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SOME LIMITING FACTORS OF TREE GROWTH IN ALBERTA - A REVIEW

by

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INTRODUCTION

In the classification of forest land under the Canada Land Inventory Program (McCormack, 1965, 1965a), part of the classification consists of indicating the limiting factors of tree growth. It is assumed in this classification that the highest productivity rating, Class 1, has no important limitations to the growth of commercial forests. It is not too difficult to determine the important limiting growth factors of the lower productivity Classes 5, 6 and 7. These classes occur frequently on steep topography, on shallow, stoney and sandy soils, on excessively-drained sand dunes, and on very poorly drained muskeg. Essentially the problem is to determine what limiting factors make Class 2 produce differently from Class 3, and to find out why Class 3 produces more wood than Class 4.

The purpose of this review is to summarize the existing information on the limiting factors of tree growth in Alberta as they are applied in the classification of forest land. This information can then be useful in applying subclass or limiting factors to this classification,

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and thus the production of more comprehensive reports and maps. In addition the deficiencies in the information on limiting factors of growth will be noted, and will form the basis for recommending research.

LITERATURE REVIEW

In the "Canadian Land Capability Classification for Forestry", McCormack (1965) lists six major factors that can be used as indicators of limitations to forest growth. These are climate, soil moisture, soil fertility or toxicity, permeability and depth of rooting zone, stoniness and inundation. It is these limiting factors that will be reviewed.

Climate

It has been common practice to accept climatic information from the older established weather stations as being representative of an area as a whole. However, Muttitt (1961) reported large increases in rainfall with increasing elevation in forest regions of Alberta. Further, data collected at Alberta Forest Service Lookout Towers (Forest Protection Section, Alberta Department of Lands and Forests, Edmonton, Alberta) indicate a longer frost-free period at these forest positions than at nearby regional weather stations at lower elevations. This evidence shows that additional climatic information more representative of the forest areas is required. Such information would allow climate as limiting factor of growth to be used with more confidence and precision. In addition, more and better related climatic data would lead to a basis for determining the influence of air temperature, precipitation, relative humidity and wind on the physiological processes of plants and on important plant growth factors like soil moisture and temperature.

Exploratory studies in the Edson and Whitecourt Forests by Knight [2] suggest that many Gleysolic and Organic Soils under mature forests do not rise above 40°F in the mineral horizons at any time. Thick organic horizons act as insulators and storehouses for water and hinder soils thawing and warming. If similar soil temperature conditions are more widespread, soil temperature could be a very important limiting factor of tree growth.

Soil Moisture

After examining the soil profile and microrelief, it is not difficult to indicate soil moisture as a limiting factor to growth where forests are growing on deep coarse sands and gravels (moisture deficiency), or depressional areas (moisture excess). However, it is often difficult to indicate soil moisture as a limiting factor on more productive areas, or where soil moisture fluctuates widely throughout the year. On these latter areas even an examination of the soil profile for mottling and other drainage characteristics does not indicate the moisture status (Matthews 1963).

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[2] Knight, H. 1966. Soil temperatures of some Alberta forest soils. Canada Dept. Forestry, Calgary, Alberta. Unpublished.

In this review only three references were found pertaining to soil moisture in forest regions of the province. Day (1963) studying forest regeneration problems in the Crowsnest Forest indicated soil moisture to be mainly responsible for seedling mortality under shaded conditions. From nursery seedbeds Day found that there was generally more moisture through the growing season at one and three inch depths under decayed wood seedbeds than seedbeds of F and H humus, Ah horizon or sandy loam soil.

Duffy (1964) in the Rocky Mountain House region found a correlation between moisture storage capacity and growth of lodgepole pine. A loam to heavy loam till had an average of 5.7 inches available water in the surface 36 inches of the soil profile, and production of 3,541 cubic feet of wood (age 60). Similarly a sandy loam alluvium had an average of 4.7 inches and 2,809 cubic feet, and a silt loam lacustrine 7.1 inches and 2,937 cubic feet. The largest volume was on the site with the intermediate amount of available moisture.

Laycock (1960) determined soil moisture deficits for Alberta using Thornthwaite's (1948) method. The determinations were based on data collected from regular weather stations with one or more complete years of recording from 1921-1950 (Canadian Monthly Weather Record, Department of Transport, Toronto, Ontario). An average moisture deficit of 0-8 inches was found in the forest regions of the province. Laycock concluded "Improved measurements of local water balance will now be more useful than additional attempts to develop or apply empirical procedures designed to define regional drought patterns." This conclusion may be taken a step further to say that information is required on soil moisture distribution and patterns in forest stands. To be able to use soil moisture as a limiting factor with more precision, specific studies should be made of the soil moisture status throughout the growing season in each of the forest regions.

Soil Fertility and Toxicity

Information on limiting factors of tree growth in Alberta may be derived indirectly through research on agricultural crops, soil survey reports, or studies supporting soil classification. Publications along these lines were reviewed as possible sources of information on soil fertility and toxicity as a limiting factor of growth.

Soil survey reports of the Peace River region (Odynsky and Newton 1950; Odynsky, Wynnyk and Newton, 1952 and 1956; and Odynsky, Lindsay, Reeder and Wynnyk, 1961) indicated low nitrogen and phosphorus for most uncultivated soils. Similar results are reported by Peters and Bowser (1960) for soils in the Rocky Mountain House region where a large percent of the soils are Gray Wooded. These authors report Gray Wooded soils to be deficient in sulfur as well.

Lowe (1965) reported the sulfur fractions of several Chernozemic and Podzolic soils from Alberta (Table 1).

TABLE 1 - Total Nitrogen, Total Sulfur, Easily Soluble Sulfate, Adsorbed Sulfate, Reducible Sulfur, Carbon Bonded Sulfur and pH of Chernozemic and Podzol Soils.

Horizon	Nitrogen Percent	Total Sulfur ppm	Easily Soluble Sulfate ppm	Adsorbed Sulfate ppm	Reducible Sulfur ppm	Carbon Bonded Sulfur ppm	pH.
Soil Series - Braeburn (Gray Wooded)							
F-H	0.69	642	5	6	191	165	6.6
Ae	0.07						5.3
AB	0.07						4.7
Bt	0.06	69	2	6	43	10	4.0
Soil Series - Antler (Orthic Black)							
Ah	0.47	576	27	15	353	126	7.3
Bm	0.12	192	7	8	169	21	7.2
Chernozemic (Orthic Brown, Dark Brown, Thin Black and Black, average of 8)							
Ah		435	18	18	269	74	
Bm		273	24	13	197	22	
Podzolic (All Gray Wooded, average of 7)							
L-H		700	39	16	218	190	
Bt		80	5	7	37	12	

These results indicate a low sulfur content in the mineral horizons of the Gray Wooded soils. However considerable amounts of sulfur were found in the L-H horizon of the Gray Wooded soils. The author states further that there was a relatively large amount of inert sulfur resistant to strong oxidizing and reducing agents in the L-H horizon of the Gray Wooded soils.

Thus it would appear that the sulfur deficiency may be due to a difficulty in transforming the sulfur to available forms.

Table 2 from Odynsky, Wynnyk and Newton (1956), and Odynsky, Lindsay, Reeder and Wynnyk (1961) presents the total nitrogen and phosphorus, the exchangeable calcium, magnesium and potassium, and pH of five common soils on different parent materials from the Peace River region. The soil series are Braeburn, Donnelly, Falher, Toad and Debolt.

The foregoing analyses indicate a relatively low nitrogen content throughout the profile for the Braeburn, Donnelly and Toad Soils. The Falher and Debolt have 2 to 3 times more nitrogen in the L-H horizon, but low and similar amounts in the B horizons. The phosphorus is low throughout the profile in the Braeburn, Donnelly and Debolt. All profiles show a decrease in pH from the L-H horizon to the C or lower B horizons. All profiles are moderately acid except where lime accumulates in the lower B or C horizons and in the L-H horizon of the Donnelly soil. Although considerable variation exists in the exchangeable cations from each soil, deficiencies of calcium, magnesium and potassium have so far not been reported from these soils.

Anderson, Hoyt and Pawlowski (1960) conducted fertilizer studies in Gray Wooded and Black soils using wheat, oats and barley as the test crops. The Soil Series were Codesa (Gray Wooded, sandy loam) near Baldonnel, British Columbia, Donnelly (Gray Wooded, clay loam) near McLennan,

TABLE 2. Total Nitrogen and Phosphorus, Exchangeable Calcium Magnesium and Potassium, and pH of Five Common Soils with Different Parent Materials from the Peace River District.

Horizon	Nitrogen Percent		Phosphorus Percent		Exchangeable Cations-Percent Ca	Mg	K	pH
Braeburn Series - on till, Orthic Gray Wooded, loam and clay loam, moderately well drained, lime concentration at depths of 36-48", relatively low in fertility but generally higher in B horizon than in leached A horizon.								
A_0 (A-H)[1]	.50		.08					5.6
A_2 (Ae)	.07	.06[2]	.03	.03[2]	62.4	12.8	3.7	5.0
B_1 (AB)	.06	.06	.03	.03		16.1	2.9	4.8
B_{21} (Bt)	.03	.06	.03	.03		19.3	1.9	4.6
B_{22} (Bt_2)	.06		.04	.04		20.2	1.8	4.5
B_3 (BC)	.06	.06	.06	.04		20.5	1.7	4.7
C		.06	.06	.06				6.2
Donnelly - lacustro - till, Gray Wooded Solod, loam and clay loam, relatively low in organic matter, imperfectly drained, sub-soil restricts water and root penetration, marked response from phosphate fertilizer.								
A_0 (L-H)	.75		.09		88.4	6.3	4.8	7.4
A_2 (Ae)	.06	.05[2]	.04	.09[2]	44.7	21.6	2.7	5.8
B_1 (AB)	.08	.10	.04	.04	45.9	31.2	3.5	5.3
B_{21} (Bt_1)	.07	.09	.05	.04	40.8	33.2	2.24	4.5
B_{22} (Bt_2)								5.5
B_3 (BC)	.06	.08	.08	.06	50.7	36.4	1.8	7.8
C C		.07	.08	.06				

[1] Revised nomenclature, Proceedings Fifth National Meeting Soils Survey Committee of Canada, Winnipeg, 1963.

[2] Data from Odynsky, W., A. Wynnyk and J. D. Newton. 1956. Soil Survey of the Grande Prairie and Sturgeon Lake Sheets. Research Council of Alberta Report No. 74. Remaining data from Odynsky, W., J. D. Lindsay S. W. Reeder and A. Wynnyk. 1961. Soil Survey of the Beaverlodge and Blueberry Mountain Sheets. Research Council of Alberta Report No. 81.

TABLE 2 - cont'd

Horizon	Nitrogen Percent	Phosphorus Percent	Exchangeable Cations-Percent Ca	Mg	K	pH
Falher - lacustrine, Dark Grey Solod, clay loam and clay, imperfectly drained.						
A_0 (L-H)	1.22	-	51.6	24.2	4.3	6.2
A_1 (Ah)	.43	-	48.7	20.1	4.4	5.7
B_1 (AB)	.13	-	35.1	27.8	1.5	5.0
B_{21} (Bt_1)	.09	-	39.1	34.9	1.9	4.6
B_{22} (Bt_2)	.08	-	49.5	42.7	1.6	6.5
C						7.5
Toad - alluvial, Bisequa Gray Wooded, sand loam and silt loam, low in organic matter, nitrogen and phosphorus, moderately well drained.						
L-H	.72	-	70.9	12.6	2.1	6.4
Ae_1	.07	-	65.9	14.6	1.2	6.2
Ae_2	.05	-	54.1	15.3	1.4	6.0
Bt	.03	-	40.9	6.8	2.3	5.7
Ae	.03	-	47.3	16.4	1.8	5.8
Bt_1	.06	-	62.4	25.5	0.4	5.7
Bt_2	.08	-	69.4	26.8	0.3	6.7
Ck						7.7
C						8.0
Debolt - residual and modified residual, Gray Wooded Solodized Solonetz, clay loam, imperfectly drained.						
L-H	1.50	.11	56.3	23.5	5.3	6.4
Ahe	.25	.08	42.0	29.3	2.3	5.9
Ae	.06	.03	49.0	23.3	1.1	6.5
Abn	.04	.03	44.4	27.5	1.4	6.7
Bnt_1	.05	.03	30.5	25.9	1.1	7.1
Bnt_2	.04	.04	30.0	26.8	0.9	7.9
Cks	.03	.04				8.1

Alberta, and Landry (Black, clay loam) near Beaverlodge, Alberta. There was a general increase in productivity in response to nitrogen, phosphorus, nitrogen plus phosphorus, and 9-27-9 fertilizers on all soils.

Elliott, Anderson and Owen (1961) studied the effect of fertilizing pastures on heavy textured Gray Wooded soil (Albright - Hythe Series) in the Peace River Region. The field chosen had been continually cropped for 25 years, and fertilizers 11-48-0 at 300 lb/ac, and ammonium nitrate at 100 lb/ac were applied. It was found that "pastures of creeping red fescue seeded alone and with alfalfa responded markedly to applications of nitrogen while responses to phosphorus were negligible. . . . . Conversely brome grass-alfalfa pastures responded strongly to applications of phosphorus and only slightly to nitrogen." These results suggest that fertilizer application does not necessarily result in significant growth response, and that considerable testing is necessary to determine the optimum response.

Russell, Smith and Pittman (1958) studied the effect of nitrogen and phosphorus fertilizers on the yield and protein content of spring wheat grown on stubble fields of Brown, Dark Brown and Shallow Black soils in southern Alberta. They found yields were increased from the use of nitrogen fertilizers when moisture was adequate. More than 40 lb of nitrogen per acre and at least 80 lb in some cases must be applied to increase protein. Addition of 20 lb or more of phosphate per acre to the nitrogen may reduce the effect of nitrogen on the protein content.

Newton (1953) determined the influence of soil zone (Brown Prairie, Black Park and Gray Wooded) on the chemical composition of wheat, barley and oats in Alberta. He found no direct relationship between total phosphorus of soil and crop. Black soils were generally highest in total phosphorus and Gray Wooded soils the lowest. Total sulfur of grains grown on sulfur-deficient Gray Wooded soils was low. There was no consistent relationship between total calcium or magnesium of soil and grain. Magnesium content of grains was much higher than calcium. Potassium content of the three grains was variable. All soils were high in total potassium, and no consistent relation existed between soil and grains. Nitrogen in wheat and barley tended to decrease from dry to moist climatic zones.

Dormaar and Webster (1963) determined the phosphorus in several Alberta soils. They found the total organic phosphorus decreased with increasing depth in all profiles. Values for the surface horizons of soils sampled from Brown, Dark Brown, Thin Black, Black, Dark Gray, and Gray Wooded soils were: 172, 247, 479, 625, 415 and 500 ppm. In terms of percent organic phosphorus of total phosphorus there were 34, 36, 47, 51, 42, and 38 percent respectively. The analysis of two soils in Table 3 is a representation from these authors' data.

TABLE 3. Organic Nitrogen, Non-sulfate Sulfur, Total Phosphorus, and pH of Black and Gray Wooded Soils. (Dormaar and Webster, 1963).

Horizon	pH	Organic N Percent	Non-sulphate S ppm	Total P ppm	Organic P of Total P Percent
Antler loam (Black) virgin soil					
Ah (10-12")	6.6	.63	697	1220	50
Bm	6.6	.091	162	441	25
C	8.2	.019	110	632	8
Cooking Lake loam (Gray Wooded) virgin soil					
L-H (2-3")	6.1	1.4	906	1310	38
A_2	6.5	.042	58	199	47
B_1	4.6	.056	94	379	22
C	7.7	.021	53	518	12

Pawluk (1961) determined the mineralogical composition of Orthic Gray Wooded soils developed from glacial till of different geological formations. The soils were Braeburn, Breton, Demmitt, Cooking Lake and Alcan Series. The clay minerals in those soils were montmorillonite, illite and kaolinite. Montmorillonite was generally the major clay mineral of the inorganic colloidal fraction in the B and C horizons. However in the C_2 of the Alcan montmorillonite was almost absent in both fine (0.2 micron) and coarse (2.0-0.2 micron) clay fractions. Generally illite was the major clay mineral of the coarse clay, but relatively low qualities occurred in the fine clay fraction.

Kaolinite was found in minor to trace quantities throughout the profiles. The cation exchange capacity of these soils is high. Thus there is a high available nutrient storage potential.

Synghal, Toogood and Bentley (1959) assessed the nitrogen requirements of Alberta soils. Seven Brown, 11 Dark Brown, 8 Thin Black, 12 Black, 7 Degraded Black, and 5 Gray Wooded were tested in greenhouse and field experiments. Nitrogen fertilizers were applied to oats in the greenhouse and wheat, oats and barley in the field. The authors found "correlation between the various nitrogen tests and increase in yield from added nitrogen were mostly negative . . . . . None of the other laboratory determinations, total nitrogen, nitrate nitrogen originally present, available nitrogen or nitrogen values appears to be potentially useful for predicting the nitrogen needs of Alberta soils . . . . . Incubation test for producing nitrates in soils appears to offer the most promise in assessing nitrogen requirements of Alberta soils."

Although lime is found in high quantities in some Alberta soils, no published information was found that indicated soil toxicity was a problem in productive forest regions of the province.

Permeability and Depth of Rooting Zone

The permeability and depth of rooting zone refers to the physical limitation to rooting depth. This limitation affects growth indirectly through its influence on factors like moisture storage capacity of a soil. It can be measured in the field by examining cutbanks and soil profiles near sample trees. However experience and careful examination are necessary, for as Horton (1958) found with species having a wide ecological amplitude like lodgepole pine, there is considerable variation in root form between individual trees in the same soil. In addition there may be difficulty in applying this limitation. If supported, trees will grow well in hydroponics where rooting depth is not a factor. Topographic position and soil texture with their influence on water holding capacity, drainage and aeration are frequently related to depth of rooting. Therefore, it is questionable if depth of rooting as a limiting factor can be applied alone. To date in the land capability classification for forestry in Alberta this subclass has not been used as a limitation[3].

Stoniness

Stoniness is not a direct limitation to growth. Stony soils as a limitation most frequently act through water holding capacity, drainage, topography, and the amount and kind of associated finer materials. Its importance as a limiting factor can be easily assessed in the field. It is anticipated that stoniness will seldom be used as a limiting factor in the land capability classification for forestry in Alberta[3].

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[3] Knight, H., J. A. Schalkwyk, J. R. Prokopchuk, N. Van Waas, E. Boyacioglu and R. Pearson. 1966. Land capability classification for forestry in Alberta. Canada Department Forestry and Rural Development, Calgary, Alberta and Alberta Forest Service, Edmonton, Alberta. 12 pp. Unpublished report.

Inundation

Inundation as a limitation to growth refers to soils periodically flooded by lakes or streams. The limitation to growth is indirect. It is the lack of oxygen in stagnant flood waters that limits plant growth. Flooding effects are governed by their duration, frequency and intensity. An intense flood such as a swollen river could cause physical damage to a bordering stand. On the other hand flooding could be beneficial by leaving detrital deposits. The application of inundation as a limiting factor in Alberta will be restricted to active flood plains and emerging deltas[3].

DISCUSSION

Information on the limiting factors of growth as applied in the land capability classification for forestry indicates two categories of limiting factors. The first group, which includes climate, soil moisture, and soil fertility and toxicity have a direct influence on growth. The second group, which includes permeability and depth of rooting, stoniness, and inundation affect growth indirectly. In the current land capability classification for forestry (McCormack, 1965) each group appears to be given equal value, although the first three are more intimately associated with growth. Evidence suggests that the latter three factors will seldom be used in the forest land classification for Alberta, and therefore may be considered relatively unimportant in the classification. Thus the discussion will emphasize climate, soil moisture, and soil fertility and toxicity as limiting factors of growth.

More representative information on climatic components in forest regions should be obtained, otherwise climate as a limiting factor can only be used in broad site evaluation. Gaps in information could be filled by initiating studies that would show relations among climate and soil factors and tree growth. For example it is important to establish air temperature-soil temperature relationships under various forest growth conditions. Soil temperature may be one of the most important limiting factors in Alberta. At present soil temperature is not one of the limiting factors applied in the forest land classification program.

Soil moisture as a limiting factor to growth is one of the most frequently applied limiting factors. However, there is a great need for information about soil moisture distribution and patterns as related to tree growth in the various regions of the province. Such information would allow soil moisture as a limiting factor to be used with more precision and confidence. Even though the present methods of assessing soil moisture in the field (Matthews, 1963) are helpful in determining soil moisture as a limiting factor, there seems to be room for developing more accurate and meaningful field descriptions of soil moisture.

Information derived from soil survey reports indicates low nitrogen and phosphorus in many forest soils in Alberta. In keeping with this result agricultural research shows a growth response to nitrogen and phosphorus fertilizers. These growth responses have not always been consistent. Further study has shown that soil moisture content must be considered when assessing the effects of fertilizers on growth. Other studies in the review have indicated soil-plant relationships, methods of assessing elemental requirements of soils, and descriptions of the mineralogical composition of soils. This information provides little for a direct forestry interpretation.

There is a lack of published information on the nutrition of the commercial Alberta forest species. Research that should be started to fill this void includes: nutrient requirements of the commercial trees; the relation between fertilizer response and soil types; the time, kind and amount of fertilizer required to produce the optimum growth; and interactions of soil nutrients with other factors such as soil moisture.

SUMMARY AND CONCLUSIONS

A review is presented of the limiting factors of growth as applied in the land capability classification for forestry under the Canada Land Inventory Program. The purpose of the review was to assess the current use and knowledge of these limitations as an aid to their more precise application to the forest land capability classification.

in the future. It was found that:

1) there was a lack of information on the limiting factors most directly related to growth - climate, soil moisture and soil fertility and toxicity. The deficiencies are magnified for these are the most important limiting factors. Deficiencies were noted and specific research was suggested.

2) the limiting factors indirectly influencing growth which include permeability and depth of rooting, stoniness and inundation, will be used infrequently and are therefore relatively unimportant.

3) There is little specific information on the limiting factors of tree growth that would enhance the current forest land capability classification in Alberta.

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