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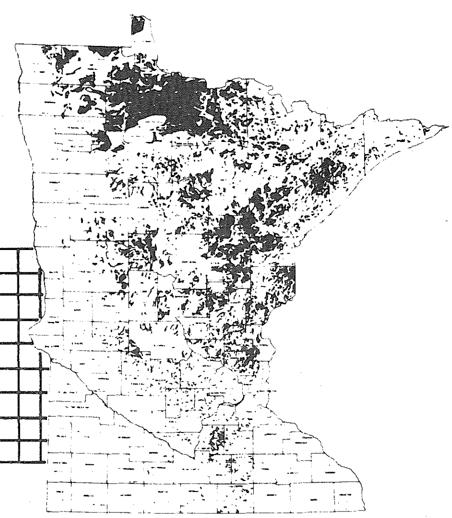
MINNESOTA PEAT PROGRAM

Revegetation of Mined Peatlands: Environmental Properties of a Mined Area



Minnesota Department of Natural Resources

REVEGETATION OF MINED PEATLANDS:

I. Environmental Properties of a Mined Area

by

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Prepared for:

Minnesota Department of Natural Resources

Minnesota Peat Program

November 1981

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INTRODUCTION

Recent figures indicate that the world's peat deposits, exceeding 30 cm in depth, total about 420 million hectares (Kivinen and Pakarinen 1980). This figure approaches a half billion hectares when tropical and subtropical peat resources are included. Although most of the peat deposits of the world are located in North America and on the Asian continent, utilization of this resource in these areas has not been great. In contrast, the middle European people have a long history of peat utilization and currently have only 10 percent of their original peatlands remaining untouched.

In the United States, peat has long been used for horticultural purposes. Recently, with the search for alternative energy sources, peat has also been investigated as a potential energy source.

Research and development of peat for energy and for horticultural purposes will continue in varying degrees as new technologies are discovered. Questions to be raised, then, are (1) what will happen to peatland areas after mining has ceased, and (2) what effect does peat mining have on the ability of an area to restore itself. These two questions are addressed in the following report.

PURPOSE AND SCOPE

For this part of the study the major objective has been to determine what factors may influence the natural revegetation of disturbed peatlands. This project is intended to serve as a beginning for more definitive research into specific physical, chemical, and biological changes that result from drainage of peatlands and removal of peat. It is hoped that this study will point the way toward discovering and refining efforts to establish some type of vegetation on abandoned peat mines.

One field season is not enough to draw complete conclusions regarding the interrelationships of ecological factors. Variations in rainfall and temperature over a number of years influence natural processes in unpredictable ways.

THE STUDY AREA

Minnesota contains about three million hectares of peatland. Some of the large bogs remain untouched while others have been subject to mining for horticultural peat for many years. About one-half of Minnesota's peatlands are state-owned or -administered. The state has leased or is considering applications for leases on over 20,000 hectares. These leases are for horticultural peat production and wild rice production.

The study area is located on the Corona Bog in Carlton County adjacent to a 280 hectare peat mining operation currently run by Michigan Peat Company. Corona Bog was formed by the lakefill process. The bog is approximately 5.5 m deep, with *Sphagnum* peat overlying reed-sedge peat.

At the site there are several abandoned fields that were cleared about 30 years ago and from which an undetermined amount of peat was removed. Two fields in particular show striking dissimilarities in terms of natural recovery of vegetation. These fields and an undisturbed area (Control) separating them were chosen as representative study areas.

Field 1 is a relatively dry area (Figure 1). Very little natural revegetation of bog species has occurred since the field was abandoned. Species present include *Picea mariana*, *Larix laricina*, *Alnus* spp., *Eriophorum* spp. and *Vaccinium* spp. In addition there are species which commonly occur on dry sites such as *Aralia hispida* and *Pinus banksiana*. The ditches that were originally constructed to drain the field are still in place but are not maintained, and the water does not flow freely in them. Adjacent to the east-west running ditches is a strip of peat material henceforth known as the Ditch Banks. The north Ditch Bank is 80 cm higher than the south Ditch Bank. These banks were apparently formed during ditch construction when the extracted peat was simply piled adjacent to the ditches. The Ditch Banks are more heavily vegetated than the remaining field.

In contrast, Field 2 is very wet and has the characteristics of a quaking bog (Figure 1). One section is a floating mat of vegetation. The vegetation on the field is dominated by *Sphagnum* spp. and other mosses, *Eriophorum* spp., *Drosera rotundifolia*, *Vaccinium oxycoccus* and a few dwarf *Picea mariana* and *Larix laricina*. There are no long parallel ditches draining this field, but rather ditch-like depressions leading

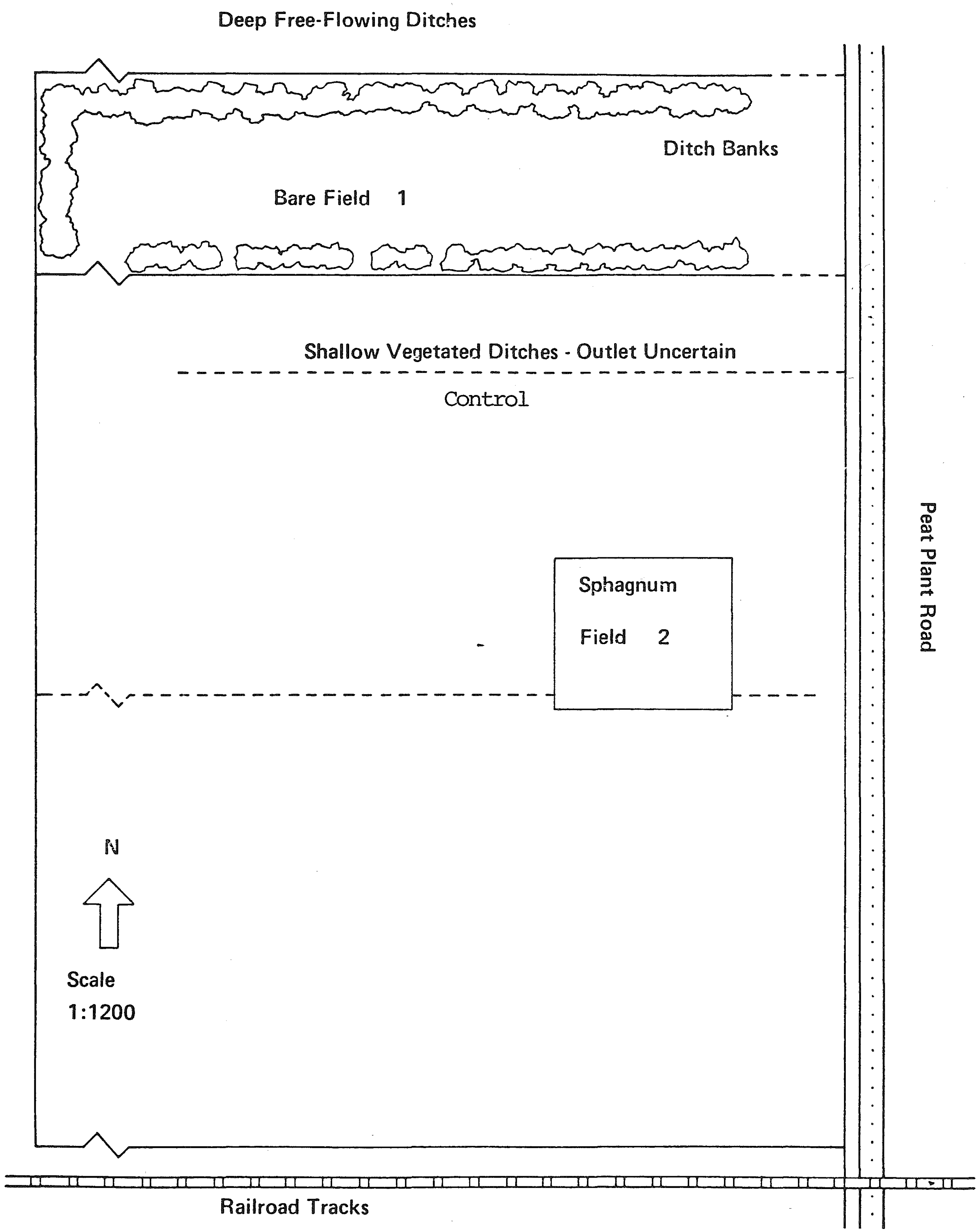

Figure 1. Corona Bog study area in Carlton County, Minnesota.

away from the southeast and southwest corners of the field. Both of these ditches have overgrown with *Sphagnum*, and no water movement was noted. Subsurface drainage may still occur. Piles of bare peat scattered around the perimeter of this field suggest that minimal efforts at draining the area were followed by a process of scooping the peat material from the field. The piles were apparently left to dry before use. Field 2 is actually a depression in relation to the surrounding peat surface. This fact, plus the marginally effective drainage system explains the excessive wetness of the field in contrast to adjacent areas.

ENVIRONMENTAL PROPERTIES

Temperature, ash content, bulk density, moisture content, ground water levels, nutrients, pH, and redox potential are all environmental properties of peatlands that may influence the revegetation of mined areas.

Temperature

Because of the dark color of the peat surface on Field 1 and uninhibited exposure to sunlight, it was considered possible that lethal temperatures may occur on the surface thereby prohibiting germination and subsequent growth of plants. No such problem was considered likely on the extremely wet surface of Field 2.

Levitt (1972) states that the greatest danger of heat injury occurs when soil is exposed to insolation reaching temperatures of 55-75°C. He further suggests that the amount and kind of heat damage to plants depends on the bulk of the plant structures, indicating that the thinner stolons of range grasses are much more susceptible to heat injury than bulky plant parts which serve to control internal temperatures. Peat temperature regime studies conducted by Brown (1973) at the U.S. Forest Service Experiment Station in Marcell, Minnesota, show that removal of the canopy alone does not affect temperatures in the peat material. It should be noted, however, that after removal of the forest canopy, a luxurious sedge cover rapidly established itself.

Soviet scientists concerned with frost damage on reclaimed bogs indicate that killing frosts are more common on such areas, but the frequency and intensity of these events decreases with cultivation (Skoropanov 1961).

Temperature data were collected on Field 1 at three levels--air, surface, and subsurface (10 cm depth). The sensing probe on the surface of the peat was covered by a thin layer of peat to protect it from direct sunlight. Daily maximum temperatures were recorded for each level using a three-pen thermograph. No temperature data were collected on Field 2 or on the Control.

Ash Content

Ash content, expressed as percent oven-dry weight, is a measurement of the mineral constituents in the peat which are derived from the original peat-forming plants as well as from water- and wind-borne mineral particles. The procedure is to dry, weigh, pulverize, and then ash a sample of peat. The ash content is then determined from:

$$\frac{\text{Weight of ash}}{\text{Oven-dry weight}} (100) = \text{Ash content } (\%)$$

Peat samples were taken from 0-2 cm and 8-12 cm depths on each field.

The ash content can vary from approximately one percent in raw, undecomposed organic material to over 40 percent in highly decomposed peat under cultivation (Skoropanov 1961). There are several relationships between ash content and other properties in peatlands. Malterer et al. (1979) indicated that ash content and bulk density are positively related. Skoropanov (1961) studied the changes in the hydro-physical properties of drained bogs and concluded that compaction and mineralization of the peat mass is accelerated by drainage. While degree of decomposition increases with ash content, obviously fiber content will decrease. Sillanpaa (1972) showed that ash content increases with depth in the peat profile.

Bulk Density

Bulk density is the weight of dry soil per unit volume. The procedure was to carefully insert a cylinder of known volume into the peat surface with the least possible disturbance to the sample itself. A large knife was then used to cut down into the peat. The cylinder was gradually worked downward until the surface of the peat was flush with the top of the cylinder. The core was then removed from the cylinder and oven-dried. Bulk density is determined on a dry volume basis from:

$$\frac{\text{Weight of dry sample (g)}}{\text{Volume of sample (cc)}} = \text{Bulk density (g/cc)}$$

The samples taken for bulk density included the upper 10 cm of peat.

Bulk density of soil varies from 0.2 g/cc in organic materials to almost 1.9 g/cc in coarse sandy soils (Wilde 1958). Brady (1974) notes that an outstanding characteristic of peat is its light weight when dry and reports bulk densities from 0.2 g/cc to 0.3 g/cc as common for well decomposed organic soils. Further, he states that a higher bulk density indicates more compaction. Skoropanov (1961) suggests that prior to drainage the bulk density of peat is comparatively uniform throughout the vertical profile. After drainage, the maximum bulk density is found in the surface layers and decreases with depth. The minimum bulk density occurs below the water table. This latter fact is substantiated by Boelter (1966) who indicates that as bulk density increases, water content decreases.

Moisture Content

Measurements for moisture content were taken once on Field 2 and three times on Field 1. The moisture contents on an oven-dry basis for Field 2 were consistently greater than 100 percent even during the driest periods so that further investigation was deemed unnecessary. Moisture content on an oven-dry basis was determined from:

$$\frac{\text{Weight of water}}{\text{Oven-dry weight}} (100) = \text{Moisture content (\%)}$$

Relatively undecomposed peat has a higher water content due to larger pore sizes (Walmsley 1977). Also, *Sphagnum* moss peat is capable of holding more water than herbaceous peat. According to Brady (1974), it is not uncommon for peat soils to hold water weighing 12 to even 20 times their dry weights.

Ground-Water Levels

The water levels in the study areas were measured to determine fluctuation over the summer. Precipitation was also measured near the study site to compare changes in water level to precipitation.

Water-table wells, constructed of 1.2 m long aluminum pipes with holes drilled at intervals along their length, were used to locate ground water levels on both fields. Weekly water-table measurements were made in 16 wells on Field 1 and eight wells on Field 2. A graduated bubbler device was used to measure the distance to the ground water level.

Platonov (1967) states that lowering the water level dries the peat and results in compaction of the upper layer of peat and increases the degree of decomposition of this layer. According to Platonov, drainage ditches had an observable influence on the original plant cover up to 50 meters from the ditch banks. The most significant effects on plant growth occurred within a 10-20-m-wide strip adjacent to the ditches. Jeglum (1971) assigned moisture class values (both numerical and descriptive) to describe a peatland area in Saskatchewan, Canada. According to Jeglum's data there are demonstrable relationships between vegetal species and pH and depth to ground-water levels on natural peatlands. Whether the same relationships remain intact on disturbed peatlands is in question.

Ivitskii (1962) states that deep drainage changes the peat mass into a kind of reservoir for snowmelt and rainwater where soil moisture is substantially protected from transpiration and evaporation losses.

In addition, Ivitskii points out that, with a water level maintained 120-130 cm below the soil surface, the composition of the soil air is optimum for moderately well-decomposed peat and suitable for sugarbeet, potato, hemp, and flax production.

Nutrients

Chemical analysis of 16 elements was conducted on peat samples from Field 1 and 2 at the 0-2 cm and 8-12 cm soil depths. Samples were collected and pulverized before being sent to the Research Analytical Laboratory at the University of Minnesota, St. Paul, for analysis.

Generally, organic soils are poor in nutrients. Fibric peat of *Sphagnum* moss origin is considered to be the lowest in nutrients of organic soils. Lishtvan (1976) states that the quantity of certain elements in peat soils changes with depth. Lähde (1969) indicated that potassium, phosphorus, and calcium quantities decrease with increased depth. Lishtvan (1976) reports that, on reclaimed peatlands, the depth of drainage and the duration of soil cultivation will alter nutrient content. Nitrogen content in peat soils is generally considered high and will increase with increasing degree of humification (Lähde 1969).

The availability of important plant nutrients is affected by pH. Small (1972) states that phosphorus uptake by plants is slow in acid soils of high organic content because phosphorus forms organic compounds which are unavailable to plants. This apparent phosphorus shortage is exacerbated in oligotrophic bogs by low phosphorus concentrations in rainfall. Under acid conditions, high concentrations of aluminum and manganese may develop, which could result in toxicity and impaired growth (Small 1972). High concentrations of aluminum ions tend to disrupt phosphorus uptake. Small concluded that the high proportion of evergreen species in bogs may be the result of a scarcity of nutrients and that bog plants have not only adapted to short nutrient supplies but may have an ability to selectively exclude toxic substances which develop in acid conditions.

pH

The pH of the peat on Fields 1, 2, and the Control was determined by combining 15 cc of lightly packed peat with 15 ml of deionized water. Samples were taken at the 0-2 cm and 8-12 cm soil depths.

Peat soils are generally acidic, but may range from pH 3.0 to 8.0 (Walmsley 1977). Brady (1974) stresses the importance of soil pH as it relates to nutrient absorption and plant growth. Soil pH affects the availability of certain essential plant elements (Figure 2). Below a pH of 5.0, aluminum, iron, and manganese are soluble and may, in sufficient amounts, be toxic to some plants.

In addition to the above considerations, low soil pH can inhibit microorganism activity and thus contribute to slow decomposition and rapid peat accumulation (Waksman and Stevens 1929). Brady (1974) points out two anomalous characteristics of peat and soil pH. One is that even though organic soils are relatively high in calcium, they are often highly acidic because of their high cation exchange capacities. Their exchange sites are dominated by hydrogen ions, thus giving a low base saturation,

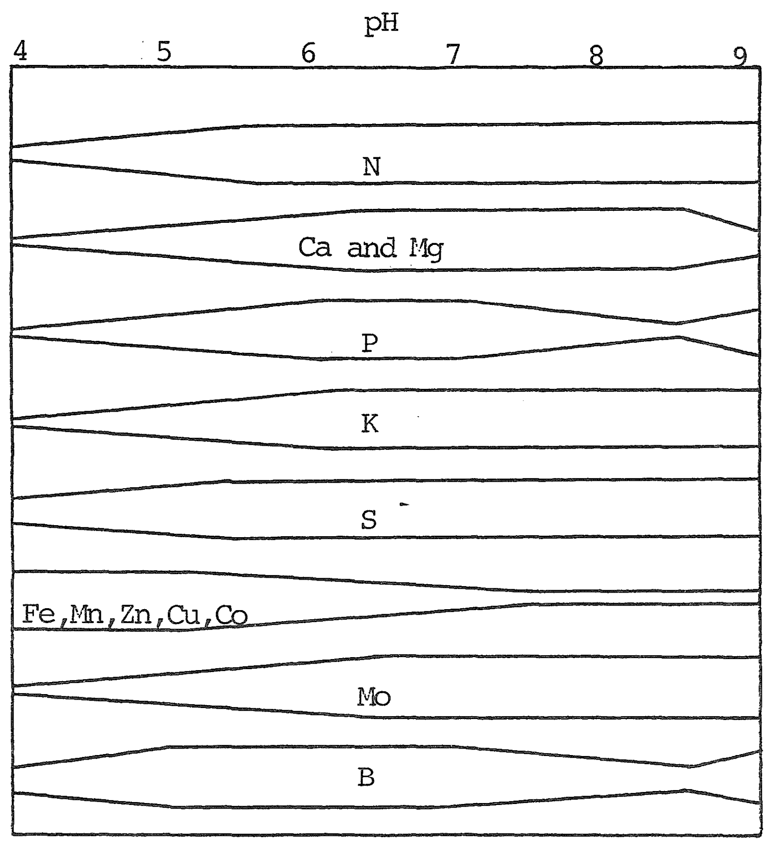

Figure 2. Effect of pH on availability of plant nutrients. From Brady 1974.

and the acidic conditions prevail. Also, nitrate accumulation occurs to a much greater extent in peat soils than in mineral soils having the same pH.

Redox Potential

The redox potential of the study areas and control area were monitored on a weekly basis throughout the field season by using platinum electrodes in the peat soil at a depth of approximately 10 cm. A calomel reference electrode was placed about 6 cm from the platinum electrode. A current was applied and several minutes were allowed for the needle to settle before a millivolt reading was recorded. High positive values indicate a greater intensity of oxidation over reduction.

There are many factors which affect the redox potential of a soil-water system. Among these, pH, moisture content, and chemical activity are only a few. Research using redox potentials has been conducted to determine how closely the aerobic limit in the soil follows the ground water table. This relationship exists, but it should be pointed out that there is no exact relationship between the exclusion of oxygen through waterlogging and the potential created (Burrows and Cordon 1936). In addition, it appears that laboratory experiments have shown that the type of organic matter undergoing decomposition has a marked effect on the redox potential (Burrows and Cordon 1936). Using a similar method, Lähde (1971) showed that the aerobic limit is an important indicator of site quality, but should be supported by other parameters of growth conditions.

Throughout the literature it is evident that waterlogged systems are characterized by reducing conditions or lower potentials. Generally, waterlogged soils have a potential of less than 200 millivolts adjusted to pH 5. But redox potential is not controlled completely by the water and air content of the soil. Soil texture appears to have some effect on potential, as do soil microflora (Pearsall 1938).

Redox potentials can change over an area for several reasons. Any alteration of water movement or levels will affect potentials. Movement of oxygenated water through a fen or swamp will keep potentials higher than if the water was stagnant. In addition, heavy rainfall can lower potentials in the surface peat layer enough to cause a significant concentration of reduced forms of iron, aluminum, and manganese (Haavisto 1974). This occurs through the mechanism of direct displacement of interstitial oxygen by water. Haavisto's research was accomplished on a floating peat mat with many similarities to Field 2 of the present study. It is suggested that the profound effects that occur on such a waterlogged site after a heavy rainfall would be significantly greater under drier conditions such as exist on Field 1.

Pierce (1953) equated redox potential and dissolved oxygen content to forest growth in a peat bog area. Pierce concluded that reducing conditions and low specific conductance in swamp areas result in the slow growth of plants adapted to acid conditions.

RESULTS

Temperature

The highest air temperature recorded during the monitoring period was 32.3°C. The surface probe recorded a high of 46.1°C, while the subsurface of the peat remained relatively cool with a high of only 24°C. The lowest temperature recorded on all three levels was about 12°C. The disparity between the high surface and subsurface temperatures indicates the insulating properties of peat.

The high surface temperature (46.1°C) is not ordinarily considered to be lethal to plants nor a major inhibitor of germination. However, damage may occur, especially when rainfall is inadequate. In such a case, it is possible that desiccation can occur because the plant roots are slow to penetrate to the ground water level and high temperatures on the surface dry out the plant parts.

Brown (1976) compared the peat temperature regime of forested and clearcut strips in Minnesota. No ground vegetation was removed from the clearcut strips. Both surface and air temperatures followed the same general trend during the monitoring period. This was also true for the bare peat area in June, July, August, and September, 1980 (Figures 3-6). However, the highest surface temperature recorded by Brown was only about 25°C,which occurred after a fairly dry period. It is evident that removal of the forest canopy alone may not alter surface temperatures, but that removal of ground vegetation will increase surface temperature.

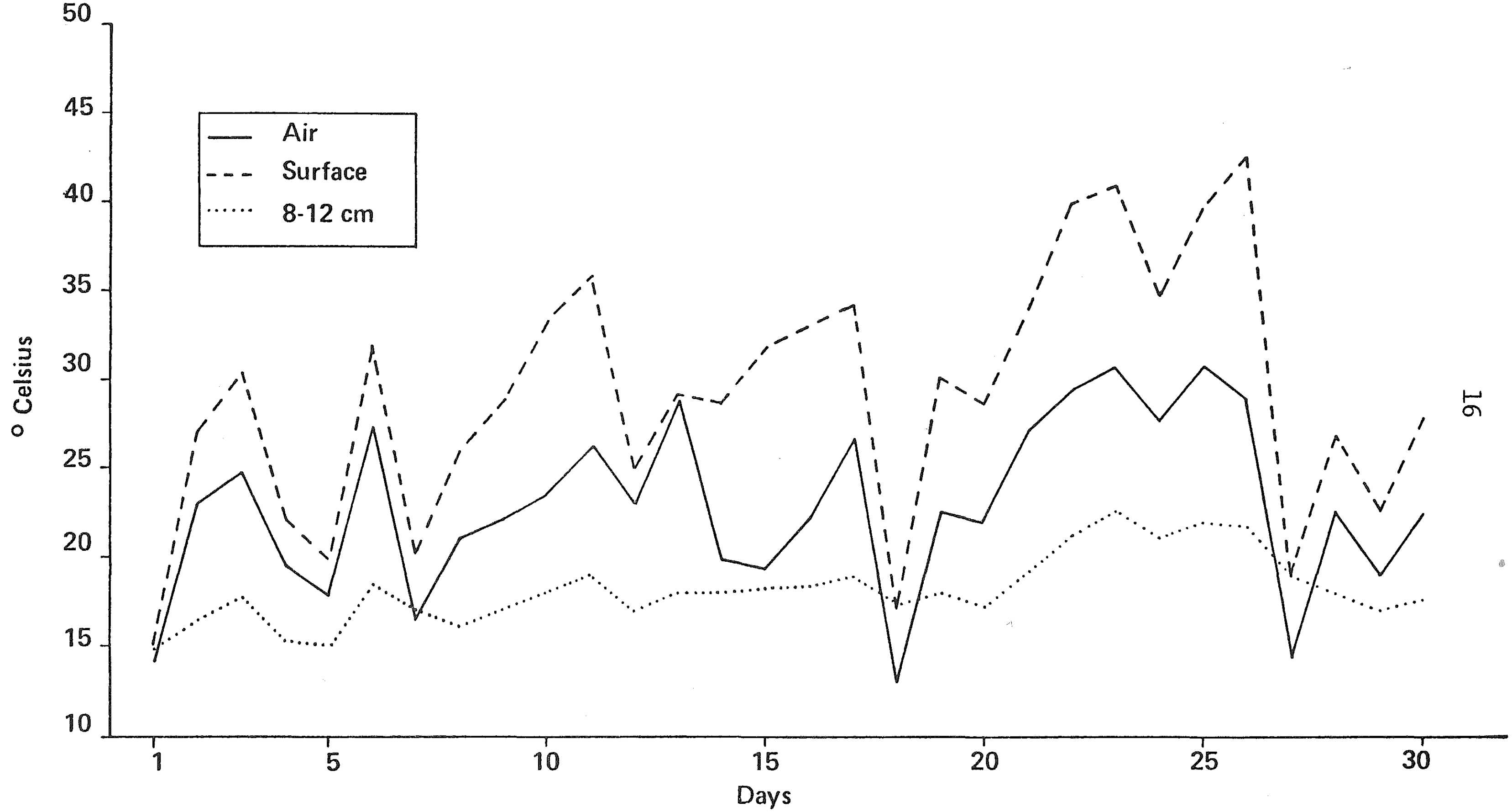

Figure 3. Daily maximum air, soil surface and subsurface temperatures for June, 1980, on Field 1, Corona Bog, Carlton County, Minnesota.

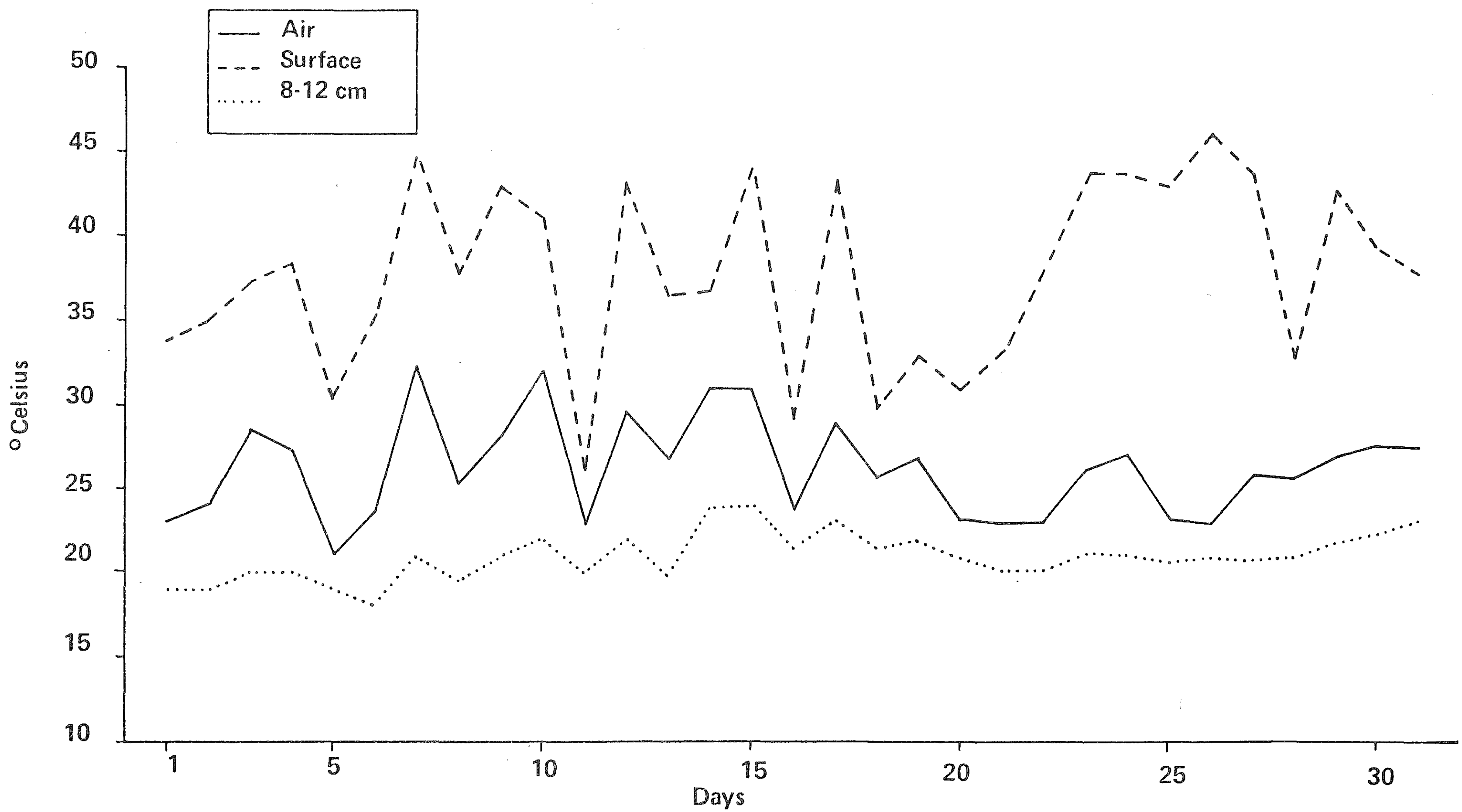

Figure 4. Daily maximum air, soil surface, and subsurface temperatures for July, 1980, on Field 1, Corona Bog, Carlton County, Minnesota.

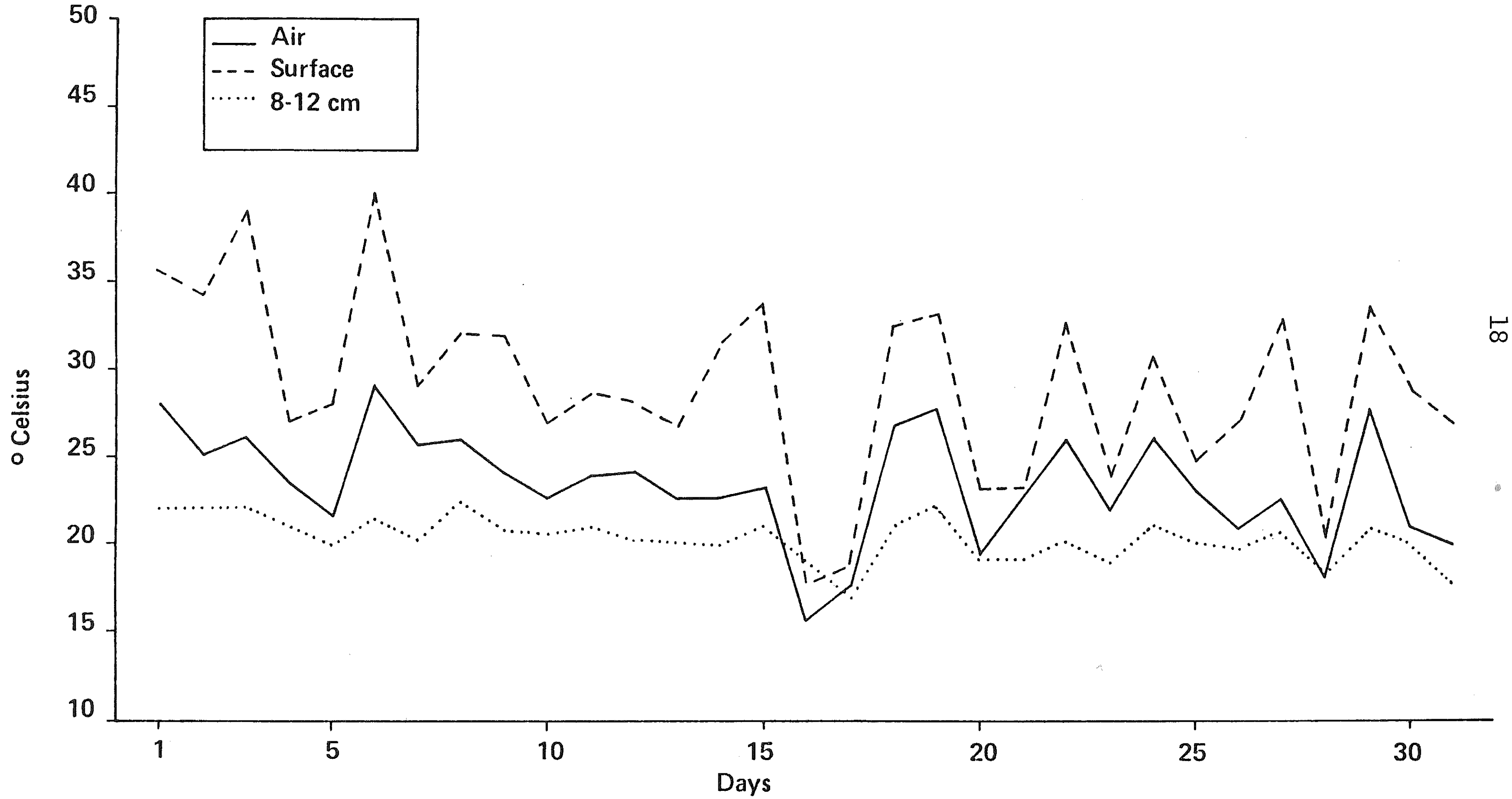

Figure 5. Daily maximum air, soil surface, and subsurface temperatures for August, 1980, on Field 1, Corona Bog, Carlton County, Minnesota.

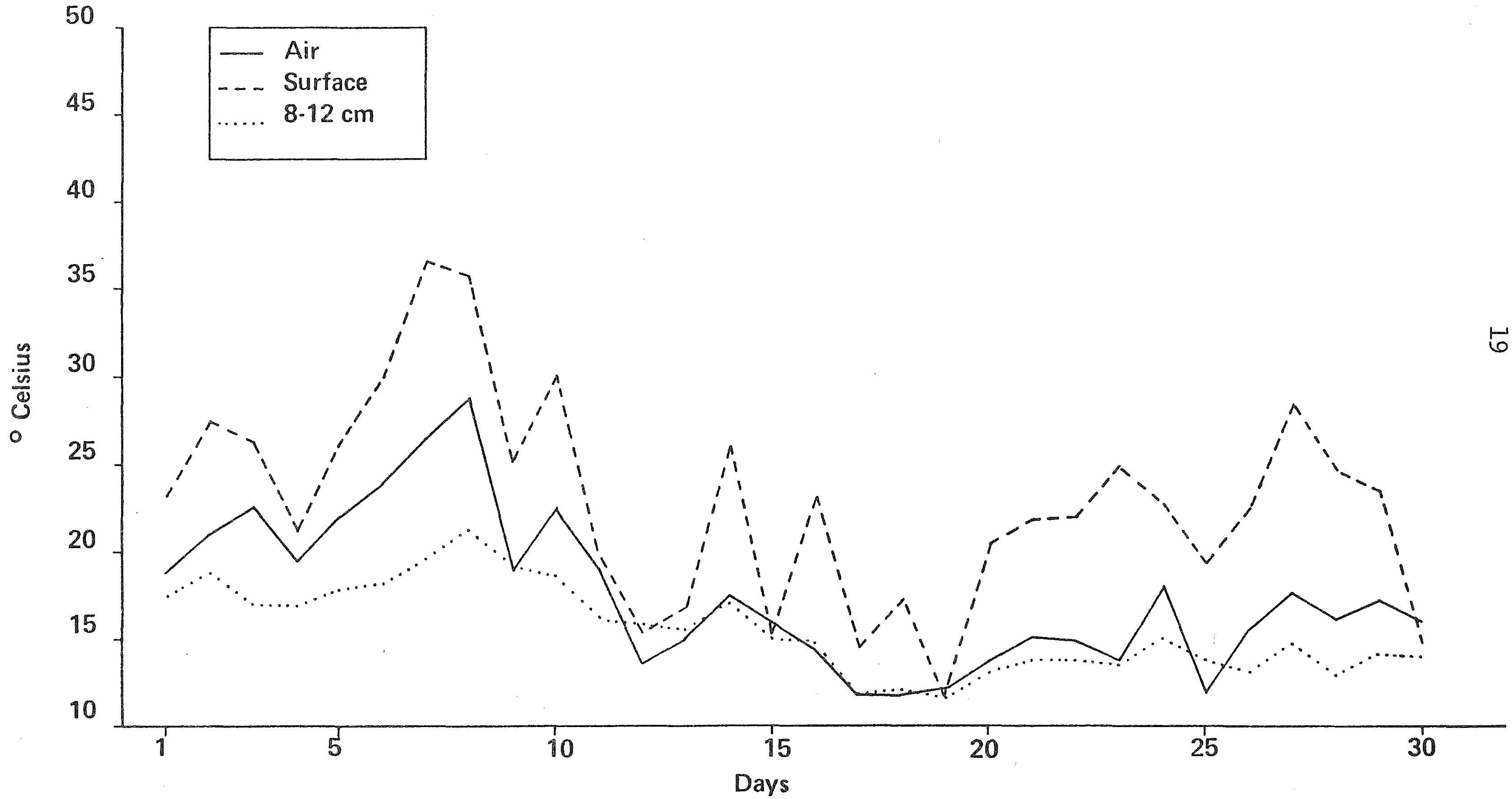

Figure 6. Daily maximum air, soil surface, and subsurface temperatures for September, 1980, on Field 1, Corona Bog, Carlton County, Minnesota.

It seems possible that temperatures on the exposed peat surface could rise to levels that are damaging to plants. One wet summer may result in the germination of seeds, but a subsequent dry summer could desiccate small plants if conditions were severe enough. This factor alone cannot explain the bareness of Field 1, but high surface temperatures probably have made plant establishment and growth difficult. Field 2 is so wet that such conditions could not occur on the surface.

Ash Content

Ash content is positively related to other physical factors in peat soils. Among these are specific gravity, bulk density, and degree of decomposition. Conversely, the fiber content of the peat will decrease as the ash content increases.

The ash content of the peat was similar at the surface of both the dry and wet fields (Table 1). However, the ash content at the 8-12 cm depth in the dry field was lower ($\alpha = 0.01$).

Table 1. Average ash content for two soil depths on Fields 1 and 2.

Soil depth (cm)	Field 1 (dry) (%)	Field 2 (wet) (%)
0-2	15	15
8-12	4	8

Sillanpaa (1972) found a higher concentration of minerals at the peat surface, with concentrations decreasing to a minimum at the midpoint in the profile and then increasing rapidly again as the mineral soil substrate is approached. A higher ash content at the surface was found in this study (Table 1). The values measured agree with those obtained by Malterer et al. (1979) for ash content on undisturbed peatlands in Minnesota.

Drainage in peatlands causes increased mineralization of the peat surface. Therefore, it is curious that the 8-12 cm depth in Field 2 has a higher ash content than the same depth on Field 1. Aerobic decomposition of peat materials should result in higher ash content on Field 1.

Bulk Density

Bulk density measurements were taken on Field 1 and Field 2, but not on the Control area. The average bulk density at the surface of the peat soil was greater ($\alpha = 0.01$) on the drained, dry field than on the wet field (Table 2). Skoropanov (1961) reports that the maximum bulk density on drained bogs will occur at the surface and the minimum will be found below the ground-water level. This agrees with the findings of this study.

Table 2. Average bulk density of peat soil (upper 10 cm).

Field 1 (dry)	Field 2 (wet)
0.163 g/cc	0.0926 g/cc

Moisture Content

Moisture content will naturally vary with the amount of precipitation that has fallen. Field 2 shows no significant differences between the surface and subsurface moisture content of the peat. There are, however, significant differences within Field 1 and between the two fields at both soil depths. Samples taken on Field 1 after several days of dry weather show that the surface of the peat contained only six percent moisture on a dry weight basis.

Table 3. Average moisture content for two soil depths on Fields 1 and 2.

Soil depth	Field 1 (dry) (%)	Field 2 (wet) (%)
0-2 cm	8	159
8-12 cm	107	161

Since the most striking difference between the two study areas is the amount of moisture present, these results were not unexpected. What is noteworthy about this data is the surface dryness of Field 1. Such desiccation of the peat surface does not occur naturally but is probably the result of drainage. While the lack of moisture makes the site suitable for horticultural mining of the peat material by using vacuum harvesters, slow rewetting of the dried surface layer adversely affects plant establishment.

The question is raised about why vegetation has been able to grow on the Ditch Banks of Field 1. An explanation may be found in the variation that occurs on the surface of Field 1 as it becomes wetted by precipitation and then dries to extremely low amounts of available water. The initial moisture supplied by rains may encourage germination of seeds, while the dry conditions that occur in late June, July, and early August serve to inhibit continuation of the growth cycle. Observations in the field show that the surface of Field 1 becomes powdery when dried. In addition, the surface of Field 1 is much darker than the surface of Field 2, indicating increased mineralization. The dark peat surface absorbs radiation, compounding the dry conditions already exacerbated by a lack of shade. It seems likely that the cycle of wetness and extreme dryness on Field 1 inhibits growth of bog species. The Ditch Banks somehow broke out of that cycle. The close proximity to the ditches probably enabled plants to capture the water necessary for growth. These areas are also closer to seed sources than the center of Field 1. The only drawback to this explanation is the fact that water levels across the field show a typical convex shape. This means that the ground-water level is farthest from the peat surface along the Ditch Banks. Again, however, the close proximity to the water-filled ditches may have been the factor that allowed establishment of plants, with the increase in shading then encouraging further initial establishment and plant growth.

Ground-Water Levels

The depth to the ground-water table, as measured on two transects across each field, varied over the summer field season. The water table was higher and fluctuated less on the wet field than on the dry field (Table 4). The ground-water table on Field 1 follows the shape expected

Table 4. Maximum and minimum depths to ground water table and seasonal fluctuation of ground water table on Fields 1 and 2.

	Date	Field 1 (dry) (cm)	Field 2 (wet) (cm)
Mean Minimum	September 9	15.9	0.9
Mean Maximum	July 7	48.0	+16.8 (above ground surface)
Fluctuation	--	32.4	17.7

in drained peatlands (Figures 7 and 8). The water level on Field 2, however, does not seem to be affected by the hydro-physical properties that result in a curved water table (Figure 9). Even though Field 1 is lower in elevation than Field 2, the drainage makes Field 1 drier, with a more variable ground water level than Field 2. Since Field 2 was mined and abandoned, the laying down of peat materials has gone on in a very wet environment, which inhibits decomposition. The situation on Field 2 is similar to a very small lake-fill process, like the one that created the Corona Bog. Compaction, mineralization, and subsidence probably never occurred on Field 2 because of the abundance of moisture. The drainage system was not nearly as effective as that on Field 1.

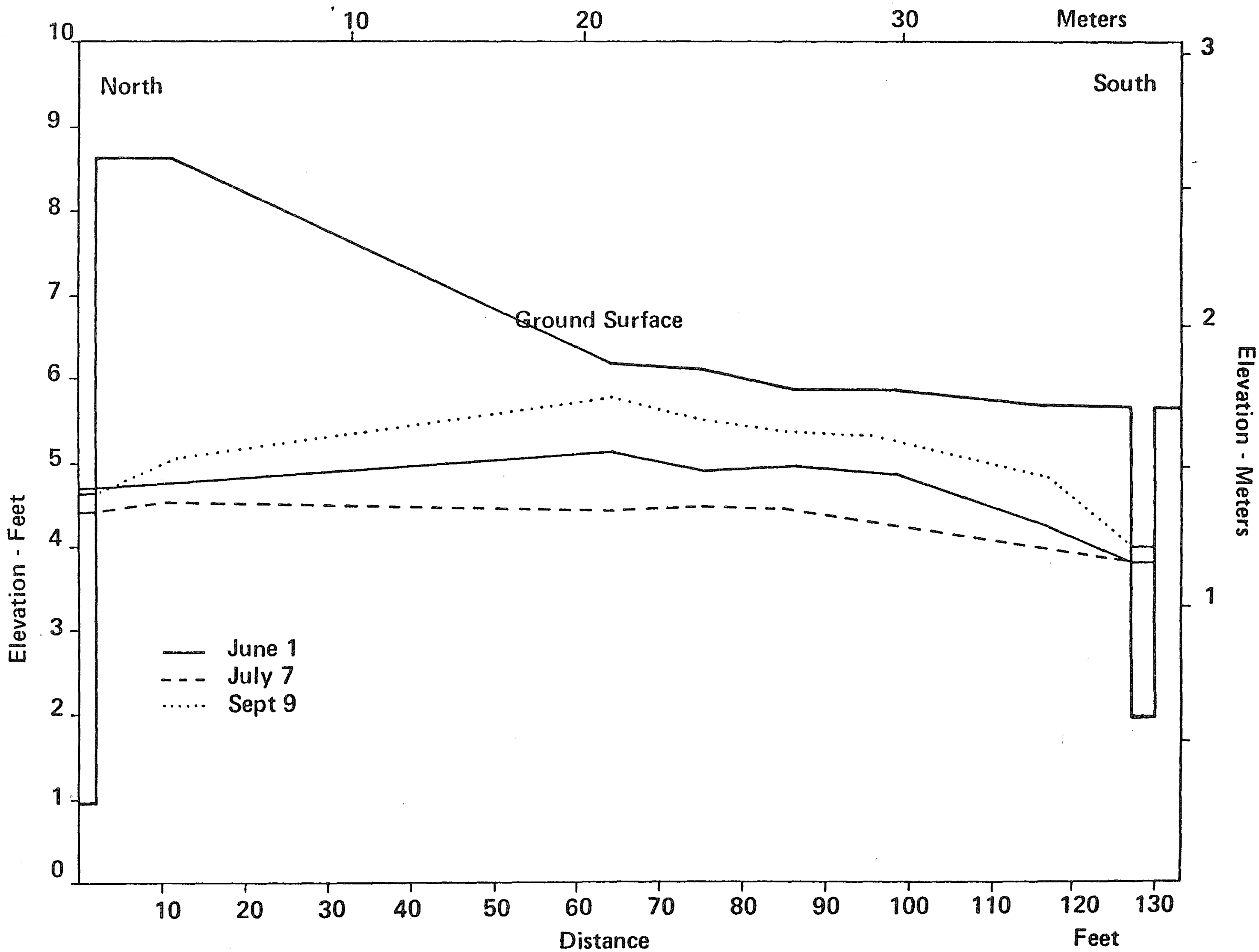

Figure 7. Ground water table of Field 1 (east transect) in Corona Bog, Carlton County, Minnesota. 1980.

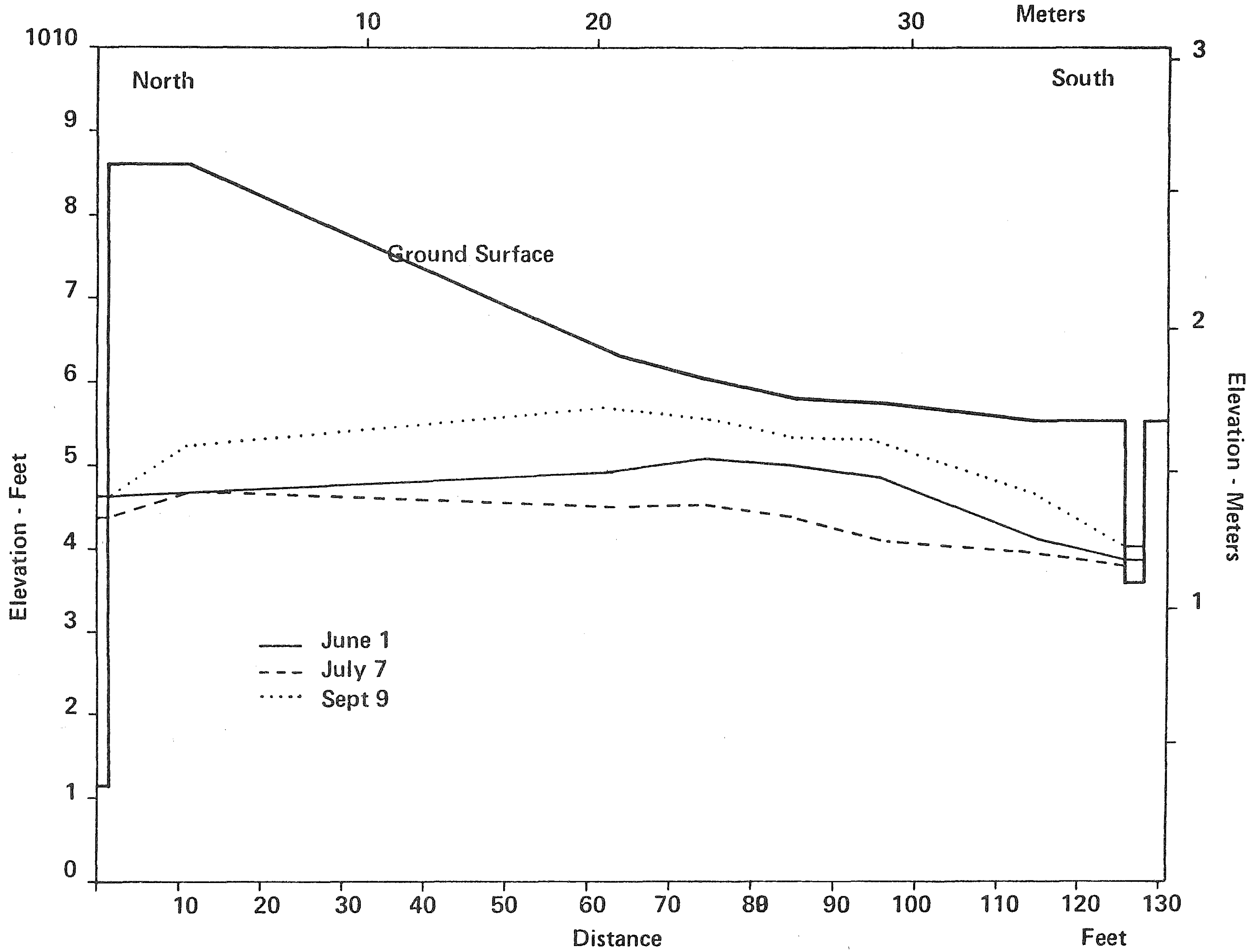

Figure 8. Ground water table of Field 1 (west transect) in Corona Bog, Carlton County, Minnesota, 1980.

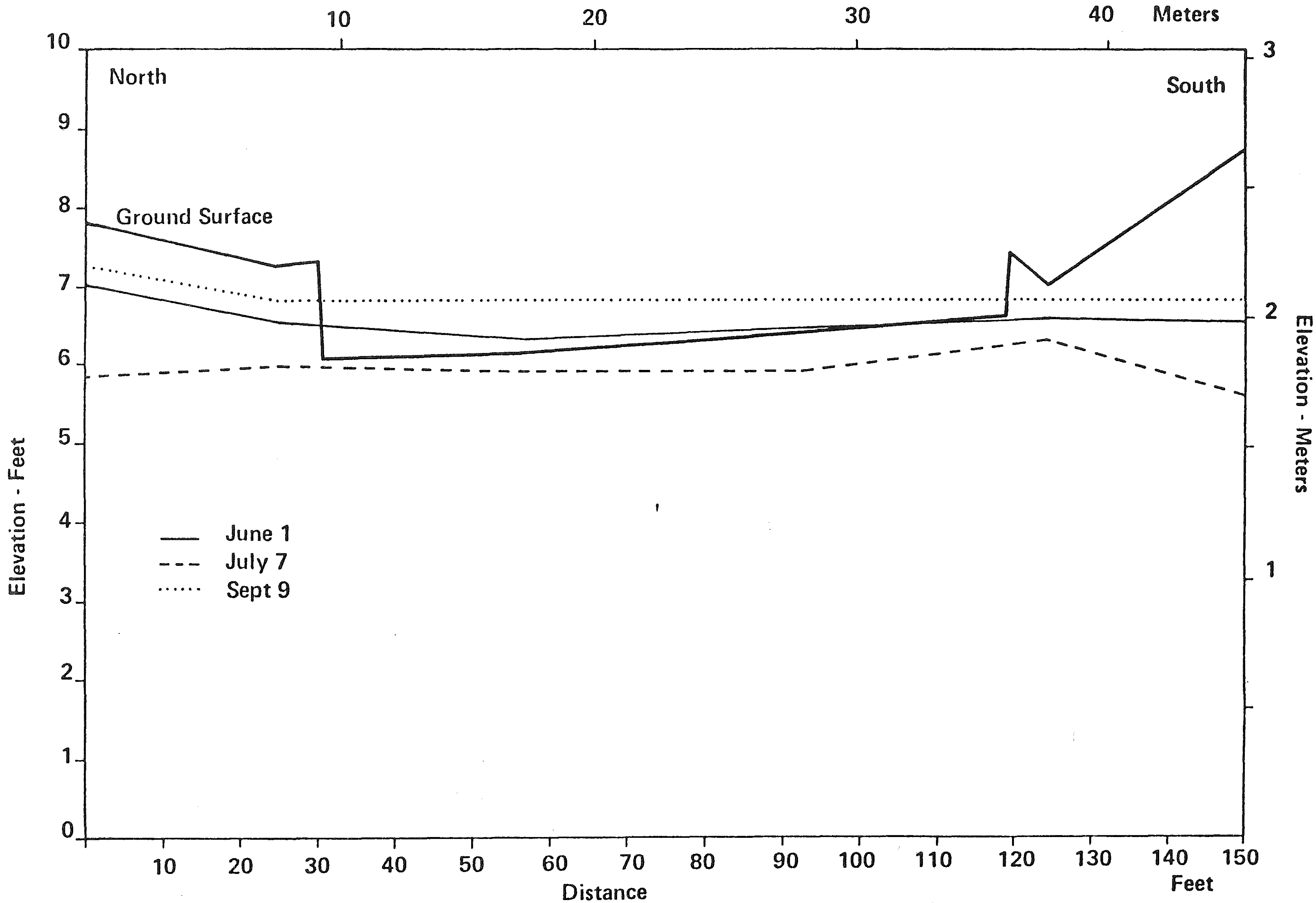

Figure 9. Ground water table of Field 2 (east transect) in Corona Bog, Carlton County, Minnesota, 1980.

The lowered ground-water levels on Field 1, therefore, produced many changes not evident on Field 2. Initially, drainage caused compaction of the peat mass, through mineralization and subsidence. Formulas used for calculating subsidence include such factors as peat thickness, depth of ditches, and a coefficient representing peat density (Nesterenko 1976). Peat subsidence will increase with the thickness of the peat, looseness of the organic material and depth of the ditches. In cultivation efforts, the problems of overdrainage have received much attention. Overdrainage of peat soils may result in super-drying of organic colloids, rendering them incapable of absorbing moisture (Skoropanov 1961). Cultivation of overdrained peat soils may cause the arable horizon to become an unwettable dust. Indications are that some, or all of these processes have occurred on Field 1 because of the drainage. Undoubtedly, compaction, mineralization, and subsidence have occurred. Other documented effects of overdrainage include a disappearance of the natural peat structure and formation of a surface layer which prevents efficient air and water movement (Olkowski and Olkowski 1976). In addition, water-holding capacity and capillary rise are decreased because of the structural breakdown of the peat, which results in extreme water deficiencies and the disappearance of even mesophilic plants. Field 1 is probably affected in all of these ways.

Nutrients

Analysis of peat samples from Fields 1 and 2 for nutrient content shows some differences between and within the two study sites (Table 5).

The surface of Field 1 has a greater concentration of elements than the 8-12 cm depth because of increased mineralization and decomposition of the exposed peat. Both fields show a greater quantity of certain elements in the surface layer. This concentration of elements was also noted in the ash contents (Table 1). The presence of significantly higher amounts of Al, Fe, and Mn in the surface of Field 1 as compared to the 8-12 cm depth may have a toxic effect on plant growth and development.

Overall, Field 2 has a greater concentration of nutrients at both depths than Field 1. Ash content data can be verified by the higher concentration of minerals in the subsurface of Field 2. The ash content for the 8-12 cm depth is more than eight percent as compared to just under four percent for the 8-12 cm depth on Field 1 (Table 1).

Brune (1948) determined the average nutrient element content of a raised bog in Germany. The values for N, Ca, and P are very similar to those obtained in this study; however, potassium was below the amount reported by Brune. In terms of forest production, Malmstrom (1956) determined minimum amounts of macronutrients in peat to be very similar to Brune's, and again, potassium quantities on both fields fell below Brune and Malmstrom's recommended minimum amounts. However, comparisons with open and forested bogs indicate that neither field in this study is seriously deficient in the major nutrients necessary for growth. Stanek

Table 5. Average concentration of nutrients for two soil depths on Fields 1 and 2.[a]

Fields	1 (dry)		2 (wet)	
Soil depth (cm)	0-2	8-12	0-2	8-12
Elements	ppm			
P	479.99	358.30	539.60	443.46
K	230.18	80.6	375.10**	164.76**
Ca	3841.63	4130.60	3694.33	4865.85**
Mg	449.84	741.79	578.95**	709.41
Al	3221.55**	1854.53	1953.53	2649.85**
Fe	2905.20	1585.93	2457.78	2852.85**
Na	28.29	43.19**	49.97**	29.49
Mn	43.19	23.37	38.45	30.77**
Zn	29.60	17.65	32.87	32.88**
Cu	3.55	2.25	4.22	4.89
B	7.81	4.25	7.61	8.93**
Pb	52.35**	5.52	37.51	19.99**
Ni	3.03	1.22	2.51	2.44**
Cr	3.17	1.60	2.77	2.81
Cd	--	--	0.815	0.230**
	percent			
N	1.15	0.988	1.79**	1.22**

[a] values joined by a line are not significantly different at $\alpha = 0.01$.

** Indicates significantly higher ($\alpha = 0.01$) than value for other field at the same depth.

(1977) observed that bog vegetation will take advantage of nutrients in the peat wherever possible. The major impediment to this process, according to Stanek, would be waterlogging, although the other extreme (desiccation) is also a formidable obstacle.

For some levels of production, the study areas have definite nutrient deficiencies. Fertilization would be required for tree production according to the results reported by Stanek (1977). The concern here, however, is not necessarily tree production, but rather the reestablishment of natural vegetation on the bare peat surface. Consequently, it does not seem that the inability of Field 1 to revegetate can be attributed to a paucity of nutrients. In fact, as mentioned earlier, the abundance of certain elements (Mn, Al, Pb) particularly in the surface, may be inhibiting growth (Table 5). Although Field 1 is not severely bereft of nutrients (according to Stanek 1977) in comparison to Field 2, it has significantly lower concentrations of certain important elements (Table 5). The dynamic process of peat formation continues on Field 2, while Field 1 seems trapped in a static, nonproductive state. Any type of nutrient cycling on Field 1 is probably minimal, due to the lack of vegetation.

pH

Sampling for peat pH was accomplished on both Fields 1 and 2, the Ditch Banks, and Control. The pH of the dry field was lower than the wet field (Table 6).

Table 6. Mean pH for two soil depths on Field 1, Field 2, Ditch Banks, and Control.

Soil depth (cm)	Field 1 (dry)	Field 2 (wet)	Ditch Banks	Control
0-2	3.53	4.69	4.02	3.68
8-12	3.69	4.80	3.47	3.46

It has been reported that soil acidity increases after drainage of peatlands, and that a permanently saturated condition produces relatively higher pH values (Pearsall 1938). The effects of drying and the attendant increases in surface oxidation are both causes for a lowering of pH (Pearsall 1938). In light of this, the differences between the various sampling sites are not remarkable in terms of inhibiting or encouraging growth.

Field 2 is consistently more basic ($\alpha = 0.01$) than the other sampling areas, probably because of its very wet condition. The ditch banks on Field 1 were also more basic at the surface than either Field 1 or the Control. A low pH alone cannot be used to explain why Field 1 remains bare. Indeed, the control area has pH values that are comparable to or lower than the same levels on Field 1. Malterer et al. (1979) reported that pH values for 61 raised bogs in northern Minnesota ranged from 2.8-4.5 in the upper layers, which is comparable with the values measured in this study.

However, the effects that low pH has on nutrient availability cannot be overlooked (Figure 2). As mentioned earlier, low pH can cause an abundance of aluminum ions, which can inhibit the uptake of phosphorous. Also, the simple presence of aluminum and other toxic ions can be detrimental.

Redox Potential

Measurement of redox potential was conducted in both fields and the Control area. A saturated calomel electrode was used. Potential values (E_h) were corrected to a pH of 5.0 by adding 58 mV for each unit of pH above 5.0 or reducing for pH values below 5.0 (Pearsall 1938).

Any measurement of redox potential taken under natural field conditions represents only a quasi-equilibrium and not a true equilibrium because of the dynamic biological processes. Additional problems of instability occur because the concentrations of oxidizing and reducing substances that control the potential are so low that the potential is sensitive to even very minor disturbances. Because of the unknown systems involved in natural soil redox processes, the potentials measured in the field are to be regarded as an indication of the intensity of reduction and oxidation reactions.

The redox potential of the dry field was much higher than the wet field (Table 7). Pearsall (1938) in an early study of redox potential in various soil complexes stated that soils (mineral or organic) below an E_5 of 320 millivolts are termed reducing because of the presence of ferrous iron and the absence of nitrates. Conversely potentials above 320

Table 7. Mean redox potentials and their ranges measured on Fields 1 and 2 and Control.

Area	Redox potential (mV)		
	Range (Eh)	Mean (Eh)	Mean E5
Field 1 (dry)	432 - 848	796	807
Field 2 (wet)	-86 - 70	-17	2
Control	665 - 874	764	854

millivolts indicate oxidation. In an example of a disturbed peatland, Pearsall noted that high acidity, partial drying, and oxidation of the original peat are all closely related. Pearsall suggests that a pH of about 4.5 in a weakly oxidizing or reducing environment represents optimum conditions for accumulation of *Sphagnum* peat. Actual conditions on Field 2 are more reducing than this optimum but nonetheless are more appropriate for such peat formation than Field 1. Pearsall states that oxidation in moist organic soils leads to increased acidity and that drainage of these soils will cause a replacement of water with air which results in a higher hydrogen ion concentration (pH) and a redox potential increase.

All of these conditions are occurring on Field 1 as a result of drainage. Coincidentally, the conditions existing on the Control are very similar to those found on Field 1 in terms of pH and redox potential. Given this, it appears that the removal of all vegetation on Field 1 results in conditions unfavorable for reestablishment but not necessarily for growth. Another factor to take into consideration is that redox measurement on the Control is difficult because the reference electrode is inserted in peat that is highly fibric and has large air spaces.

DISCUSSION

It is apparent from the results of this study that several physical and chemical differences exist between the two study fields. Most striking, of course, are the disparities in the amounts of water held in the peat and as represented by the ground-water depths. The results of many of the other measurements can be attributed to the effects of ditching and sustained depression of the ground-water level on Field 1.

There remain a few puzzling relationships, though, that must be discussed. The phenomenon of the well-vegetated Ditch Banks is one which requires additional exploration. The trees (*Picea mariana, Betula papyrifera*) on the Ditch Banks were determined to have become established about the time that the area was drained and stripped of vegetation. There are many possible reasons why trees and other plants are growing on the Ditch Banks, and perhaps a combination of these reasons provides the best explanation. The proximity of this area to the water in the ditches may have provided some additional moisture necessary for establishment. The closer proximity to a seed source may also be favorable to early establishment. Another possibility is that because the peat was scooped from lower layers and piled along the banks, the processes of compaction and subsidence were hindered. In addition, the seasonal fluctation of ground-water levels on the Ditch Banks averaged between about 10-25 cm in contrast to an average seasonal fluctuation of 36 cm in the middle of Field 1. Lähde (1969) concluded that root penetration in peat soils correlates positively with depth to ground-water level and distance from the drainage ditch. He found that the greater the distance from the ditch, the thinner the soil layer in which living root systems are found because the water table is closer to the surface near the middle of a drained field. In reference to the aerobic limit, Lähde reported that the greater the depth to this limit during the growing season, the larger the volume of timber produced. Since the ground-water level is deepest below the Ditch Banks, it can be assumed that the aerobic limit is deeper than the aerobic limit in the middle of the field, although measurements for this were not taken. Finally, as the middle of Field 1 was being worked, the Ditch Banks were allowed to naturally revegetate, and the increasing shading probably provided a good environment for additional plant establishment and growth.

The similarity between the pH and redox potentials measured on Field 1 and the Control warrant additional discussion with reference to the aerobic limit. Lähde (1971) reported results on a study of three peat-land types including treeless bogs, pine bogs, and spruce swamps. He found that the aerobic limit closely followed the ground water level with the former usually found 5-15 cm above the latter. Again, the aerobic limit was not specifically determined in the present study, but it can, with reasonable assurity, be assumed that it is considerably higher on Field 1 than on the Control. While it is true that the ground water level on Field 1 was at times in excess of 40 cm in depth, the lowering of the ground water table does not always result in a lowering of the of the aerobic limit (Lähde 1969). A rise in the ground-water table, however, is closely followed by a rise in the aerobic limit. Furthermore, it has been shown that the aerobic limit more closely follows the ground-water level when the latter is rising and is more slow to fall as the ground-water level falls (Lähde 1969). Drainage of Field 1 has resulted in compaction and probably the formation of a slowly permeable surface layer and decreasing infiltration, which will tend to limit downward movement of water. The Control can be assumed to have a deeper aerobic limit simply because of the presence of extensive root systems.

The ash content and bulk density results need further discussion as well. The distribution of elements in peat profiles are more dependent on biotic factors than on chemical or physical factors (Sillanpaa 1972). This is obvious in that peat, in a natural state, is continuously growing in depth due to an accumulation of plant materials in early stages of decomposition. Sillanpaa studied the distribution of trace elements in two peat profiles and found that ash content and the presence of certain elements increased with depth. An accumulation of minerals on the surface, however, was also noted and attributed to the activities of the most recent generations of plants. Sillanpaa postulates that the trace elements in the profile originated in the mineral soil substrate which underlies the peat. As plants grew and decayed, elements were lifted first from the mineral soil and subsequently from the peat itself. Each generation of plants would derive nutrients from below and upon dying cause an accumulation of minerals to be drawn upon by successive generations. In this way elements are translocated upward through the peat profile. As peat accumulates and depth to the mineral soil increases, plant roots are no longer in contact with the mineral substrate and continued growth becomes dependent on the nutrients found in the peat. Each additional plant community will therefore have a smaller reserve of nutrients to draw upon as the peat layer thickens. As a result, the content of trace elements will become less as peat accumulation continues. Sillanpaa (1972) cites an extreme case of this process in raised *Sphagnum* bogs which are decidedly deficient in all nutrients. This theory ignores atmospheric sources of nutrients.

Relating Sillanpaa's theory of translocation of elements upward through the peat profile to this study, it is necessary to view a cross section of the two fields in question (Figure 10). It appears that Field 2 was mined to a deeper degree than Field 1 and therefore, it can be expected that the first plants appearing on Field 2 would be able to draw on a greater proportion of minerals because of the greater depth into the profile. More minerals would be translocated upward resulting in the relatively high ash content figures for both surface and subsurface layers. In contrast, Field 1 was not mined as deeply and therefore while the surface has an ash content comparable to that on the surface of Field 2, the soil in 8-12 cm depth shows significantly less mineral content than the soil of the same depth on Field 2. The high ash content on the

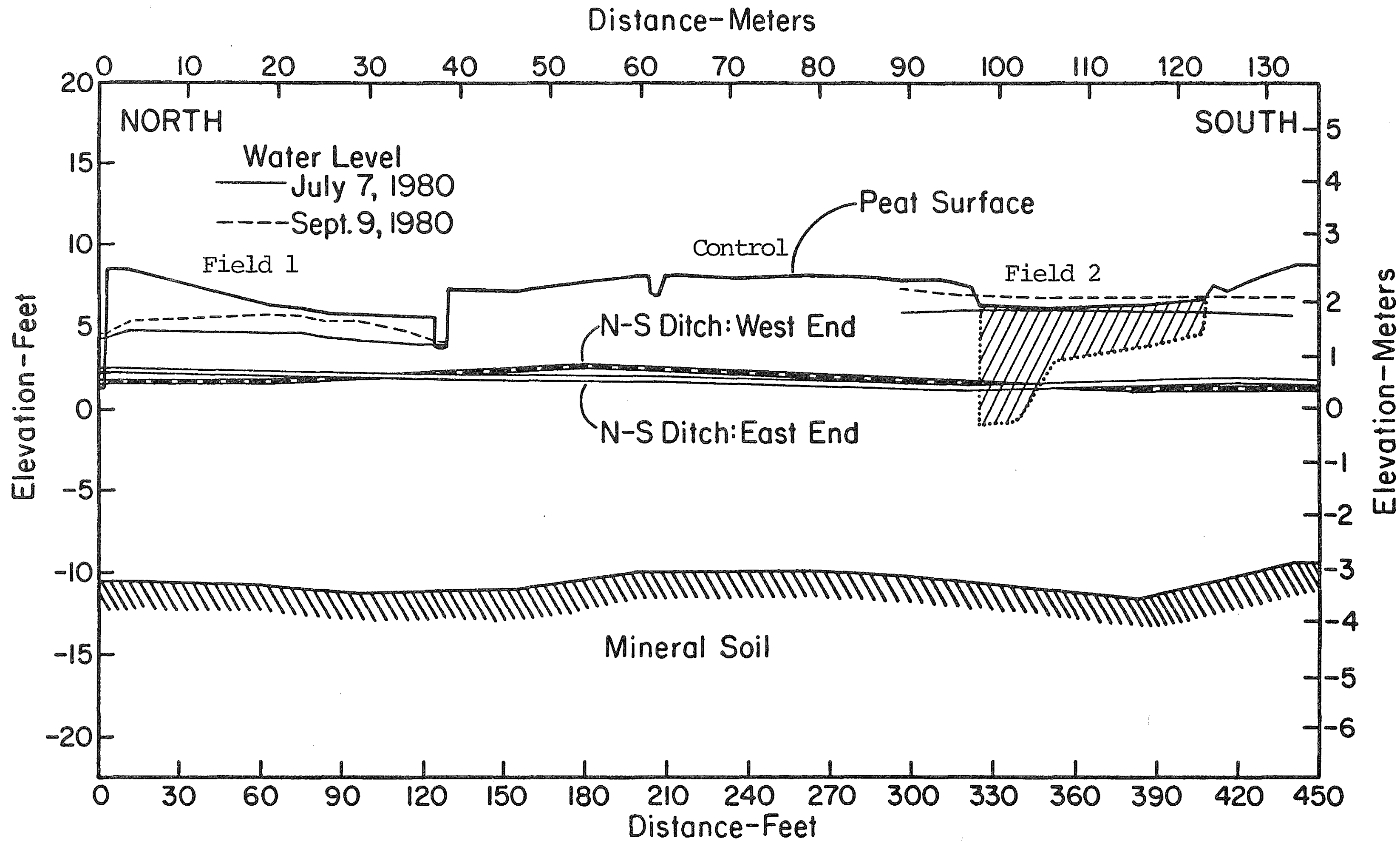

Figure 10. Cross section of Fields 1 and 2 and Control with representative ground water levels and north-south ditch locations in Corona Bog, Carlton County, Minnesota, 1980.

surface of Field 1 can be attributed to higher oxidation and mineralization of the peat than in Field 2. Bulk density is higher on Field 1 because of the effects of drainage on the peat structure. Well-documented research throughout Europe and Canada have shown that drainage of peatlands has the following physical effects:

1. decrease in permeability (fewer macropores in proportion to micropores)
2. increase in bulk density
3. increased consolidation of peat soil
4. increase in subsidence

These processes are caused by an oxidation of organic matter, shrinkage of the top soil due to drying, and compaction of subsoil due to a loss of buoyancy.

The subject of redox potential also warrants some final comments. Haavisto (1974) determined that large rainfall events affect redox potential making soil conditions more reducing. Figure 11 depicts the relation between redox potential throughout the summer and precipitation and depth to the ground-water level. It is obvious that, as Haavisto theorized, rainfall on dry peatlands causes greater changes in redox potential and consequently may affect greater changes in the chemical balance of the peat. The precipitation events occurring at the end of August and early September resulted in an abrupt and drastic drop in redox potential on Field 1. The potential on Field 2 was not affected nearly as much. On the Control, the redox potential was essentially unaffected by the rainfall.

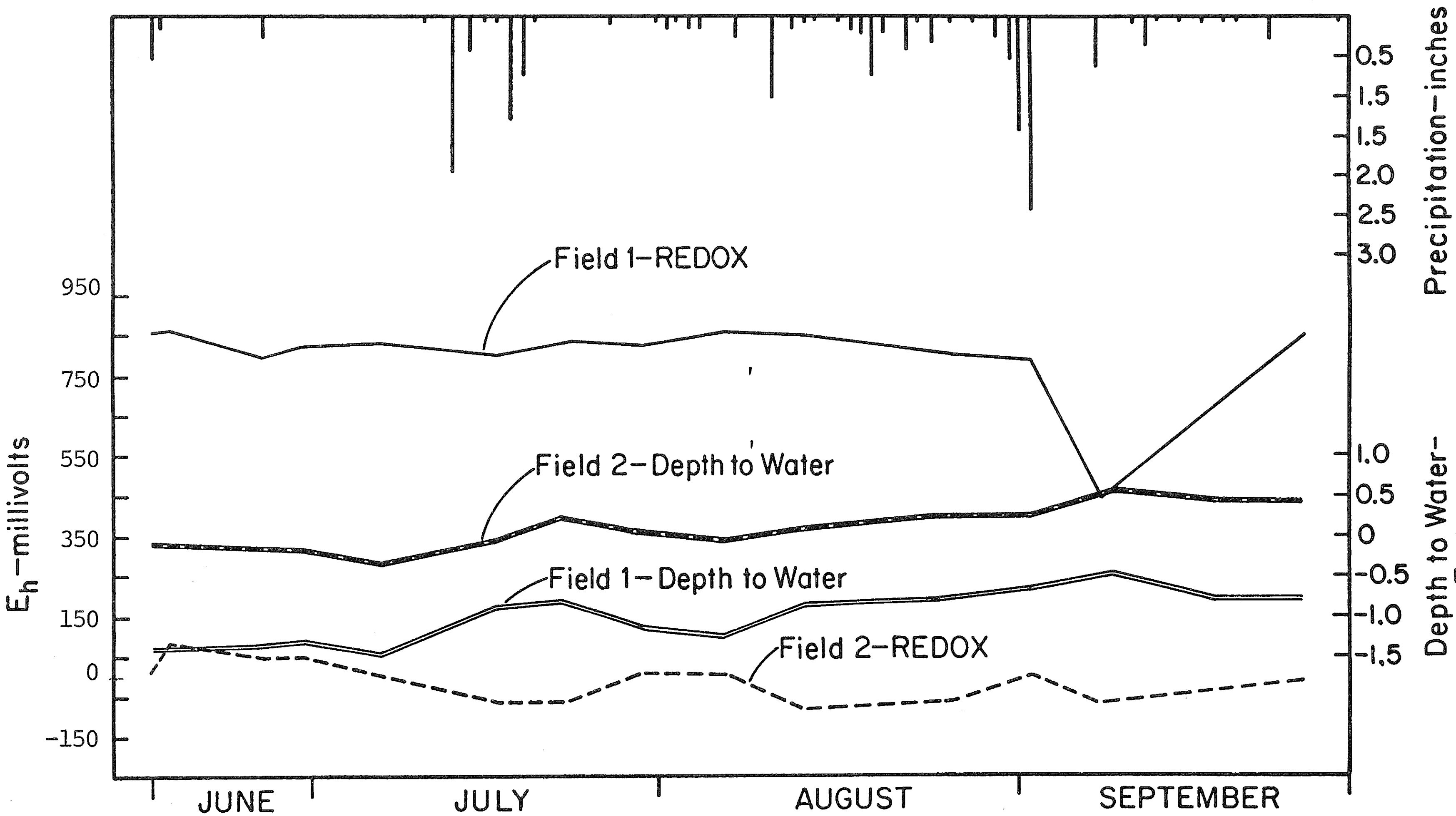

Figure 11. Relationships between redox potential, depth to ground water table and precipitation on Fields 1 and 2 in Corona Bog, Carlton County, Minnesota, 1980.

Exactly how such a rapid change from an oxidizing condition to a reducing condition may deleteriously affect growth conditions on Field 1 is uncertain except for the possibility of changes in the ionic balance of the peat that may be detrimental to plant development.

SUMMARY

Several differences in the physical and chemical characteristics of the bare and revegetated mined fields were observed. The bare field had a higher bulk density and a lower moisture content, water table level, pH, and concentration of plant nutrients than the revegetated *Sphagnum* field. Redox potential measurements indicate that the bare field is under oxidizing conditions whereas the revegetated field is under highly reducing conditions. The ash content of the peat was similar between fields and not different from other Minnesota peatlands.

The differences between the bare and vegetated fields for bulk density, pH, nutrients, and redox potential are not considered sufficient to prevent but may retard plant germination and growth. The maximum surface temperature of the bare peat of 46°C is high but not considered lethal to plants or sufficient to inhibit germination.

However, the differences in soil moisture are pronounced. The moisture content (O.D.W.) at the surface of the bare peat was only eight percent, whereas the surface of the revegetated peat contained 159 percent moisture. Drainage by ditching of the bare field has resulted in much lower water table levels in the peat than in the revegetated field where

water tables were near or above the peat surface. The lack of adequate moisture is likely the factor limiting revegetation.

To enhance revegetation of mined peatlands, it is recommended that drainage ditches be plugged or filled to raise water table levels and increase the available moisture at the surface of the peat.

ACKNOWLEDGEMENTS

The study described in this report was funded by the Minnesota Department of Natural Resources, Division of Minerals, Peat Program. Peat Program personnel who assisted in various ways with the project include Dennis G. Asmussen, Norman E. Aaseng, and John C. Clausen. The assistance of John Clausen in field instrumentation and in his critical review of the report are especially appreciated.

We would like to thank Alvin R. Hallgren, Coordinator, for use of the Cloquet Forestry Center facilities and the Center personnel for assistance.

We would also like to express our appreciation to Edwin H. White for the initial project proposal, Clifford J. Twaroski for cooperation and assistance in field data collection, and Clifford E. Ahlgren for the use of equipment.

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