Utilization of Peatlands for Wood Production [1/]

by

Bruce Harding and Edwin H. White [2/]

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2/ The authors are Research Assistant and Associate Professor, respectively, Department of Forest Resources.

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Abstract

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With forest resources being projected to be in short supply in the next century, consideration is being given to intensive peatlands forestry in the United States. This paper evaluates the parameters that will need consideration for afforestation and reforestation of America's peatlands. Reviewed are the general characteristics of organic soils, techniques to determine peatlands suitability for forest improvement purposes, and silvicultural considerations for peatlands forestry. Techniques considered in the determination of desirable peatlands include: a) plant communities, b) physical and chemical properties, and c) drainability. Silvicultural considerations include: a) drainage, b) fertilization, and c) plant site interactions on drained and fertilized peatlands.

INTRODUCTION

To meet the increasing demand for wood products in the United States on the ever decreasing land base allotted for forest production, intensive forest management practices have become essential. These intensive practices include such management procedures as artificial regeneration of forest sites, the utilization of genetically improved seedlings, and stand thinnings to enhance growth of desirable trees. Also included in intensive forestry is the enhancement of site productivity on lands considered poor for forest growth. Traditionally this enhancement has included fertilization and or drainage of mineral soils. However, with forest resources being projected to be in short supply by the year 2020 (Anonymous, 1972), the organic soils (peatlands) of the United States are now being considered for forestry purposes. Although the utilization of peatlands for wood production has been done successfully in Scandinavia, little has been done in the United States to test the feasibility of such operations. It will therefore be the purpose of this paper to evaluate the parameters that will need consideration for afforestation and reforestation of peatlands in the United States.

Before considering the factors associated with peatlands forestry, a brief discussion of peatlands themselves will be made.

Organic Soils

Brady (1974) provides a general overview of the physical and chemical properties of organic soils as well as a review of their classification, origin, development and distribution. The following brief discussion of organic soils will be based on factors noted by Brady (1974) with supplementation from Moore and Bellamy (1974), and Heikurainen (1975).

Origin, Development and Distribution

Moore and Bellamy (1974, page VII) define peatlands as "unbalanced systems in which the rate of production of organic materials by living organisms exceeds the rate at which these compounds are respired and degraded." The accumulation resulting from the under graded portion of organic matter forms peat or organic soils. In the United States, the formation of swamps and bogs, where peatlands develop, are associated with high water tables that were formed by raised ocean levels, as in Florida or Louisiana, or impeded drainage in glaciated regions, as in the Lake States. These flooded areas are normally characterized by an abundance of plant materials which provide a steady source of organic matter. The raised water tables prevent air from reaching the plant materials after death, resulting in the absence of rapid oxidation. Breakdown does occur by certain fungi, aquatic animals, algae and anaerobic bacteria, but decay is at a slower rate than accumulation. Although water levels which prevent rapid oxidation of plant organic matter are the major reasons for the development of peat, cooler climates where decay rates are slower, also play a role in rates of peat accumulation.

As the accumulation of organic matter increases in swamps and bogs, the plant communities living in the ponded areas tend to change. These changes often progress from reeds and sedges in early stages of accumulation to woody vegetation such as shrubs and trees in later stages. The type of plant material comprising peat plays a role not only in its classification, but also in the type of utilization the peat can experience. These classification and utilization factors will be considered in more detail later in this paper.

The distribution of peat in the United States covers the non-glacial regions as well as the glacial ones. Non-glaciated states having sizable organic deposits include: Louisiana, (1,200,000 hectares), Florida, (>787,000 hectares), California, (118,000 hectares) and North Carolina. Glaciated states, which contain over 75 percent of the peat deposits in the mainland include: Minnesota, Wisconsin, Michigan (4,800,000 hectares combined); Washington (787,000 hectares); Indiana, Massachusettes, New York, New Jersey (approximately 158,000 hectares each); with smaller deposits in Iowa, Illinois, and Maine (Brady 1974). In terms of world distribution of peatland, Heikurainen (1975) has noted the following (in millions of hectares): USSR, 245; Canada, 230; Alaska, 50; Finland, 10; USA (-Alaska), 10; Sweden, 7; Norway, 3; Great Britain, 3; Germany and France, 2; Poland, 2; and Ireland, 1.

Chemical Properties

Although the chemical properties of peatlands are varied, the following factors are consistent for most organic soils. Calcium content is usually high, being related to the high lime content of the water that enters peatlands through subsurface flow. Although the calcium content is high, the cation adsorption capacity of organic soils is so great that low base saturations are often present. Unless influenced by underlying bog lime or marl, organic soils are acidic ($pH \sim 5.5$) with highly acidic conditions ($pH < 5.5$) often occurring. In terms of macronutrients, nitrogen, calcium and sulfur are relatively abundant, with phosphorus, potassium and magnesium considered at low levels. The levels of micronutrients will vary with different peat locations. Deficiencies have been noted for copper, zinc, boron, manganese, sodium, and chlorine. The availability of nutrients for plant growth varies with different locations especially for micronutrients, but in general, additions of phosphorus and potassium are necessary for successful crops on organic soils. Calcium is usually in adequate supply unless extremely acidic conditions are present. Nitrogen will be available unless excessive cropping has reduced decay and nitrification to a critical point.

Physical Properties

The physical properties of peatlands are considered unique when compared to mineral soils. The soil color will be darker with variations in color from dark brown to pure black. The stage of plant decay will play a determining role in the intensity of peat color. The bulk density of peatlands are very low in comparison to mineral soils. Brady (1974) reports bulk density values of .20 to .30 for well-decomposed organic soils, and values of 1.25 to 1.45 for cultivated surface mineral soils. The water holding capacity of peatlands is very high, often retaining three times their own dry weight in water. Peat in less decomposed stages can hold even greater amounts of moisture, often in excess of 15 times their own dry weight. Although peatlands hold excessive quantities of water in relation to their dry weight, they provide plants with only a little more water than mineral soils in similar climatic conditions. The small release of water to plants by organic soils can be related to the fact that they have a higher proportion of unavailable water than mineral soils, and that comparisons of available water between the two soil types are often made on a dry weight basis, of which peat soils are considerably less. Attention will be given later in this paper to water relations of peat soils under drained, forested conditions. The structure of peat soils is considered to be good with low cohesion and plasticity. Peatlands are often porous, having openings and are fairly suitable for cultivation. The good structural quality of organic soils can be damaged by intensive cultivation and fire.

The colloidal nature of organic soils is important, and is considered along with the physical properties, because their surface areas is greater than that of the expanding mineral clays, having higher cation exchange capacities. The high cation exchange of organic soils increase their ability to adsorb greater amounts of calcium than mineral soils, and it increases their ability to exchange greater amounts of mineral elements. Since the pH of soils are largely controlled by their colloidal properties, the greater colloidal nature of organic soils result in lower pH's than comparable mineral soils. The high colloidal nature of organic soils also acts as a buffer against changes in pH.

Classification of Peatlands

A number of systems to classify peatlands have been developed and used throughout the world (Heikurainen, 1964, 1972). However, this brief review will only make reference to the Comprehensive Classification System, which places organic soils in the Histosols order. Histosols contain a minimum of 20 percent organic matter if a low clay content exists, and a minimum of 30 percent organic matter if a clay content of greater than 50 percent exists. The Histosols order has four suborders, three of which are based on their stage of decomposition (Fibrists-least, Hemists-intermediate, and Saprists-most), and the fourth (Folists) which is derived from leaf-litter, twigs and branches resting on or mixed in fragmental material in humid climates.

The classification of peatlands completes this brief consideration of organic soils. Attention will now be turned to the main emphasis of this paper, that being a review of the factors associated with establishing productive forests on peatlands.

Peatlands For Wood Production

Site Selection

Although large quantities of peatlands exist in the world, only certain portions are suitable for forestry. Heikurainen (1964, 1972) has done extensive reviews on the factors associated with peatlands forest in Europe, including proper site selection, and his work will serve as the basic outline noted in this paper. The Canadian works of Jeglum et al.(1974), and Stanek (1977), will also be considered to provide specific reference to forestry related peatlands classification in North America. Heikurainen (1964) has noted three major factors utilized in the classification of peatlands for forestry purposes. These factors include: (1) the plant communities on the peatlands, (2) the physical and chemical properties of the peatlands including degree of humification, and (3) the drainability of the peatlands. The role of plant communities as forest site indicators will be considered first.

Plant Communities

The different plant communities that occur on peatlands are a reflection of the environment in which they exist. Variations in such factors as nutrient availability, water tables, topography and climate will be reflected by the types of plants that occur. Through investigations, peatlands suitable for forestry can be determined on the basis of the presence (or absence) of certain plants, or more preferably the presence of certain plant communities. Plant communities are usually more reliable indicators of desirable sites, since they tend to reflect environmental conditions on holistic basis.

Heikurainen (1964) has reviewed some of the forestry related plant classifications schemes used in Europe (Sweden, Russia, Great Britain) with particular emphasis on his native country of Finland. For Sweden, Malmstron's (1928, 1959) work was cited, with attention being given to the need to consider other factors such as climate and peat thickness when using plant communities to determine suitability for forest drainage. For Russia, Pjavtsdenko's (1955, 1958, 1959) papers were reviewed, with reference being made to the utilization of swamp (peatland) types based on one or more dominant plants. In British swamps complexes, where emphasis for forestry purposes center on structure and topography, Zehetmayr's (1954) work was noted. Warnings from Dickson's (1962) publication as to the unreliability of plant communities on highly disturbed peatland sites, such as Britain's, was also mentioned. For Finland, forestry related works cited, were by Lukkala (1929, 1935), Kukkala and Kotilainen (1945), and Heikurainen and Huikari (1960). The Heikurainen and Huikari (1960) study, which is a good example of the Finnish classification system, consisted of dividing peatland swamps into three categories including: open swamps, spruce swamps, (mostly spruce and hardwoods) and pine swamps. Subgroups were also noted, based on the plant species that occurred in associations within each of the main groups. A similar classification system to that of the Finnish one has been developed in Canada (Jeglum, et al., 1974), and will be discussed when site selection for peatlands forestry in North America is considered.

As noted in the beginning of this section, the types of vegetation that are found in an area will depend on such factors as the topography, climate, nutrient availability and edaphic conditions. Because these factors vary throughout the world and even within the regions of one country, plant classification schemes designed to identify peatlands for drainage and forestation are often limited to the area in which they were developed.

Peat Classification

The second technique outlined by Heikurainen (1964), for determining peatland suitability for forestry was based on the classification of peat. Most peat classification systems that have been developed are found on the degree of decomposition of plant materials. Other variables included in peat classifications are, origins of peat (on site or transported), percentages of plant types composing peat, nutrient content, and peat color and structure. The use of microscopic classifications was also mentioned, but those techniques that include only degree of decomposition, color and structure were considered the most effective. It was stressed that no system of peat classification would be considered adequate without measuring the degree of humification. This is true because of the significant influence humification has on peat characteristics. Notably this includes decreasing permeability and field capabilities for peatlands as humification increases. Schemes for determination of humification ranged from broad classes to microscopic analysis. Relationships derived between the peat types of classification schemes and suitability for forestry are normally restricted to the areas of the particular study, since peat types and their relationship to forestry will vary with environmental changes.

Drainability of Peatlands

The final technique considered by Heikurainen (1964) to determine suitable peatlands for forestry, was based on the potential the peatlands had for drainage. Satisfactory drainage potential was determined only on the basis of increasing forest growth and was not related to any form of economic analysis. Drainage was considered as a way to either transform unforested areas into forested areas, or as a method to increase the productivity of areas that could or were already supporting forest vegetation.

The plant communities and peat types derived from the classification systems mentioned previously are often used to determine the suitability of organic soils for forest drainage. By measuring the growth responses of established forests on drained and undrained peatlands classified according to their peat, or plant communities (or combinations of both peat type and plant communities), relationships are often established between the peatland types of the classification systems and forest growth responses after drainage. Heikurainen (1964) cited several studies in his review that have utilized such an approach to evaluate drainage potential for peatlands (Buss, 1958; Thurmann-Moe, 1962; Lukkala, 1951; Heikurainen, 1959; Fraser, 1933; and Zehetmayr, 1954). It was also noted from these studies that the successfulness of forest peatland drainage is related to the peats fertility and its location or climate.

In relation to the utilization of site index (a measure of site productivity based on the height of the dominant or codominant trees in a timber stand at a base age) to estimate future growth on drained peatlands, Heikurainen (1964) took special efforts to point out that with the changes in site conditions that occur after drainage, such attempts are of little value. It was also noted that the variations in growth after drainage within some peat and plant community types are excessive, resulting in meaningless appraisals. On the whole however, the relationships between the peatland types of the classifications and growth after drainage were considered worthwhile within given regions.

Forest Peatland Site Selection in North America

The application of peatland classification systems for forestry purposes in North America have been limited. As Stanek (1977, page 656) stated, "in Canada, the improvement of peatlands for forestry purposes is limited largely to regenerating stands after harvesting." He also noted that little information was available on growth responses after drainage, and that intensive forest management of peatlands in Canada was only on a small scale. Similar statements could be made for the United States.

Some of the work that has been done in North America includes Jeglum et al., (1974) efforts to classify swamp lands (peatlands) for forestry purposes, and Stanek (1977) use of Jeglum's classification system to compare difference in growth responses between undrained and artificially drained sites. Jeglum (1975, page 227) observed that the classification system he and his colleagues proposed tried to separate the peatlands (specifically the black spruce forest of the northern clay section in Ontario) into, "units that would (1) be relatively easy to recognize in the field, (2) relate to differences in tree growth, (3) relate to differences in regeneration, and (4) be interpretable from air photos." Jeglum's classification system is based on vegetation with physiognomy and dominance of plant communities being stressed. Productivity was derived from the site index of the dominant forest species within each site type identified. As was noted earlier in this paper, site index will not serve as an adequate base to predict future productivity for a site type if intensive practices such as drainage occurs. Because of this inadequacy Jeglum's system alone is deficient for selecting peatland sites for intensive forest management.
To make Jeglum's classification applicable for intensive management practices, Stanek (1977) studied the differences in tree growth responses on undrained

and drained peatland site types classified by Jeglum's system. Jeglum's classifications were however modified, by assigning the peatlands site types of Jeglum's classification to five trophic groups based on the macronutrient content of the peat. The results of Stanek's (1977) study showed that the five nutrient classes could be broken down into two major suitability classes, one being bogs and the other swamps plus fen-marsh complexes. Bogs showed an average improvement in growth of 6 meters after drainage and the swamp plus fen-marsh complexes showed an improvement of 4 meters. It is these differences in growth between peatland site types that make techniques to determine peatland suitability a desirable management tool in peatlands forestry.

Silvicultural Considerations

Although techniques to identify peatland suitability for forestry purposes are helpful, the major factors associated with peatlands forestry are the silvicultural considerations. These considerations can be broken into three major divisions, those being drainage, fertilization, and plant-site interactions.

Drainage

As was noted in the beginning of this paper organic soils often hold three times their own weight in water, with peat in less decomposed stages often holding in excess of 15 times their own dry weight. Heikurainen (1964) stated that peat in natural swamp conditions contain 90 to 95 percent water. Because of the excessive amounts of water associated with peatlands, drainage is normally a part of any type of intensive peatlands forestry. Publications by Payandeh (1973) in Canada, Efremov (1967) in Russia, Boggie and Miller (1973) in Great Britain, and Heikurainen, (1964, 1968) and Jenen et al., (1964) in Finland, demonstrate that drainage of peatlands will result in successful gains in forest growth. Some of the important aspects of peatland drainage in relation to forestry considered by this paper are: (1) water relations of peat soils, (2) the influence of drainage on physical properties, (3) techniques of drainage and their influence on forest growth, and (4) physiological responses in drainage.

Water Relations

With site drainage being normal procedure in peatlands forestry, water relations noted here will be focused on drained conditions. Heikurainen (1964) has reviewed the main factors of water relations in peatlands forestry. Some of the parameters that he felt were important are noted as follows.

Peat soils contain about 80 percent water in drained conditions, a percentage value not that different from undrained peat soils. Field capacity values for peatlands are high, with decreasing field capacity and permeability occurring for peatlands increasing in their degree of humification. Even at low degrees of humification, permeability of peatlands is still considered small. Oxygen content of peat soils will increase by the amount that water is removed from pore space by drainage. Depth and intensity of ditches are a major factor determining intensity of drainage or increases in oxygen content. It should be noted however, that intensive ditching alone is unable to bring the moisture content of peat much below that of field capacity (Boggie and Miller, 1973). The impermeable nature of peat to water causes slow water movement, and water holding capacities of peat in drained conditions is high.

In terms of evapo-transpiration on unforested peatlands, drained areas tend to have less evapo-transpiration than undrained ones. However, on peatlands where drainage enhances the establishment or growth of the forest, the evapo-transpiration of the trees will increase total transpiration from peatlands. Heikurainen (1964) noted that many researchers feel that it is the increased transpiration from trees that bring about the major effects of drainage. Temperature changes after drainage are also important.

The effects of drainage on peat temperature are two fold. First, a decrease in surface water after drainage reduces surface evaporation, yielding a favorable effect on temperature relations. Secondly, drainage results in a lowering of the thermal conductivity of peat. With freezing being directly related to temperature relations, drained peatlands tend to freeze deeper and remain frozen longer than undrained ones. This increased freezing can play a role in limiting the establishment of trees during normal planting times in the spring. However, the overall effects of drainage on temperature relations in peatlands are considered to be limited in their importance.

Physical Properties

The effects of drainage on the physical properties of peat under forested conditions have received little attention. One study translated from Russian (Bel'skaya, 1961) was available and its content will be summarized to provide a general overview of the physical changes that occur. Drained forested peat soils experience greater aeration than undrained ones, increasing rates of peat decomposition. These increased rates of decomposition result in alterations of the peats physical properties. These alterations include the following (Bel'skaya, 1961 page 8):

1) The bulk density of peat increases with the age of the drainage network.
2) The specific gravity of pure peat decreases with the increasing degree of its decomposition, but the profile of thin peat may exhibit the reverse pattern in horizons containing mineral admixtures.

3) Total porosity of peat decreases as it becomes more compact in the course of decomposition; nevertheless, water permeability increases through intensification of the first period of the penetration of water into the soil, i.e., the imbibition of water by the peat on drained areas, on account of its lower moisture content.

Bel'skayas (1961) concluding remarks stated that changes in the physical properties on drained forested peatlands are slow, but noted that these changes favor tree growth.

Techniques of Drainage

The factors associated with drainage techniques for peatlands forestry received attention from Stoeckeler (1963), Burke (1973) and Heikurainen (1964, 1973). Stoeckeler (1963) centered his review on drainage methods utilized in Northern Europe. Hand ditching and dynamite were considered, but major ditching operations were accomplished by mechanized ditchers. These mechanized ditchers included: bucket type-ditchers, plowed ditchers, cable and winch ditchers, direct pull ditchers, rotary ditchers, and endless-chain ditchers. The type of mechanized ditchers utilized varied with different countries and management requirements. In Britain for example, a ditching plow was used that cut shallow furrows leaving excavated ridges on which seedlings were planted. In other areas where excavated ridges were not desirable, different types of ditchers were employed. New techniques such as plastic drains were also mentioned, but their utilization was still in pilot-stages. The major physical problems in drainage of peatlands noted by Stoeckeler (1963), were trafficiability of equipment, and the necessity of ditch cleaning and maintenance. Equipment having low track pressure was emphasized to prevent miring, and warnings in terms of limiting excessive movement on peat surfaces were given. Although beyond the scope of this paper, the major consideration determining the type of ditching machinery to utilize is economics, a factor that has received little attention for peatlands in the United States.

Heikurainen (1964, 1973) and Burke (1973) considered in their reviews, parameters involved with the intensity of drainage necessary to obtain optimum forest growth. Heikurainen (1964, page 67) noted the following factors to be of importance in determination of runoff or drainage, "size of runoff area, percentage of open water surface inside the area, moisture content of snow before melting, types of land utilization, and shape of the runoff area." Because of the variations that exist in these factors, the exact intensity of drainage needed for the peatlands of the world will vary. Three principles of drainage that are consistent with peatlands forestry on a world basis are noted as follows. First, ground water levels in peatlands play a major role in determining forest growth. The desired depth of ground water after drainage will reach an optimum point below which plant growth will decrease. This optimum depth will vary with such factors as climate, tree species, and peat type. Second, ditch spacing has a significant influence on tree growth with closer spacings yielding better growth responses. Poor sites will respond better to closer spacings than fertile ones. In terms of the correlation between ditch intensity and ground water tables, Heikurainen (1964) noted Hainla's (1957) study, on infertile Sphagnum swamps, which demonstrated that closely spaced ditches, (a) lowered the ground water table more than widely spaced ones, and (b) they increased runoff. The third factor considered for world peatlands forestry application, is the effects of ditching depth. As in the control of water table depth, forest growth will improve with greater ditch depths until an optimum point is reached. Heikurainen (1973) reports that this optimum depth is very shallow. Reasons noted for this included the fact that the entire surface layer of drained peatlands is extremely thin, and that the distribution of roots is very superficial, with the bulk of roots occurring between 0-10 cm. Heikurainen (1973) considered ditch depth the least important of the three factors considered.

Other parameters that should be considered in peatlands drainage have been noted by Burke (1973), and Boggie and Miller (1973). In terms of obtaining an optimum water table depth for forest growth, Burke (1973) pointed out that shrinkage of peat often occurs after drainage. This means that the peat surface will become closer to the water table surface, eliminating some of the depth of the lowered water table. Allowance for this shrinkage should be made when guidelines for obtaining optimum water table depths are determined. Boggie and Miller (1973) noted in their report that actual increases in forest growth after drainage may be more closely related to the increased downward movement of water, carrying dissolved oxygen and nutrients following rains, than to the limited changes in peat moisture content after drainage.

Because of the variations in responses to drainage that occur for different peatlands of the world, drainage techniques should be tried on an experimental basis in areas of concern. Research tends to indicate that numerous variations in results can be obtained from different drainage intensities, and that these variations can be of significance in obtaining optimum forest growth.

Physiological Responses

Heikurainen (1964) cited a number of reports dealing with tree growth responses after drainage on peatlands (Malmstrom, 1935; Lukkala, 1937, 1951; Elpatjevski, 1955; Hainla, 1957; Heikurainen, 1959; Buss, 1960; and Heikurainen and Kuusela, 1962). In general it was noted that smaller and younger trees responded better to drainage than older and larger ones. Stand thinnings were encouraged to eliminate older and larger trees unable to respond to drainage. The time it took trees to respond to drainage was as little as one year in some cases (Lukkala, 1937). Radial growth responded first to drainage, with height growth responding a little later. The responses of height growth lasted a longer period of time than did radial growth. Length of growth responses to drainage varied considerably between studies. Differences were related to such factors as site fertility before drainage, peat thickness, and intensity of drainage. In general, growth responses on poor sites lasted from 10 to 20 years, with better sites having responses as long as 40 years.

The physiological responses of roots to drainage were also considered by Heikurainen (1964), who noted the following points. First, rooting depths of trees on drained as well as undrained peatlands were considered very shallow. Reasons for this were related to a lack of oxygen in potential rooting zones. Second, drainage was reported to increase rooting depth and the amount of total roots developed. A general correlation of one centimeters increase in root development to 10 centimeters of drainage was noted. Third, Paavilainen's (1963) study reported the use of smaller ditch spacings to increase root development. These results in Paavilainen (1963) study can be explained by the increased effectiveness of drainage associated with closer ditch spacings. And fourth, Heikurainen (1964) noted the importance of increasing rooting depths for forest species susceptible to windthrow. Since drainage of peatlands is usually accompanied by site preparation and fertilization, Paavilainen (1967) and Kaunisto (1971, 1975) have studied the effects of these silvicultural practices on root systems. Paavilainen (1967) reported that applications of NPK increased the amount of roots in the upper 10 centimeters of peat soils. Increases in the length of roots were also observed, but short roots only increased in the first three centimeters of the profile. Kaunisto (1971, 1975) observed that fertilization on prepared sites resulted in the best root growth, and that rotavation favored root growth more than shoot growth.

Fertilization of Peatlands

The general status of macro and micro-nutrients in peatlands were considered in the introduction of this paper and only those nutrients of commercial importance will be considered here. In terms of commercial fertilization of peatlands only nitrogen (N), phosphorus (P) and potassium (K) have been widely used. Atterson and Binns (1973) have considered some of the fertilization factors associated with these macronutrients and their findings are noted as follows. Nitrogen content was considered high in most peat soils with deficiencies being noted for P and K. Values to a depth of 30 cm were cited for N, P and K, they were: 2,000-10,000 kg N; 40-300 kg P; and 30-350 kg K. Bogs having high percentages of sphagnum moss, or an oligotrophic classification, comprised the peatlands having the lowest nutrient content. It was noted that although peat normally has a high N content, large percentages of this N are tied up in organic compounds and are not available to plants. Phosphorus was considered to always be limiting to plant growth. Potassium was not considered limiting in early stages of plant growth, but was considered so in the later stages of development

(Meshechok, 1968). Potassium and nitrogen were both reported to be in decreasing availability as the depth of peat increased (Paaviliainen, 1972). Differences in the availability of K and P were also discussed. Since K content in rainfall often exceeds that of P by five times, K was considered to be more available to plants over the long term. Heikurainen (1964) has also reviewed some of the main characteristics of N, P and K in peatlands. His observations are similar to those of Atterson and Binns (1973).

Of the many articles dealing with commercial and experimental fertilization considered for this paper (Tamm, 1960; Jensen et al., 1964; Heikurainen, 1964; Meshechok, 1968, Viro, 1970; Kaunisto, 1971, 1972, 1975; Paivanen, 1972; Paavilainen, 1972; Hauge, 1972; Seppala and Westman, 1976; MacCarthy and Davey, 1976; Kaunisto and Norlamo, 1976; and Kaunisto and Paavilainen, 1977) most were in agreement that applications of NPK or PK are necessary to obtain satisfactory forest growth on peatlands. Variations to this general rule were noted as in Seppala and Westman's (1976) study, in the unfavorable climatic conditions of north-eastern Finland, where little additional growth was obtained from applications of PK. A review of the studies revealed generally that sites considered poor in their overall nutrients status (oligotrophic) were in need of NPK and those sites considered fairly fertile were in need of only PK. Overall most studies considered phosphorus the most deficient nutrient limiting forest growth. Publications such as Hauge (1972) and Meshechok (1964) revealed that it is almost impossible to establish seedlings on organic soils without applications of P. Applications of lime in conjunction with normal fertilization of peatlands has also proven to enhance forest growth (MacCarthy and Davey, 1976; and Kaunisto and Norlamo, 1976). Part of this enhancement was related to a significant enlargement of biological activity that increased fixation of nitrogen after liming.

The publications on the fertilization of peatlands also noted other important factors that affected growth responses besides the additions of macronutrients. These other parameters included time of fertilization, methods of application and types of site preparation.

Viro (1970) has studied the best time to apply fertilizers and he states that early spring is the best for pines and that late summer is the best for spruce. Viro (1970) also noted that the variations in responses to time of application were not as significant as expected. Paavilainen (1972) did warn however, that nitrogen uptake was poorest when applied in winter on top of a snow cover. Methods of applying fertilizer were considered by Mackenzie (1972), Meshechok (1968) and Hauge (1972). In general it was found that spot applications in the immediate area of trees was better than broadcasting. Meshechok (1968) also noted that additions of phosphorus in planting holes besides the trees caused a definite increase in growth when accompanied by surface fertilizer applications. Hauge (1972) warned however, that additions of super phosphate to seedling roots resulted in increased mortality. In terms of types of site preparation, Kaunisto (1972) has noted that the site preparation used will effect seedling responses to fertilizers. He also stated that if fertilizers are worked into the substrate they will be better utilized by the plants, than if just applied in surface applicaitons. Meshechok (1968) reported that the best growth responses in his studies have occurred on furrow slices. Because of the significant influences that time of application, site preparation, and methods of fertilization have on forest growth, these factors must be considered in any type of peatlands forestry.

Another area of interest in fertilizer studies is the uptake and utilization of the nutrients that are applied. For peatlands, this subject, is considered by Tamm (1960), Dickson (1973), and Atterson and Binns (1973). Tamm (1960) noted that only a small amount of the additions are used by trees. Dickson (1973) pointed out that much of the fertilizer added is used by competing vegetation. Considerable increases in growth were observed by Dickson (1973) when herbicides were used to control competing veqetation. The increases in growth were related to the increased availability of N. It was noted however, that where extremely large applications of fertilizers were made, little growth response was noted after the use of a herbicide.

The final aspect of peatland fertilization to be considered is the importance of a nutrient balance on drained peatlands. Heikurainen (1964) has considered this aspect in his review and notes some of the following nutrient relationships to be of importance: (a) additions of phosphorus can affect nitrogen mobilization, (b) applications of calcium can result in increased humification of peat, resulting in fixation of N and P in the protoplasm of microbes, and (c) additions of P can increase K deficiencies in peatlands. As can be seen from these examples, the application of fertilizers to peatlands is a matter that needs serious consideration before being carried out.

Plant Site Interactions

Species Suitability

Tree species will respond differently to the various types of peat soils, climatic conditions, drainage schemes and silvicultural practices that occur throughout the world. Because of the diverse influences of these factors, proper selection of tree species for peatlands forestry is often difficult, especially in regions where little research has been conducted to identify desirable species.

In Europe and Great Britain extensive work has been done to identify species suitable for peatlands forestry on a commercial basis. Heikurainen (1964) reviewed the countries of Europe and noted the following: In Western Europe, Norway spruce, Scots pine, and birch (Betula verucosa and B. pubesiens) were approved as suitable commercial species. Spruce was recommended in colder climates and on ombrotrophic swamps, with pines being recommended on minertrophic swamps. In Eastern Europe, spruce and pines were also approved, with the additions of larch and black alder. Species suitability work in Great Britain has been considered by Seal (1973), who noted the following species to be of importance. On fertile sites in the colder parts of Britain, Norway spruce and sitka spruce were recommended almost exclusively. Lodgepole pine and sitka spruce were noted as desirable species on Britain's deeper peat soils and infertile sites. On sites of extreme infertility, only lodgepole pine produced satisfactory results.

In the United States and Canada, little work has been done to determine species suitability for intensive peatlands forestry. In the southeast where some drainage has been done commercially on organic soils, loblolly and slash pine seem to be the best species (Walker, et al., 1961). In the Lake States and Canada consideration is usually given to the species already occurring on organic soils, these being predominately black spruce, tamarack and eastern white cedar. To identify which species would be best suited for intensive forestry on peatlands in the Lake States Dr. Ed White, of the University of Minnesota, is currently investigating the growth responses of five species (black spruce, white spruce, a hybrid poplar, Norway spruce and Scots pine) to drainage and fertilization. This type of research must be carried out in North America if intensive peatlands forestry is ever going to be considered on a commercial basis.

Site Preparation

The utilization of some form of site preparation is associated with most recent attempts to establish forest on organic soils. The type of site preparation used varied with different locations, a point demonstrated by Neustein and Rowan's (1973) review of plowing schemes for site preparation in Great Britain, and Kaunisto's (1972) work on the utilization of rotavators and plows in Finland. Advantages and types of site preparation in peatlands forestry have been considered by Kaunisto (1971, 1972, 1975), and the results from his studies are noted as follows. First, Kaunisto (1971) reported that the utilization of site preparation equalled the effects of the best fertilization treatments without site preparation. He also noted that the use of site preparation and fertilization together increased seedling growth twice as much as when either treatment was used separately. Increased mobilization of nutrients after site preparation was believed to be the major reasons for the increased growth. In a later study using a rotavator in site preparation, Kaunisto, (1975) also noted that increased seedling growth after site preparation could be related to the reduction of competing vegetation. He reported that the use of a rotavator completely destroyed the ground vegetation. In terms of plows used in site preparation, Kaunisto (1972) stated that front plows were superior to tractor pulled plows. This was related to the fact that front plows pressed turf ridges closer to the original peat surface, allowing easier seedling access to nutrients and moisture. Precautions were noted in the use of rotary cutters where excessively shallow benches prevented adequate moisture contact by seedling. Shallow furrows at a depth of 15 to 20 cm on a single tree basis were recommended to control moisture levels in site preparation. In summary, the major objectives of site preparation in peatlands forestry are (1) to regulate the moisture and temperature to which seedlings are exposed, (2) to stimulate microbal activity, and (3) to eliminate competing ground vegetation, (Kaunisto, 1971).

Problems in Forestation

The majority of the major problems associated with intensive peatlands forestry were discussed when consideration was given to techniques of site selection, drainage, fertilization, and species selection. These problems can be noted by reviewing these topics and they will therefore not be considered again. Another major problem not adequately covered beforehand involves the intensive competition on peatlands from non-forested vegetation during seedling regeneration (Maki, 1974). This competition competes with tree seedlings for both sunlight and nutrients. Heikurainen (1964) pointed out that competition not only occurs from plants that invade organic soils, but that loose sphagnum moss will compete with seedlings for sunlight. As was noted in the review of fertilization, the use of herbicides to eliminate competition for nutrients resulted in substantial increases in seedling growth after nutrient additions (Dickson, 1973). Although the use of herbicides to control competing vegetation is the best solution to the problem, Heikurainen (1964) warned that on well humified peat void of vegetation, heavy rains can splash peat mud on seedlings bending and breaking them. Although not a part of this review, it should also be remembered that tree species growing on organic soils will encounter the problems of fire, insect attacks, and diseases just as trees on mineral soils. Though the problems associated with peatlands forestry are important, most can be overcome or avoided with wise management practices.

CONCLUSION

Although a great deal is known about peatlands forestry in Europe, little work has been done in the United States to evaluate the feasibility of intensive peatlands forestry. With timber supplies projected to be in a shortage by the next decade, now is the time to begin investigating the potential of America's peatlands for forestry purposes. This investigation should include not only the specific biological requirements considered in this review, but an economic analysis should also be made that would identify when intensive peatlands forestry could be carried out on a profitable basis.

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