt concentration.

When fields are firmed prior to or shortly after watering, moisture evaporation from the surface can leave visible amounts of white salts. These are chiefly sulfates such as $CaSO_4$. Fields treated with sulfur may show marked color effect (Figure 40).

Iron (Fe) and Aluminum (Al)

Histosols contain variable amounts of Fe and Al. Biochemical oxidation and fires can result in some rather high amounts. The Fe content averages about 1% for the

Figure 40. The light colored area on left side was treated with 1,000 pounds of sulfur per acre. The reaction of the sulfur with soil calcium formed calcium sulfate which is slowly mobile in soil moisture. The right side of the field showed less surface salt.

Great Lakes deposits and 0.7% for the Everglades. Cultivated organic soils at Celeryville, Ohio were found to average about 1.6% Fe in the upper ten inch layer and 1.4% for the ten to 30 inch depth. The Al contents were 1.1% and 0.9%, respectively (90).

Ample amounts of Fe are present in most deposits for crop production. Under reducing conditions (when soils are soggy) the available Fe content can be excessive and cause crop damage. Raised peats low in total Fe can show Fe deficiency in small grain, grasses and other crops (150). Under such conditions, the plants often contain excessive (toxic) levels of manganese.

Rice plants growing on some Everglades muck show severe Fe chlorosis (73, 221) before the crop is flooded. These soils usually contain less than 0.3% Fe. The affected rice becomes chlorotic and stunted in the seedling state. Such plants are often susceptible to injury from the herbicide propanil. Iron sulfate ($FeSO_4 \cdot 7H_2O$) drilled at the rate of 50 to 100 lbs/acre prevented the chlorosis and was a suitable product for metering through most grain drills. Farmers also noted that packed soil caused less chlorosis than loose soil. (Florida Extension mimeo).

Exchangeable Al is held less firmly on mineral exchange sites compared to organic exchange sites. This permits far higher amounts of Al in organic soil before toxic levels develop for plant growth. The hydrolyzed Al ion $AlOH^{2+}$ is more tightly bound to organic matter than the Al^{3+} (15). The lower solubility (activity) of Al ions in organic soils also accounts for less phosphorus fixation.

MICRONUTRIENTS AND OTHER ELEMENTS

The micronutrients which have been shown to be deficient in organic soils for plant growth are boron, copper, iron, manganese, molybdenum and zinc. Because soil reaction is an important factor in determining the available content, it is often used as an indirect measure of determining the nutrient status.

Micronutrients may be mixed with the fertilizer that supply the major elements (N-P-K). Many, however, are not suitable in liquid fertilizers because of flocculation and sedimentation. Micronutrients can be applied as foliar sprays but at lower rates than when applied to the soil. Seed treatments are also used when only trace amounts are needed.

Boron (B)

Boron deficiency may occur on both alkaline and acid organic soils. A deficiency causes a breakdown of the young growing tissue which retards growth and eventually destroys the cells. This causes the roots of some crops to crack, blacken, and become abnormally shaped. Boron deficiency is associated with "heart-rot" of sugar beets, "black spot" or "girdling" of table beet roots, "water core" in rutabagas and turnips, "cracked stem" in celery and internal breakdown of the stalk and head of cauliflower.

Boron deficiency is usually corrected by an application of borates. Small grains, beans, peas and soybeans require very small amounts and are easily injured from boron fertilization. Corn may respond to light applications of B, but it should not be banded near the seed. The amounts generally needed are reported in Table 28. Boron in the form of sodium borate can be applied as a foliar spray. Amounts suggested are 0.1 to 0.4 pound per acre of actual boron. Rates greater than one pound per acre proved toxic to celery and other crops.

Copper (Cu)

This element is usually deficient when virgin soils are brought into crop production (2, 3, 218). Sufficiency of Cu is fairly easy to predict by determining acid extractable or total soil Cu. The total soil Cu should exceed 20 ppm for most crops and 30 ppm for responsive crops (177). This amounts to about 10 to 15 lb/6-inch acre by volume. The Cu content of virgin acid Histosols ranges from two to 20 ppm. Naturally acid soils are usually much lower in Cu than the high lime Histosols. Two conditions that increase Cu levels in the soil are burning and organic matter decomposition.

Organic matter plays an important role in removing Cu from the soil solution. The carboxyl and phenolic groups found in soil humus are important functional groups for bonding Cu (86, 118, 129). A number of divalent cations were compared on their ability to release titratable H ions at pH 5.0 from humic acids (193). Except for Cu^{2+} and Pb^{2+}, there were only slight differences. The order of attraction for those tested were Cu>Pb>Zn>Ni>Co>Mn>Ca>Ba.

The need for Cu can be predicted, to an extent, by the Cu content of the foliage. Under deficient conditions the content for plants is usually less than 6 ppm (141). The deficiency in small grains causes marked yellowing of the plant, some leaf streaking, terminal leaves fail to unfold and the tips may die as if frosted. Some crops do not show any marked visual deficiency symptoms. Besides affecting yield, inadequate Cu causes pale skin color in onions, loss of color in grain and carrots, and low sugar content.

The differential response of plants to Cu is believed associated with the type of enzyme present in the plant. Wheat, for example, responds to Cu because of the ascorbic acid oxidase which requires Cu in order to function. The

Table 28. Boron recommendations for organic soils - elemental basis.

Crop Response	Pounds of Boron per acre	
	pH 5.0 - 6.4	pH 6.5 - 8.0
High	2	3
Medium	1	1.5
Low	0	0.5

relationship between Cu and Mo (molybdenum) content of forage is important in livestock feeding. Molybdenum is toxic when the Cu content is low and the Mo is higher than 3.0 ppm (109).

Copper deficiency can be corrected by a number of Cu bearing materials. Oxide and sulfate (Figure 41) are the two principal carriers now used for agricultural purposes. They are of equal value when compared on the basis of the Cu content (62, 97). Copper applied to organic soil is not easily leached, and removal by the crop is not much of a factor.

An application of about 10 pounds per acre should be made for low or medium response crops and 20 pounds for highly responsive crops. This amount of Cu can be applied in one broadcast application and will not cause injury to crops. Additional Cu may be needed if soil erosion is serious or the field is deeply plowed. In many instances the Cu level is ample because of repeated applications of fungicide sprays or dusts containing Cu.[4]

Manganese (Mn)

The availability of Mn is influenced by soil reactions more than any other plant nutrient. Total Mn content in organic soils is of little value in predicting the need for Mn fertilizers, because availability decreases above pH 5.5. Serious deficiency in many crops occurs at pH ranges of 6.3 to 7.3 (Figures 42, 43). Shickluna and Davis (171) showed that the Mn content of onion tops dropped from 1125 ppm to 44 ppm when the soil pH was raised from 4.1 to 5.6. For another peat the content dropped from 875 ppm to 25 ppm when the pH was raised from 4.9 to 7.0. Mn toxicity is often credited with causing poor growth in very acid soils, especially if fumigated.

Very acid peats which have been limed are more apt to produce Mn deficient crops than are organic soils having that pH naturally. Here, total Mn accounts for the differences. In raised Histosols the quantity may be about 0.001% Mn; in depressional soils it is about 0.02%.

Conditions that accentuate Mn deficiency in crops are:
1) Burned-over areas
2) Calcareous soils
3) Alkaline mineral oxides such as limonite
4) Low temperatures with high water tables
5) Dry weather conditions
6) Low light intensity or short light day

Manganese oxidizing microorganisms play an important roll in the amount of available Mn (116). Steam steriliza-

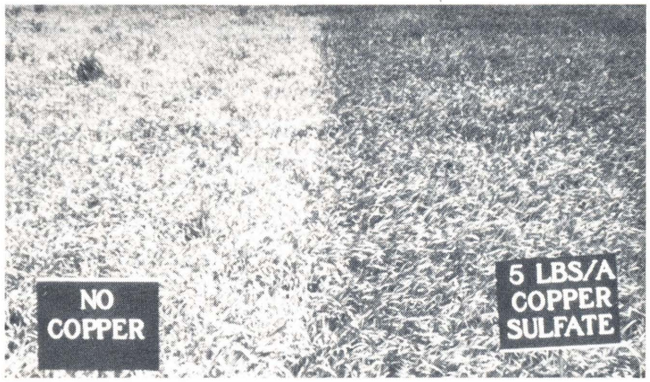


Figure 41. Effect of copper on growth of wheat. (Photo courtesy of G. W. Wallingford.)

Figure 42. Manganese deficiency on onions. The light colored rows did not have a row fertilizer containing Mn.

Figure 43. Sweet corn on right side were light colored and weak because of Mn deficiency. Plants on left were normal where the soil pH was below 6.0.

[4] Until the need for copper was apparent, it was a common view that fibrous peat was unproductive because of some excess soil toxin. Two independent field studies, however, found the problem was a lack of the essential plant nutrient copper—see publications in 1927 by Allison, Bryan and Hunter (3) in Florida and the research paper by Felix (218). Though these were the first research reports, farmers in the Everglades had already noted for over two decades the benefits of copper fungicides in plant growth. It had become the custom to first plant potatoes on virgin soil and to make certain Bordeaux fungicide was used. Corn, beans and other crops could then follow, but without the potato program the other crops were a failure.

The experience of Mr. Roscoe Braddock was particularly helpful to Dr. R. V. Allison and other Florida scientists. Braddock planted potatoes on Torrey Island in 1915. He treated the seed with copper sulfate to help control scab and other pathogens. The following crop was planted to beans but the rows were crosswise to the potato rows. Good bean growth occurred only in the position occupied earlier by the potato seed piece. Dr. Allison reported to this writer that Braddock did not receive proper recognition for his observations. Scientists also were cautious and slow to recognize the significance of the copper treatment.

tion or chemical fumigation to destroy these microorganisms can greatly increase available Mn (65) (Figure 44). Some reports suggest the maximum rate of oxidation is in the range of pH 6.5 to 7.0 (25).

Plant symptoms of Mn deficiency first appear in the new growth of leaves. For a number of crops the leaves show a mottled appearance. The leaf tissue between the veins becomes increasingly lighter green and finally yellow, with the veins remaining green. In extreme deficiency the plants are soft and have weak stems.

The crops listed in Table 29 are divided according to the degree of response to Mn. Such a listing has limitations because varieties of a given crop can show large differences in response. For example, in field experiments the Mandarin soybean yielded 16 bushels per acre without Mn and 37 bushels with Mn. However, Norchief soybeans yielded 31 bushels per acre and showed no response to added Mn.

Manganese deficiency can be corrected by applying Mn bearing materials or by the addition of sulfur to acidify the soil. Manganese materials are more effective and cheaper when immediate results are desired. Sulfur, however, is more economical when the effects are considered over a period of years. Because of large quantities and high costs,

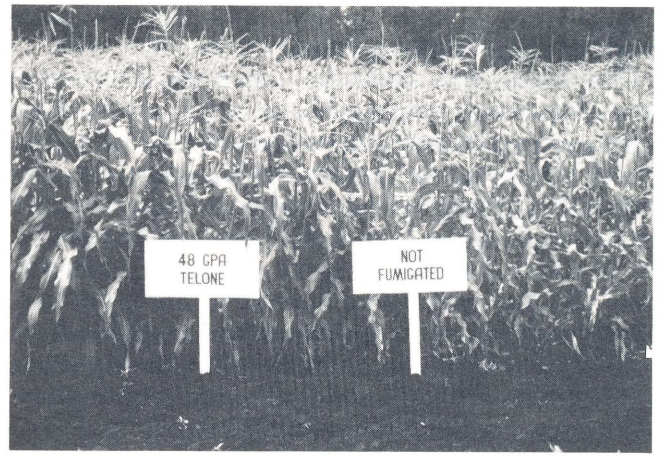


Figure 44. The beneficial effect of soil fumigation with Telone on sweet corn growing on a manganese deficient organic soil. Nematodes were not a problem.

Table 29. Relative response of selected crops to micronutrients(a).

Crop	Response to micronutrient				
	Mn	B	Cu	Zn	Mo
Alfalfa	medium	high	high	low	medium
Asparagus	low	low	low	low	low
Barley	medium	low	medium	medium	low
Beans	high	low	low	high	medium
Broccoli	medium	medium	medium		high
Cabbage	medium	medium	medium		medium
Carrots	medium	medium	medium	low	low
Cauliflower	medium	high	medium		high
Celery	medium	high	medium		low
Clover	medium	medium	medium	low	medium
Cucumbers	high	low	medium		
Corn	medium	low	medium	high	low
Grass (Ky. Blue)	medium	low	low	low	low
Lettuce	high	medium	high	medium	high
Oats	high	low	high	low	low
Onions	high	low	high	high	high
Parsnips	medium	medium	medium		
Peas	high	low	low	low	medium
Peppermint	medium	low	low	low	low
Potatoes	high	low	low	medium	low
Radishes	high	medium	medium		medium
Rice	medium	low	low	medium	low
Rye	low	low	low	low	low
Sorghum	high	low	medium	high	low
Spearmint	medium	low	low	low	low
Soybeans	high	low	low	medium	medium
Spinach	high	medium	high		high
Sudangrass	high	low	high	medium	low
Sugar beets	medium	high	medium	medium	medium
Sugar cane	medium	low	medium		
Sweet corn	high	medium	medium	high	low
Table beets	high	high	high	medium	high
Tomatoes	medium	medium	medium	medium	medium
Turnips	medium	high	medium		medium
Wheat	high	low	high	low	low

(a)The crops listed will respond as indicated to applications of the respective micronutrient when that micronutrient concentration is low.

sulfur is not advisable for soils containing considerable amounts of free calcium carbonate.

The Mn material commonly used is the sulfate form. Tests with broadcast applications of various carriers at the Michigan Muck Experimental Farm show that manganous oxide, if finely ground, is about 20% less effective than the sulfate form. However, band applications near the seed showed little differences between sulfate and oxide forms.

Soil applications of chelated Mn materials such as EDTA have not been satisfactory on organic soils (103, 166). Their use is believed to have resulted in a replacement of soil Fe for the Mn in the chelate. The Mn which was released from the EDTA was rapidly fixed in the soil and the result was to increase the available Fe level.

Manganese response may be obtained on some soils with a pH as low as 5.8. This is particularly noticeable for vegetables such as head lettuce and sweet corn growing in the winter and early spring in Florida. The amount of Mn suggested for crops as affected by pH is shown on Table 30. These recommendations assume part of the Mn fertilizer will be placed in bands near the seed at plant time. Fixation of Mn in the soil is greater when applied broadcast; thus, larger quantities may be needed than those suggested in Table 30.

Often farmers apply Mn with acid forming fertilizers in a band near the seed. The typical rate of 300-700 lb/A mixed fertilizer can markedly lower the soil pH around the band because of the acid properties of the fertilizer and the increase in the salt concentration. The poor growth of such crops as sugar beets, spinach, potatoes and onions at the ends of the rows can often be attributed to Mn deficiency even though no Mn was used in the band fertilizer.

Manganese can be applied as a foliar treatment at one to two lb/A of actual Mn or 0.2 lb Mn as Mn EDTA. Manzate D, a fungicide, can also be a good source of Mn (69). Several foliar applications may be required during the growing season to meet the plant requirements.

Molybdenum (Mo)

In contrast to the other micronutrients, Mo deficiency in crops is associated with soils that test below pH 5.5. This need occurs because of decreased solubility from reactions with Fe and Al. Other factors, however, may be involved because Mo deficiency has been observed in crops growing on acid sphagnum peats which are low in Fe and Al. It may be that plants can better utilize Mo at higher pH levels.

Table 30. Manganese (MN^{+2}) suggested for organic soils when applied in bands near the seed or plant.

Crop Response	Pounds of Mn^{+2} per acre	
	pH 5.8 - 6.3	Above pH 6.3
High	6	10
Medium	3	6
Low	0	3

Soils high in free iron oxides (bog iron) are often deficient in available Mo.

Molybdenum is required in very small amounts. Normal plant tissue contain between 0.8 and 5.0 ppm. Some plants may contain as high as 20 ppm. Certain nonresponsive crops such as grass may contain as low as 0.1 ppm. Some responsive crops are cauliflower, broccoli, lettuce, spinach, radish, onion and clover.

The deficiency of Mo in cauliflower and broccoli appears as a marginal scorching, rolling or curling upward and withering and crinkling of the leaves. In later stages of plant growth, the deficiency shows up as "whiptail" (Figure 45).

In onions, the deficiency appears as a wilting and then a drying of the leaf tips. Below the dead tip, the leaf shows about one inch of wilting and flabby tissue (Figure 46). The usual carriers of Mo are Na and NH_4 molybdate. It is often mixed with vegetable seed and is applied at the rate of 0.5 ounce of the salt per acre. If the molybdenum is mixed in band placed fertilizer, use about 0.5 pound of actual Mo per acre.

Excessive Mo in plants has caused concern for animals feeding on winter forages in Florida. In some parts of the

Figure 45. Cauliflower without molybdenum was a failure when grown on a soil high in bog iron. In early stages the deficiency symptom appears as crinkling and mottling and marginal leaf scorching. In later stages, the deficiency is known as "whiptail."

Figure 46. Onions grown in an acid, peaty soil. Note wilting and dieback of the leaves caused by molybdenum deficiency. Newaygo Co., Michigan.

world with high Mo levels, the toxicosis is sometimes referred to as "teart." Copper dosages help counteract the excessive levels of Mo in the animals. This disorder is often associated with plant accumulations of 10 ppm or more of Mo and with less than 6 ppm Cu (107, 109).

Zinc (Zn)

Zinc deficiency has been recognized on a number of crops grown on organic soil, particularly beans, soybeans, corn, barley and onions. The deficiency is most apparent when the pH is above 6.5 or when acid Histosols are limed. Large quantities of phosphorus fertilizer induce Zn disorder. The deficiency varies from year to year. Wet, cool, cloudy weather during the early growth enhances the deficiency. Crops on poorly drained soils can show the problem, probably because of restricted root growth.

Bean plants deficient in Zn first become light green in color. When the deficiency is severe the leaves become pale green and then yellow near the tips and outer edges. Zn deficiency in corn appears as a yellow striping of the leaves (Figure 47). Areas of the leaf near the stalk may develop a generally white to yellow discoloration. In severe deficiency the plants have shortened internodes and the lower nodal tissue will appear purplish-red in color. Deficiency in onions shows up as a stunting with marked twisting and banding of yellow striped tops (Figure 48).

To be effective, Zn fertilizer must be applied early in moist soil. Mixing Zn with a N-P-K fertilizer is acceptable. The suggested rate is 2-3 lb Zn/A if banded near the row or

Figure 47. Serious zinc deficiency in field corn that was planted in a marly muck soil. St. Joseph Co., Michigan.

4-6 lb/A if broadcast. Foliar applications can be used at the rate of 0.5 to 1.0 lb of Zn per acre. Plants with waxy leaves, such as onions, may need a wetting agent in the water to obtain good foliage cover. Suitable fertilizer carriers are zinc sulfate, oxides, chlorides or carbonates. In field tests, granular zinc oxide was not as effective as was the powdered formulation.

Sodium (Na)

A response to Na, applied normally as sodium chloride—common salt—has been obtained with a number of crops, mostly in the beet *(Chenopodiaceae)* family and celery. Other crops that show less response are cabbage, wheat, rape, cotton, flax, rutabagas and chicory (82). The degree of response is generally associated with the K level in the soil, which indicates a partial replacement of K by Na in the plant.

The addition of salt increases the Na content of plant tissue, imparts a salty flavor, may increase yield, acts as a deterrent to wilting in hot, dry weather, and may slightly reduce the incidence of certain diseases such as leaf spot in sugar beets.

Data reported in Table 31 show the effect of sodium chloride and potash on the yield of beets and celery. Crops growing in high levels of K are not likely to respond to sodium applications.

Silicon (Si)

Terra Ceia, Pahokee and Okleelanta mucks of the Everglades were found to contain from one to 19% Si and had a median value of 4%. Freckling of the sugar cane leaves, which is associated with low Si content, was found in all fields (67). In two field experiments the application of four and five tons of calcium silicate slag per acre increased sugar tonnage 13 and 16%, respectively (68). Recent field trials on organic soils at pH 4.9 have shown a 25% yield increase in rice (Florida data from George Snyder).

Selenium (Se)

Selenium is not an essential nutrient for plants but it is needed by animals. This element has been found to be deficient in forages and pastures in New Zealand raised peats (91). The deficiency most likely exists in many North American Histosols. Problem soils in New Zealand showed less than 0.05 ppm Se in the forage. Grazing animals should have forages that exceed 0.2 ppm Se.

Soil injection using 1.0 pound Na_2SeO_3 per acre was found effective in preventing Se deficiency in animals (91). Kubota and Allaway (109) report that 80% of the forages and grains from the Great Lakes area, northeast states and the Atlantic Coastline contain less than 0.05 ppm Se. These scientists also place the critical dietary levels of Se for ruminants on dry feeds at 0.05 ppm. When animals have access to green pastures, the critical level appears to be less.

Table 31. The effect of salt (sodium chloride) on the yield of crops grown on Houghton muck. (All plots received 100 pounds of phosphate per acre.)

Treatment (Pounds per acre)		Tons per acre		
Potash-K_2O	Salt	Table beet roots	Untrimmed celery	Sugar beet roots
100	0	22.7	27.1	13.8
100	500	27.7	34.1	16.0
200	0	25.9	33.5	18.7
200	500	29.0	38.1	21.7
300	0	27.1	33.0	20.7
300	500	27.6	38.6	22.3
600	0	30.6	38.6	23.5
600	500	30.4	40.0	23.0

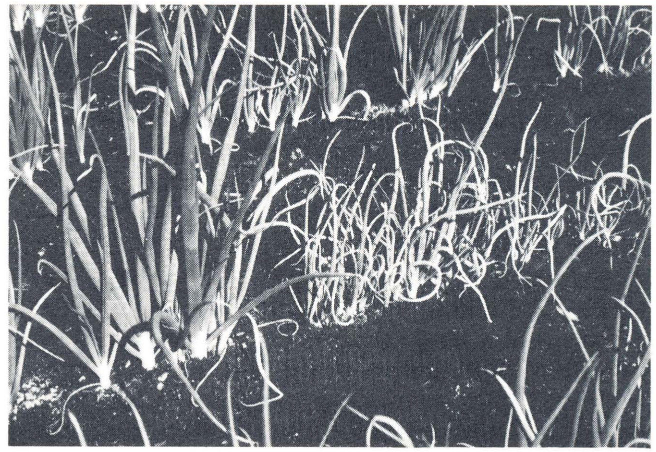


Figure 48. Normal and zinc deficient onions. Note twisting of deficient plants.

FERTILIZER PLACEMENT ON MUCK SOILS

The method of placing the fertilizer in relation to the seed may account for as much as 100% difference in yield (Table 32). Fertilizer can be applied in several ways:

1. Broadcast and disked in or plowed under
2. Drilled in
3. In contact with the seed
4. Band placement near seed or plants
5. Foliar applications
6. Sidedressing or topdressing

Onions and spinach are responsive to band placement, whereas carrots are not as responsive. Theoretically, soluble phosphate fertilizer is more efficiently utilized by plants if placed in localized bands and not mixed with the soil. Mixing with the soil tends to tie up the phosphate in a form unavailable or very slowly available to plants if the organic soil contains substantial amounts of Fe, Al and clay minerals.

Broadcast Method of Application

Where fixation of phosphorus and manganese occur, broadcast is the least efficient method of applying fertilizer. In case of severe wind erosion a large proportion of the

Table 32. Effect of fertilizer placement on the yield of dry onions grown on Houghton muck (44).

Treatment(a) Band placed	Broadcast	Yield - cwt/acre 3 Year Average
lb/acre		
N - P - K	N - P - K	
50-44-160	0 - 0- 0	397
50- 0- 0	0 -44-160	298
50-44- 0	0 - 0-160	405
44- 0-160	0 -44- 0	313
0 -44-160	50- 0- 0	370
0 -44- 0	50- 0-160	354
0 - 0-160	50-44- 0	259
0 - 0- 0	50-44-160	215

(a)The amount is equivalent to 1000 lb/acre of a 5-10-20 ($N-P_2O_5-K_2O$) fertilizer.

fertilizer may be lost. The method has a desirable feature in that the equipment is simple and the fertilizer can be applied rapidly. The inefficiency of the broadcast method may be compensated, in part, by the ease of application and by better distribution of farm labor. Broadcast applications of potash have proven equally as effective as band applications.

Drilled In

Fertilizer drilled in is usually applied with a grain drill which spaces the band about seven inches apart and places the fertilizer from three to four inches deep. This is a good method to use for supplemental applications on many crops and as a means of applying fertilizer for crops that do not respond to band placement of fertilizer near the seed.

Contact With the Seed

Fertilizer is sometimes placed in direct contact with the seed. Because of the large quantities commonly used on crops grown on organic soils, this method of application is seldom applicable except possibly on small grains. Nitrogen and potassium salts are especially injurious to small seedlings. Certain micronutrient carriers, such as copper sulfate and borax, are often injurious when applied in contact with seed.

Band Placement

In general, the recommended placement of part of the fertilizer is in a band two to three inches below the seed (Figures 49, 50, 51). Some crops which develop extensive root systems early, such as potatoes and corn, should be fertilized two inches to the side of and slightly below the

Figure 49. A comparison of 800 pounds of 5-10-20 ($N-P_2O_5-K_2O$) fertilizer per acre applied three inches below the seed (left) with the same amount applied with a grain drill (7 inch spacing).

Figure 50. All plots received 50 pounds of N, 100 pounds of P_2O_5 and 200 pounds of K_2O per acre. Good four rows on the left had N and P banded and K broadcast, the middle four rows had the fertilizer applied broadcast and the next four rows on the right had $N+P_2O_5+K_2O$ banded. See Table 32 for harvest data. Some of the placement benefits are believed caused by an increase in available Mn caused by the placement.

seed. Results at Michigan Muck Experimental Farm indicate that about 700 lb/A of 5-10-20 fertilizer is the maximum amount that should be applied where crop rows are spaced 18 inches apart. With wider row spacing the amount of fertilizer that can be tolerated in the band is decreased proportionately.

It is especially hazardous to apply large amounts of fertilizer to soils that are dry or where conditions are favorable for evaporation of moisture which will carry soluble salts to the surface. If additional fertilizer is needed over the amount which can be placed in the row, it should be broadcast or drilled in prior to planting.

The fertilizer elements most needed as band applications are Mn and P, and to a lesser extent, N. Experimental results show that if the N and P are applied in the band below the seed, K can be broadcast without any yield reduction. Similar data have been reported for small grains, sugar beets and corn grown on mineral soil. A small amount of N mixed with P increases the recovery of applied P by plants (144).

Many growers are using fertilizer placement equipment for cultivated crops. This equipment is built on a land roller with the fertilizer placement applicators mounted ahead of

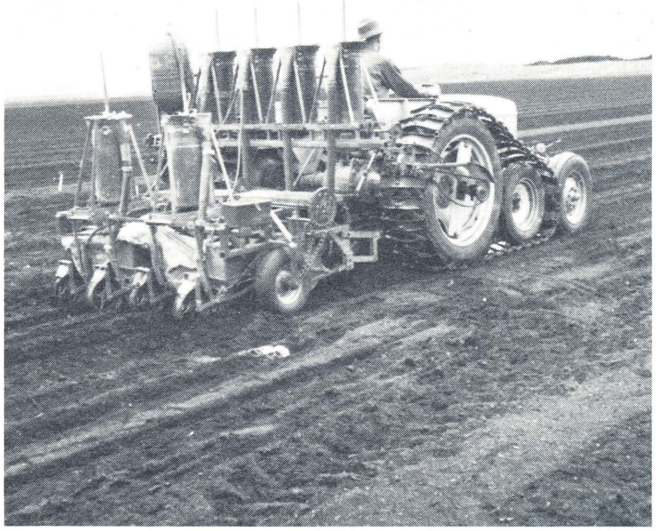


Figure 51. Research model capable of using different rates and placement of dry and liquid fertilizer.

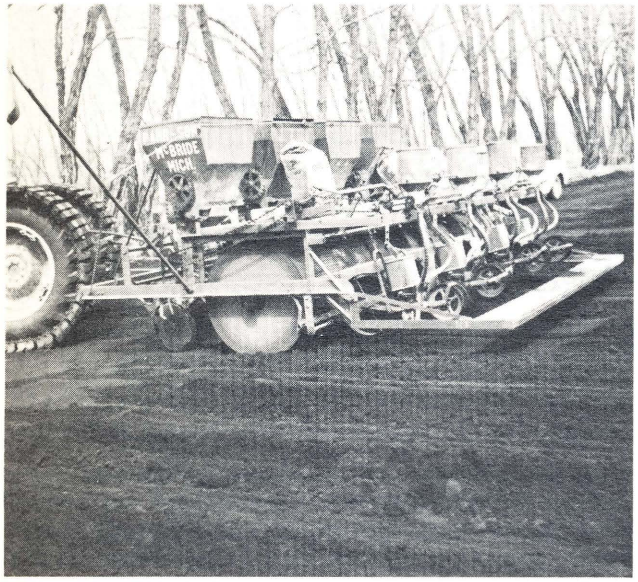


Figure 52. Commercial onion drill. Dry fertilizer drilled in bands two to three inches below the seed is applied ahead of the roller. Both small grain and onions are drilled after rolling. Later models are capable of using liquid fertilizer and special hoppers for in-row applications of fungicides and insecticides.

the roller and the seeding units located to the rear of the roller (Figure 52). Additional units are sometimes attached for seeding an intercrop of small grain. One objection to this equipment is it leaves the ground too smooth and subject to wind erosion. The use of cultivator hooks between the planted rows helps overcome this problem.

Foliar Application

Foliar application is more applicable for micronutrients than for major elements because of the small amounts required by the plant.

Efficiency in the use of elements that are easily fixed in the soil, such as Mn, can be greatly increased by leaf feeding. Foliar applications of many plant nutrients can be applied in conjunction with the regular pesticide program.

To correct magnesium deficiency in certain varieties of celery (96) the Mg should be applied as a spray. Soil applications of two tons per acre of magnesium sulfate failed to correct the deficiency symptom.

It is suggested when foliar applications of plant nutrients are used, that the toxicity of the particular carrier and the tolerance of the crop itself should be thoroughly ascertained.

Sidedressing and Topdressing

Fertilizer may be applied either as a sidedressing or topdressing after the crop has been established. Many growers follow the practice of applying part of the fertilizer at planting time and part as a sidedressing. Nitrogen materials applied as a sidedressing may be helpful, especially under wet conditions. Micronutrients can be applied as a supplemental application if situations indicate their need. Many crop failures have been averted by topdressing or sidedressing when conditions indicated a nutrient problem.

Fertilizer in the pelleted form is generally available. If applied as a topdressing when the foliage of the plant is dry, very little injury will result. If the fertilizer tends to stick to the plant, it may be necessary to follow the application with a harrow or some other drag equipment to knock off the pellets.

SOIL TESTING

Undeveloped organic soils are usually low in available P and K. Changes in fertility levels brought about by application of fertilizer can be measured by soil tests (Figure 53). They are a valuable diagnostic aid in de-

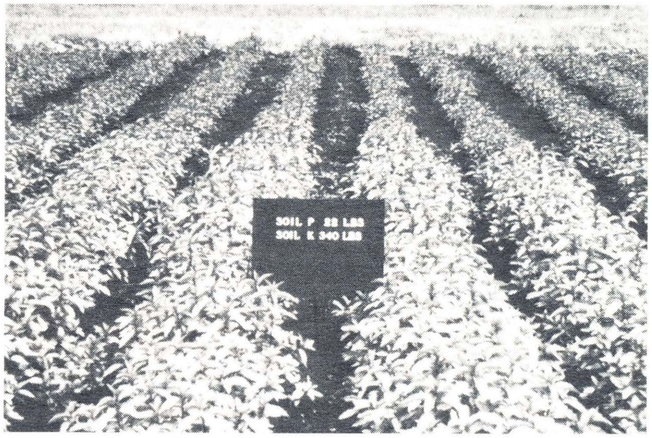


Figure 53. Top: Response of peppermint to phosphorus level. Soil in foreground tested 22 pounds P and 340 pounds of K per acre. Soil in background tested 7 pounds of P and 420 pounds of K per acre (Bray P_1 test method for both P and K.) Bottom: Response to potassium level. Soil in foreground tested 80 pounds of P and 45 pounds of K per acre. The soil in back growing normal plants tested 54 pounds of P and 225 pounds of available K per acre.

termining whether crop production has been limited because of a low or unbalanced fertility level. Routine soil tests should include pH, P and K. The nitrate test may be advisable under certain conditions, especially if a growing crop is to be sidedressed. Tests may also include Mg, Ca, Fe, Al, B, Mn, Cl, SO_4^{-2}, Cu, Zn and soluble salts.

Analysis of water, salt or dilute acid extracts are generally used in soil tests. In the mid-west states, the Bray P_1 method (104) is generally used. The water extracting method has worked satisfactorily in Florida Everglades soils for phosphorus (61). Workers (75) in New York use the Morgan sodium acetate-acetic acid extracting solution buffered at pH 4.8. North Carolina scientists (39) concluded that the double acid (0.05 *N* HCl - 0.025 *N* H_2SO_4) extractant was a good indicator of potential P supply. Unfortunately, the study was on soils that test pH 5.4 or below.

In greenhouse trials, growing sorghum-Sudan grass, the critical level was found to be about 37 pounds of extractable P per acre. The procedure used one part of soil to four parts extracting solution (by volume) and five minute shaking time. Air-dried samples were found to be superior to field-moist samples because the drying process led to mineralization of some of the organic P and this mineralization was reflected by increases in dilute acid extractable P. In contrast with Florida views the North Carolina specialists report a single water or dilute calcium chloride extractable P gave no indication of the need for P fertilizer.

Data in Tables 33, 34 and 35 show the effect of soil fertilization on the amount of extractable P and K when soils were tested by different methods. A good correlation with similar sampling variabilities was found. Dawson (47) compared several soil testing procedures. He concluded the Morgan method (140) was a good one when soluble Fe and Al are measured.

Soil test results obtained in the fall are usually higher in content than those from spring sampling, although the effect of sampling on the P test is much less than that on K.

In general, grasses and soybeans grow normally at moderate fertility levels. Celery, however, requires very high levels of K. Tables 36 and 37 show fertilizer recommendations based on the fertility requirement of different crops. The following soil test method was used: One level teaspoon of air-dried soil (approximately 1.7 cc) was added to 20 milliliters of Bray P_1 extracting solution (0.025 *N* HCl + 0.03 *N* NH_4F) and the mixture shaken for one minute. The chemical analysis was made on the extract and to convert to pounds per acre, the values in ppm in solution were multiplied by 16.

The use of volume instead of weight measurements partly corrects for differences in soil densities and moisture content. Shrinkage upon drying, however, does increase the amount of soil. Screened moist soils usually range from 0.15 to 0.25 g/cc of solids. These same soils may contain 0.4 to 0.6 g/cc air-dried and 0.5 to 0.8 g/cc oven-dried.

Thus, variability of the moisture content can greatly modify the quantity of soil in a volume measurement. Generally, in routine rapid soil testing, the Florida laboratory strives to hold the soil moisture content in the range of 40 to 50%, dry weight basis. As reported under the section on shrinkage, bulk density values increase markedly when the moisture content falls below 30%.

Fields that have been in vegetables for a number of years often show very high P and K soil tests. New York specialists used such a site near Elba to evaluate the need for N, P, K fertilizer in the production of onions. The same fertilizer treatment was applied each year to the same plot for the period of the trial. Data in Table 38 report the

Table 33. Available soil phosphorus by different testing methods on field plots that were cropped and fertilized with the same P_2O_5 rate for 15 years. (Mich. Muck Expt. Farm).

	Soil Test Method(a)			
Annual Application lb P_2O_5/A	Spurway(b) active 1:4	Bray(c) P_1 1:10	Spurway(d) reserve 1:10	Cornell(e) procedure
	Pounds of P per acre			
0	3	6	15	2.5
25	5	9	18	5
50	6	11	25	10
75	8	20	50	15
100	12	26	62	32
150	18	36	86	52
200	20	50	134	70

(a)Volume measure except the Cornell procedure which is based on 500,000 pounds of oven-dry soil per acre.
(b)0.018 *N* acetic acid (179).
(c)0.025 *N* HCl + 0.03 *N* NH_4F. (24)
(d)0.13 *N* HCl (179).
(e)Morgan's solution. 1.4 *N* NaAc + HAc pH 4.8 (140)

Table 34. A comparison of soil phosphorus test methods on Pahokee Muck. Florida Agri. Research Center.

Treatments Lb P_2O_5/A(c)	Soil Test Method(d) Water 1:25	Bray P_1 1:10	Double Acid 1:10(d)
pH 6.1	Pounds of P per acre(b)		
0	18	21	41
300	27	33	62
600	57	67	130
1200	69	107	159
pH 7.5			
0	5	5	22
300	10	14	49
600	20	23	91
1200	24	36	109

(a)2.0 gm air-dried soil shaken for 30 minutes for all samples.
(b)An acre was calculated to be 500,000 pounds of air-dried soil.
(c)Fertilizer applied in May. Soil samples collected in September on plots kept free of plant growth.
(d)0.05 *N* HCl + 0.025 *N* H_2SO_4 (39).

results. Note the variable response to N by years, the non-response to P and the response to K in the third and fourth year.

The P and K recommendations in Tables 36 and 37 are liberal—possibly as much as 25% above need. This extra fertilizer allows for soil sampling variation and for adverse weather conditions. Growers should carry out some of their own field trials so they can better evaluate fertilizer needs. Poor yields may be caused by some problem other than a lack of fertilizer.

Farmers receiving soil test reports prefer to have the nutrient values expressed as pounds per acre—plow depth. When making such calculations, the chemists use a conversion factor based upon the volume of the measuring scoop. Because of the shrinkage, the nutrients such as K show considerably higher amounts than what may actually exist. For research reports, bulk density should be determined on field samples and then weighed samples used in the chemical determination. The values then should be reported on a volume basis.

Soil Sampling

Reliable soil tests depend to a great degree on how accurate the sample represents the area being tested. Equipment needed for collecting samples includes a clean bucket for mixing, pint jars or cartons, and a spade or sampling tube. Composite samples should be taken (0 to 6 inch depth) consisting of 15 or more borings taken at

Table 35. The influence of extracting reagent, fertilizer treatment and depth of sampling on the amounts of extractable potassium. (Houghton muck). Plots fertilized and cropped ten years before sampling.(a)

Pounds per acre Annually P_2O_5 - K_2O	Extracting reagent: 0.018*N* CH_3COOH — Spurway active			0.135*N* HCl — Spurway reserve			23% $NaNO_3$ — Bray		
Sampling depth in inches	0-6	6-12	12-18	0-6	6-12	12-18	0-6	6-12	12-18
	ppm Potassium (ug/g)								
0 - 0	10	13	14	68	66	42	30	20	8
100 - 100	46	19	11	124	56	41	123	14	7
100 - 200	87	34	21	201	92	72	209	38	25
100 - 300	210	62	45	406	207	89	398	158	75
0 - 300	340	133	119	399	227	173	540	410	180

(a)Data from Bigger et al (13). One can assume the 0 to 6 inch depth weighed about 500,000 pounds per acre and the 12-18 inch depth about 300,000 pounds.

Table 36. Phosphorus (P_2O_5) recommendations for crops grown on organic soils using the Bray P_1 texting method.

Test Level lb P/acre	Blueberries Clover Oats Pasture – grass Rye Soybeans (35 bu) Sugar cane (60 T)	Asparagus Beans – snap Corn (130 bu) Mint (70 lb) Radishes Sudan grass Sweet corn Turnips	Bluegrass Sod Brussel sprouts Cabbage Cucumbers Endive Horseradish Parsnips Potatoes Rutabagas Spinach Swiss chard Sugar beets Table beets	Broccoli Cauliflower Celery (600 cwt) Home Garden Market Garden Onions – bunching Onions day (600 cwt) Lettuce (500 cwt)
	Phosphorus recommendations, lb P_2O_5/acre			
0 - 19	75	150	250	300
20 - 39	50	100	200	250
40 - 69	25	50	150	200
70 - 99	0	25	100	150
100 - 149	0	0	50	100
150 - 199	0	0	25	50
200+	0	0	0	0

To use Tables 36 and 37, look at the recommendation shown below the crop that compares to the soil test value shown in the left column. For example, 150 lbs P_2O_5/A is suggested for potatoes for a field that tests 40 to 69 lb P/acre.
Figures in parenthesis after crop is the suggested crop yield.

Table 37. **Potassium (K_2O) recommendations for crops grown on organic soils using the neutral 1 *N* ammonium acetate or the Bray P_1 method.**

Test Level lb K/acre	Blueberries Oats Rye Pasture – grass	Beans – snap Clover Corn (130 bu) Bluegrass sod Soybeans (35 bu) Sudan grass Sweet corn Turnips	Asparagus Cabbage Carrots Cucumbers Endive Lettuce (500 cwt) Mint (70 lb) Parsnips Radishes* Spinach Sugar cane (60 T)	Broccoli Brussel sprouts Cauliflower Dry Onions (600 cwt) Potatoes (400 cwt) Rutabagas Sugarbeets Swiss Chard Table beets	Celery (600 cwt)
	Potassium recommendation, lb K_2O/acre				
0 - 124	150	250	300	400	600
125 - 199	100	200	250	350	525
200 - 274	50	150	200	300	450
275 - 349	0	100	150	250	400
350 - 424	0	50	100	200	350
425 - 499	0	0	50	150	300
500 - 574	0	0	0	100	250
575 - 649	0	0	0	50	200
650+	0	0	0	0	150

Table 38. Fertilizer response of onions growing on a farm site that had a long history of onion production.

Annual Treatment Pounds per acre			Yield - Bu/acre over 1 5/8" size				
N	P_2O_5	K_2O	1968	1969	1970	1971	4 yr. average
0	0	0	892	610	950	807	815
100	0	0	984	868	904	935	923
100	100	0(a)	1000	832	956	802	898
100	0(b)	150	991	872	958	1043	966
0	100	150	864	559	888	729	760
100	100	150	945	882	1031	1074	983

Data by Minotti and Stone in Muck Crops Newsletter, 1972, New York.
(a)K soil test - 728 pounds in 1968 and 258 pounds in 1971.
(b)P soil test - 120 pounds in 1968 and 50 pounds in 1971.

random from each area. Samples from sugar cane fields should be taken to a depth of 12 inches. On an undeveloped field, sample each area having different types of vegetative cover. A sample from a uniform area may be representative of ten acres. Samples from small areas not representative of general field conditions should be kept separate.

Soil Salinity

In contrast to sandy soils, organic soils are less likely to contain excess soluble salts because of the high buffering capacity. Nonetheless, excess salts can be a factor in reducing plant growth. A suggested method for determining soluble salts is the one developed by the Salinity Laboratory (27, 192). Sufficient water is added to completely saturate the soil. At this point, the moisture content for organic soils is similar to the field capacity value. For example, a number of tests made on cultivated Florida mucks averaged about 140% moisture at field capacity and 150% at saturation.

For loam soils, however, the moisture content at saturation is about twice as much at field capacity in well-drained conditions (78). Thus, standard salt levels suggested for crops growing on organic soils can be about twice as great as the levels for loam soils. The values in Table 39 illustrate typical differences in moisture and salt content for a loam and muck soil which show the same conductivity for an extract at saturation.

ADAPTED CROPS

Specialty crops grown on organic soils exceed 700 million acres and have a gross value of about one billion dollars annually (Table 40). Some crops, such as sweet potato, pepper, eggplant, melon and tomato, are not well adapted when grown on organic soils primarily because of excessive vegetative growth or the frost hazard.

Table 39. A typical comparison of the salt and moisture contents for loam and muck soils which read 2 millimhos per cm for saturated soil extracts.

Situation	Loam	Muck
Millimhos/cm at saturation	2.0	2.0
Dry soil weight (Lb/6" acre)	1,900,000	550,000
At Saturation		
Water content	40%	150%
Lb water/acre	760,000	825,000
Salt concentration in extract - ppm	1,280	1,280
Total salts - Lb/acre	973	1,056
At Field Capacity		
Water content	20%	140%
Lb water/acre	380,000	770,000
Salt concentration - ppm	2,560	1,370

Note the two soils show similar salt values in saturated solutions, but at field capacity the salt concentration in the soil solution for the loam soil is much higher (2560 vs 1370 ppm).

Vegetables that do well if properly managed are potato, onion, carrot, parsnip, cabbage, cauliflower, celery (76), snap bean, table beet, sweet corn, lettuce, radish and spinach. Some of the adapted field crops are corn, soybeans, mint (216) and small grain used for summer pasture. In the Great Lakes area organic soil is used for hay and pasture production. Unfortunately, much of the hay land is in native grass, poorly drained and not fertilized.

Well managed pastures can carry two to three animal units per acre during the growing season. The legume in legume-grass stands is difficult to maintain, with the possible exception of alsike clover, because of winter killing of the legume and competition of the grass. In Florida over 300,000 acres of sugar cane and 10,000 acres of rice are grown on organic soils.

Extensive acreage of Kentucky bluegrass (*Poa pratensis*) sod (Figure 54) is produced in the Great Lakes States area and St. Augustine grass (*Steno-taphrum secundatum*) sod in Florida for transplanting on new lawns. The advantages of sod from organic soils over that from mineral soils are less weight and ease of harvest. The sod is ready for harvest when the rhizomes and roots have knitted sufficiently to permit handling without tearing.

For the Great Lakes area, it takes at last seven months to develop such sod. Mechanical sod cutters are utilized in the harvesting operation. The thickness of cut ranges from 1/2 to one inch depending upon the sod strength, grass specie and type of soil. Sod cut thin generally handles easier and roots faster but is more prone to moisture stress than thick-cut sod.

Cranberry production is a specialized industry found in Washington, Wisconsin and Massachusetts. Cranberries are grown in beds on acid peats which have been covered with several inches of sand. The beds must be perfectly level with adequate ditches, bulkheads for rapid flooding and drainage, plus a large and constant water supply. This is usually in the form of reservoirs several times larger than the area under cultivation. Flooding is necessary to prevent frost damage.

When compared to crops grown on mineral soils, those on organic soils often show higher moisture content, less fiber and less carbohydrates. Thus, fresh market salad crops are more brittle from mucklands. Carrots and potatoes grown on organic soils can show less sugars and starches when the same varieties are compared. Rice, small grain and grasses have softer stems and lodge easily. Barren corn (maize) stalks or poorly filled ear tips are problems for which an answer has not been found (72). Plant breeders can, through selection, overcome many of these objectionable features.

For potential crops grown on organic soils in the tropics, see the publication by Driessen and Sudewo (213).

LAND APPRAISAL AND SUITABILITY ESTIMATES

The value of organic soils is difficult to appraise because of the wide range of uses. The Soil Conservation Service has developed some guides when organic soils are considered for the production of forest and food. The guideline uses a penalty system where the higher the score, the poorer the suitability. Location, farm size and sociological influences were not considered. The physical features used in the suitability grouping and the penalty factors are shown in Table 41. If the penalty score exceeds 65, such locations are not advisable for development into agricultural purposes.

The suitability score does not include possible weed and soil borne pest problems. These pests can seriously affect land values and should be checked.

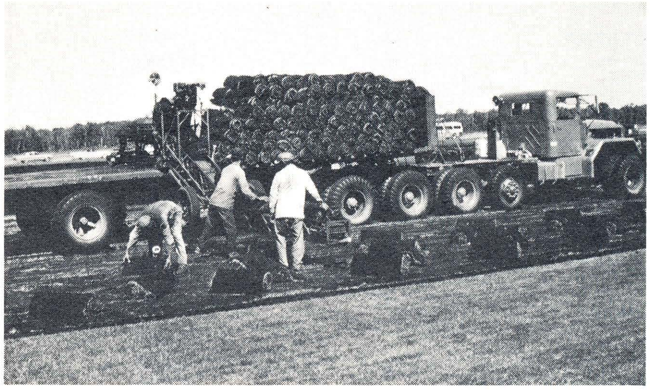


Figure 54. Commercial production of bluegrass sod on organic soils. Because of its light weight, ease of harvest and the development of strains with numerous rhizomes, sod production increased rapidly during the '60s in the Great Lakes area.

Table 40. Some production estimates for special crops grown on organic soils.

Crop and Location	Acreage (1979-81)	Yield/acre	Gross Value Million $
Sugar cane			
Florida	330,000	3.2T	500
Sod			
Michigan	10,000		30
Florida	10,000		25
New York	4,000		10.0
Wisconsin	2,000		6.0
Indiana, Ohio	1,000		3.0
Canada	1,000		2.0
Onions			
New York	14,000	300 cwt.	44
Michigan	6,500	300	13
Wisconsin	1,500	300	5.0
Ohio	500	300	1.5
Minnesota	700	300	1.5
Canada	9,000	290	14
Celery			
Florida	12,000	400 cwt.	40
Michigan	3,000	440	12
New York	600	425	2.4
Ohio	400	440	1.4
Canada	1,200	425	6.0
Lettuce, endive, escarole			
Florida	12,000	200 cwt.	24
New York	4,100	200	10
Wisconsin	1,000	200	2.0
Michigan	1,200	180	4.0
Ohio	1,200	135	5.0
Canada	3,200	180	6.0
Miscellaneous (beans, cabbage, red beets, parsley, etc.)			
Florida	3,000		15
Wisconsin	2,700		4.5
Michigan	1,000		1.0
Ohio	100		0.1
New York	2,000		3.0
Cranberries			
Massachusetts	11,000	130 cwt.	28
Wisconsin	7,200	140	25
New Jersey	3,000	130	8
Sweet corn			
Florida	35,000	100 cwt.	25
Carrots			
Michigan	6,000	240 cwt.	15
Florida	5,000	200	9.0
New York	2,000	350	8.8
Wisconsin	4,500	420	6.0
Minnesota	1,000	380	2.3
Ohio	100	315	0.4
Canada	14,700	300	23
Radishes			
Florida	30,000	23 cwt.	22
Michigan	2,500	40	1.3
Ohio	1,800	40	1.0
New York	2,200	25	1.7
Potatoes			
Michigan	5,000	300 cwt.	8
Wisconsin	8,000	300	10
Indiana	3,500	225	6
Ohio	750	325	1
Canada	1,000	250	—
New York	2,500	280	3

Tabel 40 (continued)

Crop and Location	Acreage	Yield/acre	Gross Value Million $
Mint			
Indiana	13,000	36 lb.	6.1
Wisconsin	15,000	36	7.0
Michigan	6,000	30	2.3
Others			
California	120,000		72
Total	739,650		1083

Table 41. Management suitability for specific crops growing on organic soils located in the Lake states and Northeast, U.S. (In part from SCS Mimeo, Feb. 7, 1975, Lincoln, NB).

	Penalty Rating for Extended Use				
Physical Feature	**Corn**	**Pasture**	**Cool season carrots, celery beets, onions**	**Short season lettuce, radish cabbage, spinach**	**Sod**
Growing degree days (50° F base)					
Above 3000	0	0	0	0	0
2200 - 3000	20	10	10	10	10
Below 2200	50	20	20	20	20
Thickness of organic material					
Above 52 inches	0	0	0	0	0
36 - 52 inches	5	5	10	10	10
16 - 36 inches	10	10	25	25	20
Underlying material 16 to 51"					
Loamy	0	0	0	0	0
Clayey	5	5	5	5	10
Sandy	10	10	10	10	10
Coprogenous	20	20	20	20	20
Marly	30	15	15	15	15
Rock	50	30	50	50	50
Surface texture - Top 16"					
Muck, mucky peat	0	0	0	0	0
Peat	20	20	20	20	30
Marl	40	40	40	40	40
Flooding during growing season					
None	0	0	0	0	0
Slight	20	5	20	15	15
Frequent	70	20	70	50	50
Wood Fragments 4" in diameter in top 51"					
0 - 1%	0	0	0	0	0
1 - 10%	5	0	10	10	20
10 - 25%	10	5	10	20	50
Above 25%	25	10	40	40	100
Soil Reaction (pH) in 0.01 M $CaCl_2$ (Top 16")					
Below 4.0	20	20	20	20	20
4.0 - 5.0	10	10	10	10	10
5.0 - 7.0	0	0	0	0	0
Above 7.0	10	5	10	10	10
Acid sulfate below pH 3.5	75	75	75	75	75
Salinity (mmhos/cm)					
0 - 4	0	0	0	0	0
4 - 8	20	20	20	20	20
8 - 16	50	50	50	50	50
Above 16	75	75	75	75	75

Total Penalty Score and Suitability Group

0 - 15	No limitations
20 - 30	Minor limitations
35 - 45	Moderate limitations
50 - 60	Severe limitations (high reclamation costs)
65 - 80	Severe limitations (forage only)
80 - 120	Indigenous crops only
Above 120	Not advisable for agriculture

FUMIGATION for Meadow Nematodes Treated Oct. 1947

GALLONS /ACRE	ONIONS-BAGS/ACRE 1948	ONIONS-BAGS/ACRE 1949
E.D.B.*		
0	252	289
3	400	394
4.5	446	437
6	452	479
D.D**		
0	252	289
30	448	460
45	470	496
60	470	551

DOW R.E.L

*Ethylene dibromide
**50% Dichloropropene
GEHRINGS

Figure 55. The results of the first commercial field trial for the control of lesion nematodes in the mid-West using soil fumigants. Plots were located on muck soil in Jasper Co., Indiana and were in cooperation with the Dow Chemical Company.

PEST PROBLEMS

Agricultural advisors are often called to diagnose crop problems. Crops growing on organic soils certainly receive more than the usual attention. Disorders on recently developed land are usually nutritional or are caused by excess acidity or alkalinity. Disorders that appear on land that has successfully grown crops are more likely caused by soil borne insects, diseases or nematodes (Figures 55, 56, 57). Some of the problem is caused by the monoculture programs. These problems include smut in onions, verticillium wilt in mint, leaf miner in celery and corky root rot in head lettuce.

"Exhausted or tired soil" is often caused by nematodes rather than by a lack of some nutrient or a buildup of some soil toxin. Light infestation of nematodes can activate plant disease problems such as verticillium wilt and black dot (*Colletotrichum coccodes*) in potatoes. The writer has had to carry out greenhouse pot experiments in order to diagnose crop production problems. These tests always included some sterilized soil to help determine if nematodes or soil borne diseases were a factor.

Crop rotations that include resistant or non-host plants can be effective in reducing crop damage. Alternate years of carrots and onions are helpful in reducing nematode problems which are common with these crops. Sweet corn is often used in crop sequences because of the type of plant growth and the residue returned to the soil. Special attention should always be given to prevent introducing contaminated soil on field equipment, transplants and roots.

One of the most effective pest control programs for the Everglades area is flooding. This treatment reduces soil borne insects (such as ants, grubs and wire worms), reduces weed problems, reduces nematodes and controls pink rot (*Sclerotinia sclerotiorium*). To be effective, flooding must be carried out for four or five weeks, drying the field and again flooding for several weeks during warm temperatures.

When chemicals are applied in or on the surface of organic soils, rates are normally different than for mineral soils. These rates may be two or three times greater because of increased absorption. Before using any chemical, make certain instructions include their proper use when applied to organic soils.

COMMERCIAL USES OF PEAT

Organic soils are often used in soil mixes and for soil improvement. They may bring about a number of benefits such as:

1. Increase the moisture holding capacity of sandy soils.
2. Increase the rate of water infiltration of fine textured soils.

Figure 56. Severe nematode infestation on onions, on left, because of continuous cropping. Onions on right had been preceeded by potatoes the previous year. Allegan Co., Michigan.

Figure 57. Photos illustrating two common pest problems in muck crops. Top: Verticillium wilt in mint on right and normal on left where soil was fumigated. Lower: Testing the effectiveness of different insecticides in the control of onion maggot.

3. Make soils more friable, better aerated and decrease volume weight.
4. Increase the buffering capacity, thus making it more difficult to change soil acidity and soluble salt levels.
5. Serve as a source of slow-release form of nitrogen.

The data on the utilization of organic soils, their uses and production by leading states are shown in Tables 42, 43 and 44.

Peat Specifications and Uses

The value of peat depends upon a number of factors and its use. Moss peat absorbs and retains liquid more completely than other kinds. Good commercial peat is usually fibrous, free of wood, low in weed seed count, has been shredded and screened and is low in ash and moisture. Sedimentary material as found in the bottom of lakes or the bottom layer of many deposits is generally not recommended. Acid peats should be used for acid loving plants such as blueberries, azaleas, rhododendrons and most conifers. The information in Table 45 helps summarize the suitability of different types of peat.

Table 42. Utilization of peat in the U.S.A. (Short tons)

Year	U.S. Production	Imported Peat	Total
1960	471,000	264,000	735,000
1965	604,000	275,000	879,000
1970	517,000	283,000	800,000
1975	772,000	290,000	1,062,000
1978	822,000	380,000	1,202,000
1980	790,000	335,000	1,125,000

Data from U.S. Bureau of Mines, (137).

Table 43. U.S. peat sales in 1978 in short ton equivalent and thousand dollars.

Use	Short tons	$ Value x 1,000
Earthworm culture	16,150	497
General soil improvement	441,700	7,630
Golf courses	19,800	324
Potting soils	146,100	2,300
Mixed fertilizers	20,900	203
Mushroom beds	14,900	300
Nursery	66,200	1,100
Others	20,900	467
TOTAL	746,650	12,821

Data by U.S. Bureau of Mines, U.S. Dept of the Interior (137).

Table 44. Principal states in the production of peat for sale (1978).

State	Short tons	$ Value x 1,000
Michigan	219,900	3,850
Florida	157,700	2,250
Illinois	84,300	1,590
Indiana	57,200	789
New York	49,500	770
Colorado	29,900	188
New Jersey	24,300	568
Minnesota	20,500	716
Pennsylvania	19,800	342

Data from Bureau of Mines (137).

When evaluating peat materials, the buyer usually wants to know: 1) kind of peat, 2) acidity (pH value), 3) percent organic matter, 4) percent moisture, 5) percent ash and 6) degree of decomposition (6).

The International Peat Society suggests three basic descriptions when peat is offered for sale (168). These are:

1. Botanical source
   a) moss
   b) reed - sedge (herbaceous)
   c) woody
2. Mineral content[5]
   a) Eutrophic (lime rich) pH above 4.8
   b) Mesotrophic (intermediate)
   c) Oligotrophic (lime poor) pH below 4.2

[5]The pH values are those suggested by the author. The pH are determined in two parts by volume of 0.01 M CaCl solution and one part air-dried peat.

Table 45. Recommended uses and application rates for different types of peat.

Peat Use	Normal Application(a)	Sphagnum moss peat	Hypnum moss peat	Reed sedge Peat	Peat humus (decomposed)
Soil conditioning	2" layer worked into soil	Fair	Good	Good	Good
Top-dressing lawns, golf courses	1/8-1/4" layer worked into soil	Fair	Good	Good	Good
Surface mulch	2" layer	Excellent	Fair	Fair	Poor
Potting soil mix	50% peat 50% vermiculite or soil	Excellent	Good	Good	Fair
Golf green soil mix	80% sand 10% clay loam 10% peat	Poor	Good	Good	Excellent
Rooting cuttings	50% peat 50% vermiculite	Excellent	Good	Good	Poor
Seed flat germination	Pure milled peat	Excellent	Good	Fair	Poor
For acid-loving plants	25% mixture in soil	Excellent	Not recommended	Good if below pH 4.8	Not recommended
For acid-intolerant plants	25% mixture in soil	Recommended only if limed	Good	Good if above pH 4.8	Good
Shipping tender plants	Wrap roots (wet)	Excellent	Fair	Fair	Poor
Adding stable organic matter	2" layer worked into soil	Poor	Fair	Good	Excellent
Liquid absorbent (litter)	2" layer on floor	Excellent	Fair	Fair	Poor
Nitrogen source	Soil mixes top-dressing	Poor	Good	Fair	Good

(a)By volume where applicable.
Source - Michigan State Univ. Ext. Bul. E-516 (123)

3. Degree of decomposition
   a) fibric
   b) hemic
   c) sapric

The ASTM (American Society for Testing and Materials) D 2607-69 (9), lists five major plant types of peat: 1) *Sphagnum Moss Peat*, in which the oven-dried material contains a minimum of 66 2/3% recognizable sphagnum moss fiber, 2) *Hypnum Moss Peat*, which contains at least 33 1/3% fiber of which at least half is hypnum moss fiber, 3) *Reed-Sedge Peat*, in which the oven-dried peat contains a minimum of 33 1/3% fiber, of which at least half is reed-sedge and other non-moss fibers (Figure 58), 4) *Peat Humus,* in which oven-dried peat contains less than 33 1/3% fibers and 5) *Other Peat* which includes all other forms of peat not classified in ASTM Designation D 2607-69.

Control officials prefer that products offered for sale be reported on a weight basis. This method may not be too practical because of the great variability in moisture content. Generally, bulk material and some packaged material are sold on a volume basis. Volume measure, however, does not correct for the difference in compaction or shrinkage on drying.

The variability in water content of different peats is a basis for much concern to the buyer. According to a survey made by the U.S.D.A., baled peat ranged from 21 to 49% water in the product as sold (49). Peat in moisture proof packages ranged from 30 to 80% water. Data in the Table 10 show how such differences in moisture relate to the solid material.

It is not practical to dry peats excessively because this increases cost. Furthermore, certain peats should not be too dry as they are too dusty, chaffy and difficult to rewet. A suggested value for baled moss peat is about 35 to 40% moisture and about 55 to 60% for packaged peat humus. Data in Table 46 reports the average weight per cubic yard of peat produced in the U.S. The information in Table 47 illustrates the amount of saturated peat required to make one ton of oven-dry peat.

Figure 58. Peat prepared for commercial sale. The semi-fibrous acid peat has been air-dried and ridged and is ready for screening and bagging. Sanilac Co., MI, 1964.

Table 46. Average pounds of domestic peat per cubic yard as sold in 1978.

	Sphagnum Moss	Hypnum Moss	Reed-Sedge	Humus	Other
Bulk	500	900	860	1050	970
Packaged	310	780	780	1060	880
Bulk & packaged	320	810	810	1060	960

Data reported by Bureau of Mines Mimeo, (137).

Table 47. Bulk density water - dry matter relationship for peats.

Peat Type	Bulk density (oven dry) g/cc	Lb/ft^3	Lb/yd^3	Cubic yards required for one oven dry ton of peat	Saturated Water Content (wet basis)
Fibric	0.048	3.0	81	24.7	95
	0.080	5.0	135	14.8	93
Hemic	0.128	8.0	216	9.3	88
	0.159	10.0	270	7.4	85
Sapric	0.225	14.0	378	5.3	79
	0.256	16.0	540	4.6	76

Data in part from Peat Programs Mid-West Research Institute, Minneapolis, MN 1975 (136).

Peat Harvest

Market possibilities and outlets should be investigated before attempting the sale of peat. Some producers have rather crude operations. They can make a satisfactory income by giving the consumer more individual attention in the proper use of the peat, or by selling in bulk to local buyers. Large operators, however, have to use efficient mechanical mining operations.

Draining and clearing the land of brush and roots are the first steps before peat is excavated. After draining, the land is usually plowed, which helps to loosen and dry the soil. The field is then disked several times to hasten drying and to break up large peat clumps. The roots and woody debris are removed next.

Some large scale operators use European designed equipment. Rather than disk, they use a "miller," which is a rotating drum with extended spikes that loosens the top 1/2 inch of soil. If needed, additional drying of the surface soil can be hastened by turning the peat with spoon harrows. After one or two days drying, the loose peat is ridged with a front "V" shaped or side windrower. The dried peat can then be picked up by a tractor equipped with a lift scoop or a conveyor. The dry soil is placed on

Figure 59. Stockpiling peat for late winter and early spring sale. The high stack will remain reasonably dry. The compaction also helps remove air which can cause serious decomposition.

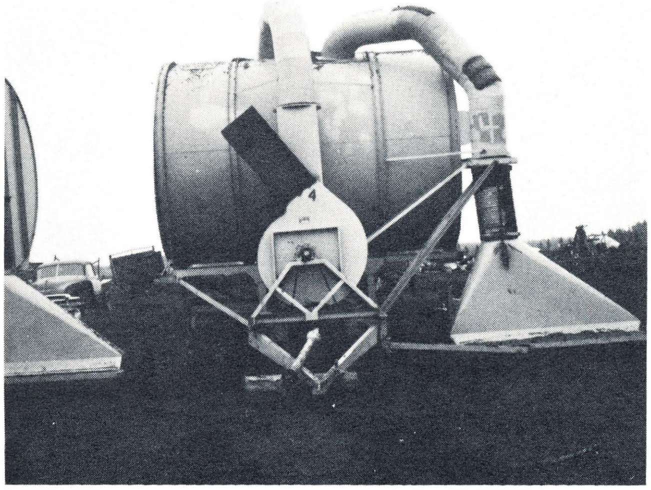


Figure 60. A pneumatic harvesting machine used for collecting air-dried peat. Such machines are common in the Soviet Union.

wagons or trucks and can be sold in bulk directly from the field or it can be further shredded and screened.

The production of peat under this system is seasonal and can take place only during periods of favorable weather. Some operators store peat in piles outside or under a large shed (Figure 59). This permits sales to continue during the less favorable winter and spring seasons. Many of the large moss peat producers use pneumatic harvesters which collect the sufficiently dry peat but leave the heavier moist peat (Figure 60).

If needed, peat can be shredded by a forage chopper or by placing it between two fast rotating drums equipped with heavy metal prongs. The peat is then elevated to a vibrating machine that is equipped with a sloping screen, which separates out wood or coarse clods. The mesh size of this screen is usually about 5/8 inch. The equipment may be so arranged that a truck can drive under the screen and collect the soil for bulk delivery. Reed-sedge and peat humus are often sold in plastic containers and moss peat in bales.

Thermophilic microorganisms can cause serious heating of peat in the stockpile (111). This heating causes rapid humification, increases the ash content and can be a fire hazard. Microbial activity is greatest when the pile is moist and loose, the peat is rich in carbohydrates and the pH is above 4.5. The heating action is often not apparent from the outside because the soil is a poor conductor of heat. To reduce this problem, pack the stockpile as much as possible and then cover with plastic covers to prevent the exchange of air. The physical changes caused by the heating in the stock pile is a source of variability in peat quality.

Peat-Lite Soil Mixes

To overcome such problems as nutrient and drainage variability, soil borne pests and excess weights, many greenhouse and bedding plant producers have turned to some standard soil-less growing media containing peat. It is estimated that in 1980 nearly 36,000 cu yds of soil-less mixes were prepared in Michigan and had a retail value of about $2 million. The mixes suggested by Cornell University specialists (21) have often been used. The peat type recommended is sphagnum. Data in Table 48 report five mixes. Because there are a number of interacting factors, plant producers should obtain the Cornell Information Bulletin 43 or contact your Horticulture Extension Specialist.

AGRICULTURAL RESEARCH CENTERS

Much of the early information about the utilization of organic soils came from small Northern European countries such as the Netherlands, Denmark, Sweden and Norway. The first research center was the Peat Research Institute established near Bremen, Germany in 1877 (110). In 1969, the Institute was assigned to the Geological Survey of Lower Saxony with the name of Ausseninstitut f. Moorforschg U Andewandte Bodenkunde. Much of the field studies have been near Koenigsmoor, situated between Hamburg and Bremen. West Germany also has research centers at Hannover, Bad Zwischenahn and other localities.

Finland is the country with the most extensive projects on organic soils. These deal with agricultural uses of peats in soil mixes, and in forest and crop production. The major

Table 48. Components for peat-lite mixes.(a)

Mixture	Cubic Yards		Pounds			
	Sphagnum	Vermiculite	Ground Limestone	Super-Phosphate	Potash	Other
1. Peat-lite Mix A for seedlings or bedding plants	0.5	0.5	5	1-2	1	
2. Peat-lite Mix A for greenhouse tomatoes with liquid feed	0.5	0.5	10	2.5	1.5	
3. Peat-lite Mix A for greenhouse tomatoes (no liquid feed).	0.5	0.5	10	2.5	1.5	Osmocote - 10 lb and Mag-Amp - 5 lb
4. Peat-lite Mix A for pot plants with slow release	0.5	0.5	10	1.0	1.5	Osmocote - 5 lb and Mag-Amp - 5 lb
5. Peat-lite Mix A with farm fertilizer	0.5	0.5	5			10-10-10 Fertilizer - 5 lb

(a)Use 3 ounces of a wetting agent and 2 ounces of fritted trace elements per cubic yard of mix. Source - Cornell Info. Bul. 43 (21).

centers are at Peat Research Institute of Satoturve Oy (Hyrylia), and the Universities of Helsinki, Turku, Oulu and Joensuu. Papers on research started as early as 1759.

Modern research was begun by A. K. Cajander (1879-1943) with his research report in 1913, "Studien uber die Moore Finlands." The Finnish Peatland Society was founded in 1949. In 1971, the Society had 600 members, 60% of them having an academic degree. The publication "Peat and Plant News," Tammisto, Helsingin pit is well recommended for both theoretical and applied information about peats.

Ireland uses extensive amounts of peat as a source of energy (Figure 61). Bord Na Mona, located at Droichead Nua, Co. Kildare, is the only organization in the world that publishes a quarterly research abstract on organic soils. Ireland also has a field research farm at Lullymore, Co. Kildare. The major research center is located at the Kinsealy Research Center, Dublin. Bord Na Mona also carries out field studies.

The English have long done numerous studies on drainage and soil management. At present, the major field station is the Arthur Richwood Experimental Husbandry Farm established 1963, located near Mepal, Ely, Cambridge. Studies deal mostly with organic soil wastage and crop production systems as the land reverts to mineral soil (skirtlands). In Scotland much of the organic soil research is done at the Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen.

The Polish Agricultural Institute has carried out numerous studies on the chemical and physical properties of organic soils. The organic soils of Poland show properties similar to the cultivated agricultural soils in the Great Lakes area (147, 148). The major Polish Research Center is at Falenty, near Warsaw, 05-550 Raszyn.

Because of extensive acreage of organic soils in Canada, a number of their professional people are studying these soils (158). The centers include the National Soil Research Institute, the Provincial Institute of New Brunswick and the major agricultural research departments.

The organization that sponsors regional and international meetings dealing with organic soils is the International Peat Society, with headquarters at Bulevardi 31, 00180 Helsinki 18, Finland. The International Congresses are held about every fourth year. The Sixth Congress was held in 1980 at Duluth, Minnesota.

Figure 61. The loading of milled peat in Ireland which will serve as a source of fuel. Will similar scenes take place in the U.S.?

U.S. History

The first published studies in the utilization of organic soils for agricultural purposes were written about 1900 (66). The first extensive bulletin was by the Department of Interior (42). The importance of potash was reported in trials carried out in the Great Lakes area in about 1912 (33, 89, 164). In 1914, a bulletin on onions (77) recommended 1,000 to 2,000 pounds per acre of a 2-8-10 (N-P_2O_5-K_2O) fertilizer.

Three state publications: The Peat Deposits of Northern Indiana in 1907 (187), Peats of Michigan in 1906 (41) and Peat Deposits of Ohio in 1912 (36) testify to the great interest in this period on the possible uses of organic soils. In 1907 an American Peat Society was organized at Jamestown, Va. The Society published a journal from 1908 to 1926 and reported on research and on uses of peats and mucks. The organization was terminated when the use of peat for fuel did not show economic promise.

The Agricultural Experiment Station of Minnesota carried out field trials in 1918-20 (4, 5). The first full time agricultural research man assigned to organic soils was Paul M. Harmer (in 1921). Under his direction work was initiated on a 14-acre site on the campus of Michigan State College (81-130). In 1941, field research plots were started on a 326-acre site located in Bath Township, Clinton County, Michigan (Figure 62).

In 1918, Michigan organized a Muck Farmer's Association. Its primary purpose was to sponsor educational meetings and research reports. This group held annual meetings until 1974. The states of Ohio, New York, Wisconsin, Indiana, Minnesota and Iowa have had similar research and extension programs. Ohio has a Research Muck Farm near Willard which was established in 1948.

The Florida Agricultural Research and Education Center at Belle Glade (formerly called the Everglades Experiment Station) was created in 1921. The first crops were started in 1924. Because of nutritional deficiencies, insects and birds, all of the field crops were lost. Research initiated in 1926 on the value of fertilizers showed the great need for micronutrients (2, 3). This Center now has an academic staff of over 20 dealing with livestock, sugar cane, rice and vegetables. The major grants are dealing with environmental and subsidence studies. In 1980 the gross value of agricultural products in the Everglades exceeded 700 million dollars.

Figure 62. View of the Michigan Muck Experiemntal Farm in 1954. During the '50s agricultural research on organic soils was substantial.

Minnesota has over 7 million acres of Histosols. Researchers in that state have obtained substantial funds to study their ecological and potential uses. The Midwest Research Institute is investigating the advisability of using peats for energy sources. The Iron Range Research in Biomass and the U.S. Department of Energy are major supporters of the study.

In California, the Sacramento-San Joaquin Delta area contains about 150,000 acres of organic soils. Of this acreage, more than one-half is located in San Joaquin County. Before levee construction and drainage the Delta was mostly tule marsh (*Scirpus lacustris*). Today the area is divided into more than a hundred named islands or tracts. Levees divide these tracts, are used as roadways and help prevent flooding as many fields are five to ten feet below sea level. Subsidence because of soil decomposition, shrinkage, wind and numerous fires have lowered the land surface from 10 to 20 feet since the peatlands were drained about 100 years ago.

The first investigation of subsidence in the Sacramento-San Joaquin Delta began in 1922. Today the major issues are salinity, water movement and weed control. Decisions involve the use of the Delta for water transfer and storage, a peripheral canal and recreational center, and possible agricultural use. In recent years about 120,000 acres are used for the production of crops–mostly corn, wheat, barley and asparagus (219-220).

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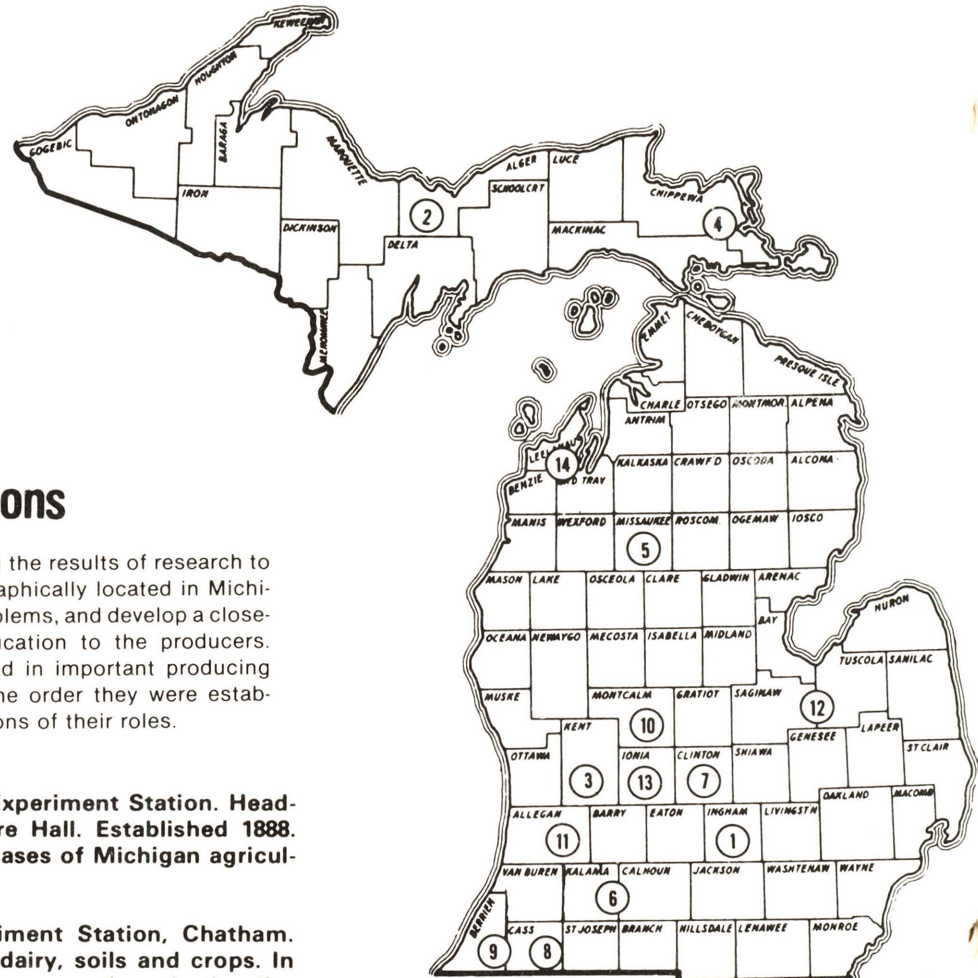

Outlying Field Research Stations

These research units bring the results of research to the users. They are geographically located in Michigan to help solve local problems, and develop a closeness of science and education to the producers. These 14 units are located in important producing areas, and are listed in the order they were established with brief descriptions of their roles.

1. **Michigan Agricultural Experiment Station. Headquarters, 101 Agriculture Hall. Established 1888. Research work in all phases of Michigan agriculture and related fields.**

2. **Upper Peninsula Experiment Station, Chatham. Established 1907. Beef, dairy, soils and crops. In addition to the station proper, there is the Jim Wells Forest.**

3. **Graham Horticultural Experiment Station, Grand Rapids. Established 1919. Varieties, orchard soil management, spray methods.**

4. **Dunbar Forest Experiment Station, Sault Ste. Marie. Established 1925. Forest management.**

5. **Lake City Experiment Station, Lake City. Established 1928. Breeding, feeding and management of beef cattle and fish pond production studies.**

6. **W. K. Kellogg Biological Station Complex, Hickory Corners. Established 1928. Natural and managed systems: agricultural production, forestry and wildlife resources. Research, academic and public service programs.**

7. **Muck Experimental Farm, Laingsburg. Plots established 1941. Crop production practices on organic soils.**

8. **Fred Russ Forest, Cassopolis. Established 1942. Hardwood forest management.**

9. **Sodus Horticultural Experiment Station, Sodus. Established 1954. Production of small fruit and vegetable crops. (land leased)**

10. **Montcalm Experimental Farm, Entrican. Established 1966. Research on crops for processing, with special emphasis on potatoes. (land leased)**

11. **Trevor Nichols Experimental Farm, Fennville. Established 1967. Studies related to fruit crop production with emphasis on pesticides research.**

12. **Saginaw Valley Beet and Bean Research Farm, Saginaw. Established 1971, the farm is owned by the beet and bean industries and leased to MSU. Studies related to production of sugar beets and dry edible beans in rotation programs.**

13. **Clarksville Horticultural Experiment Station, Clarksville. Purchased 1974. Plots established 1978. Research on all types of tree fruits, small fruits, vegetable crops and ornamental plants.**

14. **Northwest Michigan Horticultural Research Station. Established 1979. Research and education for cherry and other horticultural crops in northwest Michigan.**

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