

THE UNIVERSITY OF MANITOBA

GROWTH RESPONSE IN FERTILIZED AND THINNED NORTHERN
MANITOBA BLACK SPRUCE STANDS

by

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A Thesis Submitted to the Faculty of Graduate
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ABSTRACT

Growth response to fertilization and thinning treatments of mature black spruce (Picea mariana) were investigated in two sites in Northern Manitoba. One site near Sipiwesk Lake had plots treated in the spring of 1968 with various levels of urea and super triplephosphate fertilizer. The other study site near the town of Wanless had similar fertilization treatments plus extra plots treated with urea fertilizer and thinned to 61 % of their original stem number. The latter site, however, had fertilizer treatments applied in the fall 1968. Analysis of data determined volume change between treatments, ring increment response, and stand structure changes. The best significant growth response occurred in the Sipiwesk spring application of 280 kg/ha of urea. Fall application of fertilizer without thinning showed poor results. The thinning with fertilization treatments at Wanless, however, had good growth response, with best response being a combination of thinning and 84 kg/ha of urea. The application of phosphorus in the form of super triplephosphate had only a modest influence on growth response. The most important change in stand structure was an increased in the mortality of trees in one of the Wanless fertilization treatments. The amount of tree mortality in all of the Sipiwesk treatments were found to be similar.

For Klem Froning

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CHAPTER ONE

INTRODUCTION

1.1 Background

In 1976 it was estimated that Canada would harvest about 127 million cubic metres of wood annually, and that by the year 2000 this removal would increase to about 215 million cubic metres (Stanton, 1976). Slowly, because of this intensive harvesting, the stocks of merchantable wood in Canada are dwindling. Similar problems have occurred in Sweden, and have been overcome by several forest management practices. Sweden's most successful management technique has been forest fertilization (Holmen, 1969).

In Canada two methods are being investigated to see if they can increase the merchantable supplies of wood. These methods are fertilization and thinning. Experiments with nitrogen and nitrogen/phosphorus fertilizers have resulted in substantial increases in growth for many species of young trees (Stanton, 1976). However, the use of fertilizers as a means of increasing yield in semi-mature forest has been delayed by the simple procedure of cutting down more trees (Stanton, 1976). Several programs of forest fertilization began in Canada around 1962. The largest fertilization trials were in British Columbia, where 25,000 hectares of Douglas-fir (Pseudotsuga menziesii) forest had been fertilized with urea by the end of 1978 (Pang and

McCullough, 1982).

Little commercial thinning is practiced in Canada. There have, however, been developmemts in pre-commercial thinning, sometimes refered to as spacing (Stanton, 1976). Most pre-commercial thinning occurs in sites where the trees are between twenty to thirty years old. It is at this age that nutrient, moisture, and light resources become limiting to growth because of overcrowding. Competition for these resources causes the gradual demise of weak individuals in the forest community. Thinning causes the removal of these weak or suppressed trees before competition for resources occurs, and therefore increases the amounts of nutrients available for the trees that are left. The removal of suppressed trees over dominants is commonly refered to as 'selective thinning'.

In Manitoba, the Department of Natural Resources has expressed interest in the possibility of increasing merchantable yields of black spruce (Picea mariana) in the boreal forest (Rowe, 1972) by the application of fertilizers, or by implementing selective thinning. As a response to this need the Canadian Forestry Service established two demonstration areas in Northern Manitoba in 1968 (Nairn, 1970). The first demonstration near Sipiwesk Lake, approximately 11.2 kilometers southeast of Wabowden (Figure 1), was established in the early spring 1968, and contained nitrogen/phosphorus fertilization trials. The fertilizers at the Sipiwesk site were applied during the

last week of May. The second demonstration, approximately 4.8 kilometers south of Wanless (Figure 1), contained both thinning and nitrogen/phosphorus fertilization trials. The fertilizers in these plots were applied during the period October 15-18, 1968. In both areas nitrogen was applied in the form of urea, and phosphorus as triple superphosphate.

After fifteen years of growth the black spruce that survived in the Wanless and Sipiwesk demonstration plots were examined for growth response due to thinning and/or fertilization. During the spring of 1983 sampling of data from these demonstrations was undertaken by a crew of five (which included myself) Canadian Forestry Service workers. The sampling was designed and organized by myself. The sampling took eight days to complete, and included various measurements of diameter at breast height (DBH), height, and ring increment growth of the treated black spruce. From the fall of 1983 to the spring of 1984 the collected samples were further analyzed for growth responses in the laboratory at the University of Winnipeg. Conclusions as to the growth responses within the treatments were finished by the summer of 1984 after computer analyses of the collected data.

1.2 Objectives

Many researchers believe that fertilization and/or thinning may be used to increase the merchantable yields of wood in the Canadian boreal forest (Steward et al., 1968;

and Stanton, 1976). Studies similar to the Wanless and Sipiwesk demonstrations have concluded that fertilization and/or thinning can increase yields (Krause, 1973; Weetman and Algar, 1974; Weetman, 1975; Gagnon et al., 1976; Morrison et al., 1976 and 1977; Van Cleve et al., 1976; Kingston et al., 1978; Morrison and Foster, 1979; Van Nostrand, 1979; Krause, 1981; Morrison et al., 1981; Steinbrenner, 1981; Barclay et al., 1982; and Krause et al., 1982). However, the amount of increase in the merchantable volume is controlled by the rate of fertilization, type of soil, prevailing climate, and other environmental limiting factors that may cause or relieve growth stress (Kozlowski, 1979).

The purpose of this study is to investigate the growth response of the black spruce in the Sipiwesk and Wanless demonstration areas to fertilization and selective thinning. Also, to acquire information on site conditions and relate this data to the observed growth response. This site information may then be used to determine fertilization or thinning rates in other similar site locations in Northern Manitoba. Specific objectives include: 1) determining the volume change between treatments with the aid of DBH measurements and a volume/DBH curve, 2) determining the increment growth change in the rings after treatment as compared to the increment growth prior to treatment, 3) identify changes in the stand structure cause by the treatments, and 4) determining if the time of application

changes the resulting volume increase for identical treatments (Wanless, fall application; Sipiwesk, spring application).

1.3 Study Area and Site Description

The Sipiwesk fertilization demonstration site is located in section 15, township 68, range 7, along the north side of the Sipiwesk Lake road. This area is a dry upland site with a well drained Orthic Gray Luvisol soil developed on lacustrine clay. The soil has a well-developed Ae and Bt horizons and a thin organic surface horizon. The pH was measured in the field just below the soil surface at 5.2 (Nairn, 1970). The forest stand in 1968 consisted of 90 % black spruce, 7 % trembling aspen (Populus tremuloides), and 3 % jack pine (Pinus banksiana) (Nairn, 1970). The stand was of fire origin with the average age of the black spruce being approximately 70 years in 1968.

The Wanless demonstration is located in section 31, township 59, range 26, along the east side of highway 10. The demonstration is located on an imperfectly drained Gleyed Solonetzic Gray Luvisol soil developed on glacial till. These soils have the properties specified for the Luvisolic order, but differ by having either distinct mottles indicative of gleying within 50 cm of the mineral surface or prominent mottles at depths of 50-100 cm (Canada

Soil Survey Committee, 1978). The soil had a relatively thin LFH layer and a pH of about 5.4 just below the soil surface (Nairn, 1970). The stand in 1968 consisted of 65 % black spruce, 28 % jack pine, and 7 % trembling aspen (Nairn, 1970). The trees were of fire origin with an average age of the black spruce being approximately 75 years in 1968.

1.4 Literature Review

1.4.1 Forest Nutrient Cycling

In order to understand fertilization in forest ecosystems it is best to first review the literature on forest nutrient cycling. Nutrients circulate in a forest ecosystem in a cyclical pattern similar to what is shown in Figure 2. Patterns of nutrient circulation almost always contain five important recognizable components. These components are the atmospheric input, weathering input, soil nutrient store, organic cycling and store, and leaching loss (Trudgill, 1977). The main factor which controls the functioning of each of these components is climate (Weetman and Timmer, 1967; and Weber and Van Cleve, 1984). Climate fuels the catalysts which control the rate at which a component functions. Climate is especially important to organic cycling, because precipitation and temperature control effectively the amount of phytomass that can

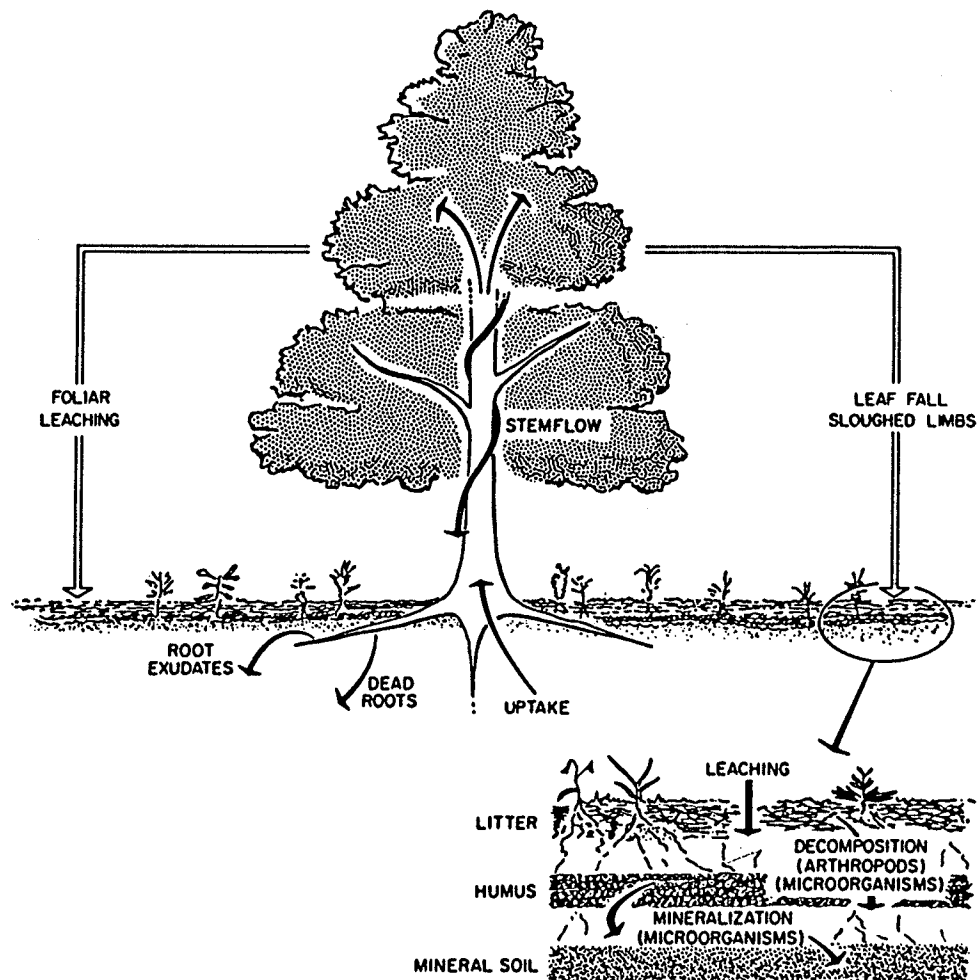


Figure 2. Major components of the nutrient cycle (reprinted from Curlin, 1970).

accumulate through forest growth.

Each nutrient has variations in its absolute quantities, rate of transfer, and method of transfer. Differences between are due to their specific natures, their physiochemical properties, and the way they are used in that particular ecosystem under investigation. In nutrient cycling there are 9 major elements (hydrogen, calcium, magnesium, potassium, carbon, oxygen, nitrogen, phosphorus, and sulphur), and 10 minor elements (iron, maganese, boron, molybdenum, copper, zinc, chlorine, colbalt, sodium and silicon). This study is primarily interested in the two major elements nitrogen and phosphorus, because these nutrients were used in the fertilization experiments.

The accumulation of nutrients in trees generally increases with biomass production. Nutrient distribution patterns in the tree usually are in the order of foliage > bark > bole > roots (Curlin, 1970). However, this is a generalized statement of nutrient distribution as a whole. Individual nutrients such as nitrogen, calcium, phosphorus and potassium may have quite different sequential patterns (Curlin, 1970). Switzer and Nelson (1972) found that the quantity of nutrients involved in accumulation within the plant system varies with its annual cycle of growth. They also found that the nutrients greatest in demand are those present in the greatest quantity within the plant. The measurement of nutrient accumulation, especially in the foliage, is important in forest fertilization because the

measurements may determine nutrient deficiencies in the soil (Steward and Swan, 1968; Pidwirny, 1982; and Timmer, 1979). These deficiencies may then be removed through the addition of the appropriate nutrients by fertilization.

Nutrient return to the forest floor may occur from three forest ecosystem processes. Firstly, nutrients may be returned to the forest floor through foliar leaching. Secondly, nutrients may be returned by the decomposition of foliage, branches, roots, and stems. Finally, nutrients may be added to the forest ecosystem by organisms which are able to accumulate nutrients from the atmosphere, rock weathering, or some other process. Alban (1982) found that nutrient accumulation rates vary with stand age, and that for most stands maximum rate of accumulation is at 20 to 30 years. He also discovered that the amounts of nutrients which accumulate seems to be directly related to the amount of litterfall.

Plants utilize soil nutrients for growth and development. Soil nutrients can be stored in the form of cations or as solutes in the soil water (Trudgill, 1977). Cation nutrients are usually held on by clay-humus complexes, and are not readily lost in the soil system by leaching. Nutrients held in soil solution, however, can be quite readily lost by leaching. Plants in most cases receive their nutrient requirements from the soil solution, which is later replenished by the various nutrient inputs.

The science of nutrient cycling is still young and

full of many problems in understanding the various processes. The following points will summarize some of the problems:

(1). Assessing the soil nutrient regime is difficult to determine because the nutritional requirements for many of the various tree species is not yet known (Foster and Morrison, 1980).

(2). Leaf (1967) has suggested that researchers have not developed adequate extractants and procedures to measure the available soil nutrients.

(3). The heterogeneity of forest soils and the complex rooting systems of trees causes problems with respect to selecting samples of soil for analysis (Foster and Morrison, 1980).

(4). Forests have a very long life, and therefore it is not possible to measure the past nutrient regimes.

(5). The cycle of nutrients between forest trees and soil is usually very close, and any release of nutrients from any component of the cycle may add considerable mineral nutrition (Miller et al., 1979). Nitrogen and phosphorus are good examples of tight cycling nutrients which are generally released very gradually from slowly decomposing humus. However, a forest fire will release these nutrients very quickly upon burning the humus layer of forest soils.

(6). Uptake of some nutrients (phosphorus) into trees must be facilitated by mycorrhizal associations with the tree. This type of symbiosis is very difficult to measure

(Foster and Morrison, 1980).

(7). It is very hard to measure the important role of mosses in the nutrition of trees (Weetman and Timmer, 1967; Weetman, 1968; and Foster and Morrison, 1980). Mosses can intercept nutrients from rainfall and dust, and offer these nutrients to advantageous rooting systems. This is especially true of shallow rooting tree species such as black spruce.

1.4.2 Nitrogen Cycle

In most boreal forest ecosystems the nutrient which most limits the growth of trees has been found to be nitrogen (Foster and Morrison, 1980). Nitrogen is available and stored in the soil in many forms (Figure 3). Nitrogen income in a forest ecosystem is derived from organic matter decomposition, nonsymbiotic and symbiotic nitrogen fixation, and ammonium and nitrate salts brought down by precipitation. Loss of nitrogen can occur because of leaching and volatilization. In this study nitrogen is added to the forest-soil internal nutrient cycle by the application of urea fertilizer. The following review will summarize the major findings on nitrogen transformations in the forest floor and soil with and without fertilization.

Much of the nitrogen in soils is immobilized in complex organic molecules, and is not available for plant nutrition or may be lost through leaching and volatilization

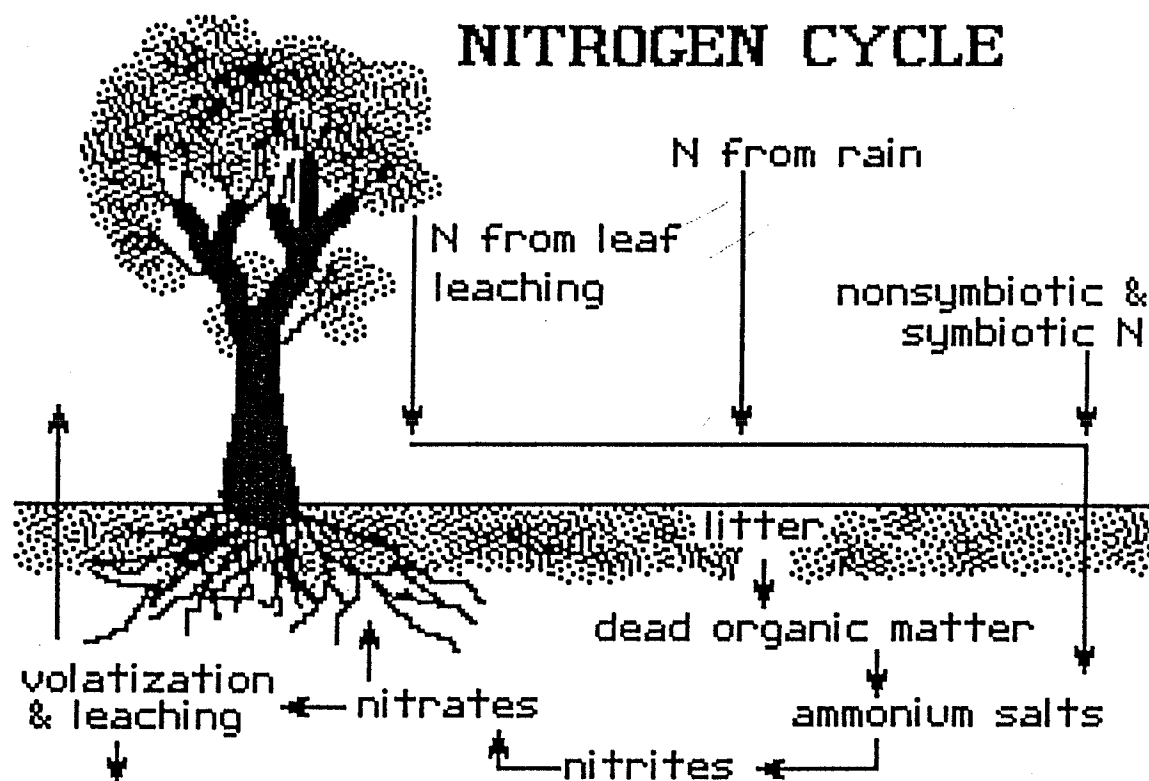


Figure 2. Major components of the nitrogen cycle.

(Brady, 1974; and Keeney, 1980). Certain microorganisms, however, can mineralize this organic nitrogen into inorganic forms, which then can be used by plants. In forest ecosystems some authors have noted that very little immobilization occurs after urea-N was added to a black spruce forest (Roberge and Knowles, 1966). Other data, however, suggest that there can be an increase in the immobilization of exchangeable ammonium when urea fertilizer is added (Salonius, 1972). This increase in immobilization, though, is probably related to a large increase in pH which had not been observed in the Roberge and Knowles study. Salonius (1972) also found that if you fertilize with ammonium salts instead of urea the amount of nitrogen lost to immobilization will be reduced because it does not raise the pH of forest soils.

Mineralization usually increases with urea fertilization, because of the accelerated decomposition of litter due to the addition of nitrogen. Researchers have discovered that with the addition of urea substantial increases in the numbers of soil flora and fauna occur (Roberge et al., 1970). These organisms are responsible for the release of several nutrient elements through mineralization, including nitrogen, phosphorus, and sulphur (Brady, 1974).

Nitrification is a process of enzymic oxidation which chemically changes ammonium salts into nitrites, and nitrites into nitrates (Brady, 1974). It is brought about

by special purpose bacteria, like nitrifiers, which live in the soil. In forest soils the organic and upper mineral layers are not conducive to autotrophic nitrification (Keeney, 1980). Rice and Pancholy (1972) found that the numbers of nitrifiers decreases with the successional movement of ecosystems to climax. They hypothesized that many soils under climax vegetation are low in nitrate, due to an inhibition of nitrification by climax plant species. Many workers have discovered little or no nitrification in samples of non-N-treated forest soils (Roberge and Knowles, 1966; Heilman, 1974; Mahendrappa, 1978; and Mahendrappa and Salonijs, 1982). However, the addition of urea, which causes an increase in soil pH, generally increases the nitrification rate for a short period of time (Heilman, 1974; Otchere-Boateng and Ballard, 1978; Mahendrappa, 1978; Mahendrappa and Salonijs, 1982; Pang and McCullough, 1982; and Nyborg, 1983). Otchere-Boateng and Ballard (1978) found that nitrate concentrations peaked at least 3 months after fertilization with urea at the rate of 448 kg/N/ha. Other researchers have concluded that in forest ecosystems temperature and precipitation, in concert, regulate the amount of microbial activity in the forest floor, and therefore nutrient transformation and cycling (Weetman and Timmer, 1967; Cowling and MacLean, 1981; and Weber and Van Cleve, 1984).

Very little information is available on the amount of denitrification, the production of nitrogen dioxide and

gaseous oxides of nitrogen, which might occur in forest soils (Keeney, 1980). Denitrification usually takes place in anoxic, warm, neutral soils that contain plenty of soluble organic matter. Forest soils do contain soluble organic matter, but are not, generally, neutral in pH or anoxic, and contain little nitrate for denitrification.

Significant amounts of nitrogen are lost in urea-treated forest soils by way of ammonia volatilization (Holmen, 1969; Baker, 1970; Watkins et al., 1972; Mahendrappa and Ogden, 1973; Nommik, 1973; Keeney, 1980; and Craig and Wollum, 1982). Maximum rates of ammonia volatilization have been observed 3 to 4 days after urea fertilizer application (Mahendrappa and Ogden, 1973). However, sudden increases were also observed in the same study on several occasions during the next 36 days immediately after rainfall. Nommik (1973) found greatest ammonia losses occurred during the spring and summer months. Craig and Wollum (1982), however, found that volatilization of ammonia from urea appeared to depend more on moisture in the soil, and time and amount of precipitation after fertilization application, then on season of application. Other research has included air movement as a factor that may increase ammonia loss (Watkins et al., 1972). Mahendrappa and Ogden (1973b) believe that volatilized ammonia may not be entirely lost to the atmosphere, because some soils have been found to absorb considerable quantities of ammonia from the air. Some researchers suggest that

ammonium nitrate should be applied instead of urea to reduce volatilization loss (Holmen, 1969; Braastad et al., 1974; and Weetman and Algar, 1974), or that you add ammonium chloride with the urea to buffer volatilization reactions (Watkins et al., 1972).

Nitrogen may be added to forest ecosystems by symbiotic and nonsymbiotic nitrogen fixation (Brady, 1974; and Keeney, 1980). Bormann et al. (1977) found that nonsymbiotic nitrogen fixation may be important in some forested ecosystems. Symbiotic nitrogen fixation, however, tends to be minimal, except in forest stands where alder is common (Keeney, 1980). The atmosphere input of nitrogen from precipitation is often equal to the nitrogen lost through leaching (Bormann et al., 1977). This makes all other inputs of nitrogen a net gain to the forest ecosystem.

1.4.3 Phosphorus Cycle

Phosphorus is considered to be the second most important nutrient in plant growth (Brady, 1974). This nutrient is extremely important in plant metabolic plant processes and functions, such as cell division, flowering and fruiting, root development and seed formation (Brady, 1974). Phosphorus exists in the soil in both organic and inorganic forms. In its inorganic form it is usually bonded to other elements like calcium, iron, and aluminum. There are three main types of organic phosphorus found in plant

structures and decaying litter. These types of organic phosphorus are phytin and phytin derivatives, nucleic acids, and phospholipids (Brady, 1974). Inorganic phosphorus availability is largely determined by soil pH, decomposition level of organic matter, and microorganism activity. Organic phosphorus, in some cases, can be directly absorbed by the plant, however, in other cases the organic molecule which houses the element must be decomposed in order to facilitate absorption.

Research has shown that phosphorus deficiencies in the soil may cause a reduction in the growth rate of nitrite-oxidizers upon nitrogen fertilization (Purchase, 1974). A lack of these organisms would limit the amount of nitrification that could occur. Other research has shown that the addition of phosphorus fertilizer reduces the amount of nitrogen leached in forest soils (Kelly and Henderson, 1978; and Mahendrappa, 1978). This reduction in leaching is caused by the increased availability of calcium for incorporation into insoluble calcium ammonium phosphate. Mahendrappa (1978) has shown that the addition of phosphorus increases organic matter decomposition. However, the rate of decomposition caused by phosphorus is not as great as with nitrogen.

1.4.4 Fertilization and Growth

There are basically three advantages to using urea as

a source of nitrogen (Gasser, 1964). Firstly, urea has a very high nitrogen content (45% N), which lessens transport and spreading costs. Secondly, urea is very soluble and becomes incorporated into the soil very quickly. Finally, hydrolysis of urea in forest soils almost always increases pH, and thus increases the soils cation exchange capacity (Gonzalez and Plamondon, 1978). Urea, however, also has some disadvantages as a fertilizer. Such disadvantages as the presence of toxic biuret as an impurity in processing, damage to germinating seeds and young plants due to ammonia toxicity, and loss of nitrogen as ammonia gas when surface applied (Gasser, 1964).

Nitrogen in the form of urea has been used in forest fertilization in Canada since 1962 (Stanton, 1976). Many of the studies that have used urea to increase growth have shown good results to fertilization (Truong and Gagnon, 1975; Weetman, 1975; Van Cleve and Zasada, 1976; Morrison and Foster, 1979; Van Nostrand, 1979; Krause, 1981; Morrison et al., 1981; and Krause et al., 1982). Conversely, though, some studies have shown only a small response to urea fertilization (Gagnon et al., 1976; and Morrison et al., 1976). One conclusion that has become evident is that the fertilization studies have not determined proper application rates for a specific growth increase on the many soil types of the Canadian boreal forest (Baker, 1972; and Krause et al., 1982). This inability to prescribe application rates may be due to the complexities in establishing what are the

nutrient quantities within forest soils, and what are the nutritional requirements of the various boreal tree species. This problem ,however, may be reduced through foliar analysis (Steward and Swan, 1968; and Timmer, 1979).

Urea fertilization can also cause changes in stand structure. The most obvious change is increased mortality (Barclay et al., 1982; and Krause et al., 1982). Mortality may be caused by increased competition, or ammonia toxicity. However, the decline that occurs in the number of stems per hectare does not usually cause a decrease in total volume when compared to control. The net increase in volume due to urea fertilization usually compensates for the volume lost due to death. The trees that usually die are those that are quite small in relation to the other members in the stand. Another study involving Douglas-fir investigated whether urea fertilization causes changes in the distribution of area increment over the tree's bole (Mitchell and Kellogg, 1972). Their results concluded that fertilization did not significantly affect tree form in the codominant and intermediate tree classes. However, the dominant tree class displayed growth response in the central third of the stem that was significantly less than the control.

Phosphorus fertilizer has been used in Canadian forestry for many years. In a study that examined triple superphosphate, ground rock phosphate, and basic slag on the growth of sitka spruce (Picea sitchensis), superphosphate was found to be most effective (Dickson,

1971). However, the use of phosphorus is usually most effective in forested ecosystems which lack available phosphorus, like trees growing on deep ombrogenous peat (Dickson, 1971). In systems which contain available phosphorus for growth, the addition of triple superphosphate may not increase the growth of the fertilized trees (Morrison et al., 1976; Morrison et al., 1977; Morrison and Foster, 1979; Van Nostrand, 1979; Krause, 1981; Morrison et al., 1981; Steinbrenner, 1981; Krause et al., 1982; and Mahendrappa and Salonius, 1982). Morrison and Foster (1979) actually found that too much phosphorus reduced growth. However, other researchers have reported growth responses to single applications of phosphorus (Krause, 1973; and Van Nostrand and Bhure, 1973).

1.4.5 Thinning and Growth

Thinning increases the growth response of trees by removing a particular percentage of the members in a stand causing a reduction in intraspecific competition. This reduction in tree numbers provides more nutrients for the remaining trees through re-distribution. Researchers have also found that thinning can cause other changes in the stand. In particular, thinning causes improved moisture content of the soils, increased light penetration, and better soil temperature regimes (Van Cleve and Zasada, 1976). In most cases the growth response to thinning is

rapid, increasing volume increments on an individual tree basis. Best results, however, seem to be produced with a combined effect of thinning and fertilization (Weetman, 1975; Van Cleve and Zasada, 1976; and Barclay et al., 1982). Growth response to this type of treatment is usually visible for quite a few years, because of the reduction in competition.

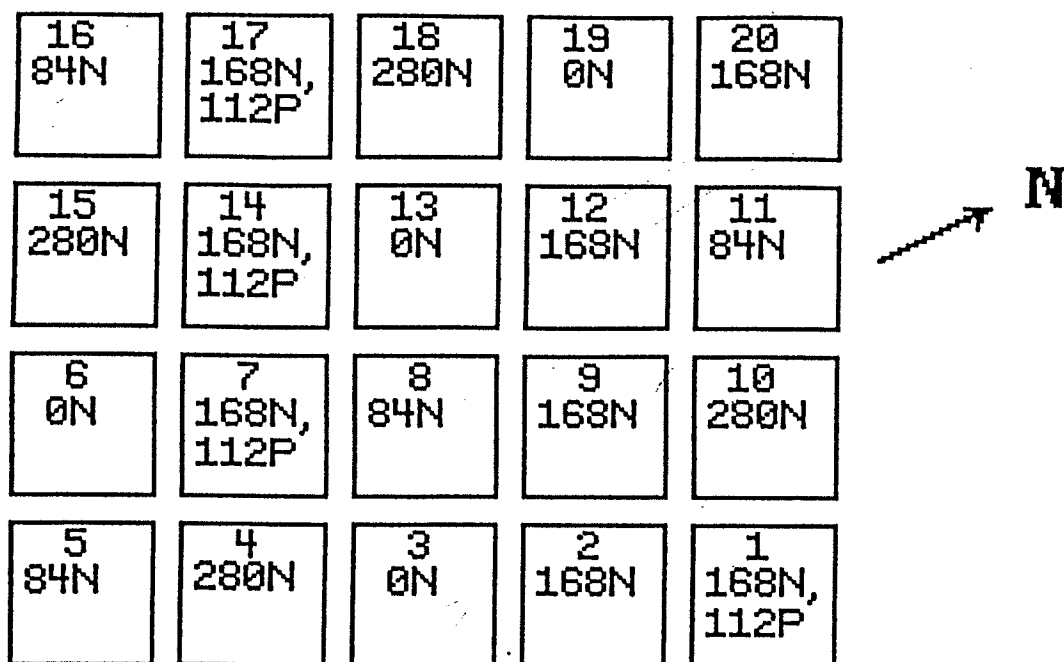
CHAPTER TWO

METHODS

2.1 Research Design and Treatments

The design of the Sipiwesk fertilization demonstration consisted of 20 plots in a randomized block (see Freese, 1967 for information on block design plots). The block contained five fertilization treatments each being replicated four times (Figure 4). Each plot consisted of a treated area 24.4 x 24.4 metres, which was surrounded by a 3 metre buffer zone to protect the plots from contamination. Figure 5 displays a typical view of the black spruce stand. The study area, where the trees were examined for response, consisted of a inner study plot measuring 12.2 x 12.2 metres. Before fertilization, all the living trees in the plot were measured for DBH with a metal DBH measuring tape (Figure 6). Fertilizers were spread evenly with a heavy duty cyclone seeder.

The design of the Wanless fertilization demonstration consisted of 28 plots in a randomized block (Figure 7). Eight extra plots were constructed in this block in order to select 20 treatment plots because of frequently occurring openings in the stand. The size of the plots and treatment amounts were exactly the same as the Sipiwesk demonstration. The Wanless thinning and fertilization demonstration consisted of one block of 6 plots. Treatments (thinned,



Sipiwek Fertilization Demonstration

Figure 4. Sipiwek fertilization demonstration plot design. Urea and triple superphosphate fertilizers were applied in these plots in the following amounts; control (0N), 84 kg/ha N (84N), 168 kg/ha N (168N), 280 kg/ha N (280N), and 168 kg/ha N + 112 kg/ha P (168N, 112P).

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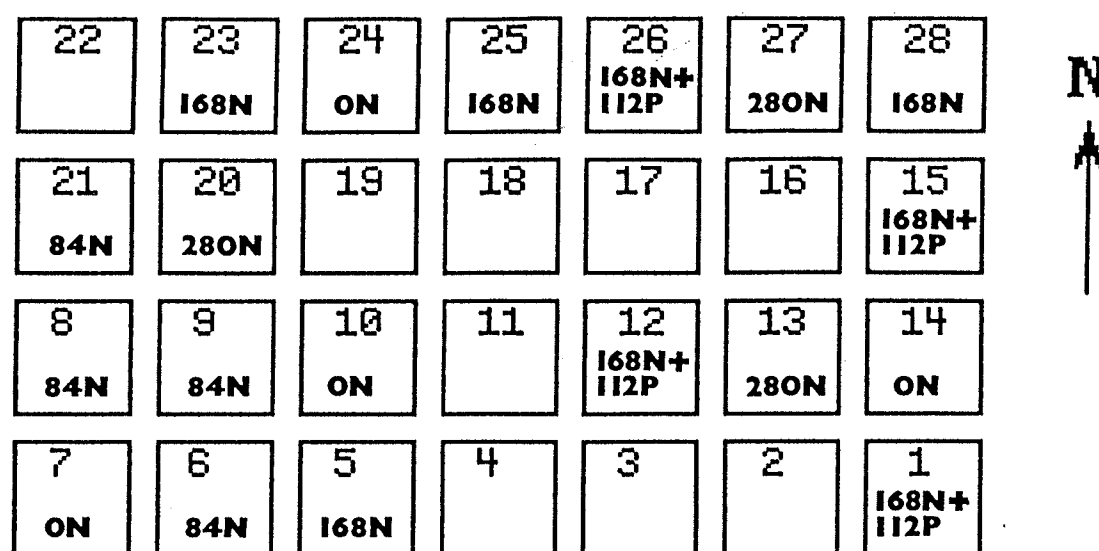
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Figure 5. Typical view of the Wanless black spruce stand. The trees in this picture are approximately 10 cm in diameter at breast height.



Figure 6. DBH measurement procedure.



Wanless Fertilization Demonstration

Figure 7. Wanless fertilization demonstration plot design. Urea and triple superphosphate fertilizers were applied in these plots in the following amounts; control (ON), 84 kg/ha N (84N), 168 kg/ha N (168N), 280 kg/ha N (280N), and 168 kg/ha N + 112 kg/ha P (168N, 112P).

thinned + 84 kg/ha N, and thinned + 168 kg/ha N) were replicated twice in a random pattern in plots of the same size as the fertilization treatments. In the thinning plots stem number was reduced by 41 % (Nairn, 1970). The construction and initial measurements of all the plots were performed under the supervision of L. Nairn, forest research officer for the Canadian Forestry Service. Initial DBH measurements for all Wanless plots were done in the fall of 1968 just prior to treatment. The Sipiwesk plot DBH measurements were done in the spring of 1968 prior to treatment.

2.2 Data Collection and Preparation

2.2.1 Sipiwesk

During the period June 4 to 6, 1983 the fertilization plots at Sipiwesk were revisited for the collection of data to determine growth response. From the time of initial fertilization to measurement, 15 years of growth had taken place. The first series of remeasurements included the DBH measurement of all black spruce trees in the various treatment plots. These measurements were made with a metal tape at the prescribed height of 1.3 metres (Metric Commission Sector Committee 8.1-Forestry, 1976). For the second series of measurements 5 sample trees were cut down in each plot at both fertilization demonstrations. These

trees were then measured for height to the nearest 10th of a metre (Figure 8), and sectioned with a chainsaw at every 1.3 metres until the crown was reached. At these cuts cross-sections approximately 3 cm thick were cut out for analysis of increment response to treatment along the tree's bole, and for the calculation of the tree's total volume (Figure 9). Each section was coded with the necessary plot, treatment, and height up bole data, using a felt tip marker.

2.2.2 Wanless

During the period between May 31 and June 3, 1983 the fertilization and thinning plots at the Wanless site were revisited for the collection of data. From the time of initial treatment to measurement, 14 years of growth had taken place. The measurements were exactly the same as that done at Sipiwesk. However, obvious changes in the undergrowth were apparent in some of the treatments. The mosses usually found in the treatment plots were absent in the 280 kg/ha N and and 168 kg/ha N + 112 kg/ha P treatments (Figure 10). What remained on the forest floor of these plots was the dead aerial leaf parts of the mosses, which were slowly decomposing.

2.3 Methods of Analysis

2.3.1 Volume/DBH Curve

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Figure 8. Height measurement of a felled tree.



Figure 9. Cutting of tree cross-sections for use in the laboratory to determine ring increment response and volume analyses.



Figure 10. This picture displays the absence of mosses on the forest floor in the 280N treatment plot at Wanless.

A volume/DBH curve had to be constructed in order to determine the volume of a tree from a DBH measurement. Five trees in each fertilization treatment plot in both Sipiwesk and Wanless were selected for the measurement of raw data for the curve. Each tree was cut down by chainsaw and then measured for height and DBH. Volume measurement required the cross-sectioning of the bole at 1.3 metre intervals. The number of cross-sections were determined by the height of the tree, and ease of cutting through smaller portions of the bole with the chainsaw. Volume determination of the sampled trees were obtained through mathematical manipulation. This manipulation used diameter measurements obtained in the laboratory from the sections cut from the felled trees, and the overall tree height measurement in the following equation:

$$\begin{aligned} & \{[(A_1)/4 + (A_1+1)/4]^2 \times 3.1415927 \times 51.181102\} + \{[(A_2)/4 + \\ & (A_2+1)/4]^2 \times 3.1415927 \times 51.181102\} + \dots + \{[(A_n-1)/4 + \\ & (A_n)/4]^2 \times 3.145927 \times 51.181102\} + \{1/3[(A_n)/2]^2 \times \\ & 3.145927 \times H\} = \text{VOLUME in cubic inches} \end{aligned}$$

Where; A = diameter of section from the bole in inches (A₁ and A₂ is the diameter of the first section, A₃ is the diameter of the second measurement at 2.6 metres height, etc., and A_n is the last section measurement). A₁ was given the same value as A₂, because no diameter measurements were

taken at the tree base. This measurement, however, should be quite accurate because of consistency; 51.181102 = the distance in inches between the section cuts; H = the measurement difference between the tree height and the height of the last section cut; and 3.1415927 = π . This equation was constructed from a synthesis of many other formulae used to determine tree volume (Husch et al., 1972; Evert, 1976; Barclay et al., 1982; Evert, 1983; and Singh, 1984), and should contain less estimate error than a generalized equation (Meng, 1972).

The volume measurements from this formula were regressed against the field DBH data using the SPSS computer program "bivariate correlation analysis" (Nie et al., 1975). Both variables were entered into regression normally and transformed. The transformation that was performed was that of a log 10 function. Separate models were made for each location so as to provide the most accurate model estimate of volume.

2.3.2 Treatment Volume Calculations

Volume calculations for all the treatments in each of the two demonstrations were accomplished with the volume/DBH models created in the prior section. These models only require field DBH measurements for total volume estimates. Actual calculations were done with the help of a microcomputer. Calculations were done for the years 1968

and 1983 to determine the growth response of the various treatments. Plot volume estimates were calculated for all trees in the plot, and only those trees that had a DBH measurement greater than 6.35 cm. The latter calculation was performed in order to exclude small stems that usually perish with the development of the stand. Tests of significance were performed on the calculated volumes for each plot using the Student's t-test (Freese, 1967). This test determines the statistical difference between the treatment means as calculated from the four replications. Comparisons between treatments were then made to see if there was a difference in growth response. Calculations were also made to determine the percentage of mortality from 1968 to 1983, and their statistical significance between treatments.

2.3.3 Ring Increment Response

The tree sections were taken to a laboratory at the University of Winnipeg where they were prepared for ring increment analysis. The sections were first routered to provide better definition of the rings. The router line ran through the centre of the section at approximately the average diameter of the section. This router line was then sanded with a file, and oiled to bring out the grain. Measurements were performed with a microscope, which measured the rings to an accuracy of 1/10 of a millimetre.

Rings were measured in 5 year increments for consistency, and ease of measurement. The Sipiwesk sections had increment measurements 5 years before fertilization, and 15 years after fertilization. The Wanless sections had increment measurements 5 years before, and only 10 years after fertilization. These plots had only experienced 14 years of growth since treatment because of their fall application. Analysis of the Wanless thinned and fertilized treatments was not possible because no samples were taken at this demonstration due to time restraints.

Response of the tree rings to treatment were measured by the relative comparison of the 5-year increment ring growth prior to fertilization to the increment ring growth 1-5, 6-10 and 11-15 years after fertilization. The increment ring growth was calculated by the addition of the measured samples divided by the number of samples. The number of measured samples varied because of poor ring definition in some of the sections. Measurements of response were determined in percentage increase over the increment period prior to treatment. Equal growth response to the prior increment period would measure 100 %. The response was measured at 7 different bole positions in order to determine if growth response was equal at different heights on the stem. The height of the 7 bole positions were, 1.3, 2.6, 3.9, 5.2, 6.5, 7.8, and 9.1 metres.

Statistical significance of the increment response between treatments was not measured for the following

reason. The collecting of samples which would be statistically comparable involves a much more precise means of increment measurement. Discussions with scientists at the Northern Forest Research Centre concluded that this would involve increment measurements based on a minimum of 4 axes, because of the common irregularities in the increment of the yearly rings. This type of sampling would have been far to time consuming for the benefit it would yield. Therefore, the sections were analyzed as described by comparing growth increments to an equal increment prior to treatment.

2.3.4 Stand Characteristic Changes

Several calculations were performed to measure the changes in stand DBH after fertilization. Simple statistics (Freese, 1967), such as means, standard deviation, and variance, were calculated for plot DBH measurements in all the treatments in the two demonstrations. These simple calculations were done with the help of a microcomputer. Statistical formulae were taken from the book "Elementary Statistical Methods for Foresters" (Freese, 1967). To test the differences in the measured variance from 1968 to 1983 for the treatments a Fmax-test was performed (Sokal and Rohlf, 1969). The test determines whether the variances of the samples are significantly heterogeneous.

Changes in the cumulative percent of trees in specific

DBH classes before and after fertilization for control and 280N treatments were also analyzed for both demonstrations. This analysis involved the calculation of the cumulative percent change in the tree numbers in the DBH classes from 1968 to 1983. The analysis was performed on the treatment level to increase accuracy. Plot analysis would have been fruitless and crude, because of low sample numbers. The DBH classes selected were, 0-2.54 cms (1), 2.55-5.08 cms (2), 5.09-7.62 cms (3), 7.63-10.16 cms (4), 10.17-12.70 cms (5), 12.71-15.24 cms (6), 15.25-17.78 cms (7), 17.79-20.32 cms (8), 20.32-22.86 cms (9), and 22.87-25.40 cms (10).

CHAPTER THREE

RESULTS

3.1 Volume/DBH Curve

The Sipiwesk volume/DBH curve was based on 100 samples. The best regression was that of log transformed volume and log transformed DBH data. The calculated correlation coefficient was .9858, with a significance better than .01 (Figure 11). The equation for the line of the best fit was:

$$\text{Log } 10 Y = 2.05942 + 2.33890 (\text{Log } 10 X).$$

Where ; $a = 2.05942$, and $b = 2.33890$.

The Wanless volume/DBH curve was based on 99 samples. One sample was omitted from analysis because of missing cross-sections. The best regression was, again, that of log transformed volume and log transformed DBH data. The calculated correlation coefficient was .9763, with significance better than .01 (Figure 12). The equation for the line of the best fit was:

$$\text{Log } 10 Y = 2.08844 + 2.30916 (\text{Log } 10 X).$$

Where ; $a = 2.08844$, and $b = 2.30916$.

The slopes of the regression lines for the two sites

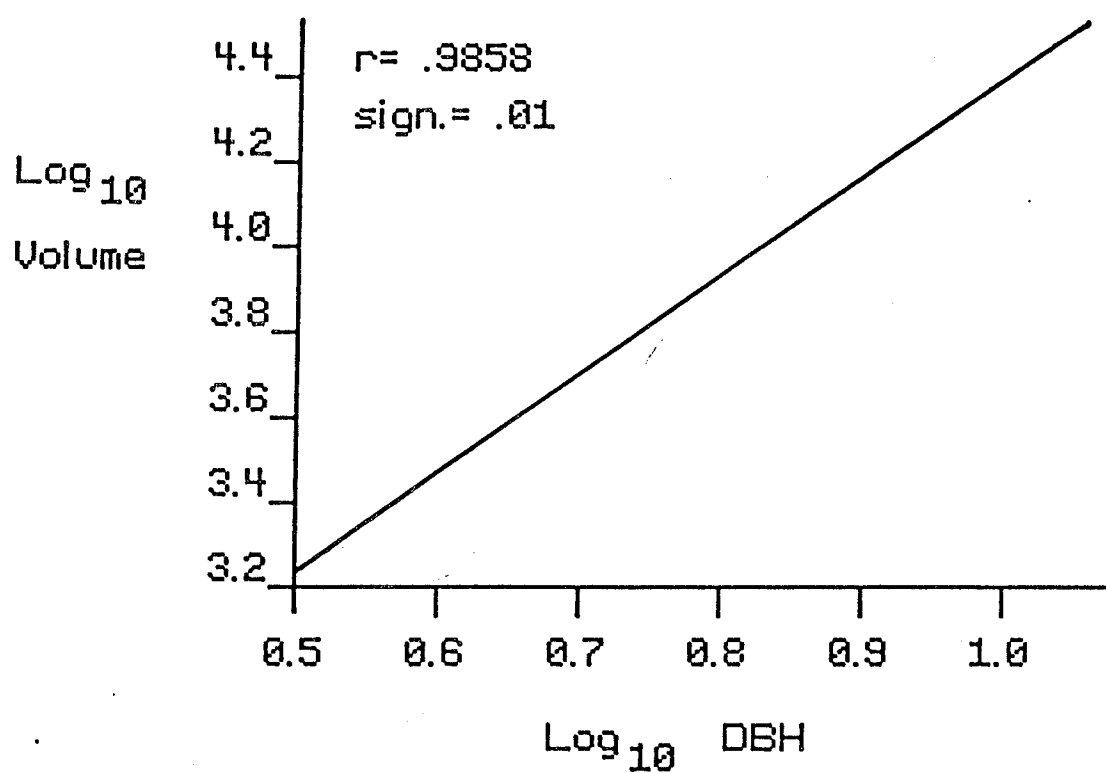


Figure 11. Sipiwesk volume/DBH curve. This curve was constructed with 100 samples of volume and DBH data (see Appendix 1).

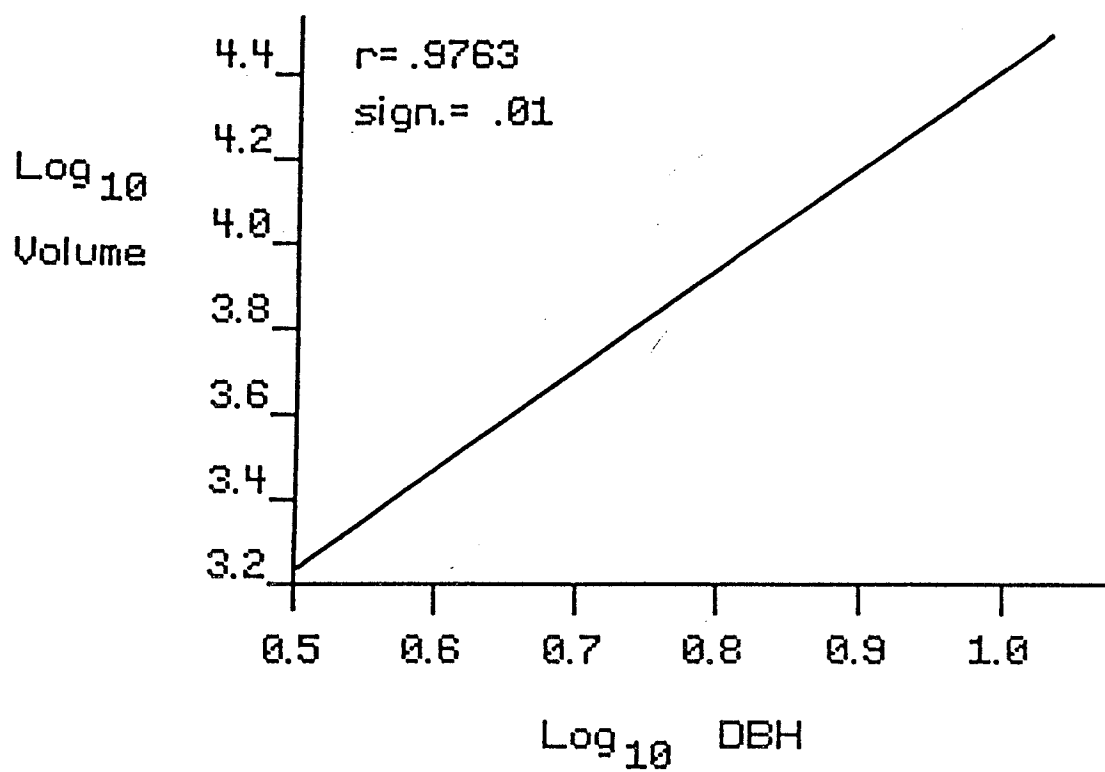


Figure 12. Wanless volume/DBH curve. This curve was constructed with 99 samples of volume and DBH data (see Appendix 2).

are almost identical. This probably indicates that the sites do not differ greatly in their growth potential.

3.2 Treatment Volume Calculations

Volume calculations for all the treatments were done with a microcomputer using the volume/DBH models. For Sipiwesk the equation for calculating tree volume was:

$$\text{VOLUME (Y)} = 114.66213 \times \text{DBH (X)}^{2.33890} .$$

Table 1 summarizes the volume calculations for Sipiwesk, for all the trees in each plot. This table presents data on volume estimates for 1968 and 1983, volume change from 1968 to 1983, percent increase in volume, and percent mortality. Variability between similar treatment plots in the relative percent increase in volume from 1968 to 1983 is noticeable. This variability is probably the result of the small sample size (Freese, 1962), or dynamic changes within the stand due to mortality. However, the average of the four replications may be a more precise estimate of the volume change. The highest average change in volume occurred in the 280N treatment, gaining 50.15 cubic metres of wood per hectare over 15 years. The lowest average change in volume occurred in the control (0N), gaining only 29.26 cubic metres per hectare of wood over 15 years. Figure 13 represents the average percent change in volume for the treatments from

Table 1. Volume calculations for Sipiwesk fertilization plots. All trees in the plot are included (for raw data see Appendices 3 and 4).

Treatment Plot		VOLUME			RESPONSE	
		1968	(m ³ /ha) 1983	Change	Percent Increase	Percent Mortality
0N	3	196.26	227.76	31.50	16.0	35.5
	6	217.93	239.74	21.81	10.0	40.0
	13	236.08	276.91	40.84	17.3	36.6
	19	239.71	262.58	22.87	9.5	32.0
AVERAGES		222.50	251.76	29.26	13.2 ^{de}	36.0
STD. DEV. +/-		19.92	22.14	8.86	4.0	3.3
84N	5	294.09	315.60	21.51	7.3	27.4
	8	292.49	318.20	25.71	8.8	38.1
	11	268.82	327.55	58.73	21.8	34.1
	16	168.81	208.48	39.67	23.5	24.2
AVERAGES		256.05	292.46	36.41	15.4 ^{de}	31.0
STD. DEV. +/-		59.30	56.22	16.79	8.2	6.3
168N	2	261.21	263.94	2.73	1.0	42.8
	9	197.05	227.12	30.70	15.3	43.3
	12	232.07	286.06	53.99	23.3	33.7
	20	152.68	198.75	36.07	30.2	41.0
AVERAGES		203.10	243.97	30.87	17.5	40.2
STD. DEV. +/-		46.76	38.73	21.24	12.5	4.4
280N	4	276.22	302.94	26.72	10.4	39.6
	10	194.16	271.80	77.64	40.0	34.9
	15	186.01	234.80	48.79	26.2	32.8
	18	210.90	258.33	47.43	22.5	35.3
AVERAGES		216.82	266.97	50.15	24.8 ^{ab}	35.7
STD. DEV. +/-		40.93	28.44	20.93	12.2	2.9
168N + 112P	1	198.24	258.39	60.15	30.3	15.1
	7	200.19	230.33	30.14	15.1	51.1
	14	241.93	286.10	44.17	18.3	46.2
	17	135.08	159.60	24.52	18.1	32.4
AVERAGES		193.86	233.61	39.75	20.5 ^{ab}	42.9
STD. DEV. +/-		44.06	54.33	15.92	6.7	16.1

Note: Corresponding letters indicate significant (5 %) differences between means of treatments (Student's t-test). [a = 0N; b = 84N; c = 168N; d = 280N; and e = 168N + 112P].

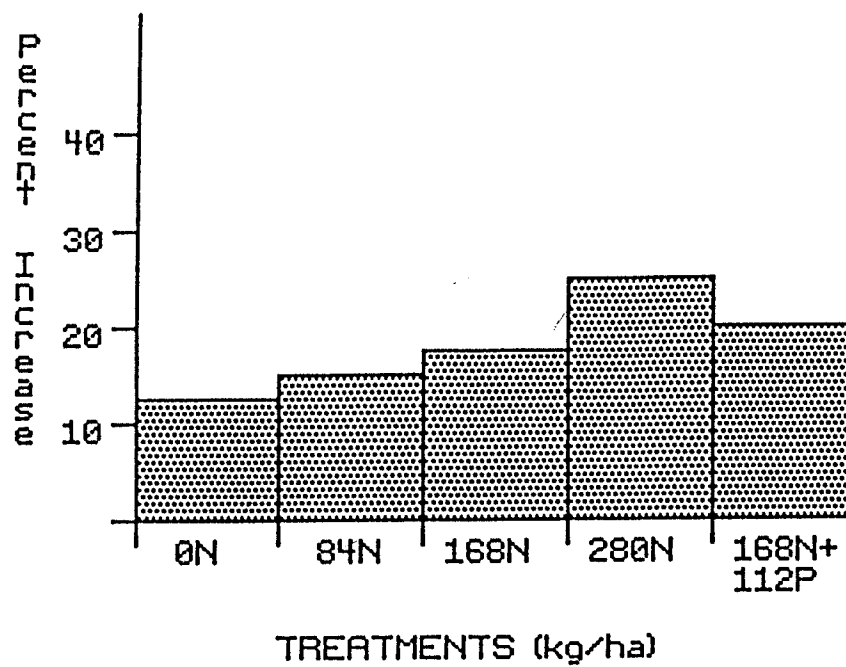


Figure 13. Average change in volume from 1968 to 1983 for the Sipiwesk fertilization treatments.

1968 to 1983 graphically. The highest average percent change occurs in the 280N treatment at 24.8 %. This change is approximately 88 % greater than the volume change experienced by the control (13.2 %). In general, it is obvious from this graph that the addition of fertilizer causes a proportional increase in stand volume.

Statistically, the Student's t-test analysis determined that there were differences between the means of several of the treatments at the 5 % level for percent increase in volume (Table 1). Specifically, the 0N and 84N treatment means were found to be statistically different from the means of the 280N and 168N + 112P treatments. This result concludes that there was a positive growth response due to fertilization. There were, however, no statistical difference between the percent mortality means of the treatments.

It is clear from the raw data (Appendices 3 and 4) that most of the trees below 6.35 cms diameter perished after 15 years of growth. These trees may be disguising the true change in volume due to treatment and perhaps should be excluded. A new series of calculations was performed and shows a much greater increase in volume for all treatments (Table 2). This volume change, however, is similar to that shown in Table 1. What is interesting is that the average percent mortality for the treatments is approximately the same, unlike the values given in Table 1. Figure 14 depicts the percent volume change from 1968 to 1983. Here, like in

Table 2. Volume calculations for Sipiwesk fertilization plots. Only trees with diameters greater than 6.35 cm are included in these calculations (for raw data see Appendices 3 and 4).

Treatment Plot		VOLUME			RESPONSE	
		1968	(m ³ /ha) 1983	Change	Percent Increase	Percent Mortality
0N	3	187.85	225.25	37.40	19.9	14.0
	6	207.40	235.22	27.82	13.4	18.4
	13	213.96	266.40	52.44	24.5	6.5
	19	230.21	257.06	26.85	11.7	18.9
AVERAGES		209.86	245.98	36.18	17.4 ^{de}	14.5
STD. DEV. +/-		17.53	19.02	11.87	5.9	5.7
84N	5	285.28	310.92	25.64	9.0	18.9
	8	274.88	313.56	38.68	14.1	15.7
	11	251.48	318.16	66.68	26.5	10.8
	16	166.80	206.68	39.88	23.9	12.0
AVERAGES		244.61	287.33	42.72	18.4 ^{de}	14.4
STD. DEV. +/-		53.76	53.85	17.23	8.2	3.7
168N	2	248.42	259.94	11.52	4.6	18.9
	9	187.41	224.84	37.43	20.0	15.4
	12	215.24	278.05	62.81	29.2	7.0
	20	138.95	192.02	53.07	38.2	10.3
AVERAGES		197.51	238.71	41.20	23.0	12.9
STD. DEV. +/-		46.32	38.17	22.38	14.3	5.3
280N	4	257.13	301.55	44.42	17.3	15.9
	10	177.85	261.51	83.66	47.0	0.0
	15	175.88	228.63	52.75	30.0	15.2
	18	192.85	244.90	52.05	27.0	16.4
AVERAGES		200.93	259.15	58.22	30.3 ^{ab}	11.9
STD. DEV. +/-		38.23	31.29	17.37	12.4	7.9
168N + 112P	1	182.74	256.03	73.29	40.1	4.3
	7	188.45	228.70	40.25	21.4	18.4
	14	221.15	282.16	61.01	27.4	9.3
	17	131.97	158.64	26.67	20.2	17.9
AVERAGES		181.08	231.38	50.30	27.3 ^{ab}	12.5
STD. DEV. +/-		36.85	53.18	20.84	9.1	6.9

Note: Corresponding letters indicate significant (5 %) differences between means of treatments (Student's t-test). [a = 0N; b = 84N; c = 168N; d = 280N; and e = 168N + 112P].

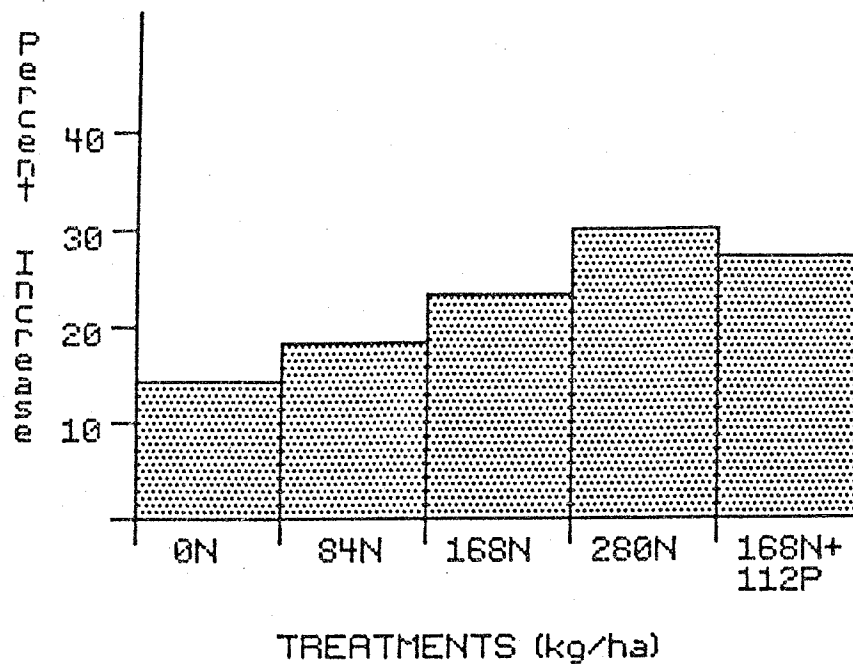


Figure 14. Average change in volume from 1968 to 1983 for the Sipiwesk fertilization treatments. Only trees with diameters greater than 6.35 cm are included in this graph.

Figure 13, the highest average percent change in volume occurs in the 280N treatment at 30.3 %. This change is approximately 74 % greater than the volume change experienced by the control. Statistically, Table 2 is identical to Table 1 showing the same significant (5 %) differences between the percent increase means, and no statistical differences between mortality means for the treatments.

The equation for calculating tree volume for Wanless was:

$$\text{VOLUME (Y)} = 122.5857 \times \text{DBH (X)}^{2.30916} .$$

Table 3 summarizes the volume calculations for the Wanless fertilization plots. Variability between similar treatment plots in the relative change of volume from 1968 to 1983 is again noticeable. The highest average percent change in volume, unlike the Sipiwek plots, occurred in the 168N treatment at 16.0 %. This increase, however, does not differ that much with the control treatment (15.0 %). The lowest percent increase in volume was in the 280N treatment (4.3 %), which is completely the opposite to the Sipiwek demonstration. Graphically displayed (Figure 15) there does not seem to be any appreciable increase in volume due to fertilization.

Statistically, the Student's t-test analysis determined that there were differences between the means of

Table 3. Volume calculations for Wanless fertilization plots. All trees in the plot are included (for raw data see Appendices 5 and 6).

Treatment Plot		VOLUME			RESPONSE	
		1968	(m ³ /ha) 1983	Change	Percent Increase	Percent Mortality
0N	7	173.07	208.85	35.78	20.7	33.3
	10	189.06	223.51	34.45	18.2	34.8
	14	225.83	238.17	12.34	5.5	38.7
	24	219.36	253.18	33.82	15.4	31.9
AVERAGES		201.83	230.93	29.10	15.0 ^{de}	34.7 ^b
STD. DEV. +/-		24.99	19.06	11.20	6.7	2.9
84N	6	220.76	270.63	49.87	22.6	20.0
	8	180.46	209.73	29.27	16.2	25.9
	9	191.62	230.32	38.70	20.2	6.7
	21	149.90	143.04	-5.86	-4.6	30.0
AVERAGES		185.69	213.43	27.74	13.6 ^d	20.7 ^{acde}
STD. DEV. +/-		29.29	53.31	24.09	12.4	10.2
168N	5	129.25	168.64	39.39	30.5	25.0
	23	93.94	99.36	5.42	5.8	52.9
	25	226.01	246.86	20.85	9.2	33.7
	28	148.99	176.78	27.79	18.6	36.8
AVERAGES		149.55	172.91	23.36	16.0 ^d	37.1 ^b
STD. DEV. +/-		55.83	60.31	14.20	11.1	11.7
280N	13	201.54	198.79	-2.75	-1.4	51.5
	19	198.10	209.95	11.85	6.0	33.3
	20	97.33	100.06	2.73	2.8	40.0
	27	157.22	172.71	15.49	10.0	27.4
AVERAGES		163.55	170.38	6.83	4.3 ^{abce}	38.1 ^b
STD. DEV. +/-		48.52	49.41	8.34	4.8	10.3
168N + 112P	1	190.66	202.65	11.99	6.3	39.5
	12	268.54	293.58	25.04	9.3	25.0
	15	148.49	165.25	16.76	11.3	36.0
	26	160.43	184.11	23.68	14.7	34.6
AVERAGES		192.03	211.40	19.37	10.4 ^{ad}	33.8 ^b
STD. DEV. +/-		54.01	56.88	6.11	3.5	6.2

Note: Corresponding letters indicate significant (5 %) differences between means of treatments (Student's t-test). [a = 0N; b = 84N; c = 168N; d = 280N; and e = 168N + 112P].

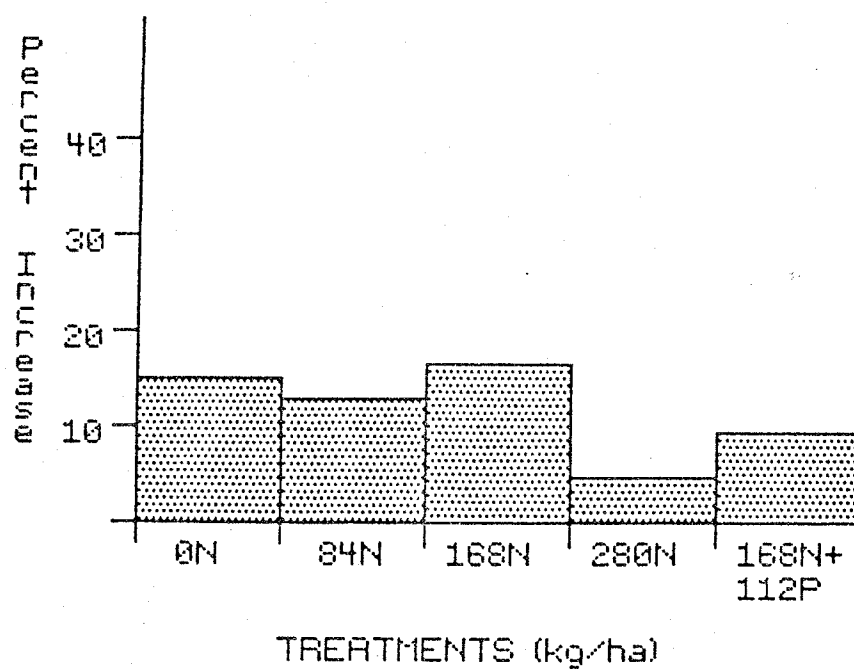


Figure 15. Average change in volume from 1968 to 1983 for the Wanless fertilization treatments.

several of the treatments at the 5 % level for percent increase in volume (Table 3). Specifically, the 280N treatment mean was found to be statistically different from the means of the 0N, 84N, 168N and 168N + 112P treatments. The 168N + 112P treatment mean was also found to be statistically different from the mean of the 0N treatment. Both of these results indicate that the application of fertilizer to the 280N and 168N + 112P treatments cause a significant decrease in the percent increase in volume when compared to the control. There were also statistical differences between the percent mortality means of the treatments. Specifically, the mean of the 84N treatment was significantly lower than the means of the other treatments.

Table 4, which excludes some of the error due to mortality, displays relatively similar results as Table 3. From this table it is quite apparent that the 280N treatment caused increase tree mortality with stems whose diameters were greater than 6.35 cm. Figure 16 displays the percent volume change from 1968 to 1983 for trees with diameters greater than 6.35 cm. This graph is almost identical to the graph in Figure 15.

Table 4 had several statistical differences from Table 3. Firstly, there was no statistical difference between the means of the 0N and 168N + 112P treatments in percent increase in volume. Secondly, the treatment that was statistically different from the other treatments in percent mortality had changed. In this table the mean of the 280N

Table 4. Volume calculations for Wanless fertilization plots. Only trees with diameters greater than 6.35 cm are included in these calculations (for raw data see Appendices 5 and 6).

Treatment Plot		VOLUME			RESPONSE	
		1968	(m ³ /ha) 1983	Change	Percent Increase	Percent Mortality
0N	7	154.56	199.46	44.90	29.0	0.0
	10	177.14	210.95	33.81	19.1	7.1
	14	218.42	237.15	18.73	8.6	21.1
	24	205.46	249.72	44.26	21.5	6.5
AVERAGES		188.90	224.32	35.42	19.6 ^d	8.7 ^d
STD. DEV. +/-		28.65	23.14	12.24	8.4	8.9
84N	6	210.03	265.83	55.80	26.6	0.0
	8	164.69	203.64	38.95	23.7	0.0
	9	183.76	228.56	44.80	24.4	0.0
	21	143.71	140.42	-3.29	-2.3	16.7
AVERAGES		175.55	209.61	34.06	18.1 ^d	4.2 ^d
STD. DEV. +/-		28.21	52.73	25.86	13.7	8.4
168N	5	120.48	167.14	46.66	38.7	0.0
	23	139.90	164.17	24.27	17.4	18.8
	25	141.00	173.81	32.81	23.4	0.0
	28	88.36	96.88	8.52	9.7	8.3
AVERAGES		122.44	150.50	28.06	22.3 ^d	6.8 ^d
STD. DEV. +/-		24.59	35.97	15.97	12.3	8.9
280N	13	181.81	196.94	15.13	8.3	21.1
	19	190.69	205.05	14.36	7.5	20.0
	20	93.12	98.79	5.67	6.1	20.8
	27	146.88	168.31	21.43	14.6	9.1
AVERAGES		153.13	167.27	14.14	9.1 ^{abce}	17.8 ^{abce}
STD. DEV. +/-		44.25	48.30	6.48	3.8	5.8
168N + 112P	1	175.82	199.39	23.57	13.4	17.2
	12	258.97	289.47	30.50	11.8	12.3
	15	139.90	164.23	24.33	17.4	11.4
	26	146.67	178.26	31.59	21.5	0.0
AVERAGES		180.34	207.84	27.50	16.0 ^d	10.2 ^d
STD. DEV. +/-		54.69	56.31	4.13	4.3	7.3

Note: Corresponding letters indicate significant (5 %) differences between means of treatments (Student's t-test). [a = 0N; b = 84N; c = 168N; d = 280N; and e = 168N + 112P].

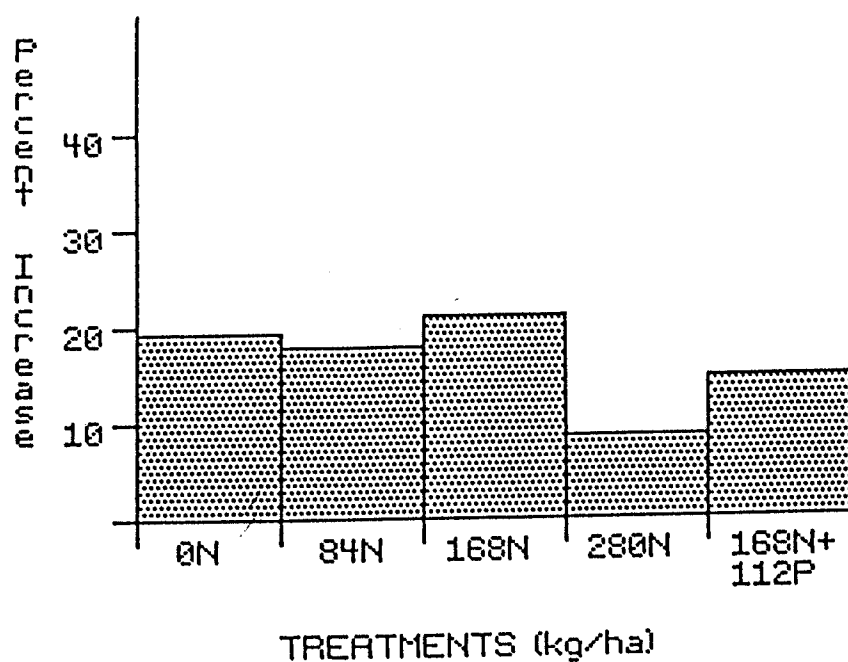


Figure 16. Average change in volume from 1968 to 1983 for the Wanless fertilization treatments. Only trees with diameters greater than 6.35 cm are included in this graph.

treatment in percent mortality was significantly higher than the means of the other treatments.

Table 5 summarizes the volume calculations for the Wanless thinning and fertilization treatments. It is obvious from this table that there was little difference between different fertilizer treatments with respect to thinning. The highest average percent change in volume occurred in the thinned + 84N treatment (27.5 %). The lowest average percent change in volume occurred in thinned + 0N treatment (24.5 %). When graphed (Figure 17) with the control response from Table 3, the thinned + 84N treatment shows a 83 % gain in volume over the control. However, the addition of 84 kg/ha of N with thinning only increases the net volume over thinning alone by 20 %. There were no statistical differences between means for percent increase in volume or percent mortality.

3.3 Ring Increment Response

The purpose of the ring increment analysis was to measure increment change as a response to fertilizer treatments. Ring increment analysis was performed only on the Sipiwesk fertilization data, because of restraints in time. Figures 18 to 24 display the response of the tree rings to treatment in 5 year increments at 7 bole positions relative to the 5 year growth increment prior to fertilization. Minimum response usually occurred in the 0N

Table 5. Volume calculations for Wanless thinning and fertilization plots. All trees in the plot are included (for raw data see Appendices 7 and 8).

Treatment Plot		VOLUME			RESPONSE	
		1968	(m ³ /ha) 1983	Change	Percent Increase	Percent Mortality
THINNED	2	143.73	171.93	28.20	19.6	11.5
+ 0N	4	190.22	246.19	55.97	29.4	6.7
AVERAGES		166.98	209.06	42.08	24.5	9.1
STD. DEV. +/-		32.87	52.51	19.64	7.3	3.4
THINNED	3	185.11	223.35	38.24	20.7	10.3
+ 84N	6	177.83	238.99	61.16	34.4	7.5
AVERAGES		181.47	231.17	49.70	27.5	8.9
STD. DEV. +/-		5.14	11.06	16.21	9.7	2.0
THINNED	1	194.91	216.96	22.05	11.3	28.6
+ 168N	5	118.01	165.88	47.87	40.6	3.8
AVERAGES		156.46	191.42	34.96	25.6	16.2
STD. DEV. +/-		54.38	36.12	18.26	20.7	17.5

Note: Corresponding letters indicate significant (5 %) differences between means of treatments (Student's t-test).
[a = 0N; b = 84N; c = 168N; d = 280N; and e = 168N + 112P].

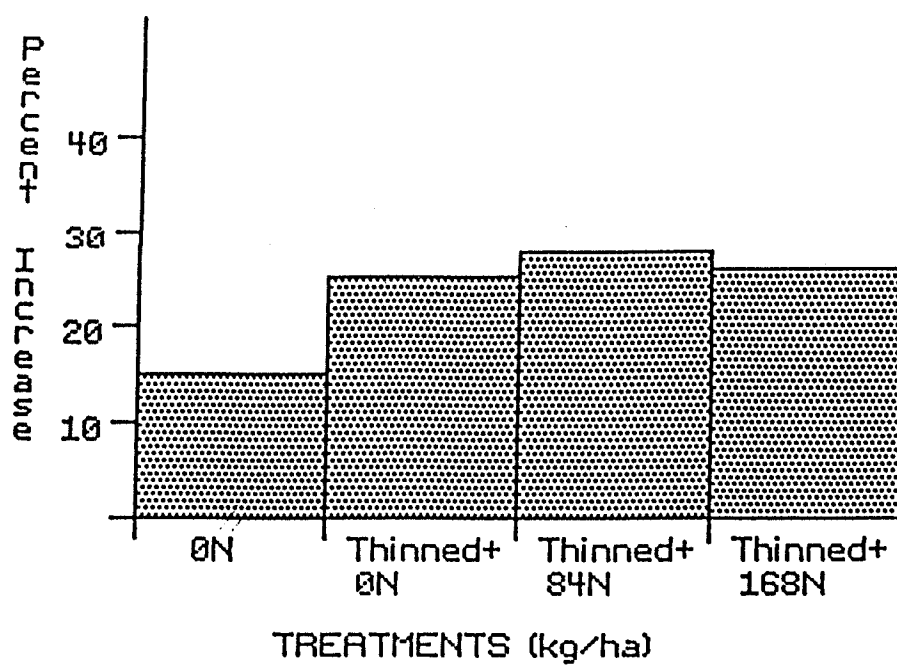


Figure 17. Average change in volume from 1968 to 1983 for the Wanless thinning and fertilization treatments. Included in this graph is the average change in volume for the control (0N) from Table 3.

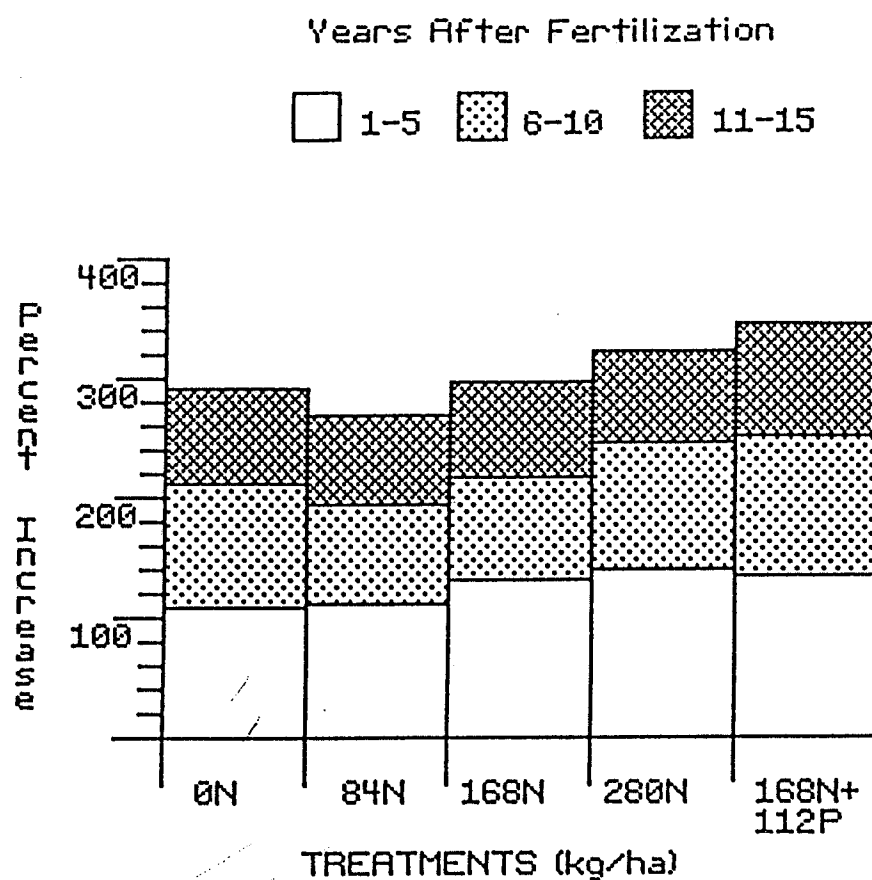


Figure 18. Sipiwesk ring increment growth response at the 1.3 metre bole position (see Appendix 9 for raw data). The 5-year increment periods were measured relative to the 5-year growth increment prior to treatment.

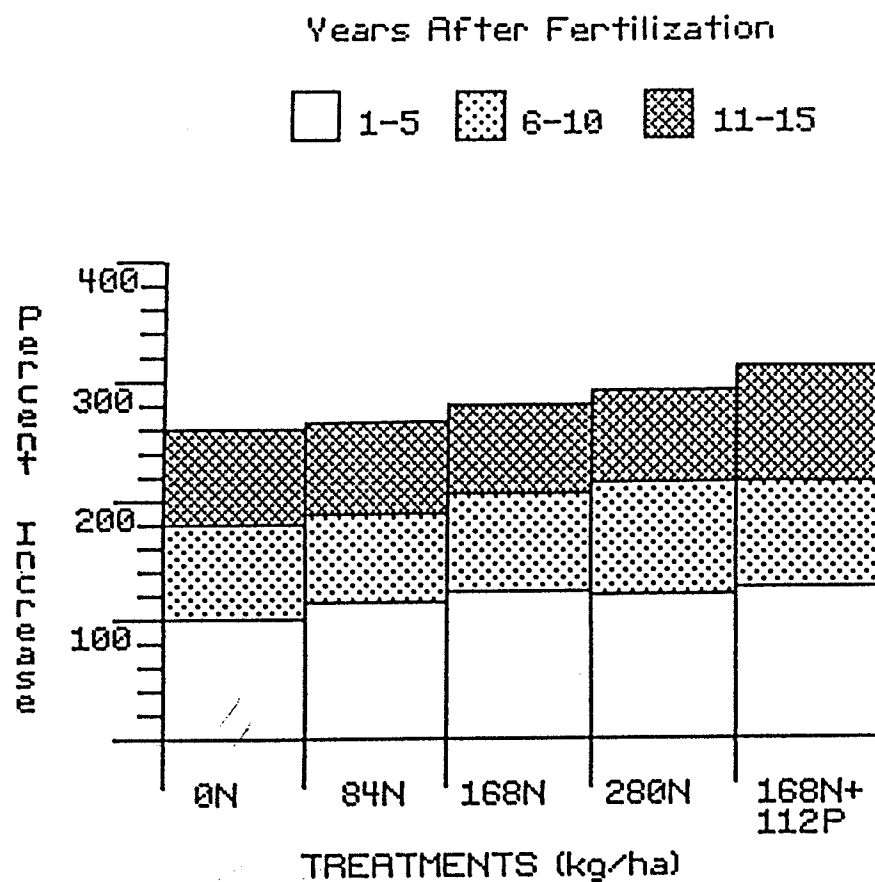


Figure 19. Sipiwesk ring increment growth response at the 2.6 metre bole position (see Appendix 9 for raw data). The 5-year increment periods were measured relative to the 5-year growth increment prior to treatment.

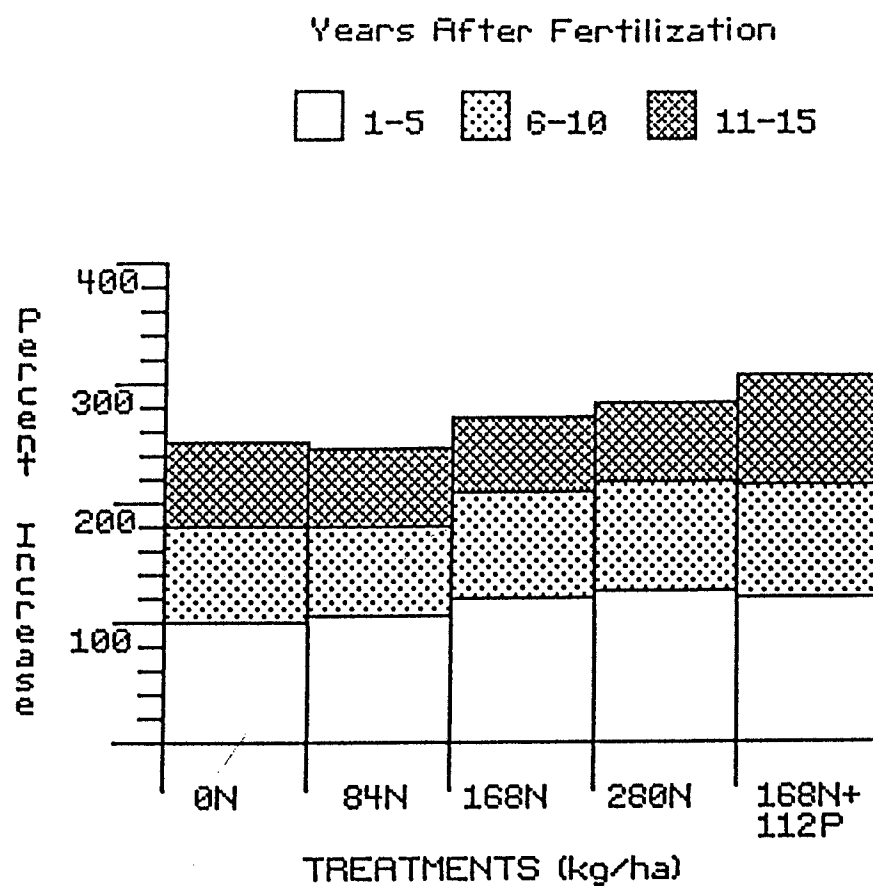


Figure 20. Sipiwesk ring increment growth response at the 3.9 metre bole position (see Appendix 9 for raw data). The 5-year increment periods were measured relative to the 5-year growth increment prior to treatment.

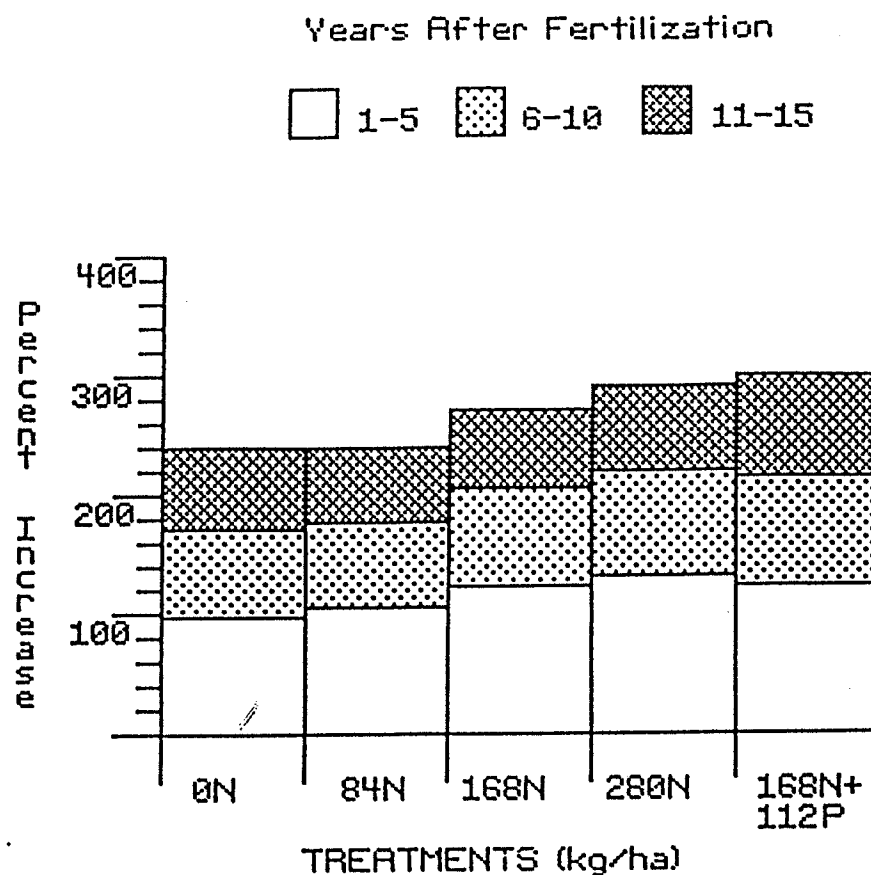


Figure 21. Sipiwek ring increment growth response at the 5.2 metre bole position (see Appendix 9 for raw data). The 5-year increment periods were measured relative to the 5-year growth increment prior to treatment.

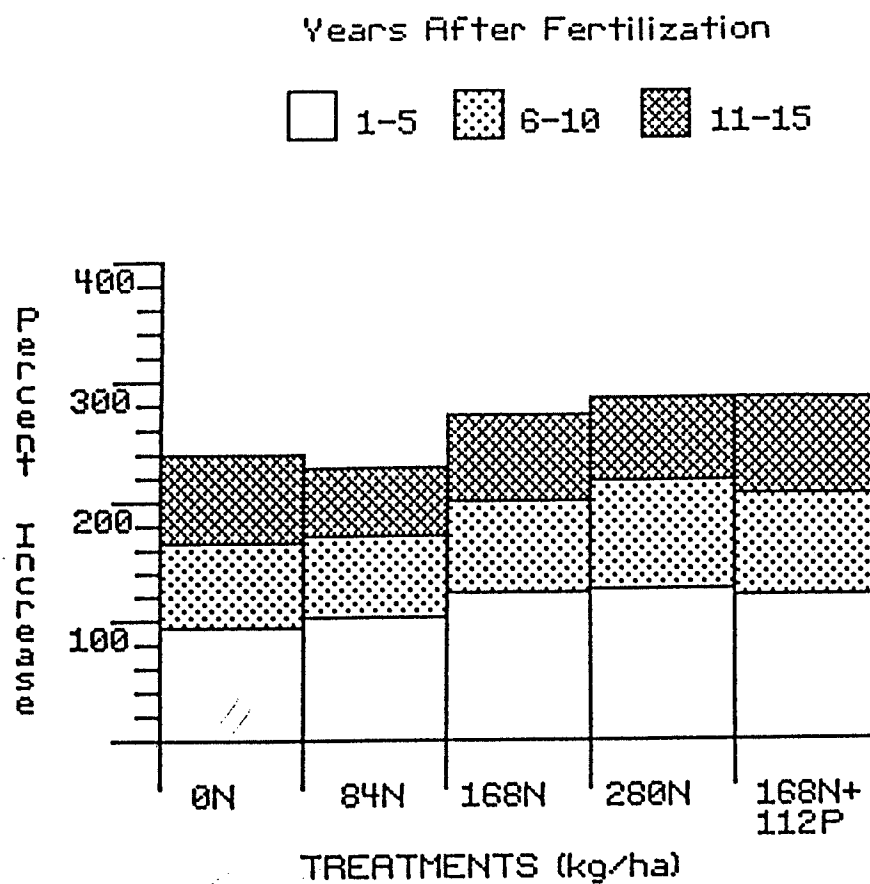


Figure 22. Sipiwek ring increment growth response at the 6.5 metre bole position (see Appendix 9 for raw data). The 5-year increment periods were measured relative to the 5-year growth increment prior to treatment.

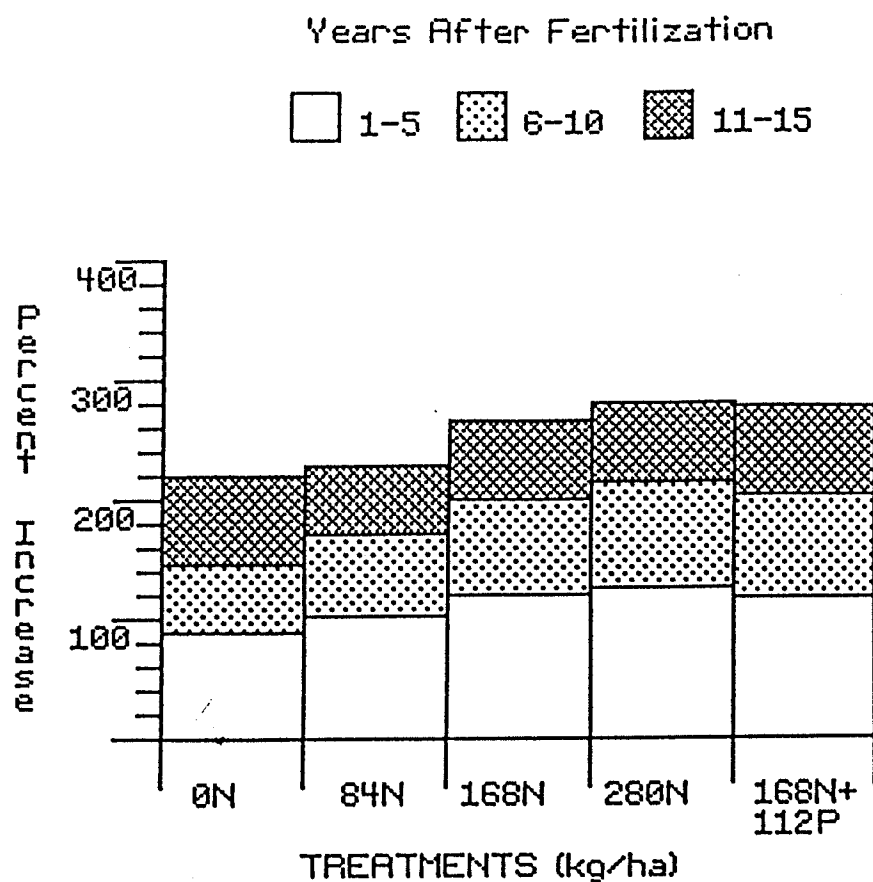


Figure 23. Sipiwesk ring increment growth response at the 7.8 metre bole position (see Appendix 9 for raw data). The 5-year increment periods were measured relative to the 5-year growth increment prior to treatment.

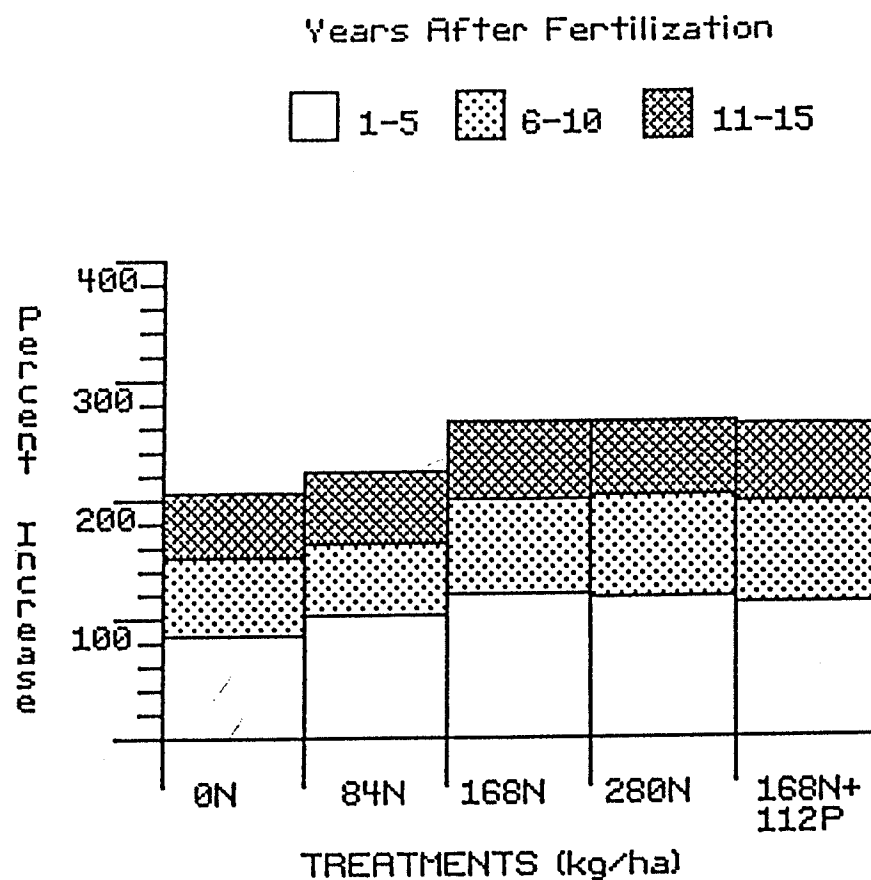


Figure 24. Sipiwesk ring increment growth response at the 9.1 metre bole position (see Appendix 9 for raw data). The 5-year increment periods were measured relative to the 5-year growth increment prior to treatment.

and 84N treatments in all graphs. Maximum response tends to occur in the 280N and 168N + 112P treatments. The graphs in these figures also show that the growth response with treatment tends to decrease steadily after the first 5 year increment.

Figures 25 to 29 display the effect of treatment on area increment over 7 positions on the bole. The increment measurement presented in these graphs is for the first 5 years of growth after treatment as compared to the prior 5 years before treatment. The graphs show a steady progression of increased growth with treatment. Maximum increment (Figure 27) occurred with the 280N treatment. Minimum increment occurred with the control (0N) treatment (Figure 24).

3.4 Stand Characteristic Changes

Tables 6, 7, and 8 present simple statistics for all the treatments in the two demonstrations. The most interesting feature of the Sipiwesk data (Table 6) is the change in variance and standard deviation from 1968 to 1983 in the various treatments. Treatments such as 0N, 84N, and 168N + 112P show a decrease in variance and standard deviation with time. Treatments such as 168N and 280N show a net gain in variance and standard deviation, which may indicate a positive growth response. However, these differences are small, and may be due to statistical chance.

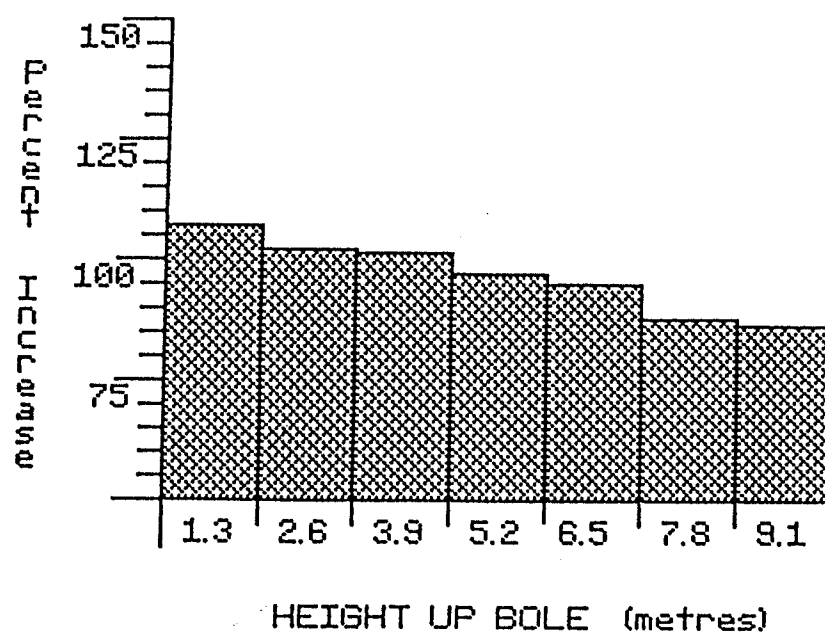


Figure 25. Sipiwesk control (0N) treatment growth response at the 7 bole positions (see Appendix 9 for raw data). The increment measurement presented in this graph is for the first 5 years after treatment.

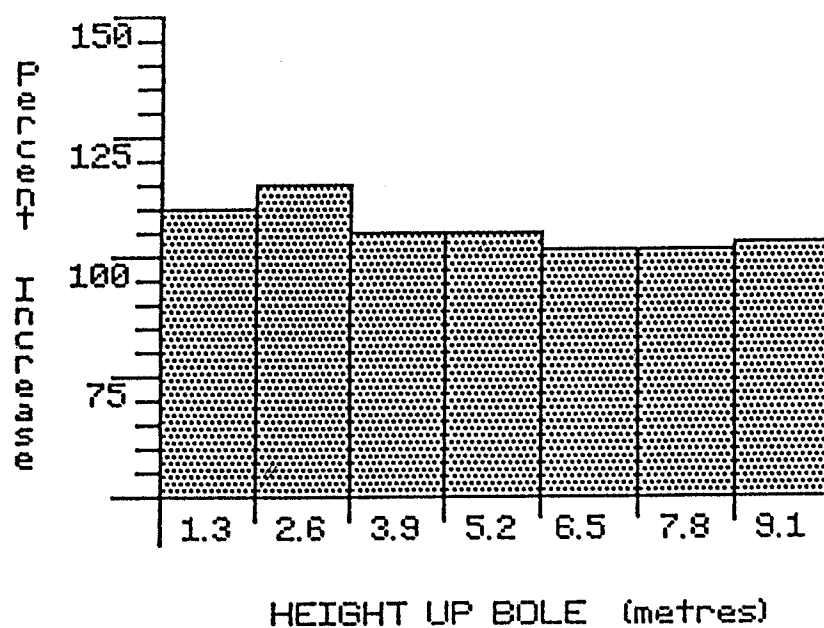


Figure 26. Sipiwesk 84N treatment growth response at the 7 bole positions (see Appendix 9 for raw data). The increment measurement presented in this graph is for the first 5 years after treatment.

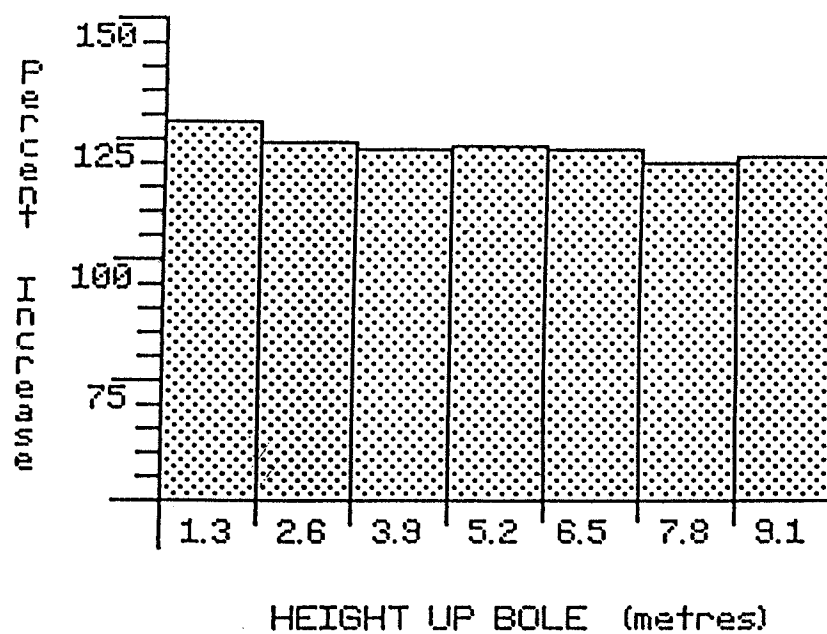


Figure 27. Sipiwesk 168N treatment growth response at the 7 bole positions (see Appendix 9 for raw data). The increment measurement presented in this graph is for the first 5 years after treatment.

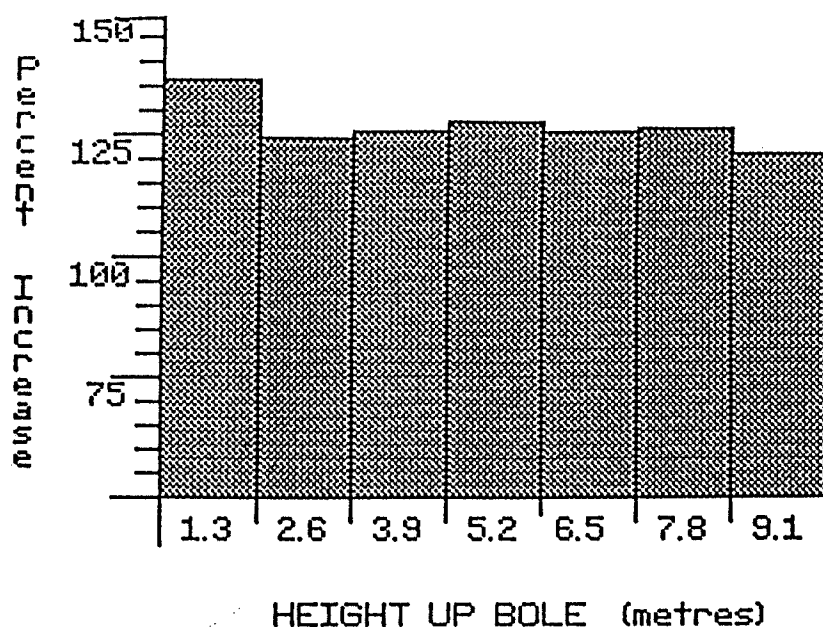


Figure 28. Sipiwesk 280N treatment growth response at the 7 bole positions (see Appendix 9 for raw data). The increment measurement presented in this graph is for the first 5 years after treatment.

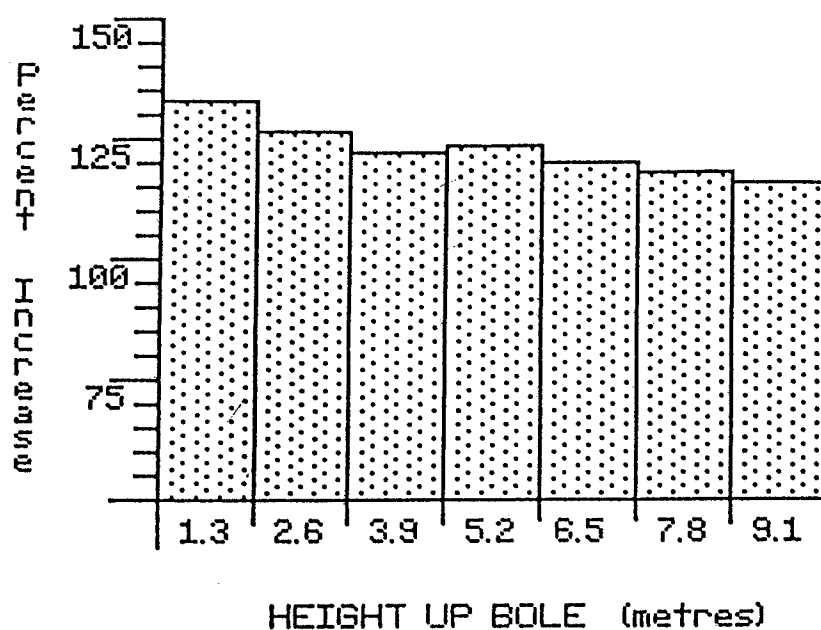


Figure 29. Sipiwesk 168N + 112P treatment growth response at the 7 bole positions (see Appendix 9 for raw data). The increment measurement presented in this graph is for the first 5 years after treatment.

Table 6. Simple statistical features of the Sipiwesk fertilization treatments (raw data Appendices 3 and 4).

Treatment	Year	Samples	Mean DBH cm	Variance	Standard Deviation	Average Tree Age *
0N	1968	334	8.10	16.597	4.074	70.7
	1983	213	11.02	16.064	4.008	
84N	1968	334	8.76	16.451	4.056	73.4
	1983	224	11.66	14.961	3.868	
168N	1968	332	7.77	17.901	4.231	77.3
	1983	200	11.12	18.011	4.244	
280N	1968	344	7.80	17.181	4.145	71.6
	1983	220	10.90	20.376	4.514	
168N + 112P	1968	323	7.62	17.289	4.158	71.6
	1983	179	11.68	15.398	3.924	

* Average age was measured from the 20 felled trees for each treatment. The measurement took place 1.3 metres from ground level. Thus the averages presented here are probably 10-15 years too young.

Note: There were no statistical differences (5 %) in measured variance from 1968 to 1983 for the treatments (Fmax-test).

Table 7. Simple statistical features of the Wanless fertilization treatments (raw data Appendices 5 and 6).

Treatment	Year	Samples	Mean DBH cm	Variance	Standard Deviation	Average Tree Age *
0N	1968	309	8.14	13.823	3.718	75.4
	1983	202	11.10	10.024	3.166	
84N	1968	245	8.83	13.646	3.694	79.0
	1983	192	10.84	11.499	3.391	
168N	1968	226	8.08	15.319	3.914	75.4
	1983	145	11.23	11.903	3.450	
280N	1968	254	8.19	12.257	3.501	76.0
	1983	153	10.96	9.841	3.137	
168N + 112P	1968	306	8.25	10.589	3.254	77.6
	1983	206	10.63	8.703	2.950	

* Average age was measured from the 20 felled trees for each treatment. The measurement took place 1.3 metres from ground level. Thus the averages presented here are probably 10-15 years too young.

Note: There were no statistical differences (5 %) in measured variance from 1968 to 1983 for the treatments (Fmax-test).

Table 8. Simple statistical features of the Wanless thinning and fertilization plots (raw data Appendices 7 and 8).

Treatment	Year	Samples	Mean DBH cm	Variance	Standard Deviation
THINNED + 0N	1968	71	11.35	8.271	2.876
	1983	65	12.93	12.355	3.515
THINNED + 84N	1968	92	10.64	6.533	2.556
	1983	84	12.31	6.548	2.559
THINNED + 168N	1968	68	11.30	7.198	2.683
	1983	55	13.57	9.236	3.039

Note: There were no statistical differences (5 %) in measured variance from 1968 to 1983 for the treatments (Fmax-test).

The Fmax-test indicated that there were no statistical differences (5 %) in measured variance from 1968 to 1983 for the treatments.

Table 7 presents the simple statistical calculations of the Wanless fertilization treatments. In this table every treatment shows a decline in variance and standard deviation. Statistically the Fmax-test indicated that there were no differences in the variance of the treatments.

Table 8 exhibits the simple statistical features of the Wanless thinning and fertilization treatments. In this table all treatments show a net increase in variance and standard deviation. This increase is surprising since the small trees were removed. These variance increases, however, were not statistically different.

Figures 30 to 33 display the change in the cumulative percent of trees in specific DBH classes before and after fertilization for control and 280N treatments for both Sipiwesk and Wanless. By comparing Figures 30 and 31 one can see that the Sipiwesk 280N treatment shows a net gain in tree numbers in the 5, 6, and 7 DBH classes when compared to the control. This same feature, however, is not evident in comparing the control and 280N treatments in Wanless (Figures 32 and 33). What is evident at Wanless is that there is a net reduction in tree numbers in DBH classes 4 and 6, and only a modest increase in DBH class 5.

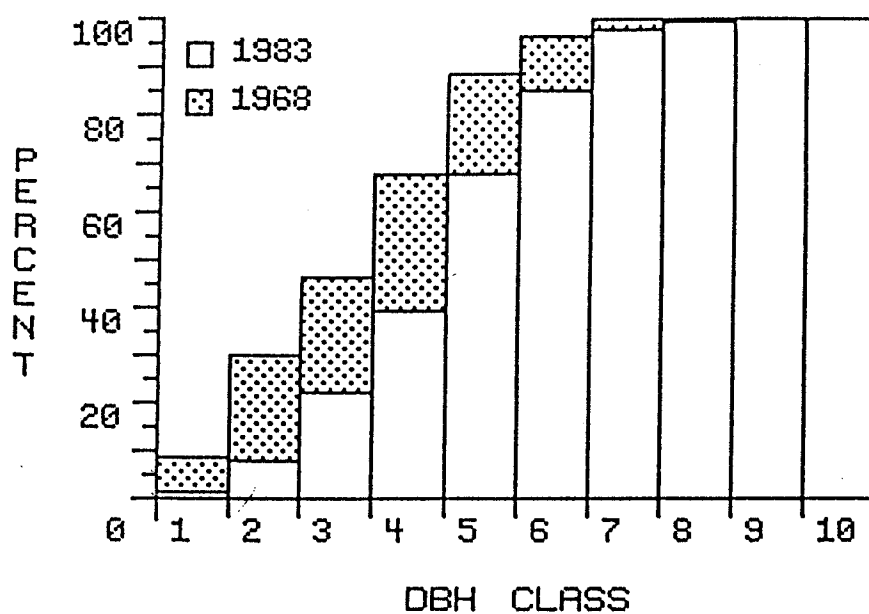


Figure 30. Cumulative percent change in tree numbers from 1968 to 1983 for specific DBH classes. This graph displays the change in the control (ON) treatment at Sipiwesk (for raw data see Appendices 3 and 4).

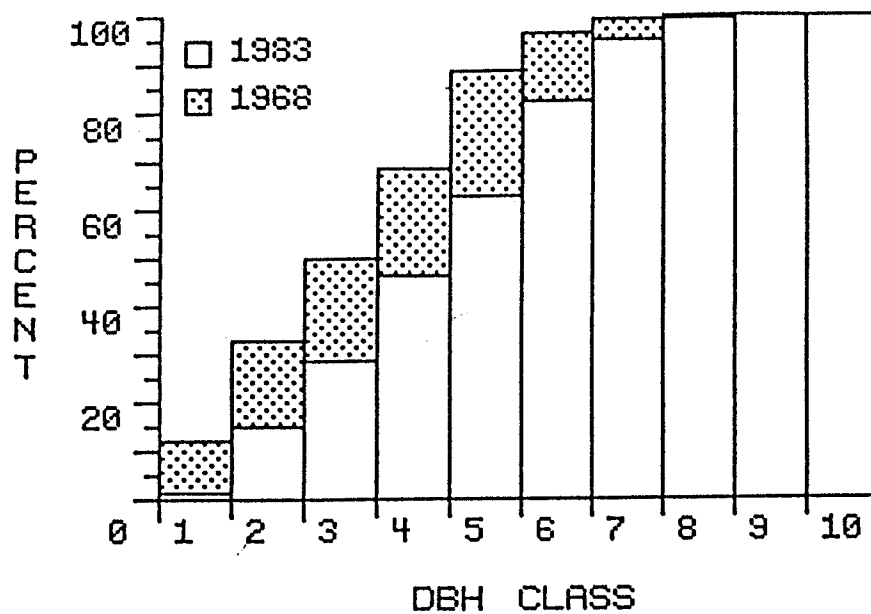


Figure 31. Cumulative percent change in tree numbers from 1968 to 1983 for specific DBH classes. This graph displays the change in the 280N treatment at Sipiwesk (for raw data see Appendices 3 and 4).

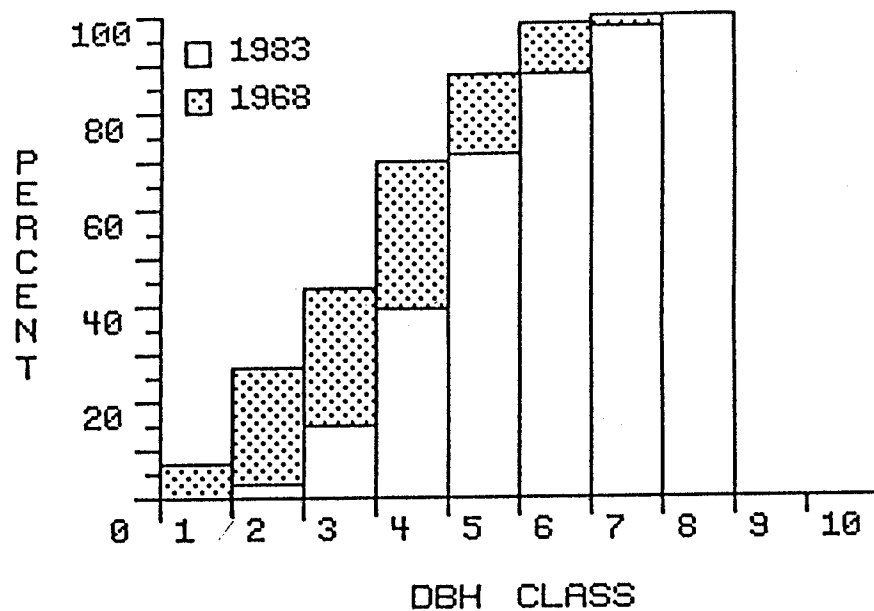


Figure 32. Cumulative percent change in tree numbers from 1968 to 1983 for specific DBH classes. This graph displays the change in the control (ON) treatment at Wanless (for raw data see Appendices 5 and 6).

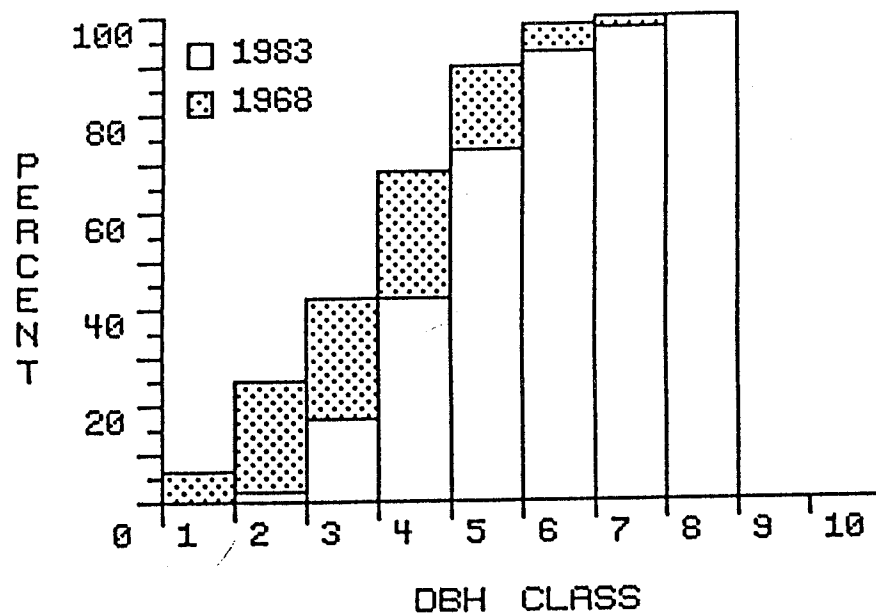


Figure 33. Cumulative percent change in tree numbers from 1968 to 1983 for specific DBH classes. This graph displays the change in the 280N treatment at Wanless (for raw data see Appendices 5 and 6).

CHAPTER FOUR

DISCUSSION

4.1 Volume/DBH Curve

Both the Sipiwesk and Wanless volume/DBH curves (Figures 11 and 12) express an exponential relationship between tree DBH and total volume. More specifically, a linear increase in the tree's DBH cause an exponential increase in its volume (Husch et al. 1972). Both models have excellent correlation with DBH and volume (Sipiwesk $r = .9858$, and Wanless $r = .9763$). These models may be used by foresters in Manitoba for detemining the volume of black spruce individuals and stands. Similarities in the slope of the regression line of the two models indicate that the two stands show almost identical growth response to their particular sites. Visually when working in the two stands it was hard to determine particular site differences.

4.2 Treatment Volume Calculations

The results obtained from the fertilization of the Sipiwesk plots are very promising. They indicate that volumes of timber can be increased by the addition of fertilizer. The 280N and 168N + 112P treatments were found to significantly increase the percent change in volume over control (Table 1). However, this study was unable to

determine statistically which one of these treatments had the best growth response. Figure 34 provides a graphic display of the percent change in volume, relative to the control, with the various treatments. From this graph best results seemed to be obtained with the 280N treatment, which caused a 88 % increase in wood volume increment over the control. The 168N treatment caused a 32 % increase in volume over 15 years. The addition of 112 kg/ha of P with the 168N treatment increased volume another 23 %. The 84N treatment produced the lowest volume increase over the control (17 %), and was found not to be statistically different from the control (Table 1).

Direct comparisons between this study and other fertilization studies are difficult because of differences in the study species, age of the treated trees, soil type, prevailing climate, and means of volume estimation. Several studies, however, may provide a standard for comparison. Krause et al. (1982) examined the fertilizer response in 5 black spruce stands from Manitoba and Saskatchewan, which included a wide range of tree age and site conditions. Their most successful growth response was a 20 % increase in volume increment over the control using 224 kg/ha of urea N. The time for response, however, was only 5 years as compared to 15 years for this study. Mahendrappa and Salonius (1982) measured growth response to treatments in 10 year basal area increments before and after fertilization. In their study the application of 336 kg/ha urea N caused a 26 % increase

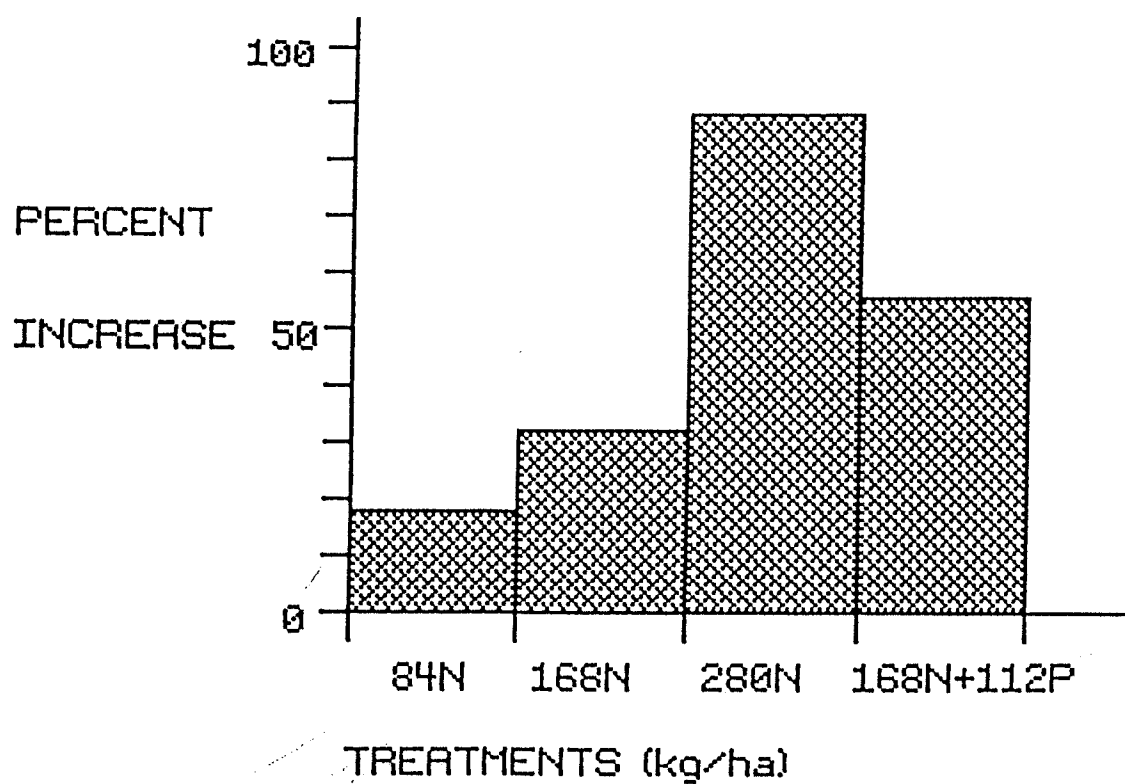


Figure 34. Percent change in volume relative to the control treatment, Sipiwesk plots.

in basal area increment over control. Many other studies use similar means of measurement of response (Morrison et al., 1976; 1977; and 1981). These measurements, nonetheless, do not give any indication of the percent increase in volume because of treatment.

Percent increase in volume was measured in a study by Barclay et al. (1982), which involved the fertilization of Douglas-fir. Urea fertilizers were applied in this study at the rates of 0, 224, and 448 kg/ha of urea N. Growth response was measured for 9 years. The net gain in volume for the 224N treatment was 41 %, while the 448N treatment caused a 110 % increase in volume over control. If these responses can be assumed linear the percent increase in volume for a 280N treatment would be about 63 %, which is quite similar to the results obtained in this study.

Some researchers have noted that urea fertilization, especially at high rates of application, causes increased mortality in the stand (Krause, 1981; and Barclay et al., 1982). Kingston et al. (1978), however, have observed highest mortality in their fertilization trials of jack pine in the control. These contradictory results may be explained by the particular soil-fertilizer response, stand structure differences between plots, or by some hidden factor such as insect or disease infestation.

The Wanless demonstration displayed a poor response to fertilization (Table 3 and 4). Statistically none of the treatments displayed an increase in percent volume over the

control. One cause of this poor response was the increase in mortality of trees with diameters greater than 6.35 cm in the 280N treatment plots (Table 4). The percent mortality in these plots was found to be statistically (5 %) different from the mortality in the other plots (Student's t-test). The mortality in this treatment was double the mortality in the control. The other fertilization plots (especially 168N, and 168N + 112P), however, did not show the same increase in mortality.

Poor growth response may also be caused by the same factor that killed many of the mosses in the heavily fertilized plots. The moss die-back in the fertilized plots may have been caused by ammonia toxicity (Gasser, 1964). Because the fertilizers were applied in the late fall the usual immediate release of ammonia gas to the atmosphere could have been reduced by a blanket of snow. This would then result in a concentration of ammonia at the soil surface, which would have poisoned the ground vegetation and surface soil organisms. The removal of these two important organisms may have then affected the pattern of nutrient cycling by increasing nutrient loss and reducing nutrient stores. Some research has suggested that mosses play an important role in forest nutrition by intercepting nutrients from rainfall (Weetman and Timmer, 1967; Weetman, 1968; and Foster and Morrison, 1980). Soil organisms such as mycorrhizae form important associations with tree roots, which facilitates the uptake of important nutrients. Gill

and Lavender (1983) have found that urea fertilization can cause significant changes in total numbers of mycorrhizae. They noted that a reduction in the numbers of these soil organisms, because of urea fertilization, caused primary root mortality in the higher vegetation that the soil supported.

Several studies have shown that thinning, alone or in combination with fertilizers, can cause substantial increases in tree growth (Weetman, 1975; Steinbrenner, 1981; and Barclay et al., 1982). In this study similar results were found (Table 5). Thinning, at a rate of 40 % trees removed, with no fertilization caused an increase in tree volume, relative to control, of 63 %. In combination with fertilization (84 kg/ha N), thinning resulted in an increase of 83 %. The thinning + 168N treatment did not increase volume as much as thinning + 84N. Statistically, however, the differences between the means of the treatments were not significant, and therefore indicate that the fall application of fertilizer did not increase the growth response over thinning alone.

4.3 Ring Increment Response

The ring increment analysis was performed to determine increment change due to treatment, time length of the treatment's affect, and whether the growth response occurs evenly at different heights along the bole. Generally, the

treatments indicate there was an increase in growth response with the level of fertilization. However, this result could not be statistically analyzed. In Figures 18 to 24 all fertilization treatments show a decrease in the growth response in 5-year increments with time. This result was expected because many studies have found that fertilizers are generally absent from the soils in which they were applied after one year (Morrison and Foster, 1977; Mahendrappa, 1978; Mahendrappa and Salonijs, 1982; and Pang and McCullough, 1982).

Figures 25 to 29 display the effect of treatment on area increment over 7 positions on the bole. The results from this analysis are quite different from other similar research (Mitchell and Kellogg, 1972). Mitchell and Kellogg (1972) studied the distribution of ring growth increment at 6 points up the stem of Douglas-fir trees 5 years after urea fertilization. Their results indicated that there was no change in the tree form because of fertilization. They found that the growth increment of the rings generally decreased the higher up the stem one went until the crown was reached, even when the trees were fertilized. The Sipiwek study results do display the similar reduction in growth response with increasing height in the control. However, in the fertilized treatments the data indicated an increasing growth response with amount of fertilizer applied, and a general leveling of growth response in the last 5 to 6 bole positions. These results greatly differ

with the results obtained by Mitchell and Kellogg. One reason for this difference may be that black spruce react differently to fertilization than do Douglas-fir. Nonetheless, the results presented here indicate that volume increment growth, because of fertilization, does not only occur in the first few metres of stem, but equally up the stem to a height of 9.1 metres.

4.4 Stand Characteristic Changes

The data presented in Tables 6,7, and 8 offer no clarification of the growth response results already obtained. It was hypothesized that differences in variance of plot DBHs from 1968 to 1983 may occur due to fertilization. The Fmax-test, however, indicated that there were no statistical differences in the measured variances from 1968 to 1983 for the treatments.

Gagnon et al. (1976) studied the growth response following fertilizer application of 35 year old white spruce. In their analysis they measured the cumulative percent change in number of tree stems in particular DBH classes in 1962, and control and fertilized trees 10 years later. Their analysis indicated that the cumulative percent of trees decreased in all DBH classes for both control and fertilized treatments. The fertilized treatment, however, showed a greater decrease in cumulative percent of trees for all DBH classes when compared to the control. This result

indicated a movement of more trees into higher DBH classes as a result of fertilization.

Similar analysis was performed in this study for the Sipiwesk and Wanless control and 280N treatments. The Sipiwesk 280N treatment (Figure 31) showed a net gain in tree numbers in the 5,6, and 7 DBH classes when compared to the control (Figure 30). The Wanless 280N treatment (Figure 33) when compared to the control (Figure 32) shows a net reduction in DBH classes 4 and 6, and only a small increase in class 5. These results indicate the difference in growth response between the two demonstrations. The Sipiwesk analysis shows a positive growth response, while the Wanless analysis shows a negative growth response. The positive response in the Sipiwesk analysis indicates the movement of more individual trees into higher DBH classes. The negative result in the Wanless analysis probably indicates stagnation, or no movement of individuals into higher DBH classes. Both of these results are concurrent with the results obtained in the other analyses.

CHAPTER FIVE

SUMMARY AND CONCLUSIONS

5.1 Summary

The purpose of this thesis has been to determine the growth response of mature black spruce to thinning and fertilization treatments in Northern Manitoba. Analysis of collected data determined, volume change between treatments, ring increment response, stand structure changes, and the best time for treatment application. All analyses provided information on the effectiveness of the treatments. This information can now be used in the implementation of these forest management techniques in similar sites in Northern Manitoba.

Fertilization treatment volume calculations indicated promising results. The Sipiwesk spring application indicated best growth response with the 280 kg/ha of urea N treatment. Increases in volume in this treatment were 88 % higher than the control. The Wanless fall fertilizer application had poor results, which may be caused by the timing of the application. The Wanless thinning and fertilization demonstration, however, showed promising results. Thinning in combination with 84 kg/ha urea N resulted in a 83 % increase in growth over the control. However, statistical analysis was unable to detect a significant growth response due just to the fertilizer in

the thinning and fertilization combination treatments.

The ring increment response analysis measured the same variable as the treatment volume calculations. Results, however, were a little less rigorous because of the method used to obtain samples. Nonetheless, this analysis determined that again the best growth response was in the 280N treatment at Sipiwesk. The ring increment analysis also determined the distribution of ring growth increment at 7 positions up the bole of the black spruce. These results indicated an increasing growth response at all bole positions with the amount of fertilizer applied.

The analysis of stand characteristic changes measured several statistical features of the population of black spruce in the various treatments. The features measured in this analysis were mean, standard deviation, and variance of the tree DBHs in all the treatments. Generally, this analysis provided information on the change of these characteristics from 1968 to 1983.

A final analysis was performed to measure the cumulative percent change in number of stems by DBH class before and after fertilization. Analysis indicated a net gain in tree numbers after 15 years in the Sipiwesk 280N treatment in three DBH classes when compared to control. The Wanless 280N treatment when compared to the control showed a net reduction after 14 years in two DBH classes, and only a small increase in one class.

5.2 Conclusions

The application of urea fertilizer to Northern Manitoba mature black spruce can increase growth response. Best application time from the results in this study was in the spring. The fall application of urea fertilizer caused a poor growth response. The addition of super triplephosphate to the urea did not appreciably increase growth response. It may be concluded that the particular soils of the study sites are not lacking in this nutrient. Thinning was also found to be a way of increasing growth response. However, the addition of urea with thinning did not greatly increase growth response. This lack of response may be caused by the same factors that reduced response in the fall application of the fertilizers.

The impact of fertilizers and thinning on growth response requires further study. The results presented here only provide information on one tree species and two sites. Many other tree species and sites exist in Manitoba, and should be investigated for the usefulness of these management practices in increasing growth response.

My analysis supports the hypothesis that fertilization or thinning can be used to increase tree volumes. However, certain data suggests that caution must be taken in application rates, and time of treatment. What is needed is increased research into fertilization and thinning to establish management programmes on a more scientific basis.

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APPENDICES

Appendix 1. Sipiwesk volume and DBH data for Volume/DBH curve (volume = inches cubed, DBH = inches *).

Tree #	DBH	Volume	Tree #	DBH	Volume
1	6.6	10503.1	51	6.2	7358.7
2	4.8	4840.0	52	5.6	6292.7
3	6.5	8714.3	53	6.7	9921.4
4	5.9	7573.9	54	4.7	4039.8
5	4.3	3704.5	55	4.6	3892.6
6	5.3	6227.3	56	5.1	4836.7
7	7.8	15103.1	57	6.9	10680.0
8	4.7	4386.8	58	5.9	7851.3
9	5.3	7455.4	59	5.7	6573.3
10	6.4	9291.7	60	5.9	7397.1
11	4.9	4729.6	61	4.4	3408.5
12	6.9	11556.4	62	6.2	8066.5
13	4.8	4993.2	63	3.9	2621.3
14	6.1	8224.8	64	6.0	6602.6
15	5.6	6709.9	65	5.6	7025.1
16	6.4	9444.9	66	7.6	11822.2
17	6.1	7245.4	67	7.0	11266.4
18	6.7	10567.3	68	3.4	2101.7
19	4.7	4172.8	69	4.4	3648.5
20	4.9	4926.3	70	5.3	6086.4
21	7.3	13016.5	71	8.1	13592.5
22	5.0	5250.4	72	6.1	7267.0
23	6.0	8037.1	73	8.4	15972.0
24	6.3	8597.4	74	6.9	10204.4
25	4.8	4638.7	75	5.6	6639.9
26	5.4	6231.1	76	9.0	20678.2
27	4.3	3104.2	77	6.2	8532.1
28	5.8	6395.2	78	9.0	18599.8
29	6.7	8518.7	79	8.1	14996.7
30	5.1	4701.1	80	8.2	14933.1
31	7.4	12443.3	81	6.6	9500.3
32	5.6	6144.0	82	5.0	3591.4
33	4.3	3023.8	83	6.2	7556.3
34	6.3	8025.7	84	7.9	14173.0
35	6.0	6607.8	85	6.0	7227.3
36	5.5	6343.2	86	6.5	9294.9
37	6.2	9518.4	87	4.9	4823.6
38	5.6	6496.3	88	4.2	3402.8
39	5.5	5323.1	89	4.1	2917.0
40	6.9	9764.4	90	4.7	4227.6
41	8.8	19323.2	91	6.8	9678.0
42	5.7	6800.8	92	6.1	8577.2
43	7.1	11777.5	93	9.3	21751.6
44	5.6	7008.6	94	5.9	7492.5
45	6.1	8058.2	95	3.2	2182.0
46	7.8	14449.5	96	6.7	11343.9
47	7.9	14254.5	97	4.7	4048.5

48	6.0	7470.5	98	4.8	3922.3
49	5.9	7425.6	99	5.9	6706.7
50	7.0	11744.6	100	6.7	9942.4

* Data was transformed to metric in computer.

Appendix 2. Wanless volume and DBH data for Volume/DBH curve
(volume = inches cubed, DBH = inches *).

Tree #	DBH	Volume	Tree #	DBH	Volume
1	5.1	4746.9	51	4.5	4264.5
2	4.5	3844.7	52	6.8	10138.9
3	6.2	6988.8	53	7.0	11731.4
4	5.8	6605.9	54	5.3	6368.1
5	6.2	7119.5	55	6.5	8296.6
6	7.4	14924.9	56	6.5	8708.0
7	6.8	8926.8	57	5.4	6378.8
8	6.1	8796.3	58	5.1	5505.4
9	5.3	5438.2	59	5.7	6324.4
10	5.8	7549.7	60	7.0	10578.9
11	6.3	8573.2	61	5.4	6411.1
12	6.5	9796.3	62	5.7	7055.2
13	6.3	8440.9	63	7.8	13170.1
14	5.6	6815.2	64	5.0	4461.1
15	6.4	8301.2	65	6.1	8191.0
16	4.7	4329.8	66	5.9	6882.8
17	5.0	5058.8	67	5.8	7038.4
18	5.1	4325.1	68	6.8	10599.1
19	4.8	4278.6	69	5.0	5195.9
20	4.6	4215.9	70	6.8	10265.6
21	5.1	5519.4	71	7.0	11741.6
22	5.0	4884.5	72	6.0	7675.0
23	5.5	5810.0	73	7.2	11688.4
24	5.6	5450.0	74	7.5	13623.1
25	5.6	6884.3	75	4.3	3746.9
26	7.0	11751.2	76	7.9	14245.1
27	6.2	8797.6	77	5.3	5492.2
28	6.5	9003.5	78	6.0	7134.7
29	6.2	7782.0	79	6.1	8288.9
30	6.5	10897.8	80	6.9	11110.4
31	7.1	10543.3	81	5.3	5983.4
32	4.5	4128.5	82	5.9	8914.1
33	5.2	5211.8	83	6.1	7837.4
34	6.7	8927.5	84	4.6	4189.1
35	6.3	7290.8	85	6.2	7552.7
36	5.6	6402.5	86	5.8	7407.7
37	4.6	4573.7	87	5.6	5956.9
38	5.5	6819.9	88	6.4	8446.9
39	7.0	11055.2	89	4.0	2922.6
40	6.1	7893.5	90	6.2	9363.4
41	4.3	3550.4	91	7.0	10842.0
42	4.4	3406.1	92	5.7	7495.7
43	6.0	8605.1	93	4.5	4402.0
44	4.9	5197.4	94	6.4	10241.5
45	6.9	10226.8	95	6.6	9961.1
46	5.4	5973.7	96	4.7	4777.6
47	5.1	5392.6	97	4.5	4122.4

48	6.3	8995.2	98	4.8	4149.5
49	4.5	3950.3	99	6.9	11096.2
50	6.0	8198.1			

* Data was transformed to metric in computer.

Appendix 3. Plot DBH measurements for Sipiwesk 1968 (measured in inches).

Plot Number 1 (168N + 112P)

0.6, 0.6, 0.7, 0.8, 0.8, 0.8, 1.0, 1.1, 1.1, 1.1, 1.1, 1.3,
1.3, 1.3, 1.4, 1.4, 1.4, 1.4, 1.5, 1.5, 1.5, 1.5, 1.7, 1.7,
1.7, 1.8, 1.8, 1.9, 2.0, 2.0, 2.0, 2.0, 2.0, 2.3, 2.5, 2.5,
2.5, 2.5, 2.7, 2.8, 2.8, 2.8, 2.8, 2.8, 3.1, 3.1, 3.2, 3.3,
3.4, 3.5, 3.5, 3.6, 3.6, 3.6, 3.7, 3.8, 3.9, 4.1, 4.1, 4.2,
4.2, 4.3, 4.3, 4.5, 4.5, 4.5, 4.5, 4.6, 4.8, 4.8, 4.8, 4.8,
5.0, 5.0, 5.1, 5.2, 5.2, 5.2, 5.4, 5.7, 5.9, 5.9, 5.9, 5.9

Plot Number 2 (168N)

0.6, 0.6, 0.6, 1.0, 1.0, 1.1, 1.1, 1.1, 1.2, 1.2, 1.3, 1.3,
1.3, 1.3, 1.5, 1.6, 1.7, 1.7, 1.7, 1.7, 1.8, 1.8, 1.9, 2.0,
2.1, 2.2, 2.2, 2.2, 2.3, 2.3, 2.5, 2.7, 2.8, 2.8, 2.9, 2.9,
2.9, 3.0, 3.2, 3.2, 3.3, 3.4, 3.5, 3.5, 3.6, 3.7, 3.7, 3.8,
3.9, 4.2, 4.2, 4.2, 4.3, 4.3, 4.3, 4.4, 4.4, 4.4, 4.5, 4.6,
4.6, 4.8, 4.8, 4.9, 4.9, 4.9, 5.0, 5.0, 5.1, 5.1, 5.2, 5.4,
5.5, 5.5, 5.5, 5.5, 5.7, 6.0, 6.0, 6.1, 6.2, 6.7, 6.8, 7.0

Plot Number 3 (0N)

1.0, 1.1, 1.1, 1.1, 1.1, 1.2, 1.2, 1.4, 1.4, 1.5, 1.6, 1.8,
1.8, 1.9, 2.2, 2.2, 2.3, 2.4, 2.4, 2.7, 2.7, 2.7, 3.0, 3.1,
3.1, 3.3, 3.3, 3.4, 3.5, 3.5, 3.5, 3.8, 3.8, 4.0, 4.2, 4.3,
4.3, 4.3, 4.3, 4.4, 4.4, 4.5, 4.6, 4.6, 4.7, 4.7, 4.7, 4.8,
4.9, 4.9, 4.9, 5.1, 5.1, 5.4, 5.4, 5.4, 5.6, 5.7, 5.9, 6.0,
6.2, 6.6

Plot Number 4 (280N)

0.6, 0.6, 0.7, 0.7, 0.8, 0.8, 0.8, 0.9, 1.0, 1.1, 1.1, 1.2,
1.2, 1.3, 1.3, 1.3, 1.4, 1.4, 1.6, 1.6, 1.6, 1.6, 1.8, 1.8,
1.8, 1.9, 2.1, 2.1, 2.1, 2.2, 2.3, 2.3, 2.3, 2.5, 2.5, 2.5,
2.5, 2.5, 2.6, 2.8, 3.0, 3.0, 3.0, 3.1, 3.1, 3.1, 3.2, 3.2,
3.2, 3.2, 3.2, 3.3, 3.3, 3.4, 3.6, 3.7, 3.7, 3.7, 3.8, 3.9,
3.9, 4.0, 4.0, 4.0, 4.0, 4.0, 4.1, 4.1, 4.2, 4.2, 4.4, 4.4,
4.4, 4.5, 4.5, 4.5, 4.6, 4.6, 4.6, 4.6, 4.7, 4.7, 4.8, 4.9,
4.9, 5.0, 5.0, 5.0, 5.0, 5.3, 5.3, 5.4, 5.4, 5.5, 5.7, 5.7,
5.8, 5.9, 6.1, 6.1, 6.1

Plot Number 5 (84N)

0.6, 1.4, 1.5, 1.5, 1.5, 1.8, 1.9, 1.9, 2.0, 2.1, 2.2, 2.3,
2.3, 2.4, 2.4, 2.6, 2.7, 2.7, 2.7, 3.0, 3.1, 3.1, 3.2, 3.4,
3.5, 3.6, 3.7, 3.8, 3.8, 3.8, 3.8, 4.0, 4.0, 4.0, 4.1, 4.1,
4.1, 4.1, 4.2, 4.2, 4.2, 4.4, 4.4, 4.4, 4.5, 4.5, 4.5, 4.6,
4.7, 4.8, 4.8, 4.9, 4.9, 5.1, 5.2, 5.2, 5.2, 5.3, 5.3, 5.3,
5.4, 5.5, 5.6, 5.8, 6.1, 6.1, 6.3, 6.3, 6.4, 6.8, 6.9, 7.0,

7.0

Plot Number 6 (0N)

0.6, 0.6, 0.6, 0.7, 0.7, 0.8, 0.8, 0.8, 0.8, 0.9, 1.0, 1.0,
 1.0, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.2, 1.2, 1.3, 1.3, 1.4,
 1.5, 1.5, 1.7, 1.7, 1.8, 1.9, 1.9, 2.0, 2.2, 2.3, 2.3, 2.5,
 2.6, 2.6, 2.7, 2.8, 2.9, 3.0, 3.0, 3.2, 3.3, 3.3, 3.4, 3.4,
 3.4, 3.4, 3.5, 3.6, 3.7, 4.0, 4.0, 4.1, 4.2, 4.2, 4.2, 4.3,
 4.4, 4.4, 4.5, 4.6, 4.6, 4.6, 4.7, 4.7, 4.8, 4.8, 4.9, 4.9,
 5.0, 5.2, 5.2, 5.2, 5.3, 5.4, 5.4, 5.8, 6.0, 6.0, 6.1, 6.3,
 6.4

Plot Number 7 (168N + 112P)

0.6, 0.6, 0.6, 0.7, 0.7, 0.7, 0.7, 0.8, 0.8, 0.8, 0.8, 0.8,
 0.8, 0.8, 0.9, 0.9, 0.9, 0.9, 1.0, 1.0, 1.0, 1.1, 1.1, 1.1,
 1.1, 1.2, 1.2, 1.2, 1.2, 1.3, 1.3, 1.3, 1.4, 1.4, 1.5, 1.5,
 1.9, 1.9, 2.0, 2.0, 2.1, 2.1, 2.3, 2.4, 2.5, 2.8, 3.0, 3.0,
 3.1, 3.2, 3.2, 3.2, 3.3, 3.3, 3.4, 3.4, 3.4, 3.4, 3.5, 3.6,
 3.7, 3.7, 3.8, 3.8, 3.8, 3.8, 4.0, 4.1, 4.1, 4.1, 4.2, 4.5,
 4.5, 4.5, 4.5, 4.6, 4.6, 4.7, 4.8, 4.8, 4.8, 4.8, 4.9, 5.0,
 5.0, 5.0, 5.0, 5.2, 5.3, 5.3, 5.4, 5.5, 6.1, 6.5

Plot Number 8 (84N)

0.8, 1.0, 1.0, 1.2, 1.2, 1.3, 1.4, 1.4, 1.5, 1.5, 1.5, 1.5,
 1.5, 1.5, 1.5, 1.6, 1.6, 1.7, 1.8, 1.8, 1.9, 1.9, 1.9, 2.0,
 2.0, 2.1, 2.1, 2.2, 2.2, 2.2, 2.2, 2.4, 2.4, 2.4, 2.5, 2.6,
 2.6, 2.7, 2.7, 2.7, 2.7, 2.9, 2.9, 3.0, 3.2, 3.2, 3.3, 3.3,
 3.4, 3.4, 3.5, 3.5, 3.5, 3.6, 3.6, 3.6, 3.7, 3.9, 3.9, 4.0,
 4.0, 4.0, 4.0, 4.0, 4.1, 4.2, 4.2, 4.2, 4.2, 4.3, 4.4, 4.4,
 4.4, 4.4, 4.4, 4.4, 4.4, 4.5, 4.5, 4.6, 4.6, 4.6, 4.6, 4.6,
 4.6, 4.6, 4.7, 4.9, 4.9, 4.9, 5.0, 5.0, 5.1, 5.1, 5.1, 5.1,
 5.2, 5.2, 5.3, 5.4, 5.8, 5.9, 6.0, 6.0, 6.3

Plot Number 9 (168N)

0.6, 0.7, 0.8, 0.8, 1.0, 1.0, 1.0, 1.0, 1.1, 1.1, 1.1, 1.1,
 1.1, 1.2, 1.2, 1.3, 1.5, 1.5, 1.6, 1.6, 1.6, 1.7, 2.1, 2.2,
 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 3.0, 3.2, 3.4, 3.5, 3.6, 3.6,
 3.7, 3.9, 3.9, 4.0, 4.0, 4.1, 4.2, 4.2, 4.3, 4.4, 4.4, 4.6,
 4.6, 4.7, 4.7, 4.7, 4.8, 5.0, 5.1, 5.1, 5.2, 5.2, 5.2, 5.3,
 5.3, 5.9, 5.9, 6.0, 6.1, 6.2, 8.0

Plot Number 10 (280N)

0.6, 0.6, 0.6, 0.7, 0.7, 0.7, 0.7, 0.9, 0.9, 1.0, 1.0, 1.0,
 1.1, 1.1, 1.2, 1.2, 1.3, 1.3, 1.4, 1.4, 1.4, 1.5, 1.5, 1.6,
 1.6, 1.7, 1.9, 1.9, 1.9, 2.0, 2.0, 2.1, 2.3, 2.3, 2.3, 2.4,
 2.4, 2.5, 2.5, 2.5, 2.6, 2.8, 3.0, 3.0, 3.0, 3.1, 3.1, 3.1,
 3.2, 3.2, 3.2, 3.2, 3.3, 3.4, 3.5, 3.5, 3.8, 3.8, 3.9, 4.1,
 4.1, 4.2, 4.2, 4.3, 4.4, 4.4, 4.5, 4.6, 4.7, 4.7, 4.9, 4.9,

5.0, 5.1, 5.2, 5.3, 5.3, 5.6, 5.7, 6.2, 6.5, 6.6, 6.8

Plot Number 11 (84N)

0.6, 0.6, 0.6, 0.7, 0.8, 0.8, 0.9, 0.9, 0.9, 0.9, 1.0, 1.0,
 1.0, 1.0, 1.0, 1.1, 1.1, 1.1, 1.1, 1.2, 1.2, 1.2, 1.3, 1.3,
 1.3, 1.3, 1.4, 1.5, 1.5, 1.5, 1.5, 1.5, 1.6, 1.7, 1.8, 1.8,
 1.9, 1.9, 1.9, 2.0, 2.0, 2.0, 2.2, 2.3, 2.3, 2.3, 2.4, 2.4,
 2.5, 2.6, 2.6, 2.7, 2.8, 2.8, 2.8, 3.0, 3.0, 3.0, 3.0, 3.1,
 3.1, 3.1, 3.2, 3.3, 3.3, 3.3, 3.3, 3.4, 3.5, 3.5, 3.5, 3.6,
 3.6, 3.7, 3.7, 3.7, 3.7, 3.7, 3.7, 3.8, 3.8, 3.8, 3.8, 3.8,
 3.9, 3.9, 3.9, 3.9, 3.9, 4.0, 4.1, 4.1, 4.1, 4.2, 4.2, 4.2,
 4.2, 4.2, 4.2, 4.3, 4.3, 4.3, 4.5, 4.5, 4.5, 4.5, 4.6, 4.6,
 4.7, 4.7, 4.8, 4.8, 4.8, 5.0, 5.0, 5.0, 5.1, 5.1, 5.3, 5.4,
 5.5, 5.5, 5.6

Plot Number 12 (168N)

0.6, 0.7, 0.7, 0.7, 0.7, 0.8, 0.8, 0.9, 0.9, 0.9, 1.0, 1.0,
 1.1, 1.1, 1.1, 1.1, 1.2, 1.2, 1.2, 1.3, 1.3, 1.4, 1.5, 1.6,
 1.6, 1.6, 1.7, 1.7, 1.9, 2.0, 2.0, 2.2, 2.2, 2.4, 2.4, 2.4,
 2.4, 2.4, 2.5, 2.5, 2.5, 2.6, 2.6, 2.6, 2.7, 2.8, 3.0, 3.0,
 3.0, 3.2, 3.2, 3.2, 3.2, 3.4, 3.5, 3.5, 3.6, 3.6, 3.6, 3.6,
 3.6, 3.6, 3.7, 3.8, 3.8, 3.8, 3.9, 3.9, 4.0, 4.0, 4.0, 4.1,
 4.1, 4.2, 4.2, 4.5, 4.6, 4.6, 4.6, 4.7, 4.8, 4.8, 4.9, 4.9,
 5.0, 5.0, 5.0, 5.0, 5.2, 5.3, 5.3, 5.3, 5.3, 5.3, 5.6, 5.7,
 5.8, 6.2

Plot Number 13 (0N)

0.6, 0.6, 0.8, 0.8, 0.9, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0,
 1.1, 1.1, 1.1, 1.1, 1.2, 1.2, 1.2, 1.2, 1.2, 1.2, 1.3, 1.4,
 1.6, 1.6, 1.6, 1.6, 1.7, 1.7, 1.8, 1.8, 1.8, 1.9, 1.9, 2.1,
 2.1, 2.1, 2.2, 2.2, 2.3, 2.3, 2.3, 2.3, 2.3, 2.5, 2.5, 2.5,
 2.5, 2.5, 2.6, 2.6, 2.7, 2.8, 2.9, 2.9, 2.9, 2.9, 2.9, 3.0,
 3.0, 3.1, 3.2, 3.2, 3.2, 3.3, 3.3, 3.4, 3.4, 3.5, 3.5, 3.5,
 3.5, 3.5, 3.5, 3.6, 3.7, 3.7, 3.7, 3.7, 3.8, 3.8, 3.9, 3.9,
 4.0, 4.0, 4.1, 4.1, 4.1, 4.2, 4.2, 4.2, 4.3, 4.4, 4.5, 4.5,
 4.6, 4.7, 4.8, 4.9, 4.9, 4.9, 5.0, 5.0, 5.0, 5.1, 5.3, 5.5,
 5.5, 5.8, 6.3, 6.4

Plot Number 14 (168N + 112P)

0.7, 0.7, 0.7, 0.8, 0.9, 0.9, 0.9, 0.9, 0.9, 1.0, 1.0, 1.1,
 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.2, 1.2, 1.2, 1.2, 1.2, 1.3,
 1.4, 1.4, 1.5, 1.5, 1.5, 1.5, 1.5, 1.5, 1.5, 1.6, 1.6, 1.6,
 1.7, 1.7, 1.7, 1.7, 1.8, 1.8, 2.0, 2.0, 2.1, 2.1, 2.3, 2.3,
 2.4, 2.4, 2.5, 2.5, 2.5, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.0,
 3.1, 3.2, 3.2, 3.3, 3.4, 3.4, 3.4, 3.4, 3.5, 3.7, 3.7, 3.8,
 3.8, 3.9, 3.9, 3.9, 3.9, 4.0, 4.0, 4.2, 4.3, 4.3, 4.5, 4.5,
 4.5, 4.6, 4.6, 4.6, 4.7, 4.9, 4.9, 5.0, 5.1, 5.1, 5.1, 5.2,
 5.3, 5.3, 5.3, 5.3, 5.4, 5.5, 5.5, 5.5, 5.6, 5.8, 5.8, 5.9

Plot Number 15 (280N)

0.6, 0.6, 0.7, 0.8, 1.1, 1.1, 1.2, 1.2, 1.3, 1.6, 1.6, 1.6,
 1.6, 1.6, 1.6, 1.7, 1.7, 1.7, 1.7, 1.8, 2.1, 2.2, 2.3, 2.4,
 2.5, 2.9, 3.2, 3.4, 3.4, 3.5, 3.5, 3.6, 3.8, 4.0, 4.2, 4.2,
 4.3, 4.5, 4.5, 4.6, 4.6, 4.7, 4.7, 4.8, 4.8, 4.8, 4.9, 4.9,
 5.0, 5.4, 5.5, 5.7, 5.8, 6.2, 6.2, 6.7, 7.5, 7.6

Plot Number 16 (84N)

0.6, 0.7, 1.0, 1.3, 1.4, 1.5, 1.6, 1.9, 2.9, 2.9, 3.2, 3.3,
 3.5, 3.5, 3.9, 4.3, 4.5, 4.5, 5.0, 5.2, 5.4, 5.4, 5.4, 5.5,
 5.5, 5.6, 5.9, 6.3, 6.5, 7.0, 7.3, 8.0, 8.5

Plot Number 17 (168N + 112P)

0.7, 0.8, 1.2, 1.4, 1.4, 1.4, 1.8, 1.9, 2.3, 2.7, 3.1, 3.2,
 3.5, 3.6, 3.6, 3.7, 3.8, 4.0, 4.1, 4.2, 4.3, 4.3, 4.4, 4.5,
 4.5, 4.9, 4.9, 4.9, 5.1, 5.2, 5.4, 5.7, 5.7, 5.7, 6.0, 6.3,
 6.4

Plot Number 18 (280N)

0.6, 0.7, 0.7, 0.7, 0.7, 0.7, 0.8, 0.8, 0.8, 0.8, 0.8, 0.8,
 0.8, 0.8, 0.9, 1.0, 1.0, 1.2, 1.3, 1.3, 1.4, 1.4, 1.5, 1.5,
 1.5, 1.5, 1.5, 1.6, 1.7, 1.7, 1.7, 1.7, 1.8, 1.8, 1.8, 1.9,
 2.0, 2.0, 2.2, 2.2, 2.3, 2.3, 2.4, 2.4, 2.4, 2.5, 2.5, 2.7,
 2.7, 2.8, 2.8, 2.8, 2.8, 2.9, 2.9, 2.9, 3.0, 3.0, 3.1, 3.1,
 3.1, 3.2, 3.3, 3.3, 3.5, 3.5, 3.6, 3.6, 3.6, 3.7, 3.7, 3.7,
 3.7, 3.8, 3.8, 3.9, 4.0, 4.0, 4.1, 4.1, 4.1, 4.1, 4.2, 4.3,
 4.4, 4.4, 4.6, 4.6, 4.6, 4.8, 4.8, 4.8, 4.9, 5.0, 5.0, 5.0,
 5.1, 5.2, 5.4, 5.9, 6.6, 6.8

Plot Number 19 (0N)

0.6, 0.7, 0.7, 0.8, 1.1, 1.2, 1.4, 1.4, 1.5, 1.5, 1.6, 1.6,
 1.6, 1.8, 1.8, 1.8, 1.8, 2.0, 2.2, 2.4, 2.5, 2.5, 2.7, 2.7,
 2.7, 2.7, 2.9, 3.0, 3.1, 3.2, 3.2, 3.3, 3.3, 3.3, 3.4, 3.6,
 3.6, 3.6, 3.7, 3.7, 3.7, 3.7, 3.8, 3.8, 3.9, 3.9, 3.9, 4.0,
 4.0, 4.0, 4.1, 4.3, 4.4, 4.5, 4.5, 4.5, 4.5, 4.6, 4.6, 4.7,
 4.7, 4.7, 4.7, 4.8, 4.8, 5.1, 5.2, 5.2, 5.5, 5.9, 6.6, 6.9,
 7.0, 7.8, 8.1

Plot Number 20 (168N)

0.6, 0.7, 0.7, 0.7, 0.7, 0.7, 0.8, 0.8, 0.8, 0.8, 0.8, 0.8,
 0.9, 1.0, 1.0, 1.1, 1.1, 1.1, 1.2, 1.2, 1.2, 1.2, 1.3, 1.3,
 1.3, 1.4, 1.4, 1.5, 1.5, 1.5, 1.5, 1.6, 1.6, 1.6, 1.9, 2.0,
 2.0, 2.0, 2.1, 2.1, 2.2, 2.2, 2.5, 2.5, 2.6, 2.6, 2.8, 2.9,
 3.0, 3.0, 3.2, 3.2, 3.3, 3.3, 3.4, 3.5, 3.5, 3.6, 3.6, 3.7,
 3.8, 3.8, 3.8, 3.8, 3.8, 3.9, 3.9, 4.1, 4.1, 4.3, 4.3, 4.4,
 4.4, 4.6, 4.8, 4.9, 3.9, 5.0, 5.1, 5.4, 5.7, 5.8, 7.0

Appendix 4. Plot DBH measurements for Sipiwesk 1983 (measured in inches).

Plot Number 1 (168N + 112P)

4.3, 4.5, 4.7, 4.8, 1.7, 6.9, 1.8, 6.2, 3.7, 3.6, 5.6, 5.3,
5.4, 4.1, 1.5, 5.1, 6.2, 5.7, 6.6, 6.6, 4.9, 2.8, 5.5, 2.7,
5.9, 5.5, 4.8, 6.5, 6.7, 4.8, 3.5, 3.4, 3.5, 5.8, 5.1, 6.2,
4.3, 2.1, 3.9, 4.2, 3.3, 3.9, 1.6, 4.1, 5.6, 6.3, 5.4, 6.5,
4.5

Plot Number 2 (168N)

6.8, 4.4, 6.4, 5.8, 3.3, 4.0, 3.7, 6.1, 2.8, 7.8, 3.3, 6.5,
6.0, 4.9, 5.5, 3.6, 5.3, 5.7, 2.0, 4.7, 5.3, 3.7, 2.2, 6.4,
1.8, 7.8, 2.9, 5.0, 2.5, 6.8, 5.2, 5.4, 3.7, 6.0, 2.8, 6.3,
5.2, 4.8, 3.4, 3.6, 5.1, 2.4, 4.8, 4.6, 5.5, 5.8, 4.0, 4.9

Plot Number 3 (0N)

4.9, 4.7, 5.9, 6.9, 4.4, 6.8, 5.7, 5.6, 5.0, 2.0, 6.3, 2.5,
5.8, 5.2, 3.4, 4.6, 5.6, 6.1, 4.8, 6.2, 2.9, 5.0, 4.8, 5.4,
4.3, 2.7, 6.1, 5.7, 5.6, 3.6, 4.4, 4.9, 2.2, 4.5, 3.5, 4.7,
5.4, 4.8, 5.2, 7.4

Plot Number 4 (280N)

2.5, 3.0, 5.2, 4.4, 5.0, 2.8, 3.2, 6.2, 4.4, 1.8, 5.6, 3.0,
4.9, 5.7, 3.4, 4.0, 5.0, 6.4, 6.8, 4.1, 6.1, 3.2, 5.3, 1.6,
6.7, 4.9, 3.8, 4.9, 5.3, 4.0, 3.0, 3.4, 1.8, 5.9, 2.0, 3.8,
5.2, 6.8, 6.0, 6.9, 3.3, 6.5, 4.2, 6.9, 5.7, 1.4, 2.3, 2.1,
5.5, 5.2, 2.7, 3.9, 3.4, 6.7, 4.7, 7.6, 6.7, 1.6, 2.4, 4.9,
3.5, 3.9

Plot Number 5 (84N)

4.8, 4.3, 6.2, 2.1, 2.4, 3.3, 6.8, 5.1, 6.2, 6.2, 3.3, 3.9,
4.3, 4.0, 5.8, 4.7, 5.0, 4.7, 4.5, 6.9, 5.7, 7.6, 4.8, 4.9,
6.0, 6.4, 5.6, 5.0, 7.5, 6.5, 4.2, 4.1, 7.0, 7.3, 2.0, 4.3,
5.7, 2.3, 2.3, 3.5, 5.1, 5.7, 6.3, 5.4, 5.4, 4.0, 4.5, 4.8,
4.8, 1.9, 4.8, 6.0, 5.4

Plot Number 6 (0N)

4.3, 5.8, 6.7, 5.1, 4.9, 4.5, 3.5, 2.0, 2.3, 4.3, 6.0, 4.4,
4.9, 3.3, 6.1, 5.1, 5.6, 6.1, 6.7, 2.0, 5.1, 3.9, 5.7, 4.8,
2.7, 1.3, 1.2, 1.1, 4.5, 6.2, 1.2, 6.7, 4.7, 3.1, 5.9, 5.4,
5.6, 5.2, 3.9, 6.7, 4.0, 1.2, 2.6, 1.0, 5.0, 5.2, 7.2, 2.4,
1.4, 4.5, 4.1

Plot Number 7 (168N + 112P)

5.3, 4.7, 3.2, 4.5, 5.1, 5.6, 4.2, 6.3, 3.9, 3.7, 3.7, 4.5,
 3.9, 4.1, 5.9, 2.0, 3.6, 7.4, 2.6, 4.3, 6.4, 5.0, 1.6, 2.0,
 2.1, 3.9, 5.0, 6.0, 6.3, 4.4, 2.2, 5.4, 6.1, 5.0, 3.8, 5.6,
 5.5, 5.1, 5.4, 2.2, 5.7, 4.8, 3.2, 4.4, 7.3, 6.0

Plot Number 8 (84N)

4.4, 5.1, 7.0, 7.0, 2.4, 4.6, 6.6, 6.2, 4.2, 6.0, 5.5, 5.1,
 5.3, 4.6, 5.2, 3.3, 5.9, 4.7, 3.5, 4.6, 3.0, 2.9, 3.4, 5.6,
 3.8, 4.3, 5.5, 5.3, 4.6, 2.2, 4.7, 2.5, 4.9, 4.9, 5.4, 4.9,
 5.0, 5.3, 2.2, 4.8, 5.5, 3.4, 6.9, 6.0, 3.2, 3.8, 2.3, 5.2,
 4.3, 4.4, 5.4, 3.4, 5.0, 5.5, 5.5, 2.7, 3.9, 5.0, 5.8, 4.8,
 3.8, 1.9, 4.4, 4.8, 4.6

Plot Number 9 (168N)

4.8, 7.0, 1.3, 6.7, 8.8, 6.5, 2.5, 3.9, 1.1, 6.6, 6.6, 5.8,
 6.1, 5.6, 1.7, 4.1, 7.1, 1.6, 5.4, 2.6, 3.0, 5.7, 6.6, 4.2,
 5.0, 5.1, 6.1, 5.6, 4.8, 5.7, 4.0, 5.5, 5.2, 3.8, 4.1, 4.7,
 2.6, 4.8

Plot Number 10 (280N)

6.0, 3.7, 7.0, 5.9, 4.2, 4.0, 3.4, 5.3, 3.5, 3.7, 7.9, 2.3,
 6.2, 1.8, 1.4, 7.0, 3.5, 6.1, 5.1, 6.2, 4.4, 5.5, 7.8, 5.3,
 3.5, 2.7, 4.5, 2.6, 6.0, 1.8, 5.2, 4.6, 7.7, 3.5, 5.5, 5.4,
 2.5, 6.2, 6.0, 4.5, 2.0, 5.0, 5.4, 4.4, 1.7, 1.4, 3.8, 2.5,
 3.5, 5.5, 4.4, 3.6, 1.9, 1.0

Plot Number 11 (84N)

6.2, 5.6, 6.7, 4.7, 4.6, 3.3, 3.7, 1.6, 5.6, 4.3, 4.4, 4.0,
 5.9, 4.7, 5.2, 2.2, 2.5, 4.4, 3.2, 3.6, 6.3, 1.4, 5.0, 2.8,
 3.5, 4.4, 6.1, 1.8, 4.2, 3.8, 5.4, 4.4, 5.0, 4.1, 5.2, 3.0,
 5.9, 3.3, 2.5, 2.5, 5.6, 5.7, 4.5, 3.0, 2.0, 6.2, 4.1, 3.5,
 4.9, 5.2, 2.9, 1.7, 2.5, 1.1, 5.0, 4.2, 3.8, 4.6, 4.2, 1.3,
 5.0, 4.3, 4.5, 4.5, 3.0, 6.0, 1.2, 1.9, 2.8, 3.9, 5.0, 4.4,
 4.7, 5.6, 4.3, 5.8, 4.7, 4.7, 2.3, 5.9, 5.3

Plot Number 12 (168N)

5.1, 6.9, 5.9, 5.7, 5.9, 5.6, 2.4, 3.9, 6.5, 3.9, 3.9, 3.2,
 4.0, 4.5, 5.8, 4.4, 5.6, 4.7, 4.3, 2.3, 2.4, 6.4, 4.1, 4.4,
 3.2, 4.4, 4.3, 2.4, 6.3, 2.5, 3.6, 6.4, 5.9, 5.7, 3.3, 3.5,
 6.0, 1.3, 1.1, 3.3, 4.5, 1.6, 5.1, 6.3, 3.5, 4.3, 4.5, 5.6,
 2.5, 5.7, 3.1, 5.3, 4.7, 1.8, 4.5, 2.9, 1.6, 1.6, 4.8, 2.6,
 6.2, 5.5, 3.7, 5.2, 3.1

Plot Number 13 (0N)

4.4, 6.2, 3.9, 6.0, 5.6, 1.8, 3.5, 3.3, 4.1, 2.7, 3.7, 2.9,
 2.0, 1.6, 5.9, 3.9, 5.9, 5.1, 2.2, 1.9, 4.1, 4.3, 4.4, 2.3,
 4.4, 2.4, 3.4, 3.5, 6.2, 6.2, 6.3, 6.2, 4.3, 3.0, 5.2, 4.8,

2.3, 3.8, 3.3, 2.9, 3.7, 3.0, 5.8, 2.8, 6.1, 4.9, 2.8, 2.5,
4.6, 5.5, 4.6, 5.5, 4.4, 2.2, 3.2, 4.2, 7.2, 2.7, 5.7, 4.4,
3.8, 4.5, 3.2, 2.5, 4.5, 4.3, 5.6, 3.9, 2.3, 4.2, 2.4

Plot Number 14 (168N + 112P)

7.6, 7.0, 3.4, 4.4, 5.3, 3.5, 4.5, 6.4, 4.4, 2.1, 4.7, 3.0,
1.3, 5.5, 3.9, 2.1, 4.7, 2.6, 6.2, 3.7, 4.0, 4.5, 6.8, 4.9,
2.8, 3.3, 5.5, 6.0, 5.8, 6.3, 3.7, 3.5, 4.2, 5.6, 6.5, 6.0,
1.2, 5.1, 1.5, 6.0, 2.0, 3.9, 3.4, 6.9, 2.7, 2.1, 5.5, 3.1,
5.7, 4.0, 6.3, 6.2, 5.5, 1.3, 5.8, 5.8, 3.9, 1.1

Plot Number 15 (280N)

2.4, 2.0, 6.3, 8.1, 6.1, 8.4, 6.9, 5.6, 9.1, 5.4, 2.6, 6.2,
1.1, 1.8, 5.1, 3.8, 1.6, 4.9, 5.0, 4.2, 2.5, 6.4, 1.7, 5.7,
5.6, 6.5, 5.2, 5.1, 5.9, 3.9, 1.7, 2.3, 3.7, 7.1, 1.3, 1.7,
5.9, 5.7, 5.7

Plot Number 16 (84N)

9.0, 6.2, 9.0, 8.1, 8.2, 6.0, 3.0, 4.2, 6.1, 6.7, 7.0, 5.2,
8.5, 2.2, 4.8, 5.9, 3.1, 4.3, 3.4, 5.2, 6.0, 4.9, 1.9, 1.7,
6.5

Plot Number 17 (168N + 112P)

6.6, 6.2, 7.9, 6.0, 5.0, 4.4, 5.0, 5.8, 6.0, 1.9, 7.0, 4.8,
7.2, 2.9, 5.2, 1.6, 4.4, 4.3, 3.7, 5.9, 4.2, 5.0, 5.1, 4.0,
6.5

Plot Number 18 (280N)

6.5, 4.2, 4.1, 4.7, 4.9, 2.5, 3.9, 2.6, 4.5, 1.5, 5.6, 2.1,
4.6, 6.1, 3.7, 3.0, 4.1, 3.0, 3.6, 6.7, 5.3, 5.3, 1.5, 3.4,
1.9, 1.9, 5.5, 6.1, 4.3, 5.8, 2.2, 7.7, 1.8, 3.4, 5.6, 4.0,
3.1, 4.6, 4.5, 1.7, 1.5, 1.6, 2.9, 2.5, 1.9, 5.3, 5.2, 1.6,
4.7, 6.3, 2.4, 7.6, 4.8, 5.5, 2.5, 3.7, 4.8, 6.5, 3.5, 4.0,
4.2, 3.5, 4.5, 2.8, 1.0, 2.5

Plot Number 19 (0N)

6.8, 9.3, 5.9, 3.2, 3.7, 4.2, 3.7, 4.7, 4.4, 2.0, 4.5, 3.4,
6.1, 4.9, 4.3, 4.1, 2.5, 1.8, 7.6, 4.8, 4.1, 3.6, 2.1, 8.0,
2.6, 4.4, 5.2, 5.1, 9.0, 5.0, 6.1, 8.0, 1.6, 5.2, 2.2, 4.3,
5.6, 3.7, 3.2, 3.6, 3.4, 3.3, 1.5, 5.2, 3.9, 3.6, 4.0, 4.7,
4.1, 2.5, 4.9

Plot Number 20 (168N)

6.7, 4.7, 4.8, 5.9, 6.7, 1.1, 3.0, 6.8, 8.1, 2.6, 4.9, 4.8,
3.8, 2.6, 1.8, 5.5, 5.0, 4.9, 4.4, 2.0, 4.2, 1.3, 0.9, 4.1,
2.9, 3.3, 5.0, 5.8, 5.7, 2.4, 1.2, 4.7, 6.5, 2.2, 4.4, 1.3,

1.2, 2.0, 1.6, 5.9, 2.3, 2.6, 3.3, 4.5, 5.8, 2.2, 3.8, 4.6,
5.7

Appendix 5. Plot DBH measurements for Wanless 1968 (measured in inches).

Plot Number 1 (168N + 112P)

0.6, 0.8, 0.8, 0.9, 1.2, 1.4, 1.4, 1.5, 1.5, 1.6, 1.6, 1.7,
1.9, 1.9, 1.9, 2.0, 2.0, 2.4, 2.4, 2.4, 2.5, 2.5, 2.5, 2.5,
2.5, 2.6, 2.6, 2.6, 2.6, 2.7, 2.7, 2.8, 2.8, 2.8, 2.8, 3.0,
3.0, 3.0, 3.1, 3.1, 3.1, 3.3, 3.3, 3.4, 3.5, 3.5, 3.5, 3.6,
3.6, 3.6, 3.6, 3.6, 3.6, 3.6, 3.7, 3.8, 3.8, 3.8, 3.8, 3.9,
3.9, 3.9, 3.9, 4.0, 4.0, 4.1, 4.1, 4.2, 4.3, 4.4, 4.5, 4.5,
4.5, 4.5, 4.5, 4.6, 4.6, 4.8, 4.8, 5.1, 5.2, 5.3, 5.8

Plot Number 5 (168N)

0.6, 1.1, 1.5, 1.5, 1.7, 1.9, 1.9, 1.9, 2.0, 2.0, 2.3, 2.5,
2.5, 2.5, 2.9, 3.0, 3.1, 3.5, 3.6, 3.7, 3.7, 3.9, 3.9, 4.0,
4.0, 4.5, 4.5, 4.5, 4.5, 4.6, 4.8, 4.9, 4.9, 5.1, 5.2, 5.2,
5.4, 6.2, 6.2, 6.8

Plot Number 6 (84N)

0.6, 0.9, 1.1, 1.2, 1.2, 1.4, 1.4, 1.5, 1.5, 1.5, 1.6, 1.6,
1.6, 1.7, 1.7, 1.8, 1.9, 2.0, 2.0, 2.2, 2.3, 2.4, 2.4, 2.7,
2.8, 2.8, 2.8, 2.9, 2.9, 3.0, 3.0, 3.3, 3.3, 3.3, 3.4, 3.4,
3.4, 3.4, 3.5, 3.7, 3.7, 3.8, 3.9, 4.0, 4.1, 4.2, 4.2, 4.3,
4.3, 4.4, 4.5, 4.5, 4.5, 4.7, 4.7, 4.8, 4.8, 4.8, 4.8, 4.8,
4.8, 4.9, 4.9, 4.9, 4.9, 4.9, 5.1, 5.1, 5.2, 5.3, 5.4, 5.7,
5.7, 5.9, 6.0

Plot Number 7 (0N)

0.6, 0.7, 0.7, 0.7, 0.8, 0.8, 1.0, 1.1, 1.1, 1.1, 1.2, 1.2,
1.2, 1.2, 1.3, 1.3, 1.3, 1.4, 1.4, 1.4, 1.4, 1.4, 1.5, 1.5,
1.6, 1.6, 1.6, 1.6, 1.6, 1.6, 1.7, 1.7, 1.8, 1.8, 1.8, 1.9,
1.9, 2.0, 2.0, 2.0, 2.2, 2.2, 2.2, 2.4, 2.4, 2.5, 2.6, 2.7,
2.8, 2.8, 2.8, 2.8, 2.8, 2.8, 2.9, 2.9, 3.0, 3.1, 3.1, 3.1,
3.2, 3.2, 3.3, 3.4, 3.4, 3.4, 3.5, 3.5, 3.5, 3.6, 3.6, 3.6,
3.6, 3.6, 3.6, 3.7, 3.8, 3.9, 3.9, 3.9, 4.0, 4.0, 4.0, 4.0,
4.1, 4.1, 4.1, 4.3, 4.3, 4.3, 4.3, 4.4, 4.4, 4.4, 4.7, 4.8,
4.8, 5.0, 6.3

Plot Number 8 (84N)

0.7, 0.8, 0.8, 1.1, 1.2, 1.3, 1.4, 1.4, 1.5, 1.5, 1.5, 1.6,
1.6, 1.6, 1.6, 1.7, 1.7, 1.8, 1.8, 1.8, 1.8, 1.9, 1.9, 2.0,
2.0, 2.1, 2.3, 2.5, 2.5, 2.5, 2.5, 2.8, 2.8, 2.8, 2.8, 2.8,
2.8, 2.8, 2.8, 2.9, 3.0, 3.1, 3.1, 3.2, 3.2, 3.3, 3.3, 3.3,
3.3, 3.3, 3.4, 3.4, 3.5, 3.6, 3.6, 3.6, 3.6, 3.7, 3.8, 3.8,
3.8, 3.9, 3.9, 4.0, 4.0, 4.0, 4.0, 4.0, 4.1, 4.1, 4.2, 4.2,
4.2, 4.3, 4.4, 4.5, 4.7, 4.8, 4.8, 4.8, 4.8, 4.9, 4.9, 4.9, 5.0,
5.7

Plot Number 9 (84N)

1.2, 1.4, 1.5, 1.9, 2.0, 2.2, 2.3, 2.3, 2.3, 2.4, 2.5, 2.7,
 2.9, 3.0, 3.0, 3.1, 3.1, 3.2, 3.6, 3.6, 3.7, 4.0, 4.2, 4.8,
 4.8, 4.8, 4.9, 4.9, 5.1, 5.2, 5.2, 5.3, 5.4, 5.4, 5.5, 5.5,
 5.5, 5.5, 5.6, 5.6, 5.9, 6.1, 6.3, 6.5, 7.6

Plot Number 10 (0N)

0.6, 0.6, 0.7, 0.7, 0.8, 0.9, 0.9, 0.9, 1.1, 1.1, 1.3, 1.5,
 1.8, 1.8, 1.9, 2.0, 2.3, 2.3, 2.3, 2.4, 2.4, 2.4, 2.5, 2.5,
 2.6, 2.6, 2.9, 2.9, 3.1, 3.2, 3.2, 3.2, 3.5, 3.7, 3.8, 3.8,
 3.8, 3.8, 3.9, 4.0, 4.0, 4.0, 4.0, 4.1, 4.1, 4.1, 4.1, 4.1,
 4.5, 4.6, 4.6, 4.7, 4.7, 4.9, 4.9, 5.0, 5.1, 5.2, 5.2, 5.4,
 5.5, 5.7, 5.7, 5.8, 6.0, 6.6

Plot Number 12 (164N + 112P)

0.6, 0.8, 1.0, 1.0, 1.1, 1.3, 1.5, 1.7, 1.7, 1.8, 1.8, 1.8,
 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.6, 2.6, 2.7, 2.8,
 2.8, 2.9, 2.9, 2.9, 3.0, 3.0, 3.0, 3.0, 3.0, 3.0, 3.1, 3.1,
 3.1, 3.2, 3.2, 3.2, 3.3, 3.3, 3.4, 3.4, 3.4, 3.4, 3.5, 3.5,
 3.5, 3.5, 3.6, 3.6, 3.7, 3.8, 3.9, 3.9, 3.9, 4.0, 4.0, 4.0,
 4.1, 4.2, 4.2, 4.3, 4.3, 4.3, 4.4, 4.4, 4.4, 4.4, 4.4, 4.4,
 4.5, 4.6, 4.6, 4.6, 4.7, 4.8, 4.8, 5.0, 5.0, 5.1, 5.1, 5.2,
 5.2, 5.2, 5.6, 5.8, 5.9, 5.9, 6.2, 6.2

Plot Number 13 (280N)

0.7, 0.9, 1.0, 1.0, 1.0, 1.0, 1.2, 1.2, 1.3, 1.4, 1.4, 1.5,
 1.5, 1.5, 1.6, 1.6, 1.6, 1.7, 1.7, 1.7, 1.7, 1.7, 1.7, 1.8,
 1.8, 1.8, 1.9, 1.9, 1.9, 1.9, 1.9, 2.0, 2.0, 2.1, 2.2, 2.3,
 2.4, 2.5, 2.5, 2.5, 2.6, 2.6, 2.7, 2.7, 2.7, 2.8, 2.8, 2.9,
 2.9, 2.9, 3.0, 3.0, 3.1, 3.1, 3.1, 3.2, 3.2, 3.2, 3.2, 3.2,
 3.3, 3.3, 3.3, 3.5, 3.5, 3.5, 3.7, 3.8, 3.9, 3.9, 3.9, 4.0,
 4.0, 4.0, 4.0, 4.1, 4.1, 4.1, 4.2, 4.2, 4.2, 4.3, 4.3, 4.3,
 4.4, 4.4, 4.5, 4.5, 4.7, 4.9, 5.0, 5.1, 5.2, 5.3, 5.4, 5.5,
 6.1

Plot Number 14 (0N)

0.7, 0.7, 0.8, 0.8, 0.9, 1.1, 1.2, 1.5, 1.5, 1.7, 1.8, 1.8,
 1.9, 2.0, 2.0, 2.1, 2.2, 2.3, 2.6, 2.8, 2.8, 2.9, 3.0, 3.1,
 3.1, 3.1, 3.1, 3.2, 3.4, 3.5, 3.5, 3.5, 3.6, 3.6, 3.6, 3.7,
 3.7, 3.7, 3.8, 3.9, 3.9, 4.0, 4.0, 4.0, 4.0, 4.0, 4.2, 4.3,
 4.3, 4.4, 4.4, 4.4, 4.4, 4.4, 4.5, 4.5, 4.5, 4.5, 4.5, 4.6,
 4.6, 4.7, 4.7, 4.8, 5.1, 5.1, 5.1, 5.1, 5.2, 5.2, 5.2, 5.6,
 5.7, 5.8, 5.9

Plot Number 15 (168N + 112P)

0.9, 0.9, 1.0, 1.1, 1.3, 1.6, 1.7, 1.8, 2.0, 2.1, 2.2, 2.3,

2.4, 2.5, 2.5, 2.8, 2.8, 3.0, 3.1, 3.2, 3.2, 3.3, 3.3, 3.5,
 3.5, 3.6, 3.7, 3.7, 3.7, 3.8, 3.8, 3.8, 4.0, 4.2, 4.3, 4.3,
 4.4, 4.6, 4.8, 4.8, 4.8, 4.9, 4.9, 5.1, 5.1, 5.2, 5.3, 6.0,
 6.0, 6.5

Plot Number 19 (280N)

0.6, 1.0, 1.1, 1.5, 1.6, 1.7, 1.8, 1.8, 1.8, 1.8, 2.0, 2.0,
 2.1, 2.1, 2.3, 2.6, 2.6, 2.6, 2.8, 3.0, 3.1, 3.1, 3.1, 3.3,
 3.3, 3.5, 3.5, 3.8, 3.8, 3.9, 3.9, 4.1, 4.2, 4.2, 4.2, 4.2,
 4.4, 4.5, 4.6, 4.6, 4.6, 4.6, 4.6, 4.7, 4.7, 4.9, 4.9, 4.9,
 5.0, 5.0, 5.1, 5.2, 5.2, 5.2, 5.4, 5.6, 5.7, 5.8, 5.8, 6.3

Plot Number 20 (280N)

0.6, 0.8, 0.9, 0.9, 1.0, 1.1, 1.7, 1.9, 2.1, 2.1, 2.4, 2.6,
 2.8, 2.8, 2.9, 3.2, 3.3, 3.3, 3.5, 3.6, 3.8, 3.8, 3.9, 4.2,
 4.2, 4.2, 4.3, 4.3, 4.4, 4.5, 5.0, 5.0,
 6.0, 6.3, 6.6

Plot Number 21 (84N)

0.7, 1.2, 1.6, 1.7, 2.0, 2.1, 2.1, 2.1, 2.4, 2.5, 2.7, 2.7,
 2.7, 3.3, 3.3, 3.4, 3.5, 3.7, 3.9, 4.1, 4.5, 4.5, 4.5, 4.6,
 4.6, 4.8, 4.9, 5.0, 5.1, 5.1, 5.1, 5.2, 5.2, 5.3, 5.4, 5.5,
 5.6, 6.0, 6.1, 6.2

Plot Number 23 (168N)

0.6, 0.7, 0.8, 0.8, 0.9, 1.0, 1.0, 1.2, 1.2, 1.3, 1.4, 1.4,
 1.6, 1.7, 1.8, 1.9, 1.9, 2.5, 3.3, 3.3, 3.4, 3.6, 3.7, 4.0,
 4.5, 4.5, 4.9, 5.0, 5.2, 5.4, 6.1, 6.5, 6.6, 6.8

Plot Number 24 (0N)

1.0, 1.0, 1.0, 1.1, 1.2, 1.3, 1.3, 1.5, 1.7, 1.7, 2.0, 2.0,
 2.0, 2.1, 2.2, 2.2, 2.2, 2.3, 2.3, 2.4, 2.5, 2.5, 2.5, 2.7,
 2.8, 2.8, 2.8, 2.9, 3.2, 3.2, 3.3, 3.3, 3.3, 3.3, 3.6, 3.6,
 3.6, 3.7, 3.8, 3.8, 3.9, 4.0, 4.0, 4.0, 4.1, 4.1, 4.2, 4.4,
 4.6, 4.7, 4.7, 4.7, 4.9, 5.0, 5.1, 5.1, 5.2, 5.3, 5.3, 5.3,
 5.4, 5.4, 5.4, 5.6, 5.7, 5.9, 6.2, 6.6, 7.0

Plot Number 25 (168N)

0.7, 1.0, 1.0, 1.0, 1.1, 1.1, 1.2, 1.2, 1.3, 1.3, 1.4, 1.4,
 1.4, 1.4, 1.4, 1.5, 1.7, 1.7, 1.7, 1.8, 1.8, 1.8, 1.9, 2.0,
 2.1, 2.1, 2.2, 2.3, 2.3, 2.3, 2.3, 2.3, 2.4, 2.4, 2.4, 2.5,
 2.5, 2.5, 2.5, 2.5, 2.7, 2.7, 2.7, 3.0, 3.0, 3.1, 3.1, 3.1,
 3.1, 3.2, 3.2, 3.3, 3.3, 3.3, 3.5, 3.6, 3.6, 3.6, 3.7, 3.7,
 3.7, 3.8, 3.9, 3.9, 3.9, 4.0, 4.0, 4.1, 4.1, 4.1, 4.1, 4.3,
 4.3, 4.3, 4.4, 4.4, 4.4, 4.5, 4.5, 4.6, 4.6, 4.9, 4.9, 5.0,
 5.0, 5.0, 5.0, 5.0, 5.1, 5.2, 5.2, 5.3, 5.3, 5.6, 5.7

Plot Number 26 (168N + 112P)

0.7, 0.9, 1.0, 1.0, 1.1, 1.1, 1.2, 1.2, 1.3, 1.4, 1.5, 1.5,
 1.5, 1.7, 1.7, 1.7, 1.7, 1.8, 2.0, 2.0, 2.0, 2.0, 2.1, 2.1,
 2.1, 2.1, 2.2, 2.2, 2.3, 2.4, 2.4, 2.4, 2.5, 2.5, 2.5, 2.6,
 2.7, 2.7, 2.7, 2.7, 2.8, 2.8, 2.8, 2.9, 3.0, 3.0, 3.2, 3.2,
 3.3, 3.3, 3.4, 3.4, 3.4, 3.5, 3.5, 3.5, 3.6, 3.7, 3.7, 3.8,
 3.8, 3.8, 3.8, 3.9, 4.1, 4.2, 4.4, 4.5, 4.5, 4.6, 4.6, 4.7,
 4.7, 4.7, 4.8, 4.8, 4.8, 4.9, 5.3, 5.6, 5.7

Plot Number 27 (280N)

0.9, 1.0, 1.2, 1.2, 1.5, 1.5, 1.5, 1.6, 1.7, 1.9, 1.9, 2.1,
 2.1, 2.3, 2.4, 2.4, 2.4, 2.5, 2.6, 2.7, 2.8, 2.8, 2.8, 2.9,
 2.9, 2.9, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.4, 3.4, 3.5, 3.5,
 3.5, 3.5, 3.6, 3.6, 3.6, 3.6, 3.6, 3.9, 3.9, 3.9, 3.9, 4.2,
 4.2, 4.2, 4.3, 4.4, 4.5, 4.5, 4.5, 4.9, 5.2, 5.3, 5.4, 5.7,
 6.4, 6.4

Plot Number 28 (168N)

0.7, 0.8, 0.8, 0.8, 1.0, 1.0, 1.0, 1.0, 1.1, 1.1, 1.4, 1.4,
 1.6, 1.7, 1.7, 1.9, 2.0, 2.1, 2.1, 2.4, 2.5, 2.6, 2.6, 3.0,
 3.1, 3.1, 3.1, 3.1, 3.2, 3.4, 3.4, 3.5, 3.5, 3.6, 3.9, 4.0,
 4.0, 4.1, 4.2, 4.3, 4.3, 4.3, 4.3, 4.5, 4.5, 4.5, 4.5, 4.8,
 5.0, 5.0, 5.1, 5.2, 5.3, 5.3, 5.5, 5.9, 6.3

Appendix 6. Plot DBH measurements for Wanless 1983 (measured in inches).

Plot Number 1 (168N + 112P)

5.1, 3.6, 3.0, 4.4, 5.0, 4.0, 4.4, 6.0, 5.0, 3.5, 5.8, 4.7,
2.9, 4.0, 4.1, 5.6, 6.2, 5.1, 4.3, 2.9, 2.7, 4.2, 4.0, 4.5,
3.8, 5.0, 2.4, 4.7, 3.6, 4.4, 3.6, 3.5, 2.5, 3.8, 4.7, 4.9,
2.5, 4.5, 4.5, 5.8, 3.1, 6.2, 3.3, 3.3, 4.0, 5.0, 4.9, 4.4,
3.6, 3.4, 3.1, 2.7

Plot Number 5 (168N)

2.6, 5.6, 6.5, 5.3, 6.9, 2.0, 2.9, 6.3, 4.0, 5.3, 4.2, 5.7,
3.8, 5.6, 5.0, 3.4, 4.9, 4.0, 5.0, 4.0, 3.7, 5.2, 6.1, 5.8,
7.4, 5.8, 4.2, 4.9, 5.5, 2.2

Plot Number 6 (84N)

3.0, 4.4, 6.2, 5.9, 3.8, 3.3, 6.4, 6.0, 5.8, 6.5, 3.0, 5.4,
2.8, 5.2, 6.0, 3.1, 3.4, 4.0, 5.1, 5.4, 3.3, 6.3, 3.8, 5.9,
1.5, 3.5, 4.9, 2.8, 3.5, 4.2, 4.9, 5.1, 3.9, 5.0, 5.3, 3.8,
6.3, 5.6, 2.5, 2.6, 4.2, 3.5, 2.5, 2.4, 2.0, 4.7, 5.4, 3.7,
4.3, 5.4, 1.8, 3.6, 4.8, 5.2, 2.7, 2.8, 5.6, 5.3, 5.3, 4.6

Plot Number 7 (0N)

3.9, 3.4, 4.5, 4.1, 3.9, 4.4, 4.5, 2.2, 3.6, 4.9, 3.4, 3.4,
5.1, 4.0, 3.8, 4.2, 4.1, 4.0, 2.0, 4.7, 5.2, 5.0, 3.3, 2.4,
2.5, 2.9, 5.0, 3.1, 2.9, 4.7, 3.8, 1.9, 3.3, 3.2, 4.0, 5.6,
2.0, 4.9, 4.0, 4.0, 4.4, 2.4, 3.5, 5.8, 4.6, 2.9, 2.7, 3.7,
2.8, 4.5, 3.1, 5.5, 2.2, 5.2, 3.7, 4.4, 4.0, 2.5, 2.0, 4.3,
3.2, 2.2, 4.8, 4.3, 4.1, 3.2

Plot Number 8 (84N)

2.3, 3.1, 2.9, 2.6, 4.0, 6.4, 4.5, 3.3, 4.2, 4.8, 1.7, 4.8,
3.8, 2.9, 4.1, 4.1, 3.8, 5.6, 4.0, 3.5, 3.1, 3.0, 4.3, 1.8,
3.3, 3.7, 4.2, 4.7, 2.6, 4.2, 5.9, 2.6, 5.3, 3.4, 1.9, 3.2,
3.4, 3.5, 5.1, 5.1, 4.5, 5.0, 2.1, 2.8, 2.5, 3.8, 5.6, 3.0,
4.7, 4.0, 5.3, 2.8, 2.7, 4.6, 3.4, 5.3, 3.9, 5.5, 2.5, 4.5,
3.3, 5.0, 1.9

Plot Number 9 (84N)

3.2, 3.3, 4.1, 2.8, 3.3, 5.9, 6.5, 2.7, 4.0, 6.0, 5.7, 5.6,
5.5, 6.5, 4.8, 6.2, 5.9, 6.4, 2.7, 3.1, 5.5, 6.1, 2.6, 6.2,
3.0, 6.2, 5.1, 5.1, 5.9, 7.0, 3.2, 4.0, 2.3, 4.5, 7.5, 3.8,
5.1, 5.2, 4.2, 2.2, 4.6

Plot Number 10 (0N)

4.0, 3.3, 4.4, 5.8, 6.7, 2.5, 6.5, 4.6, 4.8, 2.5, 4.5, 5.5,
 4.4, 3.5, 4.1, 7.1, 4.3, 3.6, 4.4, 6.0, 3.3, 6.3, 2.2, 5.2,
 5.5, 4.2, 4.5, 4.2, 3.6, 4.5, 5.2, 4.9, 4.3, 3.4, 6.1, 5.3,
 2.6, 2.6, 4.9, 6.2, 6.5, 5.4, 6.3

Plot Number 12 (168N + 112P)

3.3, 5.1, 6.1, 6.1, 6.6, 5.6, 4.8, 3.2, 4.9, 5.0, 5.9, 2.8,
 5.1, 5.4, 4.8, 4.2, 3.6, 1.9, 3.1, 5.2, 2.5, 4.1, 4.2, 3.8,
 4.8, 5.2, 3.9, 5.3, 7.0, 2.1, 4.0, 4.6, 4.3, 5.6, 4.8, 4.5,
 3.7, 3.8, 4.2, 2.7, 3.1, 3.7, 3.8, 4.3, 3.5, 4.7, 3.0, 5.4,
 5.2, 4.9, 5.2, 3.4, 1.8, 5.5, 3.8, 5.4, 3.1, 6.0, 4.2, 4.5,
 3.2, 2.5, 3.2, 3.1, 5.8, 3.0, 5.6, 3.4, 3.5

Plot Number 13 (280N)

3.0, 4.5, 2.8, 5.9, 5.9, 2.8, 4.4, 4.3, 4.4, 3.1, 5.3, 4.0,
 4.8, 5.1, 3.9, 3.8, 3.4, 3.2, 3.0, 4.8, 5.6, 5.0, 2.4, 5.6,
 4.9, 2.7, 5.4, 3.5, 6.1, 4.2, 3.2, 4.9, 4.3, 5.7, 4.7, 4.8,
 5.0, 2.2, 3.3, 3.5, 3.3, 4.8, 4.5, 4.9, 4.6, 6.0, 3.9

Plot Number 14 (0N)

2.4, 4.5, 5.5, 3.2, 4.8, 3.1, 4.3, 4.0, 5.2, 4.3, 2.9, 5.0,
 5.4, 6.4, 5.4, 6.1, 6.3, 5.9, 4.3, 6.3, 4.3, 6.1, 3.4, 2.9,
 3.8, 3.8, 4.0, 4.2, 4.8, 3.9, 4.1, 4.7, 4.8, 4.3, 6.9, 5.4,
 5.3, 5.0, 6.4, 5.6, 3.3, 4.1, 5.6, 5.1, 4.6, 4.4

Plot Number 15 (168N)

3.5, 5.6, 2.4, 5.3, 4.8, 5.1, 5.4, 5.4, 4.3, 3.6, 3.0, 5.5,
 4.2, 3.2, 6.8, 5.4, 6.7, 4.2, 4.0, 4.1, 7.0, 3.6, 3.3, 6.4,
 4.5, 3.8, 6.0, 3.5, 3.4, 4.1, 6.1, 4.5

Plot Number 19 (280N)

2.1, 5.2, 5.8, 3.3, 4.9, 5.3, 6.9, 3.5, 3.5, 5.9, 2.5, 5.4,
 4.8, 3.8, 3.5, 4.8, 6.5, 3.5, 4.8, 6.0, 4.4, 5.1, 5.3, 5.8,
 5.7, 3.2, 5.1, 6.2, 2.8, 5.4, 5.7, 5.4, 4.7, 4.3, 4.1, 4.6,
 6.5, 3.0, 5.6, 1.9

Plot Number 20 (280N)

1.5, 4.2, 2.6, 5.0, 7.8, 4.4, 3.6, 5.0, 4.8, 2.8, 2.3, 3.5,
 4.3, 5.0, 4.0, 3.5, 4.4, 7.0, 4.8, 4.5, 3.9, 5.7

Plot Number 21 (84N)

4.8, 6.1, 5.2, 6.8, 2.9, 5.9, 4.8, 4.2, 5.9, 5.0, 5.0, 5.8,
 5.6, 5.4, 2.0, 5.8, 2.5, 6.7, 3.6, 3.8, 5.0, 3.7, 4.1, 2.8,
 3.6, 2.2, 3.0, 5.8

Plot Number 23 (168N)

7.2, 4.4, 2.5, 1.8, 6.0, 6.8, 4.2, 5.0, 4.8, 7.5, 5.4, 2.2,
4.0, 5.8, 7.0, 3.0

Plot Number 24 (0N)

5.8, 4.6, 4.0, 7.5, 5.5, 4.0, 5.1, 3.1, 4.3, 5.0, 2.4, 4.1,
3.5, 7.9, 4.6, 2.8, 3.8, 6.0, 3.4, 6.1, 4.2, 5.0, 3.2, 4.8,
5.3, 2.4, 5.3, 6.0, 6.3, 4.0, 5.9, 2.8, 4.2, 3.4, 6.2, 3.5,
6.0, 6.1, 6.5, 2.0, 4.2, 5.8, 6.6, 4.3, 5.5, 2.1, 4.4

Plot Number 25 (168N)

3.9, 5.4, 6.0, 2.3, 4.3, 5.3, 2.3, 2.8, 2.8, 4.3, 3.9, 2.7,
4.4, 3.6, 2.6, 4.9, 5.7, 2.5, 5.1, 2.4, 4.2, 2.1, 2.2, 1.8,
6.9, 2.1, 4.8, 2.6, 4.4, 3.4, 3.1, 5.5, 4.0, 3.2, 5.3, 3.4,
3.8, 4.3, 6.1, 3.2, 5.7, 2.7, 5.9, 4.0, 3.4, 3.5, 4.8, 4.5,
5.2, 4.8, 4.6, 4.6, 4.1, 5.3, 3.2, 4.1, 4.3, 3.2, 3.2, 6.5,
4.8, 4.2, 5.9

Plot Number 26 (168N + 112P)

3.4, 4.2, 2.1, 2.6, 2.6, 2.5, 3.6, 6.2, 2.8, 2.7, 2.1, 4.5,
4.9, 3.1, 2.8, 2.6, 5.3, 4.6, 4.0, 4.3, 4.4, 3.8, 3.1, 6.6,
2.5, 4.0, 5.6, 5.5, 4.6, 3.2, 3.5, 1.8, 5.0, 4.4, 2.8, 3.3,
2.1, 2.8, 4.0, 5.8, 5.4, 4.9, 3.6, 5.8, 4.0, 3.8, 5.1, 4.0,
2.2, 2.8, 3.5, 3.7, 5.4

Plot Number 27 (280N)

4.8, 3.1, 3.7, 2.8, 5.1, 3.4, 4.8, 3.8, 4.4, 2.2, 4.6, 5.0,
3.2, 5.1, 3.8, 6.4, 3.7, 3.0, 3.3, 2.6, 7.3, 2.8, 5.1, 3.5,
4.1, 5.2, 3.8, 4.4, 5.7, 1.9, 2.4, 7.0, 3.9, 4.1, 2.5, 4.5,
3.3, 3.6, 3.0, 4.3, 3.8, 2.2, 3.0, 4.3, 6.2

Plot Number 28 (168N)

3.7, 2.2, 5.6, 3.4, 3.6, 4.9, 2.4, 4.7, 2.5, 4.7, 6.9, 4.7,
3.1, 5.5, 4.1, 6.5, 6.1, 5.3, 2.9, 4.8, 6.6, 5.0, 3.5, 5.0,
4.6, 6.3, 3.2, 4.9, 4.8, 3.5, 4.5, 3.9, 3.8, 4.9, 5.2, 6.0

Appendix 7. Plot DBH measurements for thinning and fertilization demonstration at Wanless 1968 (measurements in inches).

Plot Number 1 (Thinned + 168N)

2.1, 2.5, 2.9, 2.9, 2.9, 3.1, 3.3, 3.3, 3.3, 3.4, 3.4, 3.4,
3.7, 3.8, 4.0, 4.1, 4.2, 4.3, 4.4, 4.4, 4.4, 4.5, 4.6, 4.6,
4.7, 4.7, 4.9, 5.0, 5.1, 5.2, 5.2, 5.2, 5.2, 5.3, 5.5, 5.6,
5.6, 5.9, 6.1, 6.2, 6.5, 7.1

Plot Number 2 (Thinned + 0N)

3.4, 3.5, 3.6, 3.7, 4.0, 4.3, 4.4, 4.4, 4.5, 4.5, 4.6, 4.7,
4.9, 5.0, 5.0, 5.0, 5.1, 5.2, 5.2, 5.4, 5.4, 5.4, 6.2, 6.3,
6.5, 6.8

Plot Number 3 (Thinned + 84N)

2.1, 2.7, 2.8, 3.2, 3.2, 3.4, 3.5, 3.7, 3.8, 3.9, 4.1, 4.2,
4.2, 4.2, 4.2, 4.3, 4.4, 4.5, 4.5, 4.5, 4.7, 4.8, 5.0, 5.0,
5.0, 5.0, 5.1, 5.2, 5.2, 5.3, 5.3, 5.3, 5.4, 5.5, 5.5, 5.5,
5.7, 6.2, 6.8

Plot Number 4 (Thinned + 0N)

1.8, 2.3, 2.4, 2.5, 2.6, 2.9, 3.0, 3.3, 3.4, 3.4, 3.5, 3.5,
3.5, 3.6, 3.7, 3.7, 3.7, 3.9, 3.9, 3.9, 4.0, 4.0, 4.0, 4.1,
4.2, 4.2, 4.3, 4.5, 4.6, 4.6, 4.6, 4.7, 5.0, 5.0, 5.0, 5.0,
5.1, 5.2, 5.3, 5.7, 5.8, 6.4, 6.5, 6.8, 7.2

Plot Number 5 (Thinned + 168N)

2.8, 2.9, 3.1, 3.3, 3.7, 3.8, 3.9, 3.9, 4.1, 4.3, 4.3, 4.4,
4.4, 4.4, 4.5, 4.8, 4.8, 4.9, 4.9, 5.1, 5.1, 5.3, 5.4, 5.5,
6.1, 6.4

Plot Number 6 (Thinned + 84N)

2.1, 2.5, 2.6, 2.8, 3.2, 3.2, 3.2, 3.3, 3.3, 3.3, 3.3, 3.3,
3.4, 3.4, 3.5, 3.6, 3.6, 3.7, 3.7, 3.8, 3.8, 3.8, 3.9, 3.9,
3.9, 3.9, 3.9, 4.0, 4.0, 4.0, 4.0, 4.0, 4.1, 4.1, 4.2, 4.2,
4.2, 4.3, 4.3, 4.4, 4.4, 4.4, 4.5, 4.5, 4.6, 4.8, 4.9, 4.9,
5.0, 5.1, 5.2, 5.3, 5.4

Appendix 8. Plot DBH measurements for thinning and fertilization demonstration at Wanless 1983 (measurements in inches).

Plot Number 1 (Thinned + 168N)

5.9, 3.9, 6.2, 3.5, 4.7, 4.8, 6.0, 8.3, 7.0, 6.5, 6.8, 6.9,
3.2, 3.5, 7.4, 5.5, 4.0, 5.8, 4.0, 5.3, 6.1, 6.5, 5.0, 4.9,
5.4, 3.8, 5.9, 5.2, 5.6, 5.1

Plot Number 2 (Thinned + 0N)

7.7, 4.8, 5.7, 3.5, 5.7, 5.3, 5.0, 7.3, 6.0, 5.7, 5.7, 6.6,
6.1, 5.3, 3.8, 6.8, 4.2, 8.0, 4.7, 5.8, 3.8, 4.9, 4.6

Plot Number 3 (Thinned + 84N)

5.0, 6.2, 6.8, 4.8, 6.7, 5.7, 5.0, 5.1, 3.4, 5.8, 4.9, 5.4,
6.0, 5.5, 5.9, 3.9, 5.2, 4.6, 5.0, 5.5, 4.2, 5.1, 5.4, 5.7,
5.8, 8.0, 6.1, 6.7, 4.0, 2.4, 4.8, 3.5, 4.7, 3.7, 4.1

Plot Number 4 (Thinned + 0N)

6.4, 2.7, 6.0, 7.2, 3.6, 7.5, 6.3, 4.4, 5.4, 3.6, 6.0, 4.4,
2.7, 4.6, 4.2, 8.5, 4.8, 5.5, 4.9, 7.8, 3.6, 4.8, 4.7, 7.8,
4.6, 4.0, 3.8, 4.0, 4.5, 4.5, 5.6, 5.8, 4.3, 5.2, 4.1, 4.3,
2.5, 3.8, 3.9, 3.6, 4.8, 3.1

Plot Number 5 (Thinned + 168N)

3.6, 7.4, 5.8, 6.0, 5.6, 6.1, 6.5, 4.5, 3.7, 6.3, 5.6, 5.2,
3.8, 4.7, 7.3, 5.5, 6.2, 4.2, 4.1, 4.2, 5.1, 5.8, 4.7, 6.0,
3.3

Plot Number 6 (Thinned + 84N)

6.3, 4.2, 6.5, 4.4, 4.6, 4.0, 6.8, 4.9, 5.6, 5.8, 5.3, 6.4,
3.8, 4.7, 6.2, 5.0, 4.1, 4.9, 3.8, 5.0, 3.6, 4.5, 4.3, 5.5,
3.9, 5.1, 5.0, 4.3, 3.8, 3.2, 4.4, 4.0, 4.1, 5.0, 5.9, 3.8,
3.7, 3.8, 4.6, 4.5, 3.8, 3.9, 4.2, 4.5, 3.6, 5.0, 4.2, 4.2,
3.7

Appendix 9. Sipiwesk 5 year ring increment treatment response calculations for 7 bole positions. Response was calculated relative to the 5 year period prior to treatment, and is presented here as a percent (100 % = identical growth to 5 year period prior to treatment).

Bole Position	Treatment	Years After Fertilization		
		1-5	6-10	11-15
1.3 metres	0N	107.7	97.0	84.2
	84N	109.1	88.5	69.5
	168N	128.3	91.7	72.9
	280N	136.4	108.4	79.4
	168N + 112P	132.9	114.1	98.7
2.6 metres	0N	101.8	79.7	76.5
	84N	114.9	79.5	66.6
	168N	123.9	84.2	73.3
	280N	123.1	95.9	70.8
	168N + 112P	125.9	92.5	92.6
3.9 metres	0N	100.8	77.8	69.3
	84N	104.4	74.8	64.6
	168N	121.7	83.5	70.0
	280N	125.0	94.8	72.3
	168N + 112P	121.7	95.5	86.7
5.2 metres	0N	97.2	74.7	70.0
	84N	105.0	71.4	64.4
	168N	123.2	82.5	69.1
	280N	128.1	92.2	73.6
	168N + 112P	124.3	91.4	82.9
6.5 metres	0N	94.9	72.8	72.5
	84N	102.8	68.7	56.6
	168N	122.1	79.4	70.1
	280N	125.5	91.6	69.5
	168N + 112P	120.2	86.0	79.1
7.8 metres	0N	88.8	66.3	63.8
	84N	102.3	68.0	57.2
	168N	119.9	78.2	68.7
	280N	125.8	88.8	66.0
	168N + 112P	118.3	83.9	75.9
9.1 metres	0N	86.9	63.0	56.9
	84N	103.4	63.4	56.0
	168N	121.0	78.6	64.9
	280N	120.4	82.9	62.4
	168N + 112P	115.0	78.9	69.7