SEVEN-YEAR RESPONSE OF DENSELY STOCKED, JUVENILE JACK PINE STANDS TO SPOT FERTILIZATION TREATMENTS IN SASKATCHEWAN'S MIXEDWOOD FOREST SECTION

by

Brian Reader

A Practicum Submitted
in Partial Fulfillment for the Degree
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ABSTRACT

This study of spot fertilization -- a technique designed to use fertilizers as both a growth enhancing and thinning agent in young, densely stocked, even-aged jack pine stands -- tested the effects of 14 different fertilizer treatments on three different sites in the Mixedwood forest section of Saskatchewan. Height and diameter measurements from treatment and control trees were collected seven years after fertilization. Treatment minus control difference figures were produced and subjected to statistical analysis [including one and two way analysis of variance (ANOVA) and simple contrast]. This analysis revealed that spot fertilization treatment effects were similar on all sites and only 2 out of 14 treatments (treatments 2 and 12) produced a significant difference between the heights and diameters of treatment and control trees at the 95% level of confidence. An overwhelming majority of the treatments (10 out of 14) produced positive but not necessarily significant results. Over a period of seven years treatment 2 at 200 grams of urea per spot produced an average of 56 cm additional height increment and 6.3 mm additional diameter increment than control trees. Similarly, treatment 12 at 400 grams of urea and 300 grams of 10-30-10 fertilizer produced an average of

35 cm additional height increment and 5.0 mm additional diameter increment. It could not be deduced from the data why treatment 2 and 12 were successful while others were not; although, it is believed that statistical variability and the variability of response common to fertilizer research are responsible for masking responses which would be evident in a larger scale study.

Weak evidence pointing to the success of spot fertilization led to recommendations that it not be established on a large scale but rather evaluated on a similar scale to determine whether self-thinning can be increased and dominance establishment induced with this procedure. Information and experience gained during the present study were used to incorporate features into the experimental design which would have benefited the analysis of spot fertilization in the present study.

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Chapter I

INTRODUCTION

Jack pine (*Pinus banksiana* Lamb.), one of the Prairie provinces most important tree species, is commonly found in pure, densely stocked, even- aged stands of fire origin on deep, acid, glacio-fluvial sands (Morrison, Foster, and Swan, 1981). It regenerates easily after fire, is relatively free of insects and diseases, grows rapidly, and has good potential for intensive forest management (Morrison, Winston and Foster 1976 b). This species makes its most rapid growth on sites of high fertility, but is commonly associated with sites of low fertility; consequently, application of fertilizer (particularly nitrogen) can significantly enhance stand growth characteristics on sites lacking these nutrients (Morrison, Foster, and Swan 1981).

Spot fertilization -- the application of fertilizer at regularly spaced intervals -- is designed to enhance stand growth characteristics in densely stocked stands of young jack pine by increasing self-thinning and inducing the onset of dominance expression in the stand. In theory, these processes are encouraged by (1) causing trees growing on the fertilized spots to succumb to a toxic concentration of nutrients (known as fertilizer "burn") and (2) boosting the growth of trees directly surrounding the fertilzed spot, which in turn suppress the growth of neighbouring trees whose root systems cannot avail themselves of the added fertilizer. An analogous situation to this would be one that exists on the lawns of many pet owners. Spots are evident on the lawn where the grass has completely died out but directly surrounding this spot is grass of very luxuriant growth. This luxuriant growth quickly tapers off with radial distance outwards from the spot.

The sites chosen for the analysis of spot fertilization were located within Saskatchewan's Mixedwood forest section. Height and diameter data collected from these sites in 1982 were analyzed in an attempt to determine whether spot fertilization significantly enhanced jack pine growth on treated plots as compared to untreated (control) plots. Based upon results of this analysis, recommendations for further study of spot fertilization's potential use in jack pine stand management were made.

1.1 PROBLEM STATEMENT

Jack pine are prone to dense regeneration following fire, producing intense competition for nutrients, light, water and growing space within the stand (Figs. 1 and 2). When stocking is high the growth potential of the site is spread over many more trees than will reach merchantable size. Also the time required to reach merchantable size is long in

Figure 1: Dense Jack Pine Stand - Elaine Lake Site

Figure 2: Dense Jack Pine Stand - Fort a la Corne Site

comparison to managed stand. Commercial thinning of jack pine provides revenue to pay for the operation but the stand must be left under intense intraspecific competition for many years before the trees reach a size suitable for commercial use. Precommercial management can substantially reduce competition and the rotation period encouraging good stand development at an early age. This has been attempted with techniques such as manual and mechanical precommercial thinning but the compounded costs of the thinning are greater than the benefit of increased productivity. Consequently, silviculturists are seeking more efficient methods for managing densely stocked jack pine stands.

This study analyzes the effectiveness of spot fertilization in Saskatchewan's Mixedwood forest section as a means for improving stand growth characteristics in young, densely stocked juvenile jack pine stands and makes recommendations based upon results of this analysis concerning further study of this stand management technique.

1.2 STUDY IMPORTANCE

In Saskatchewan the forest industry is of great importance (being second only to the food and beverage industry in the manufacturing sector) and jack pine is one of the major commercial tree species. The annual allowable cut in this province is set to equal annual growth. Forest losses through the allocation of forest lands for other uses such as agriculture and recreation reduce the annual allowable cut. Alternatively, as the level of forest managment rises there will be a corresponding increase in the annual allowable cut.

Finding a practical method for early release of densely stocked jack pine stands will allow more efficient use of available forest resources and provide additional resources from otherwise unproductive stands. This study is an important first step in an attempt to develop a technique capable of efficiently releasing the potential of these stands. It provides the baseline data which has not been available beforehand upon which decisions concerning the future analysis and implementation of spot fertilization may be based.

1.3 RESEARCH OBJECTIVES

The primary purpose of this study is to (1) analyze the effectiveness of spot fertilization as a method for improving height and diameter growth in treated plots versus control plots in densely stocked, even-aged, juvenile jack pine stands, and (2) to recommend follow-up procedures for subsequent phases in determining the physical response of jack pine trees to spot fertilization. Specific sub-objectives are:

1. To determine whether a significant difference in height and diameter exists between treatment and control data in each of the fourteen fertilizer treat-

ments for (1) each site separately and (2) all sites when analyzed collectively.

2. To recommend follow-up procedures, using results and experience gained while conducting the present study, for further testing the ability of spot fertilization treatments to increase self-thinning and induce the establishment of dominance in a densely stocked, even-aged, juvenile jack pine stand.

1.4 HYPOTHESES

The major suppositions of this study were the following:

1. Spot fertilization treatments significantly improved tree height and diameter growth in treated plots compared to control plots.
2. Tree growth response to spot fertilization is dependent on site quality.
3. A significant difference exists in the effectiveness of the spot fertilization treatments to enhance height and diameter growth of trees within treated plots as compared to control plots.

1.5 DELIMITATIONS OF THE PROBLEM

1. All statistical analyses will be based upon height, diameter and height x diameter treatment-control unit differences (T-C unit differences).

2. Statistical analyses will be limited to determining the effects of site on spot fertilization and the effectiveness of the fertilizer treatments to produce a significant response.
3. There is no extrapolation of the data to estimate additional wood volume produced through spot fertilizing or to determine whether early stand dominance resulted from the application of spot fertilization.
4. Recommendations for follow-up procedures will be limited to preliminary design suggestions for further experimentation.
5. Conclusions of this study pertain specifically to Saskatchewan's Mixedwood forest section.

1.6 ASSUMPTIONS

1. Significantly positive T-C unit differences resulted due solely to the effect the fertilizer treatments had on jack pine development.
2. Any significant growth differences found between treatment and control for a particular fertilizer treatment were assumed to be the increment gained over the seven year period between 1975 and 1982.
3. Each study site was assumed to be uniform with respect to physical conditions such as soil type, climate and topography.

1.7 STUDY OUTLINE

Chapter 2, the Review of Related Literature, discusses supporting studies, alternatives to spot fertilization, jack pine fertilization, the forest management implications of spot fertilization, and some economic considerations of forest fertilization. Chapter 3 (Methods) describes the field plot layout, fertilizer treatments, types of data collected and the handling of data to meet each specific sub-objective. Chapter 4 includes an analysis of the numerical data collected in this study, discussion of results and follow-up testing recommendations. Chapter 5 provides summary, conclusions, and general recommendations.

Chapter II

REVIEW OF RELATED LITERATURE

2.1 SUPPORTING STUDIES

Winston (1977) reported on a height and diameter growth response experiment involving fertilization of a 10 year old densely stocked (88% stocked) jack pine stand in northwestern Ontario. A section 0.48 ha in area was left unthinned and divided into 12 plots (0.04 ha each) for treatment. Four fertilizer levels were used; 0 (control), 56 kg N/ha, 168 kg N/ha, and 168 kg N/ha + 112 kg P/ha. This was applied as urea (46% N) and triple superphosphate (45% P2O5). Each was replicated three times. On unthinned plots the percentage of trees in the 2.5 centimeter (cm) class (0-3.8 cm) decreased with increased fertilizer treatment and total mortality (including missing and presumed dead) tended to increase with increasing fertilizer levels. Comparing the thinned and unthinned stands, Winston found that mortality was generally higher in unthinned stands than in thinned stands. Total height and periodic height increment were also found to be greater in unthinned stands and mean diameter tended to increase slightly with increasing fertilizer levels. Winston (1977) commented that the positive effects of fertilization were apparent and should become more pronounced in the later years of stand development due to the increased number of trees in larger diameter classes.

Lee (1974) and De Bell et al. (1975) discussed the possibility that fertilizer applications could be used to induce self-thinning in dense stands by stimulating dominance. Lee (1974), working with 25 year old Douglas fir in the Pacific Northwest, found that annual mortality in unthinned stands was significantly affected by rate of fertilization in the fourth year after treatment. He commented that this was perhaps due to accelerated growth of dominant trees resulting in stand breakup. Furthermore, he concluded that mortality rises with site index as well as nitrogen addition and the nitrogen was effective over a seven year period. Several other workers (Gessel and Shareef 1957, Gessel et al. 1965, 1969) working in dense stands of Douglas fir found that increased mortality occurs in unthinned stands following fertilization. De Bell et al. (1975) working with western hemlock could not conclude whether increased mortality was due to suppression or toxicity of large doses of fertilizer but felt that thinning by fertilizer does merit some additional research for use in inaccessible locations.

The increased mortality found in unthinned, fertilized plots in the above studies could have been the result of some trees (which may previously have had a slight edge on its neighbours with respect to factors such as height, diameter, crown development, photosynthetic area or efficiency, or genetic superiority) utilizing the nutrient addition more efficiently. The increased competition can result in mortality of some of the surrounding trees. Alternatively, the fertilizer may have only served to increase the magnitude of difference between successful trees and their neighbours. For example, if two trees, one taller than the other benefit from the nutrient addition by growing 10% taller than would have occurred naturally in the same period of time the taller tree will have a greater absolute increase. This extra increase in their size difference may be sufficient to cause the inferior trees to succumb to the increased competition. Toxicity of large doses of fertilizers also appears to play a role in thinning with fertilizers. It is believed that spot fertilization has a greater likelihood of increasing self-thinning and stimulating dominance than the above studies which employed broadcast fertilization as spot fertilization has been specifically designed to maximize these effects.

2.2 ALTERNATIVES TO SPOT FERTILIZATION

The trial of spot fertilization in this study is the first study of this type in heavily stocked, juvenile jack pine. The techniques most commonly used to release such stands from competition are selective and mechanical thinning. Chemicals are occasionally used in attempts to thin these stands.

Thinnings can be either precommercial or commercial. Precommercial thinning is carried out on juvenile trees which are not of sufficient size to be sold commercially. To be of practical value the increased revenue from final merchantable yield should cover the compounded cost of precommercial thinning (Bella and De Franceschi 1974 a). Commercial thinning provides revenue which pays for or offsets operation costs. The physical response from this type of thinning is commonly much less than that produced in precommercial thinning as the trees are older and nearer maturity having less time and potential for a response.

Bella and De Franceschi (1974 a) in their analysis of jack pine thinning experiments in Manitoba and Saskatchewan claim that precommercial selection thinning may double board foot volume production by final harvest but that this increase is not sufficient to cover the compounded cost of thinning. In short, they recommend low commercial thinning (i.e., thinning which favors dominants and codominants) of thrifty, middle-aged stands on good yielding sites. In another report Bella and Defranceschi (1974 b) concluded from their study of commercial jack pine thinning that a combination of low and crown thinning would result in improved stand growth and yield and would lower logging costs at final harvest as a result of greater tree size. The revenue from the thinning can cover the cost of the operation so that any increase in merechantable yield at final harvest is a clear gain.

Mattice and Riley (1975) working on a commercial strip thinning of 45 year old densely stocked jack pine found the operation profitable but concluded that a precommercial thinning at a much earlier age would have made harvesting during commercial thinning much easier with less waste and greater profit. Bella (1974) working on precommercial strip thinning of young jack pine concluded that strip thinning should be carried out in conjunction with selective thinning along the strip borders. In this way only about one-quarter of the area would have to be selectively thinned using brush saws. Strip thinning without selective thinning only allows trees growing on the edge of the strip an opportunity for release on the thinned side. The residual strips remain at their original density.

Bella and De Franceschi (1974 a) found that good tree (especially crown) development at a very young age that occurs under less dense conditions is an important prerequisite to fast tree growth and vigor of jack pine. Thus thinning at ages as low as 5 years may be desirable to maintain maximum diameter increment in young trees; however, manual selection thinning is too costly to justify the final compounded cost. They feel the solution to low-cost precommercial thinning may lie in mechanization through the use of heavy equipment such as the drum chopper or light portable machines such as a brush saw. A combination of these two methods such as the one described by Bella (1974) may also be feasible.

Heilman (1975) reported that a combination of thinning and fertilizing is desirable in dense stands because fertilizers alone cannot increase mortality in unthinned stands to optimum stocking levels. In his study volume growth response to fertilization was found to be similar or greater on chemicallly thinned plots than on saw-thinned plots. Chemicals such as cacodylic acid have been found to be toxic to jack pine (Brown 1970).

Thinning chemically has the advantage of increased versatility and sometimes reduced costs. Bower (1965) working with 15 year old loblolly pine in Arkansas commented that chemical thinning methods could be used as a substitute to the traditional, relatively expensive precommercial thinning techniques. However, chemical thinning methods are commonly environmentally and politically unacceptable alternatives.

2.3 JACK PINE FERTILIZATION AND SILVICAL CHARACTERISTICS

Fertilization with urea provides readily available nitrogen which often increases photosynthetic effectiveness (Bengston 1979). This stimulation commonly persists for 5 to 10 years, and sometimes longer (Atkinson 1974). In suppressed jack pine stands, it is hoped that this stimulation through spot fertilization may be sufficient to trigger early succession towards a dominant stand structure.

Spot fertilization can be carried out on sites where a nutrient deficiency is known to exist and where growth is not severely limited by environmental factors other than tree density. Nitrogen is commonly a limiting factor to growth on jack pine sites. Extra growth has also been elicited in some experiments through phosphorus and potassium additions in conjunction with nitrogen but generally responses are not significantly greater than with nitrogen alone (Morrison, Foster, and Swan 1981 and Morrison 1981). Morrison et al. (1976) and Morrison, Winston and Foster (1976) found that when employing broadcast fertilization (the even distribution of fertilizer throughout the stand) maximum response of jack pine to urea occurred in excess of 200 kg N/ha.

In an unthinned stand, growth increases due to broadcast fertilization result in increased growth of small and suppressed trees, which may eventually die before harvest, as well as the larger trees (Roberge, Weetman, and Knowles 1970). Spot fertilization should, theoretically, concentrate growth on trees which will have a greater chance of reaching merchantable size. If spot fertilization performs as theorized, maximum response to fertilizer input may be achieved.

Most fertilization trials in jack pine have been in the semimature age classes; however, examination of data from several sources suggests no obvious relationshp between stand age and responsiveness (Morrison 1981). Very young stands may be the best candidates for spot fertilization as they are susceptible to fertilizer "burn".

In a young, even-aged stand a wide range of growth rates occur before competition begins because of differences in seed size, time of germination, and individual genotype. Such stands consist of many small plants and a few large plants leading to a dominance hierarchy in competing populations. When jack pine reproduce densely, eventually, as their size increases individual plants begin to interfere with each other's growth by competing for the same essential resources (Hutchings and Budd 1981). 'When the immediate supply of a single factor necessary (for growth) falls below the combined demands of the individual plants competition begins' (Donald 1963). Under competition a plant may alter its form or size to best adapt itself to severe conditions. These are known as plastic responses. If the capacity of a plant to withstand competition through these responses is exceeded, it will die (Hutchings and Budd 1981). The smallest plants being under the greatest competitive stress have the heaviest mortality risks and highest mortality. A dominant stand structure develops as a natural outcome of these processes.

Ford (1974) claims that the regular distribution of large plants is a strong indication that competition has taken place and the stand is developing a distinct upper canopy of large plants; thereby, progressing towards a dominant stand structure. Other researchers claim that regular populations are rare in nature (Yeaton 1978 and Pielou 1961). They find the occurrence of competition is seldom detectable from a consideration of population patterning over a large area.

2.4 FOREST MANAGEMENT IMPLICATIONS OF SPOT FERTILIZATION

In Saskatchewan, the forest industry, is of great importance being second only to the food and beverage industry in terms of salaries and wages earned and value of shipments in the manufacturing sector. In 1979-1980 the value of shipments of forest products produced in Saskatchewan was $355 million (Samoil and Turtle 1982).

The annual allowable cut in Saskatchewan is set to equal annual growth so that the current level of growing stock can be maintained. Significant forest losses due to fire, insects and diseases, and allocation of forest lands for other uses such as agriculture and recreation all serve to reduce the annual allowable cut. On the other hand, as the level of intensive forest management (such as thinning and fertilization) increases there will be a corresponding rise in the annual allowable cut (Samoil and Turtle 1982).

In Saskatchewan, jack pine is one of the major commercial tree species. A survey of 21 million acres of provincial forest, ranked jack pine first by volume (with 33.5% of the coniferous merchantable cubic foot volume). Stands with jack pine as a major species occupied 12.8% of the productive forested land (Kabzems and Kirby 1956).

In 1956, approximately 30% of forested area covered by jack pine stands were classified as "d" density (crown closure 71% or more). From a review of literature on jack pine stand management it was evident that these dense stands are often naturally good pulpwood producers. Management of these stands does not normally increase pulpwood production but a stand of optimally spaced and sized trees can be produced in a shorter rotation period. Such stands can be more efficiently harvested than natural stands and used for either pulpwood or sawtimber.

From 1966-1975 61,000 ha of "d" density jack pine in the age-class 0-10 years were added to the forest inventory in Saskatchewan's commercial forest area. From 1976-1982 142,000 ha of similar stands were produced (Benson 1983). (The increased production of such stands in this period was due to several years of widespread fires.) Adding these two figures (the former being a low production rate and the latter a high rate) and dividing by the combined number of years they span we arrive at an estimate for annual production of approximately 13,000 ha per year. Consequently, there would be an average of 130,000 ha of "d" density jack pine in the age-class 0-10 at any one time. Stands in this category would be assessed based on site characteristics as to their suitability for spot fertilization.

In Saskatchewan, poor sites are characterized as the jack pine - Cladonia type with ground vegetation dominated by

Cladonia rangiferina, other lichens, and bearberry (*Arctostaphylos uva-ursi*) (Kabzems, Kosowan and Harris 1976). On these sites lack of moisture and nutrients are the main obstacles to growth.

The average sites are characterized as jack pine - Vaccinium type with a more varied ground vegetation containing species such as *Vaccinium vitis idaea*, *Arctostaphylos uva-ursi*, *Vaccinium myrtilloides*, *Cladonia rangiferina*, and *Polytrichum juniperum* and other mosses and some sedge grasses (Kabzems, Kosowan and Harris 1976). These, the most common jack pine type in Saskatchewan, would be the most common candidates for spot fertilization application.

Good sites are characterized as the jack pine-feather moss/club moss type (Kabzems, Kosowan and Harris 1976). The understory vegetation is composed primarily of *Pleurozium shreberi*. This site supports the best jack pine growth within Saskatchewan.

Tree growth response to fertilizers has been found to be better in less thrifty jack pine stands, whether they be stands of low site quality or low periodic increment (Foster and Morrison 1980). Debell et al. (1975) working with western hemlock and Douglas fir also found that there was a tendency for response to nitrogen fertilizer to decrease as site index increased. Such a trend is to be expected when nitrogen is a limiting factor. The inherent productivity of jack pine, commonly associated with sites of low fertility, make their most rapid growth on sites of high fertility (Morrison, Winston and Foster 1976). On good sites nutrients may be supplied in adequate amounts; nutrients added in excess of plant requirements do not contribute further to plant growth (Waring and Youngberg 1972). Poor sites with an inadequate moisture regime should not be considered for fertilizer applications as the added nutrients will be ineffective if moisture is an extreme limiting factor. As well, if a very poor nutrient supply exists spot fertilization on that site may not be suitable as it does not supply a massive substitute of nutrients but rather attempts to stimulate natural processes within the stand. This leads to the conclusion that the greatest benefit from spot fertilization may be derived when it is applied to sites which (1) have neither a totally adequate nutrient supply or a nutrient supply which is severely deficient and/or (2) are not severely limited in their growth by environmental factors (such as a poor moisture regime) other than tree density. Generally speaking, average growth sites, which are the most common, would be well-suited for spot fertilization trials.

Fertilizers, when used on a commercial scale, have been found to occasionally contaminate local watersheds by causing excessively high levels of nitrates and phosphates in lakes and streams. Erosion of fertilized soil by wind and water poses the greatest risk of this occurring. Where soil is kept in place, such as in a forest stand, there are only limited possibilities of pollution by fertilizers (Alberta Institute of Agrologists).

Environmental contamination from fertilization has occurred in agricultural regions susceptible to wind and water erosion. In spot fertilization application, only densely stocked forest stands having a very low susceptibility to soil erosion will be involved. Also sites chosen for this application will typically be on coarse soils (upon which jack pine are commonly found) with low concentrations of nutrients and little surface runoff occurring.

Nitrate nitrogen on agricultural land is released from the soil largely due to cultivation and practices such as summerfallowing. In spot fertilization applications no such soil disturbance will occur.

Phosphorus, acts quite differently from nitrogen in the soil. [Nearly all soils in western Canada are deficient in available phosphate for crop growth requiring its addition for maximum economic returns (Alberta Institute of Agrologists).] Most phosphorus added to the soil is absorbed or precipitated as phosphates of calcium, iron or aluminum and cannot be readily removed by water. Essentially the only way phosphate may be removed is through erosion of topsoil. Erosion and phosphorus loss from forest soils is very low in comparison to agricultural soils, so applications last long into the rotation (Bengston 1979).

Although spot fertilization should present little or no adverse environmental impact, monitoring of nitrate and phosphorus levels in lakes and streams, in areas where commercial spot fertilization is carried out, should be undertaken before application to obtain background readings. Following this, periodic monitoring of water quality is recommended.

2.5 ECONOMIC CONSIDERATIONS

With respect to jack pine, forest managers must continue research into fertilization to determine what rate of return on investment can be expected. In the analysis of spot fertilization financial viability was not analyzed. Only it's effect on tree height and diameter was tested. In the long term, before spot fertilization can be considered for commercial application, a benefit-cost analysis must be undertaken via the implementation and analysis of results from larger scale fertilization trials.

The question of whether to invest in fertilization or not depends on the cost of treatment, present and forecasted wood demand, the amount of additional wood produced, and the value of that wood at harvest (Fight and Dutrow 1981). Further economic considerations are the possible reduction of logging costs, and the foregone benefits of and cost savings over other options (Morrison 1981). In the case of densely stocked, juvenile, jack pine, these considerations are important, particularly the value placed on extra wood and possible cost reductions. This is due to the fact that, in their natural state, these stands may be good pulpwood producers, but the time required to reach merchantable size is relatively long and logging costs quite high. Spot fertilization could reduce the rotation period and create a uniform stand of larger trees that would be cheaper to harvest.

Le Doux and Brodie (1982) claim that much of the gain from intensive silviculture is derived from the decrease in total logging costs, supplemented by an increase in quality and total growth. Doyle and Calvert (1961) studying jack pine in Northern Ontario claimed that tree size is one of the most important factors affecting tree extraction and conversion. They also mention that although lumber values for jack pine are highest for the smaller diameter logs (because, on the average, smaller logs produce higher quality lumber than large ones) the higher value of the small lumber is more than offset by the much lower cost of logs delivered to the mill for larger logs. Hauling costs decrease with increasing log size and this rate of decrease is most rapid in the smallest size logs. In addition, the time required to cut and prepare the trees for hauling decreases with increasing tree size. Similarly log diameter has a marked effect on the sawing time and, therefore, mill costs. From their study Doyle and Calvert concluded that, in 1961, jack pine trees less than 19 cm diameter at breast height (dbh) failed to pay their way through the operation since production costs were greater than the value of the lumber recovered. One of the greatest benefits of managing a forest stand (as in spot fertilization) is the production of a stand of optimally spaced and sized trees in a shorter period of time than would have occurred naturally. As shown by Doyle and Calvert (1961) this can significantly reduce production costs.

If the same volume increase could be produced using less fertilizer, or more growth for the same amount, fertilization would increase in economic viability (Morrison 1981). Consequently, identifying, responsive stand and site types, the effect of weather conditions at time of application, overcoming urea volatilization problems, (i.e., the problem of applied nitrogen escaping into the atmosphere as gaseous nitrogen) and cost-efficient application methods are areas where improvement could make forest fertilization more economically attractive.

2.6 CONCLUSIONS

Some of the basic concepts underlying the theory of spot fertilization have been described by other workers; however, this specific type of fertilization has not been undertaken before. Increased mortality of jack pine and other species has been observed in unthinned plots fertilized with urea. Mortality has also been found to increase with increasing fertilizer levels in unthinned stands. This evidence points to the conclusion that fertilizer can perform as both a thinning agent and stimulant to tree growth. Further research into using fertilizer applications as a thinning agent has been recommended. In addition, the concept that fertilizer applications could be used to induce self-thinning in dense stands by stimulating dominance has been speculated upon.

Manual and mechanical, precommercial and commercial thinnings are the techniques most commonly used to release densely stocked jack pine stands. While commercial thinning has been shown to pay for itself and provide additional benefits at final harvest an acceptable precommercial thinning method has yet to be proven. The primary problem with precommercial thinning is that it provides no immediate revenue and the additional production it generates must be sufficient to cover the compounded costs of the thinning. One worker conluded that precommercial thinning at an early age would make harvesting of jack pine during commercial thinning easier with less waste and greater profit. Good tree development at a very young age is important to jack pine and thinning at ages as low as 5 years may be desirable; however, a low-cost precommercial thinning method is needed. Chemical methods may be effective but are often environmentally and politically unacceptable. Upon further analysis spot fertilization may prove to be an attractive precommercial thinning and fertilizing technique for commercial forestry operations.

On the average about 130,000 ha of densely stocked young jack pine should be available for assessment as to their suitablity for spot fertilization treatment at any one time in Saskatchewan. From the review of literature the best response to fertilizer application was generally found in stands of low site quality or low periodic increment. However, very poor growth sites are probably not suitable for spot fertilization as they are often limited by environmental factors other than nutrient deficiency and tree density. In addition, spot fertilization does not supply the massive substitutes of nutrients they often require for good growth. Fertilizer applications on good sites are often less effective than on poorer sites as nutirents supplied in excess of plant requirements do not contribute to growth. Average growth sites, the most common site type in Saskatchewan, would be well-suited for spot fertilization trials; having good potential for improved development.

Largescale fertilizer applications have contaminated local watersheds in the past; however, these problems occur due to the agricultural practices employed. Largescale spot fertilization in forests is not expected to incur any adverse environmental impacts but monitoring for impacts in sensitive areas is recommended.

The question of whether to invest in jack pine fertilization depends on many factors particularly the value placed on extra wood and reduction of logging costs. This is due to the fact that while dense stands are often good pulpwood producers they reach merchantable size slowly and logging costs are high. Management of these stands reduces total logging costs, increasing total growth through the production of optimally spaced and sized trees in a reduced period of time.

Chapter III

METHODS

3.1 EXPERIMENTAL DESIGN

Three sites in Saskatchewan were chosen for study. These sites were selected for (1) the prescence of relatively pure, even-aged, densely stocked, juvenile jack pine, (2) uniformity of habitat type within each site, (3) ease of access, and (4) uniqueness of the ecosystem (as compared with the other sites). In the spring of 1975, various fertilizer applications were applied to treatment plots at each site. Seven years later in July, 1982 the heights and diameters of selected trees were measured for comparison with similar measurements taken from control plots.

The three sites selected for study were the following (Fig. 3):

1. Site 1. Fort a la Corne site, S 5, Tp 50, R 19, W 2 meridian, is characterized by rolling topography. This site is a rapidly drained upland location with coarse sandy soil most closely associated with the jack pine-Cladonia site type (poor growth site). The area burned in 1967.
2. Site 2. Elaine Lake Road Site, S 30, Tp 62, R 2, W 3 meridian, 31 km west on Elaine Lake Road. This is a

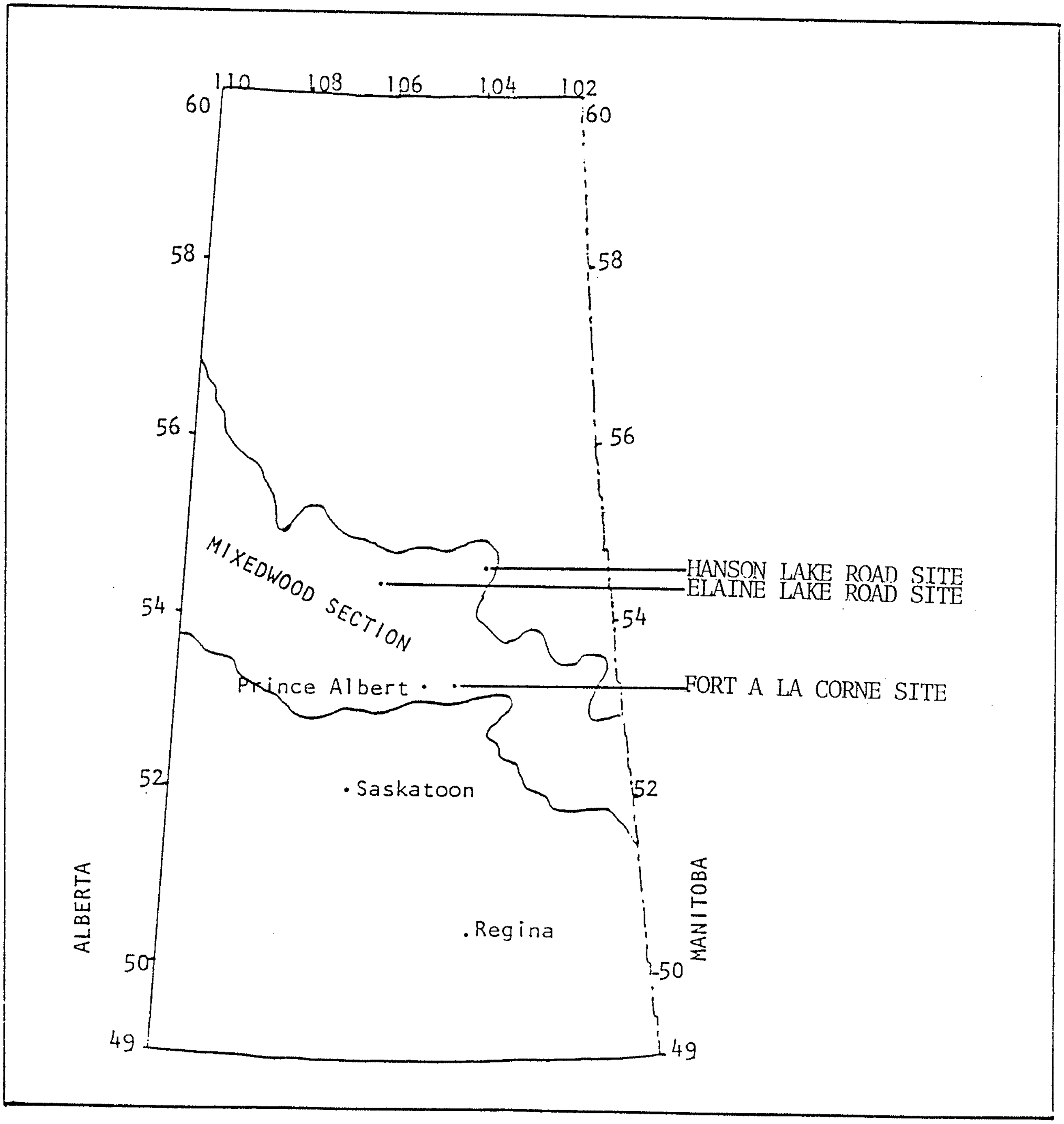

Figure 3: Study Site Locations

rolling area located just outside Prince Albert National Park. The soil is sandy with a substantial clay and silt fraction below 35 cm and is most closely represented by the jack pine-feather moss/club moss site type (good site). This site was burned in 1964.

3. Site 3. Hanson Lake Road Site, S 16, Tp 64, R 13, W 2 meridian, near Mile 115 marker on Hanson Lake Road. This is a bottomland site with a humic podzol soil and thick lichen, moss, and vaccinium understory most closely represented by the jack pine-Vaccinium site type (average site). The area burnt in 1964.

The sites used in this study each contained 70 treatment plots and 70 control plots. The trial areas were rectangular in shape, consisting of 5 rows; each row containing 14 treatment plots and 14 control plots. The rows were 5 m apart. Treatment plots were 5 m apart along the rows with control plots located between the treatment plots. Each plot was circular and contained 4 square m in area (Fig. 4).

Fertilizer was applied on May 14, 1975 at Fort a la Corne; May 2, 1975 at the Elaine Lake Road site; and on April 30, 1975 at the Hanson Lake Road site.

A circular area one square m in size recieved the fertilizer treatment (Fig. 4). Fourteen different fertilizer treatments were used in this study (Tables 1 and 2), being replicated 5 times on each site. The fertilizer treatments

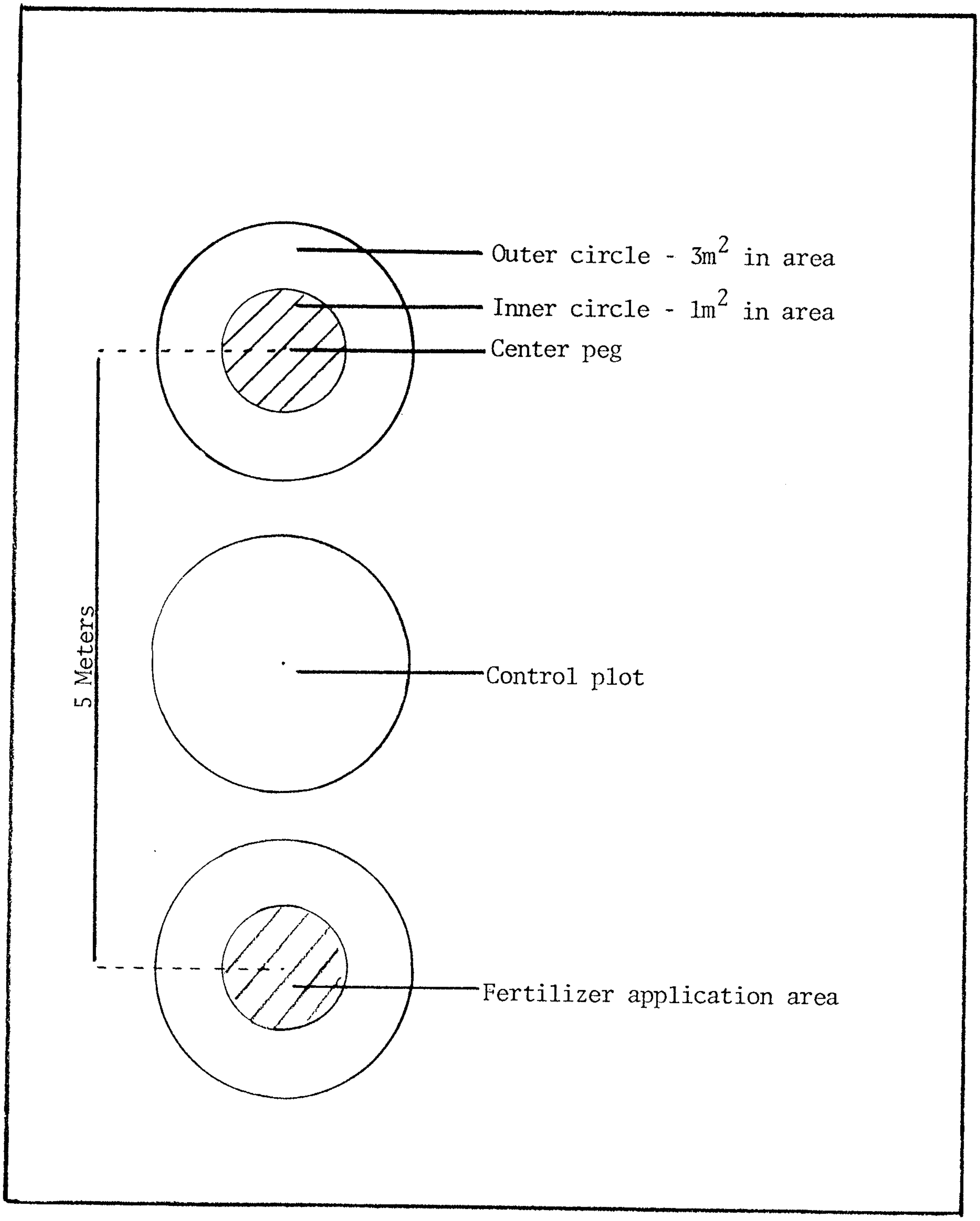

Figure 4: Diagrammatic Representation of Treatment and Control Plots.

TABLE 1

Fertilizer Treatments Applied To Each Location

P2O5 = Triple Superphosphate Fertilizer
Reps. = Replications

Treatment	Fertilizer (grams)				Total (grams)		
	Urea	P2O5	10-30-10	Reps.	Urea	P2O5	10-30-10
1	100			5	500		
2	200			5	1000		
3	400			5	2000		
4	800			5	4000		
5	50	50		5	250	250	
6	100	100		5	500	500	
7	200	200		5	1000	1000	
8	400	400		5	2000	2000	
9	45		50	5	225		250
10	90		100	5	450		500
11	180		200	5	900		1000
12	360		400	5	1800		2000

13 Tree Feed 19-8-16
(25 tablets)
1.71 x 25 tablets = 42.75 g N.
(@ 9 g/tablet)

14 Agriform 22-8-2
(25 tablets)
1.98 x 25 tablets = 49.5 g N.
(@ 9 g/tablet)

TABLE 2

Grams Of Nutrient Added Per Treatment Plot

* N = nitrogen, P = phosphorus and K = potassium

Treatment	g N/plot	g P/plot	g K/plot
1	46.0	0.0	0.0
2	92.0	0.0	0.0
3	184.0	0.0	0.0
4	368.0	0.0	0.0
5	23.0	22.5	0.0
6	46.0	45.0	0.0
7	92.0	90.0	0.0
8	184.0	180.0	0.0
9	20.7 + 5.0 = 25.7	15.0	5.0
10	41.4 + 10.0 = 51.4	30.0	10.0
11	82.8 + 20.0 = 102.8	60.0	20.0
12	165.6 + 40.0 = 205.6	120.0	40.0
13	42.75	18.0	36.0
14	49.5	18.0	4.5

were pre-weighed and bagged in a laboratory with the treatment number marked on the outside of each bag. At each site the bags were placed in their respective plots. The fertilizer was evenly applied over the one square m area using two transverse wooden slats as a guide, each slat being equal to the diameter of a one square meter circle (Fig. 5).

Figure 5: Fertilizer Application Guide

Each of the fourteen fertilizer treatments occur once in every row being applied in a predetermined pattern. The patterning was used to ensure that fertilizer treatment replications were well distributed and did not lie in close proximity to one another. This patterning produced a non-random experimental design. The following chapter discusses the problem of using statistics based on random distributions with an incompletely random data base.

Any micro site effects which may have existed were minimized by the design of the experiment. The 3 study areas were small and selected for their relative uniformity. Addtionally, each treatment was replicated 5 times per site and means used in all calculations. Problems due to any translocation of the fertilizer away from its original application area were negligible due to the coarse nature of the soil on all 3 sites. Their coarse texture allowed fertilizer to percolate readily into the soil; thereby, reducing surface runoff and lateral movement of the nutrients through the soil. Furthermore, the area measured for spot fertilizing effects was 4 square m while the fertilizer was placed on a 1 square m area.

3.2 CRITERIA FOR THE ADMISSIBILITY OF THE DATA

During July, 1982 the sites were revisited. At this time dbh and height of the 5 tallest trees in each plot were measured. Diameter measurements were taken using a diameter wedge. Heights were measured to the nearest 5 cm using a telescoping height measuring pole (shown in Fig. 6) demarcated at 1 cm intervals (except when trees were less than 142 cm in height; in such cases the trees were measured using a pole marked off at 10 cm intervals). Measurements were taken by the same individual for greater consistency in data collection.

Figure 6: Measuring Jack Pine With A Telescopic Height Pole

All plots did not have 5 measurable trees; consequently, treatment-control pairs (T-C pairs) which had a difference greater than 2 in the number of trees per plot were rejected. For example, if a T-C pair were used which had one measurement from the treatment and five measurements from the control then, statistically, there would be a much greater chance that the averages from the treatment and control would not appear to be from the same population of trees than if a relatively equal number of measurements were used in calculating the means. Using this method of rejection we discard statistical "noise" or bias in sampling. This was necessary to maintain relatively equal weighting between treatments and their adjacent control for greater statistical accuracy.

Results from statistical analyses of the height and diameter data collected in this study were treated as significant when a significance level of 5% or less was found.

3.3 HANDLING OF THE DATA

The height and diameter data collected in this study are in the class of observational differences. The experimental method and analytical survey method were used to analyze the treatment and control data. Sub-objective 2 was carried out with the aid of literary data related to the designing of experiments in the natural sciences. Results of the statistical analyses and descriptive data (including experience gained while conducting this study) were also used to carry out sub-objective 2.

The first step in analyzing the data was to calculate the mean heights and diameters of the measured trees in each treatment and control plot (Figs. 11, 12 and 13). Ultimately, this difference in means is of prime importance in determining the effectiveness of the various fertilizer treatments as it reveals the actual physical differences achieved over the control with the various fertilizer treatments; however, the significance of these differences must be proven statistically through an analysis of variance before any conclusions can be drawn as to their importance. Using the mean height and diameter figures T-C unit differences were calculated (Appendix C) and used as the data points for the statistical analysis.

Initially, to analyze the height and diameter data collected in this study a sign test on the positive and negative T-C unit differences was done to test the null hypothesis (Ho) that the gain in growth from fertilization was 0 against the alternative hypotheses that it was positive. The Ho for the sign test is that half the T-C unit differences will be positive and half negative. This means that in an untreated or "natural" sample of jack pine we would expect to find a rather even variance in the size of the trees around some average. Consequently, if we find a statistically uneven number of positive versus negative values we may suspect the fertilizers had some influence on jack pine growth.

To test whether the calculated T-C unit differences were large enough to be considered statistically significant (i.e., whether the fertilized trees had significantly larger measurements) we employed firstly a two way analysis of variance (ANOVA) and secondly a one way ANOVA. (The t-test was not used as it is not as easily extended to handle a large number of treatments as an ANOVA.) The ANOVA attempts to analyze the variation of a response and to assign portions of this variation to each of a set of independent variables (i.e., the fertilizer treatments). The reasoning is that response variables (such as height and diameter) vary only because of variation in a set of unknown independent variables. Since the experimenter will rarely, if ever, include all the variables affecting the responses in an experiment (for example, genetic variability of the seed stock and microclimatic differences) random variation in the response is observed even though all independent variables (i.e., the fertilizer treatments) considered are held constant. The objective of the ANOVA is to locate independent variables of importance in a study and to determine how they interact and affect the response (Mendenhall 1979).

A two way ANOVA was done for the entire data set with site being the qualitative factor and treatments being the quantitative factor. The two way ANOVA tested the Ho that all groups come from the same population. A one way ANOVA was done for each site with the T-C unit differences being the single factor. The one way ANOVA was done to test the T-C unit differences over the entire experiment and to test if significant differences existed between treatments.

In conducting the ANOVA, confidence intervals were charted and displayed graphically. These figures give a convenient display of how each fertilizer treatment differed from the control. Following this, simple contrasts were made between treatments, for all sites collectively, up to the point at which no significant difference existed. It was important to conduct this test following the ANOVA so that we could determine how selected treatments responded in relation to the remaining fertilizer treatments. The ANOVA told us which treatments produced a significant growth difference over their respective controls while the simple contrast analyzed whether these treatments produced a significantly different response from other treatments.

Chapter IV

STATISTICAL ANALYSIS AND DISCUSSION OF RESULTS

4.1 DATA RANDOMIZATION

In this study fertilizer treatments were not applied randomly; however, to analyze a dataset using parametric statistical methods we must assume complete randomization in the experimental design. Complete randomization was not adhered to in this study but because discrete units (i.e. T-C unit differences) were used in all statistical calculations the problem of randomization is limited to where or on which side each control plot was located with respect to its respective treatment plot. For example, if the controls were located west of the treatment plots and there was a natural east to west gradient of increasing fertility then the control measurements could be consistently larger than expected. Consequently, for the data collected in this study to be completely random, the only randomization needed was to randomly choose which of the T-C pair would be control and which treatment. Although this was not done, it is not that crucial as the controls were located on the alternate side of their respective treatment plot as rows were changed.

4.2 SIGN TEST ANALYSIS

Results of the sign test analysis shown in table 3, indicate that on the average fertilizer treatments had a growth enhancing effect on trees in the treated plots at sites 1, 2, and 3, particularly sites 1 and 3. Results from site 2 indicate that there is less than a 95% chance that the diameter measurements recorded at site 2 were significantly greater than the control measurements that were recorded. This implies that the diameter data for site 2 was not as strongly significant as the remainder of the data. The height data for site 2 was significant so the fact that diameter measurements for site 2 were not significant at the 95% level of confidence is not of great concern. For details of the sign test analysis refer to Appendix D.

TABLE 3

Sign Test Results For Height And Diameter

* Rej = Reject, or Acc = Accept)

	Diameter				Height			
Site	Mean	Stan. Dev.	Stan. Var.	Rej, Acc Ho	Mean	Stan. Dev.	Stan. Var.	Rej, Acc Ho
1	27.0	3.7	2.2	Rej	27.0	3.7	3.0	Rej
2	33.0	4.1	0.98	Acc	33.0	4.1	1.7	Rej
3	22.5	3.7	1.8	Rej	27.5	3.7	2.0	Rej

4.3 TWO WAY ANOVA

The two way ANOVA was carried out for height, diameter and height x diameter (height x diameter is often used in forestry to accentuate the differences among data.) All calculations revealed the following.

1. The interaction of factors (i.e., the measurement of fertilizer treatment reaction as affected by site) was highly insignificant, or rephrased, any fertilizer differences observed were statistically similar at each site. In other words, a fertilizer treatment which responded well (poorly) at one site also responded well (poorly) at the other sites.
2. The A (or site) main effects were insignificant, indicating that site had no significant effect on determining the magnitude of the T-C unit differences that were calculated for sites 1, 2 and 3.
3. The B (or fertilizer treatment) main effects were highly significant, implying that we can be confident there is some difference between the effectiveness of the fertilizer treatments.

Basically, this test told us that, although there is visually apparent differing productive capacities between the 3 sites in this study, the magnitude of response to each type of treatment was statistically similar on all sites. This allowed us to treat the data as coming from one site and to analyze it using a single factor or one way ANOVA. Additionally, the two way ANOVA revealed that the fertilizer treatments did not affect the growth of measured jack pine trees similarly. This allowed a determination of which treatments were most successful.

For details of the two way ANOVA calculations refer to Appendix E.

4.4 ONE WAY ANOVA (ALL SITES COLLECTIVELY)

Because site did not significantly affect the response of trees to fertilizer the data was pooled, treating it as coming from one site, and analyzed using a simpler test; the one way ANOVA. This test treated all data as though from one site having 15 replications; thereby, increasing statistical accuracy. The completion of this analysis resulted in the production of confidence interval graphs (Figs. 7, 8, and 9). A confidence interval displayed in this way shows the range of values within which we can be 95% confident that the true difference value between treatment and control lies for each particular fertilizer treatment. From these graphs we see that only treatment 2 and 12 had positive lower limits to their confidence intervals. All other treatments had some portion of their confidence intervals in the negative region of the graph. What this indicates is that, statistically, we are not sure (or confident at the 95% confidence level) that treatments other than 2 and 12 significantly improved height and diameter growth of trees in the

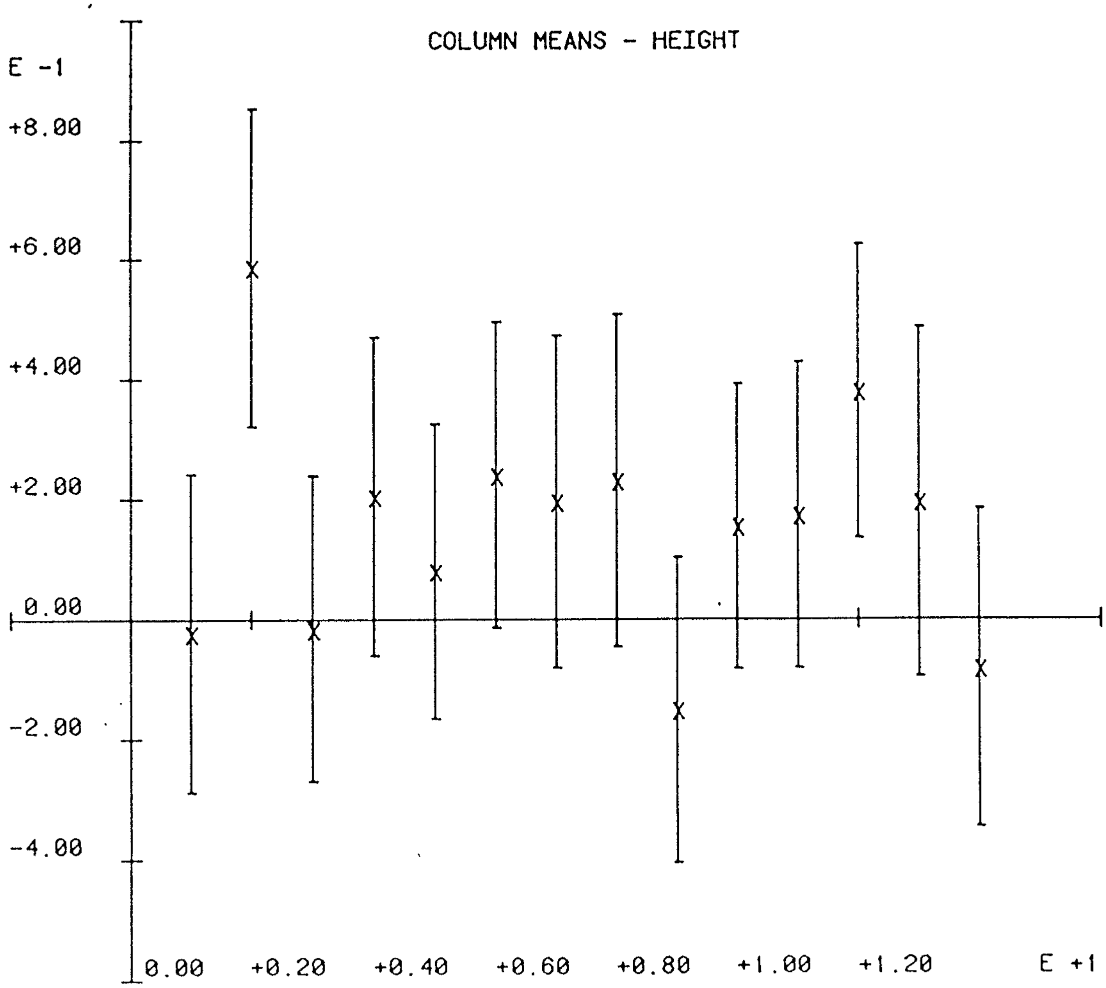

Figure 7: Confidence Intervals for Height

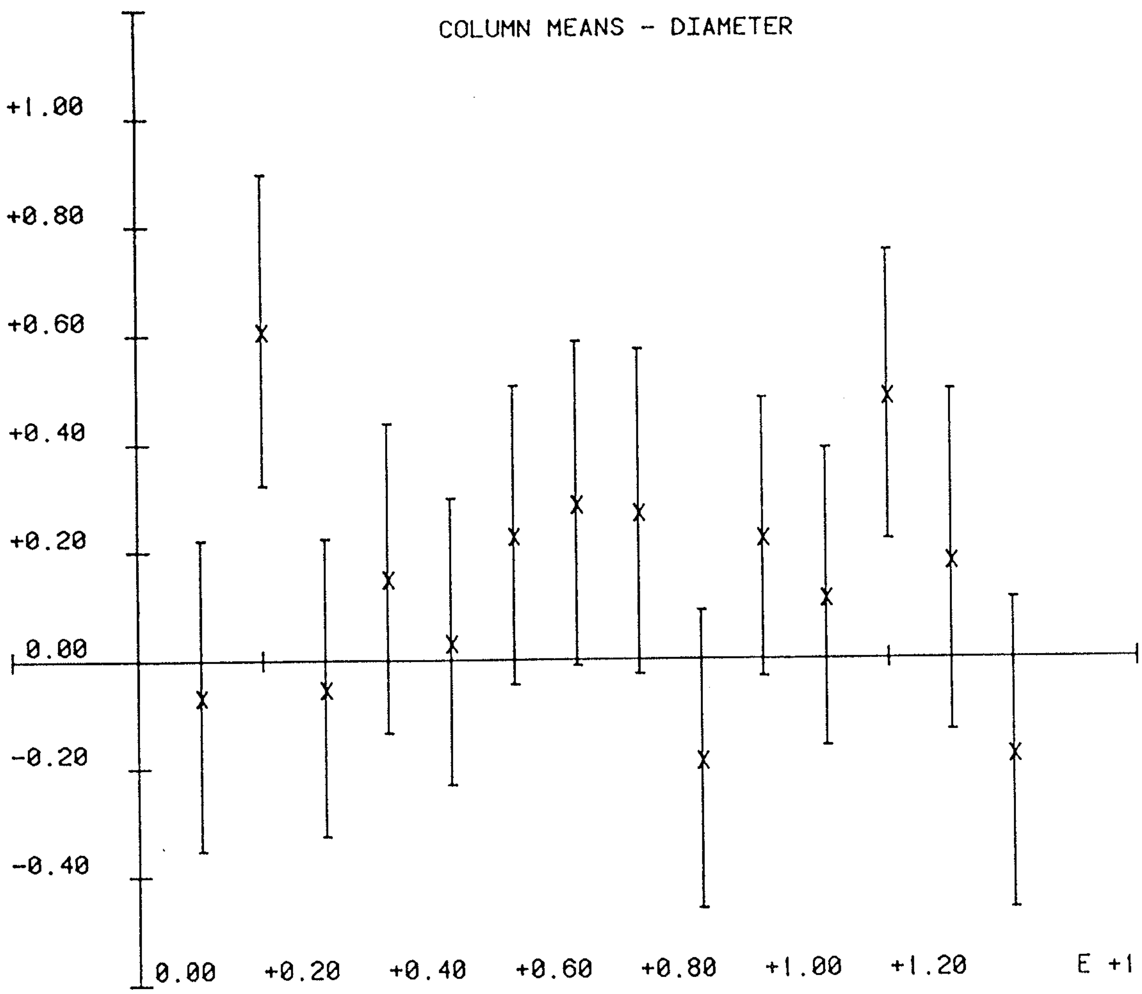

Figure 8: Confidence Intervals for Diameter

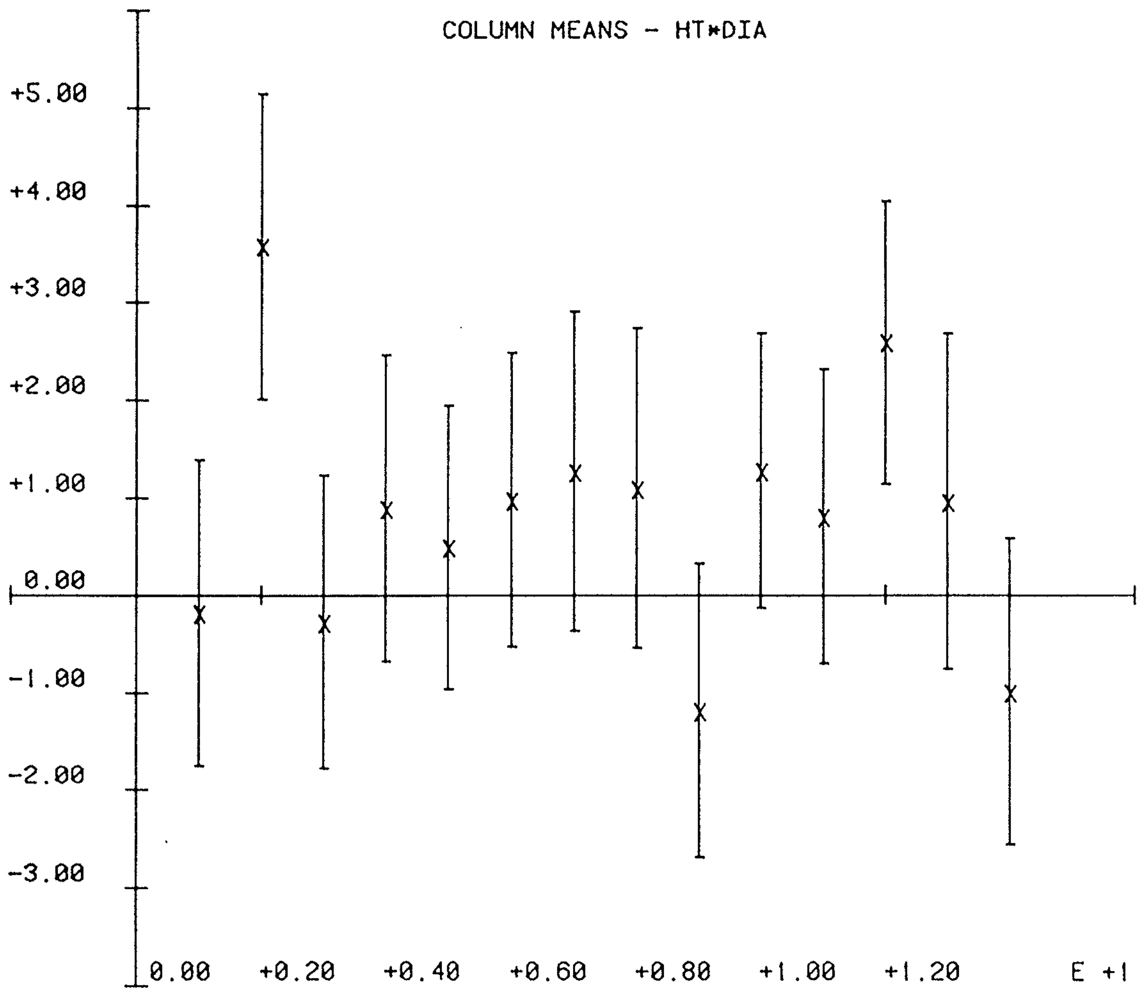

Figure 9: Confidence Intervals for Height X Diameter

treatment plots over tree growth in their respective control plots. The details of the one way ANOVA test may be found in Appendix F.

4.5 SIMPLE CONTRAST

A simple contrast tests the significance of confidence intervals to determine which treatments were most sucessful in relation to one another, also verifying if these treatments differed significantly in their effects on jack pine growth. The comparison was done for all sites collectively.

If the confidence intervals displayed on any of the above graphs were placed one on top of another, overlapping of their ranges would result. When the confidence interval of one treatment overlaps with some portion of another it indicates there is a chance these treatments had a similar effect on jack pine growth.

Table 4 reveals that treatments 2 and 12 produced significantly larger T-C unit differences than those from several other treatments. It is also apparent that treatment 2 was significantly different from the largest number of treatments. Comparisons other than with 2 and 12 showed significant differences but since only 2 and 12 had entirely positive confidence intervals we were only interested in how these two treatments compared to the others. For detailed results of the simple contrast see Appendix F.

TABLE 4

Simple Contrast Results

* = significant difference
x = insignificant difference

	Height		Diameter		Ht. x Dia.	
Treatments	2	12	2	12	2	12
1	*	*	*	*	*	*
2		x		x		x
3	*	*	*	*	*	*
4	*	x	*	x	*	x
5	*	x	*	*	*	*
6	x	x	x	x	*	x
7	*	x	x	x	*	x
8	x	x	x	x	*	x
9	*	*	*	*	*	*
10	*	x	x	x	*	x
11	*	x	*	x	*	x
12	x		x		x	
13	*	x	x	x	*	x
14	*	*	*	*	*	*

4.6 DISCUSSION OF RESULTS

The confidence interval display (Figs. 7, 8 and 9) reveals that although only treatments 2 and 12 were significantly different from their controls at greater than the 95% confidence level the majority of the other treatments showed highly positive results. The fact that 10 out of 14 treatments had the majority of their confidence interval in the positive region of the graph suggests that treatments other than 2 and 12 were effective in significantly increasing growth of treated jack pine. In addition, none of the confidence intervals showed a totally negative response. Therefore, we cannot confidently say any of the treatments had a negative effect on jack pine growth. To be more confident of the effect the fertilizer treatments had on jack pine growth a larger scale study would be required, the increased number of sample points would increase the reliability of such results.

There is reliable evidence that treatments 2 and 12 significantly improved both height and diameter growth of jack pine in plots treated with these fertilizer applications compared to growth in their respective control plots. Treatments 2 and 12 have also been shown to be superior, in terms of stimulating height and diameter growth development, when compared with some of the other fertilizer treatments. This implies that these treatments could be successfully used in a refined trial of spot ferilization. Such results do not tell us control trees are being suppressed by fertilized trees but the fact that fertilzer "burn" was visually evident on some plots (Fig. 10) and fertilized areas produced larger trees (which naturally suppress and outcompete smaller neighbours) reinforces the theory behind spot fertilization, prompting us to further study.

Figure 10: Jack Pine Mortality Due To Fertilizer Toxicity

From the following bar graphs (Figs. 11, 12, and 13) it can be seen that treatment 2 resulted in treated trees having, on the average, about 56 cm additional height increment and 6.3 mm additional diameter increment than control trees. Treatment 12 resulted in treated trees having, on the average, 35 cm additional height increment and 5.0 mm additional diameter increment than control trees.

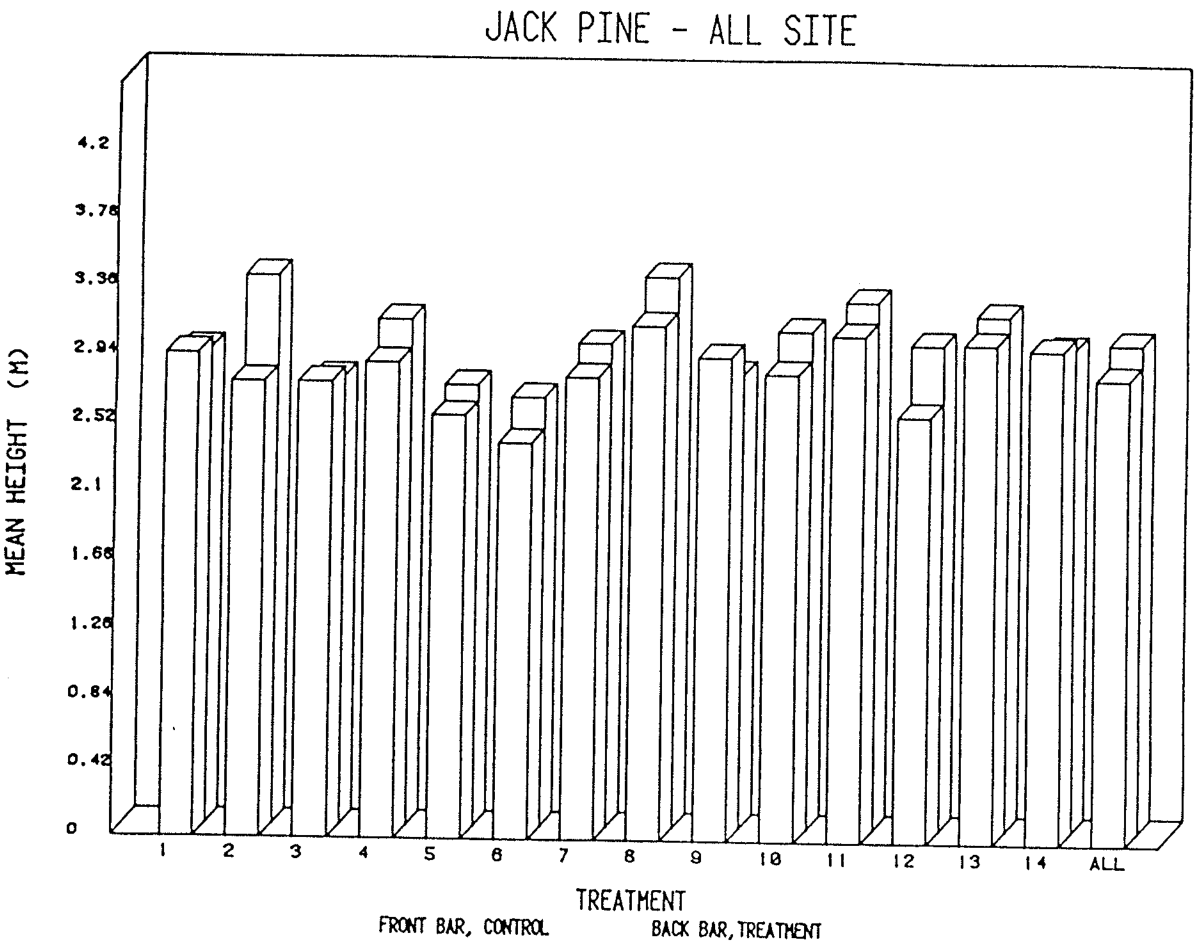

Figure 11: Treatment and Control Height Bar Graph

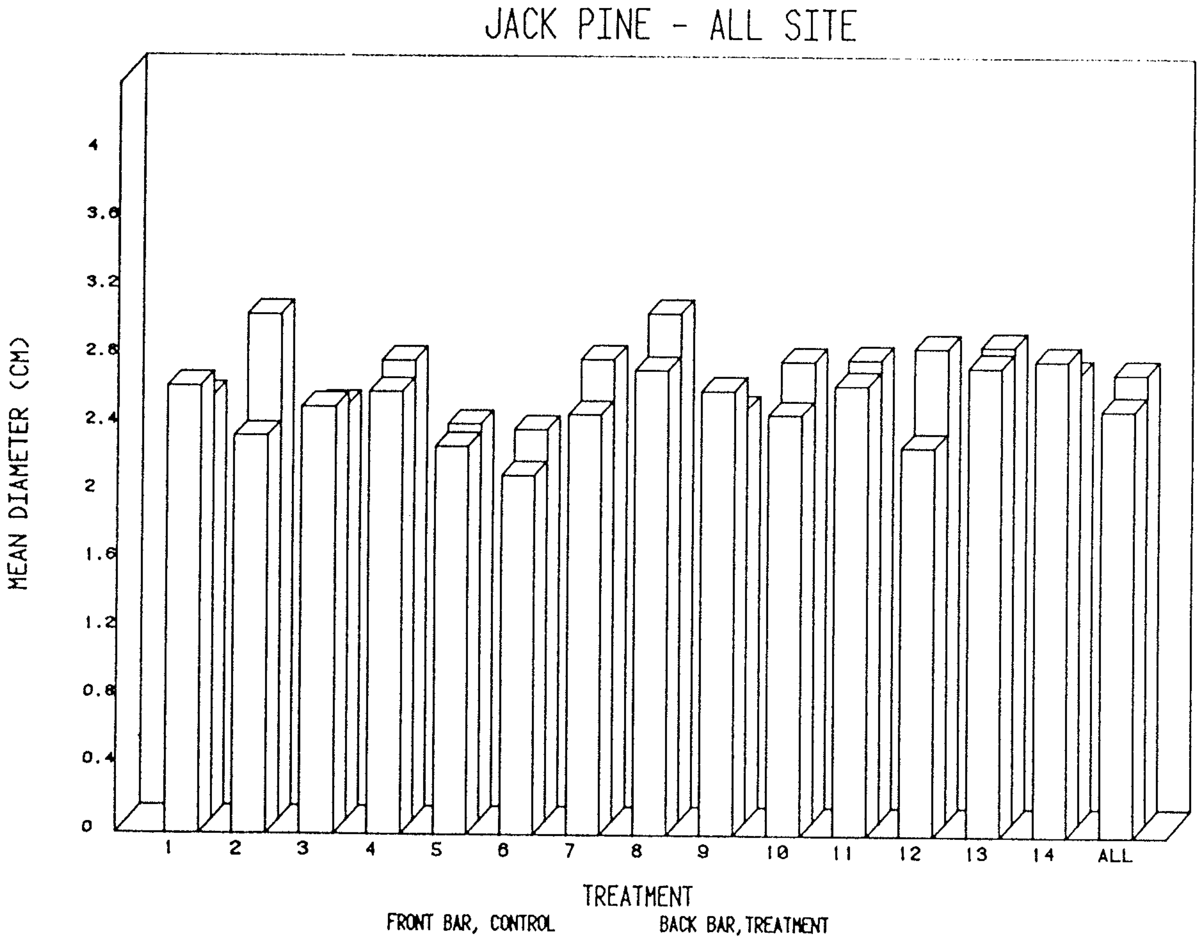

Figure 12: Treatment and Control Diameter Bar Graph

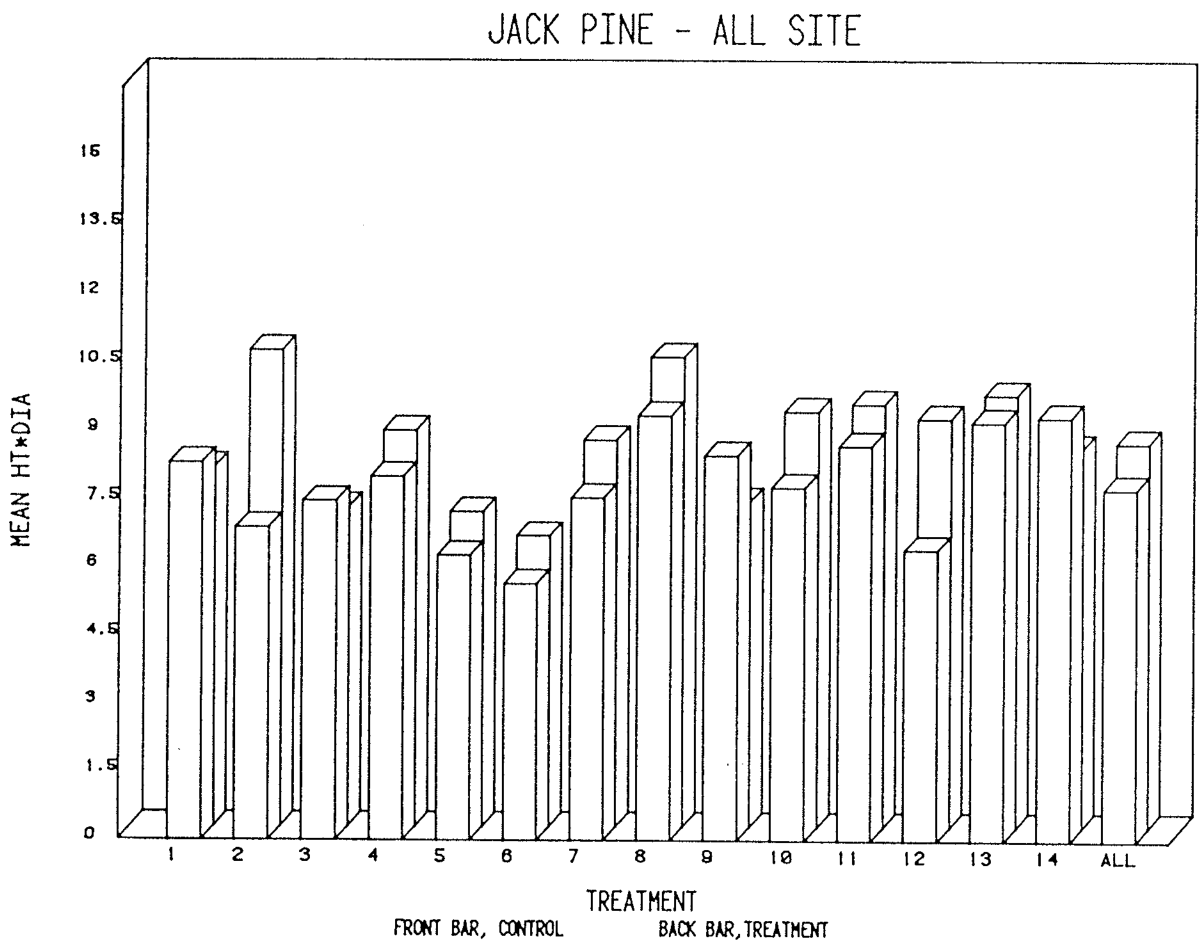

Figure 13: Treatment and Control Height x Diameter Bar Graph

The results obtained in this study are somewhat encouraging that spot fertilization may be practical; however, it is confusing why 2 and 12 were successful while others were less successful. There appears to be no pattern or trend of increased or decreased growth with increased fertilizer concentration. De Bell at al. (1975) working with western hemlock found that the greatest problem in hemlock fertilization research is the determination of the nature and causes of extreme variability in response. They found that individual hemlock trees must be in the upper crown class to respond. This led them to suspect that differences in tree characteristics (i.e., vigor) and stand structure in general -- competition and growing space relationships as well as stocking and density per se -- may be major causes of variability in response to fertilization. Similar conditions likely contributed to the variable response generated in the present study.

It may be possible that treatment 2 at 92 g nitrogen was the optimal nitrogen concentration for increasing height and diameter of jack pine on the sites studied. Any further addition of nitrogen may have been unutilized and damaging to plant growth (reducing tree vigour within the plots receiving higher nitrogen doses than treatment 2). Why then did treatment 12 prove successful as well? If we follow the above suggestion that treatment 2 was a near optimal concentration of nitrogen then the nitrogen in treatment 12 at

205.6 g nitrogen should have been excessive. However, it may have been the case that the addition of phosphorus and potassium in conjunction with nitrogen may have increased the plants tolerance of nitrogen and ability to utilize the nutrient addition.

It must also be remembered that when looking at the bar graph display the differences observed should not be considered absolute, but rather the magnitude of this difference is important. Small differences, whether positive or negative, must be considered due to chance circumstances. For example, when we see a treatment bar on the bar graphs which is shorter than a control bar we cannot assume the treatment was totally ineffective or counterproductive but rather did not significantly increase growth. It may have been the case that without fertilizer the negative differences would have been greater. In other words, even though the control appears larger the fertilizer could still have assisted growth within the treated plot. If similar measurements were taken in an untreated population of jack pine the controls would not all equal the "pseudo-treatments" rather there would be normal variation about the mean. Consequently, weak trends in growth can become lost in this variation and only strong evidence (such as 2 and 12) can be considered significant.

From our analysis we found that spot fertilization is capable of producing significantly larger trees around the treated area than beyond this area. Some treatments were found to produce a significantly better response than others but the evidence was not conclusive as to why. As far as site quality is concerned, treatments tested produced a similar magnitude of response on each site. Implications drawn from this are that fertilizer applications behave similarly on various site types; although, the poorest response, in terms of absolute height and diameter increase is concerned, would be on the best site (Elaine lake site) which, initially, had the largest trees. Literature on this subject suggests that the greatest response to a fertilizer addition is produced on sites where nutrient deficiencies (but not other environmental factors) are a limiting factor to growth.

Very poor growth sites, which are severely restricted in their growth potential by nutrient deficiencies, may not be suitable for spot fertilization as massive nutrient additions are not supplied. Average growth sites, the most common site type, may be the best candidates for spot fertilization.

In conducting this study much was learned about the importance of a good experimental design. The author was not involved in the initial stages of developing this study but was commissioned in 1982 to complete an analysis of the 1975 spot fertilization trial. Having no control over the original design, site selection, fertilizer application method etc., the study had to be modelled after receiving the initial procedural data in 1982. In retrospect I realize that many of the problems encountered in this study were the result of a poor original design which lacked clear objectives and a plan which would take the examination to completion in a logical, compatible manner. However, if this study had had to adhere to such rigorous standards at the outset it would likely never have been initiated. The study began as a novel idea which some forestry researchers felt merited a trial; consequently, room for spontaneity should exist but whenever possible serious forethought should be given to any experimental design.

In this study 3 sites which regenerated in the same year should have been located as fertilization of trees in different age classes was not being examined. As well, the fertilizer treatments should have been applied in a completely random pattern. It would also have been helpful to have a complete set of height and diameter data from treatment and control trees at the time of fertilization. These trees could have been tagged and then remeasured in 1982. In this manner a much more accurate determination of how the fertilizer treatments affected jack pine growth could have been achieved. The study could have been further improved if a soil and foliar nutrient content analysis was undertaken at each site to determine what nutrients were in short supply. The fertilizer concentrations applied would then have the most likelihood of achieving the desired response.

Finally, better site documentation would have been of value as some sites were difficult to locate.

Chapter V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

In Saskatchewan, forestry is of great importance being second only to the food and beverage industry in terms of salaries and wages earned and value of shipments in the manufacturing sector. One of the primary commercial tree species in Saskatchewan is jack pine (Pinus banksiana Lamb.). This species commonly regenerates after fire producing densely stocked, even-aged stands. Dense stocking results in severe competition between individual trees for nutrients, light, water and growing space spreading the growth potential of the site over many trees which will not reach merchantable size. Forest managers are seeking a practical method for efficiently thinning these stands in order that the growth potential of the site will be concentrated on trees with a greater chance of reaching merchantable size.

Management of these stands can result in the production of optimally spaced and sized trees in a shorter period of time than would have occurred naturally, substantially reducing logging and milling costs at harvest time. However, the compounded cost of conventional precommercial thinning techniques is generally believed to be greater than the benefits derived. Forest managers are, therefore, seeking more efficient methods for improving growth characteristics in densely stocked jack pine stands.

In this study, spot fertilization -- a technique designed to use fertilizers as both a growth enhancing and thinning agent in young, densely stocked, even-aged jack pine stands by applying fertilizer in spot doses at regularly spaced intervals -- was tested using 14 different fertilizer treatments on three sites in Saskatchewan's Mixedwood forest section. Spot fertilization is theorized to increase self-thinning in a dense stand by providing (1) toxic concentrations of nutrients to trees on fertilized spots and (2) additional nutrients to trees around the fertilized spot so that their increased growth lethally suppresses the growth of neighbouring trees on the perimeter of this fertile ring. These processes should induce the stand to begin expressing dominance earlier than would have occurred naturally.

5.2 CONCLUSIONS

Conclusions of this study are:

1. The magnitude of tree growth response to spot fertilization treatments is similar on various site types.
2. Spot fertilization treatments differ significantly in their ability to stimulate height and diameter growth of jack pine trees within treatment plots.

3. Some spot fertilization treatments were successful in producing larger jack pine trees, in terms of height and diameter, within the treated plots in comparison to trees within the control plots.
4. Mortality of jack pine trees via fertilizer "burn" can be induced by spot fertilization.

5.3 RECOMMENDATIONS

Based upon results from the analysis of spot fertilization in this study it is recommended that a second phase in testing this technique be undertaken incorporating into it's design (1) the capability to analyze the thinning and dominance inducement effects of spot fertilization and (2) features which would have benefited the analysis of spot fertilization in the present study. Preliminary design suggestions for this study are given in Appendix G.

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Appendix A

DEFINITION OF TERMS

1. Densely stocked (Overstocked): this situation is found when growth and mortality are both unusually low and is marked by large numbers of trees which are very small for their age (Baker 1950).
2. Dominance: is expressed in a forest stand when the crowns of dominant trees rise somehwat above the general level of the canopy , so that they enjoy full light from above and, to a certain degree, laterally (Baker 1950).
3. Even-aged stand: one in which all the trees are of one age, arising from the germination or sprouting of one year or having been planted at one time (Baker 1950).
4. Juvenile: trees still in rapid height or pole growth stage, vying for dominance amongst their neighbours. This refers to small to large sapling jack pine from 0.9-3 m tall (small saplings) or 3 m tall to 10 cm dbh (large saplings).
5. Null hypothesis or Ho: a hypothesis formulated for the sole purpose of rejecting or nullifying it, for example, if we want to see whether one treatment is

different than another we formulate the hypothesis that there is no difference between the treatments. Such hypotheses are called null hypothesis or Ho.

6. Pure stand: stands are customarily designated as pure when the canopy is composed of 90 per cent or better of a single species (Baker 1950).
7. Silviculture: the methods of handling a forest in view of its silvics modified in practice by economic factors. Silvics itself has been identified by Baker (1950) as the field of forestry concerned with developing a knowledge of the nature of forests and trees, how they grow, reproduce, and respond to changes in their environment.
8. Spot Fertilization: a silvicultural technique designed to release supressed jack pine stands by boosting tree growth in uniformly spaced patches of the stand. Spot fertilization is theorized to increase self-thinning in a dense stand by providing (1) toxic concentrations of nutrients to trees within the fertilized spots and (2) additional nutrients to trees around the fertilized spot so that their increased growth lethally suppresses the growth of neighbouring trees on the perimeter of this fertile ring.
9. Stand: an individual body of timber of similar age, composition, and general appearance. The term is

customarily used in a loose manner and has little specific meaning.

10. Stand release or unlocking: the natural or artificial unlocking of the stands growth potential via the onset of dominance expression amongst superior individuals within the stand.

11. Suppressed or overtopped: these trees are definitely submerged members of the forest community having no free overhead light worth considering. They exist by virtue of the sunlight that filters through the canopy or the skylight that may be received through some chance break. They are weak and slow growing (Baker 1950).

12. 10-30-10: a common form of fertilizer containing 10% nitrogen, 30% phosphorus, and 10% potassium.

13. Treatment-Control pairs: this corresponds to a set of 4 square m circular plots with their centers separated by 2.5 m, one being treated with one of the fourteen fertilizer treatments and the other being untreated (control).

14. Treatment-Control Unit Differences: the remainder left after subtracting the mean of treatment measurements from a single plot from the mean of control measurements from a single plot.

15. Urea: a form of nitrogenous fertilizer containing 46% nitrogen.

Appendix B

MEAN HEIGHT, DIAMETER AND HEIGHT X DIAMETER CALCULATIONS

TREATMENT		LOCATION 1	2	3	ALL
1	HT-MEAN-TREATED	2.67	3.65	1.87	2.90
	HT-MEAN-CONTROL	2.64	3.70	2.06	2.96
	DIA-MEAN-TREATED	2.62	2.81	1.81	2.49
	DIA-MEAN-CONTROL	2.76	2.92	2.00	2.63
	H*D-MEAN-TREATED	7.30	10.88	3.46	7.92
	H*D-MEAN-TREATED	7.74	11.16	4.30	8.34

TREATMENT		LOCATION 1	2	3	ALL
2	HT-MEAN-TREATED	2.60	4.11	2.90	3.35
	HT-MEAN-CONTROL	2.10	3.55	2.21	2.79
	DIA-MEAN-TREATED	2.70	3.39	2.63	2.97
	DIA-MEAN-CONTROL	2.20	2.69	1.96	2.34
	H*D-MEAN-TREATED	7.22	14.31	7.87	10.49
	H*D-MEAN-TREATED	4.64	9.78	4.40	6.90

TREATMENT		LOCATION 1	2	3	ALL

3	HT-MEAN-TREATED	2.61	3.13	2.52	2.73
	HT-MEAN-CONTROL	2.40	3.57	2.39	2.79
	DIA-MEAN-TREATED	2.52	2.41	2.42	2.44
	DIA-MEAN-CONTROL	2.31	2.92	2.29	2.51
	H*D-MEAN-TREATED	6.73	7.85	6.64	7.04
	H*D-MEAN-TREATED	5.72	10.85	5.79	7.49

		LOCATION			
TREATMENT		1	2	3	ALL
4	HT-MEAN-TREATED	2.83	3.69	2.39	3.09
	HT-MEAN-CONTROL	2.53	3.51	2.29	2.91
	DIA-MEAN-TREATED	2.86	2.89	2.36	2.70
	DIA-MEAN-CONTROL	2.58	2.93	2.13	2.60
	H*D-MEAN-TREATED	8.22	10.92	5.97	8.73
	H*D-MEAN-TREATED	6.61	10.58	5.28	8.03

		LOCATION			
TREATMENT		1	2	3	ALL
5	HT-MEAN-TREATED	2.27	3.65	1.80	2.69
	HT-MEAN-CONTROL	2.54	3.19	1.90	2.59
	DIA-MEAN-TREATED	2.14	2.99	1.64	2.33
	DIA-MEAN-CONTROL	2.47	2.57	1.75	2.28
	H*D-MEAN-TREATED	5.05	11.25	2.98	6.94
	H*D-MEAN-TREATED	6.58	8.46	3.36	6.28

TREATMENT		LOCATION 1	2	3	ALL
6	HT-MEAN-TREATED	2.69	3.09	2.15	2.62
	HT-MEAN-CONTROL	2.41	3.06	1.87	2.43
	DIA-MEAN-TREATED	2.55	2.42	2.01	2.30
	DIA-MEAN-CONTROL	2.26	2.38	1.76	2.11
	H*D-MEAN-TREATED	7.07	7.86	4.65	6.41
	H*D-MEAN-TREATED	5.66	8.21	3.35	5.66

TREATMENT		LOCATION 1	2	3	ALL
7	HT-MEAN-TREATED	2.70	3.48	2.65	2.95
	HT-MEAN-CONTROL	2.42	3.40	2.49	2.83
	DIA-MEAN-TREATED	2.65	2.83	2.65	2.71
	DIA-MEAN-CONTROL	2.24	2.69	2.39	2.47
	H*D-MEAN-TREATED	7.58	10.61	7.27	8.53
	H*D-MEAN-TREATED	5.56	9.86	6.41	7.57

TREATMENT		LOCATION 1	2	3	ALL
8	HT-MEAN-TREATED	3.14	3.63	3.09	3.36
	HT-MEAN-CONTROL	3.00	3.65	2.16	3.15
	DIA-MEAN-TREATED	3.23	2.81	2.98	2.98
	DIA-MEAN-CONTROL	2.90	2.88	2.07	2.73
	H*D-MEAN-TREATED	10.63	10.55	9.29	10.34

	H*D-MEAN-TREATED	9.15	11.46	4.56	9.37

TREATMENT		LOCATION 1	2	3	ALL
9	HT-MEAN-TREATED	2.68	3.46	2.05	2.77
	HT-MEAN-CONTROL	2.74	3.66	2.22	2.96
	DIA-MEAN-TREATED	2.45	2.67	2.10	2.42
	DIA-MEAN-CONTROL	2.72	2.91	2.13	2.61
	H*D-MEAN-TREATED	6.96	9.69	4.47	7.18
	H*D-MEAN-TREATED	8.09	11.46	4.87	8.50

TREATMENT		LOCATION 1	2	3	ALL
10	HT-MEAN-TREATED	2.84	3.87	2.45	3.04
	HT-MEAN-CONTROL	2.58	3.67	2.32	2.86
	DIA-MEAN-TREATED	2.87	3.06	2.21	2.70
	DIA-MEAN-CONTROL	2.45	2.73	2.22	2.47
	H*D-MEAN-TREATED	8.65	13.44	5.65	9.15
	H*D-MEAN-TREATED	6.71	10.90	5.71	7.80

TREATMENT		LOCATION 1	2	3	ALL
11	HT-MEAN-TREATED	2.81	3.91	2.76	3.22
	HT-MEAN-CONTROL	2.82	3.78	2.44	3.10

	DIA-MEAN-TREATED	2.56	3.08	2.39	2.71
	DIA-MEAN-CONTROL	2.74	2.88	2.22	2.64
	H*D-MEAN-TREATED	7.37	12.76	6.83	9.31
	H*D-MEAN-TREATED	8.27	11.22	5.77	8.71

		LOCATION			
TREATMENT		1	2	3	ALL
12	HT-MEAN-TREATED	2.73	3.62	2.49	2.96
	HT-MEAN-CONTROL	2.29	3.37	2.05	2.61
	DIA-MEAN-TREATED	2.73	3.00	2.59	2.78
	DIA-MEAN-CONTROL	2.21	2.61	1.98	2.28
	H*D-MEAN-TREATED	8.30	11.35	7.51	9.00
	H*D-MEAN-TREATED	5.21	9.26	4.30	6.42

		LOCATION			
TREATMENT		1	2	3	ALL
13	HT-MEAN-TREATED	2.92	3.91	1.81	3.14
	HT-MEAN-CONTROL	2.61	3.85	1.78	3.05
	DIA-MEAN-TREATED	2.97	3.11	1.77	2.79
	DIA-MEAN-CONTROL	2.62	3.23	1.69	2.75
	H*D-MEAN-TREATED	9.14	12.62	3.25	9.51
	H*D-MEAN-TREATED	7.36	12.89	3.05	9.23

		LOCATION			
TREATMENT		1	2	3	ALL

14	HT-MEAN-TREATED	2.30	3.92	2.26	2.95
	HT-MEAN-CONTROL	2.65	3.95	2.06	3.02
	DIA-MEAN-TREATED	2.45	3.08	2.19	2.63
	DIA-MEAN-CONTROL	2.48	3.43	2.15	2.79
	H*D-MEAN-TREATED	5.70	12.55	5.15	8.36
	H*D-MEAN-TREATED	6.72	14.35	4.58	9.34

		LOCATION			
TREATMENT		1	2	3	ALL
ALL	HT-MEAN-TREATED	2.71	3.66	2.38	2.98
	HT-MEAN-CONTROL	2.57	3.57	2.18	2.85
	DIA-MEAN-TREATED	2.67	2.91	2.28	2.63
	DIA-MEAN-CONTROL	2.51	2.84	2.07	2.50
	H*D-MEAN-TREATED	7.63	11.26	5.83	8.47
	H*D-MEAN-TREATED	6.84	10.74	4.81	7.77

Appendix C

T-C UNIT DIFFERENCES

HEIGHT

T-C UNIT DIFFERENCES (SITE 1)

	REPLICATION				
TREATMENT	1	2	3	4	5
1	*	-0.12	-0.08	0.22	0.25
2	*	0.26	*	0.53	0.75
3	-0.22	*	0.56	0.10	0.31
4	*	*	0.41	0.13	0.36
5	-0.50	0.22	-0.40	0.20	-0.21
6	0.19	0.70	*	0.64	0.23
7	*	0.37	0.16	0.62	*
8	0.04	0.23	0.30	0.20	*
9	-0.06	0.36	-0.21	-0.55	*
10	0.71	0.28	0.19	0.25	0.05
11	*	-0.44	0.54	-0.29	0.26
12	*	1.37	0.09	-0.11	0.21
13	-0.65	0.80	1.04	0.34	*
14	-1.08	*	-0.13	-0.02	*

HEIGHT

T-C UNIT DIFFERENCES (SITE 2)

REPLICATION

TREATMENT	1	2	3	4	5
1	0.06	0.55	-0.48	0.26	-0.41
2	0.70	0.15	0.62	0.91	0.26
3	*	-0.30	0.31	-1.67	0.04
4	0.48	-0.37	0.18	0.30	0.32
5	-0.14	0.87	0.17	0.24	1.00
6	-0.06	0.63	0.13	*	-0.60
7	-0.21	-0.04	0.28	0.34	*
8	-0.48	0.32	0.33	-0.57	0.31
9	-0.34	-0.40	0.13	0.52	-0.77
10	0.40	0.31	-0.45	-0.66	0.62
11	0.46	0.37	-0.14	-0.15	0.07
12	0.78	0.69	-0.82	-0.01	0.72
13	0.18	0.29	-0.03	*	-0.21
14	-1.08	*	-0.13	-0.02	*

HEIGHT

T-C UNIT DIFFERENCES (SITE 3)

REPLICATION

TREATMENT	1	2	3	4	5
1	0.12	*	-0.54	*	-0.10
2	0.01	0.81	0.89	1.15	*
3	0.67	-0.55	0.35	0.12	0.07
4	0.56	*	0.14	-0.22	0.16

5	-0.08	*	-0.23	-0.28	0.26
6	0.46	0.96	0.39	-0.25	-0.30
7	0.22	0.40	-0.35	*	0.36
8	*	0.80	1.05	*	*
9	-0.06	0.05	*	-0.10	-0.53
10	1.02	-0.30	-0.04	1.11	-1.17
11	*	-0.01	0.04	1.05	0.49
12	-0.09	0.93	1.04	0.00	0.51
13	*	*	*	0.21	-0.02
14	-0.33	0.37	*	0.41	0.09

DIAMETER

T-C UNIT DIFFERENCES (SITE 1)

	REPLICATION				
TREATMENT	1	2	3	4	5
1	*	0.50	-0.37	-0.49	0.49
2	*	0.09	*	0.49	0.75
3	-0.17	*	0.47	0.32	-0.02
4	*	*	0.75	-0.30	0.29
5	-0.65	0.13	-0.32	0.18	-0.42
6	0.14	0.50	*	0.58	0.44
7	*	0.20	0.30	1.03	*
8	0.27	-0.01	0.39	0.87	*
9	-0.50	0.28	-0.39	-0.55	*
10	0.41	0.50	0.31	0.88	0.34
11	*	-0.58	0.55	-0.50	-0.02

12	*	1.98	-0.05	-0.31	0.07
13	-0.07	1.03	0.89	0.13	*
14	-0.58	*	0.23	0.01	*

DIAMETER

T-C UNIT DIFFERENCES (SITE 2)

	REPLICATION				
TREATMENT	1	2	3	4	5
1	-0.05	0.22	-0.26	0.58	-0.90
2	0.54	0.49	0.56	1.32	0.39
3	*	-0.06	0.10	-1.92	-0.03
4	0.08	-0.37	-0.30	0.23	0.13
5	0.11	0.36	0.42	-0.17	1.24
6	-0.02	0.64	0.24	*	-0.71
7	0.01	-0.01	0.18	0.41	*
8	-0.73	0.31	0.14	-0.20	0.13
9	-0.17	-0.55	-0.15	0.48	-0.76
10	0.48	0.47	-0.40	-0.49	0.94
11	0.46	0.51	-0.09	-0.20	0.38
12	0.29	0.43	-0.25	0.17	1.30
13	-0.48	0.14	0.02	*	-0.15
14	-0.58	0.32	-0.05	-1.13	-0.44

DIAMETER

T-C UNIT DIFFERENCES (SITE 3)

REPLICATION

TREATMENT	1	2	3	4	5
1	0.16	*	-0.50	*	-0.16
2	0.32	0.59	0.87	0.91	*
3	0.68	-0.55	-0.02	0.29	0.24
4	1.10	*	0.04	-0.25	0.41
5	-0.24	*	-0.18	-0.08	0.08
6	0.57	1.19	0.15	-0.15	-0.58
7	0.21	0.66	-0.20	*	0.38
8	*	0.91	0.92	*	*
9	0.05	0.20	*	-0.10	-0.25
10	0.88	-0.79	-0.38	0.94	-0.72
11	*	0.04	-0.08	0.96	0.05
12	-0.16	1.05	0.64	0.10	0.54
13	*	*	*	0.22	0.08
14	-0.10	-0.11	*	0.56	-0.24

HEIGHT X DIAMETER

T-C UNIT DIFFERENCES (SITE 1)

REPLICATION

TREATMENT	1	2	3	4	5
1	*	0.90	-1.52	-0.60	1.50
2	*	1.28	*	2.43	3.85
3	-0.71	*	2.52	0.98	0.58
4	*	*	3.12	-0.28	1.78
5	-2.23	0.67	-2.02	0.80	-1.91

6	0.65	2.52	*	2.92	2.03
7	*	1.40	0.86	5.15	*
8	1.15	0.81	1.52	3.65	*
9	-1.99	1.37	-1.42	-3.62	*
10	3.40	2.09	1.07	3.63	0.84
11	*	-3.14	2.44	-2.69	0.47
12	*	10.67	0.06	-0.95	0.63
13	-2.01	5.80	5.00	1.04	*
14	-4.53	*	0.37	-0.02	*

HEIGHT X DIAMETER

T-C UNIT DIFFERENCES (SITE 2)

	REPLICATION				
TREATMENT	1	2	3	4	5
1	0.03	2.25	-2.08	3.27	-3.61
2	4.01	2.12	4.53	8.96	1.77
3	*	-0.74	1.08	-11.43	-0.08
4	1.47	-2.30	-0.54	1.41	1.65
5	-0.15	3.81	1.80	-0.36	7.89
6	-0.18	2.99	0.84	*	-5.02
7	-0.52	-0.22	1.11	2.73	*
8	-5.69	1.49	1.13	-2.57	1.09
9	-2.13	-3.35	-0.07	2.89	-5.53
10	3.50	2.82	-1.58	-2.62	6.30
11	3.65	3.34	-0.47	-1.04	2.35
12	3.56	3.83	-2.93	0.31	5.95

13	-1.35	1.55	-0.30	*	-0.95
14	-3.64	2.96	0.24	-6.87	-1.82

HEIGHT AND DIAMETER

T-C UNIT DIFFERENCES (SITE 3)

	REPLICATION				
TREATMENT	1	2	3	4	5
1	0.50	*	-2.16	*	-0.61
2	0.74	3.06	4.82	5.39	*
3	3.50	-1.89	0.63	1.38	0.62
4	4.10	*	0.39	-1.31	1.21
5	-0.63	*	-0.74	-0.64	0.62
6	1.90	5.44	1.00	-0.68	-1.69
7	0.70	2.84	-1.65	*	1.56
8	*	3.97	5.50	*	*
9	-0.17	0.71	*	-0.39	-1.62
10	3.89	-2.65	-0.83	4.74	-5.45
11	*	0.07	-0.21	4.19	1.54
12	-0.39	4.45	8.79	0.18	2.16
13	*	*	*	0.72	0.14
14	-0.86	0.58	*	2.09	-0.31

Appendix D

SIGN TEST

The sign test preliminarily tested the significance of the T-C unit differences for sites 1, 2, and 3 with respect to how they deviated from the expected frequency for a normal population. In other words, it answers the question; if we have x positive values and y negative values at site A are there enough positive values to be confident at the 95% confidence level that fertilizer had a positive effect on jack pine growth? Basically, the differences are replaced by their signs (+ or -); the sizes of the differences are ignored. The test was employed for an initial, quick, look over the data before the ANOVA was employed. An example of the detailed calculation is presented below.

Diameter Site 1

The sign test showed there were 19 negative values (i.e., where the summation of the control means was greater than the summation of the treatment means) and 35 positive values, the remainder being rejected due to insufficient data. If fertilizer had no effect on jack pine growth, a more even split in these values (eg., 27 negative values and 27 positive values) would be expected.

Testing, at the 5% level of significance, the Ho that the median T-C unit difference is 0 against the alternative that it is positive it was revealed that Y=35 (where Y=the number of positive values). The mean and standard deviation of Y are

n x 0.5 = 27 (where n = the number of T-C unit differences used for this test = 54), and

the square root of n x 0.5 = (approximately) 3.7

the standardized variable is (Y-27)/3.7 = 2.2

In other words, Y, which equals the number of positive values, is 2.2 standard deviations from the mean or 27. Since even at forty degrees of freedom the upper 5 percentage point $t_{.05,40}$ is 1.684 we reject the Ho. Simply stated, this means that if t has a (normal) t-distribution with 40 degrees of freedom then the probability that t will be greater than 1.684 is 5%. Therefore, this sign test with n-1=53 degrees of freedom and 2.2 standard deviations from the mean, because it has a greater value than 1.684 and has more degrees of freedom indicates that the treatment means were derived from a population of trees having greater diameters than the trees from control plots at more than a 5% level of significance.

Appendix E

TWO WAY ANOVA CALCULATIONS

ANALYSIS OF VARIANCE (WEIGHTED SQUARES OF MEANS) FOR HEIGHT

SOURCE	DF	SS	MS	F	SIG LEVEL	
A	2	0.66078	0.33039	1.53305	0.21967	
B	13	6.38824	0.49140	2.28016	0.00953	**
INT	26	1.28786	0.04953	0.22984	0.99997	
ERROR	133	28.66320	0.21551			

ANALYSIS OF VARIANCE (WEIGHTED SQUARES OF MEANS) FOR DIAMETER

SOURCE	DF	SS	MS	F	SIG LEVEL	
A	2	1.21355	0.60677	2.40470	0.09421	
B	13	8.72566	0.67120	2.66005	0.00242	**
INT	26	1.49640	0.05755	0.22809	0.99997	
ERROR	133	33.55964	0.25233			

ANLAYSIS OF VARIANCE (WEIGHTED SQUARES OF MEANS) FOR HEIGHT X DIAMETER

SOURCE	DF	SS	MS	F	SIG LEVEL	
A	2	18.47382	9.23691	1.22398	0.29735	
B	13	257.90192	19.83861	2.62880	0.00272	**
INT	26	49.13858	1.88995	0.25044	0.99993	
ERROR	133	1003.70162	7.54663			

Appendix F

ONE WAY ANOVA CALCULATIONS WITH SIMPLE CONTRASTS

ONE WAY MEANS FOR HEIGHT

			STD ERROR	95% CONFIDENCE INTERVAL	
ROW	N	MEAN	OF ROW MEAN	LOWER LIM	UPPER LIM
1	54	0.17407	0.06317	0.04912	0.29903
2	66	0.08652	0.05714	-0.02651	0.19954
3	55	0.21291	0.06260	0.08909	0.33673

			STD ERROR	95% CONFIDENCE INTERVAL	
COL	N	MEAN	OF COL MEAN	LOWER LIM	UPPER LIM
1	12	-0.02250	0.13401	-0.28758	0.24258
2	12	0.58667	0.13401	0.32159	0.85174
3	13	-0.01615	0.12876	-0.27083	0.23852
4	12	0.20417	0.13401	-0.06091	0.46924
5	14	0.08000	0.12407	-0.16541	0.32541
6	13	0.24000	0.12876	-0.01468	0.49468
7	11	0.19545	0.13997	-0.01841	0.47232
8	11	0.23000	0.13997	-0.04686	0.50686
9	13	-0.15077	0.12876	-0.40545	0.10391
10	14	0.15467	0.11986	-0.08243	0.39176
11	13	0.17308	0.12876	-0.08160	0.42775
12	14	0.37929	0.12407	0.13387	0.62470

13	10	0.19500	0.14680	-0.09538	0.48538
14	12	-0.08167	0.13401	-0.34674	0.18341

SIMPLE CONTRASTS FOR HEIGHT

(Note: df may vary due to data rejection)

(* indicates significant difference)

LEVEL 2 AND LEVEL 8

COMPARISON = 0.35667 SUM OF SQUARES = 0.73008 F = 3.474

SIGNIFICANCE LEVEL = 0.07105

LEVEL 2 AND LEVEL 4

COMPARISON = 0.38250 SUM OF SQUARES = 0.87784 F = 4.176

SIGNIFICANCE LEVEL = 0.04884 *

LEVEL 12 AND LEVEL 10

COMPARISON = 0.22462 SUM OF SQUARES = 0.36535 F = 1.738

SIGNIFICANCE LEVEL = 0.19622

LEVEL 12 AND LEVEL 5

COMPARISON = 0.29929 SUM OF SQUARES = 0.62700 F = 2.983

SIGNIFICANCE LEVEL = 0.09326

LEVEL 12 AND LEVEL 3

COMPARISON = 0.39544 SUM OF SQUARES = 1.05407 F = 5.015

SIGNIFICANCE LEVEL = 0.03181 *

ONE WAY MEANS FOR DIAMETER

STD ERROR 95% CONFIDENCE INTERVAL

ROW	N	MEAN	OF ROW MEAN	LOWER LIM	UPPER LIM
1	54	0.19426	0.06836	0.05905	0.32947
2	66	0.05455	0.06183	-0.06776	0.17685
3	55	0.22091	0.06773	0.08693	0.35489

			STD ERROR	95% CONFIDENCE INTERVAL	
COL	N	MEAN	OF COL MEAN	LOWER LIM	UPPER LIM
1	12	-0.06500	0.14501	-0.35183	0.22183
2	12	0.61000	0.14501	0.32317	0.89683
3	13	-0.05154	0.13932	-0.32711	0.22404
4	12	0.15083	0.14501	-0.13599	0.43766
5	14	0.03286	0.13425	-0.23269	0.29841
6	13	0.23000	0.13932	-0.04557	0.50557
7	11	0.28818	0.15146	-0.01140	0.58776
8	11	0.27273	0.15146	-0.02685	0.57231
9	13	-0.18538	0.13932	-0.46096	0.09019
10	14	0.22467	0.12970	-0.03188	0.48121
11	13	0.11385	0.13932	-0.16173	0.38942
12	14	0.48571	0.13425	0.22017	0.75126
13	10	0.18100	0.15885	-0.13320	0.49520
14	12	-0.17583	0.14501	-0.46266	0.11099

SIMPLE CONTRASTS FOR DIAMETER

LEVEL 13 AND LEVEL 2

COMPARISON = -0.42900 SUM OF SQUARES = 1.00386 F = 3.981

SIGNIFICANCE LEVEL = 0.05276

LEVEL 4 AND LEVEL 2

COMPARISON = -0.45917 SUM OF SQUARES = 1.26500 F = 5.016

SIGNIFICANCE LEVEL = 0.03065 *

LEVEL 4 AND LEVEL 12

COMPARISON = -0.33488 SUM OF SQUARES = 0.72463 F = 2.874

SIGNIFICANCE LEVEL = 0.09770

LEVEL 11 AND LEVEL 12

COMPARISON = -0.37187 SUM OF SQUARES = 0.93215 F = 3.697

SIGNIFICANCE LEVEL = 0.06156

LEVEL 5 AND LEVEL 12

COMPARISON = -00.45286 SUM OF SQUARES = 1.43556 F = 5.693

SIGNIFICANCE LEVEL = 0.02178 *

ONE WAY MEANS FOR HEIGHT X DIAMETER

			STD ERROR	95% CONFIDENCE INTERVAL	
ROW	N	MEAN	OF ROW MEAN	LOWER LIM	UPPER LIM
1	54	0.96870	0.37383	0.22926	1.70815
2	66	0.46273	0.33815	-0.20613	1.13158
3	55	1.07709	0.37042	0.34440	1.80978

			STD ERROR	95% CONFIDENCE INTERVAL	
COL	N	MEAN	OF COL MEAN	LOWER LIM	UPPER LIM
1	12	-0.17750	0.79302	-1.74610	1.39110
2	12	3.58000	0.79302	2.01140	5.14860

3	13	-0.27385	0.76191	-1.78091	1.23322
4	12	0.89167	0.79302	-0.67693	2.46027
5	14	0.49357	0.73420	-0.95867	1.94581
6	13	0.97846	0.76191	-0.52860	2.48552
7	11	1.26909	0.82829	-0.36926	2.90744
8	11	1.09545	0.82829	-0.54289	2.73380
9	13	-1.17846	0.76191	-2.68552	0.32860
10	14	1.27667	0.70930	-0.12633	2.67966
11	13	0.80769	0.76191	-0.69937	2.31475
12	14	2.59429	0.73420	1.14204	4.04653
13	10	0.96400	0.86871	-0.75431	2.68231
14	12	-0.98417	0.79302	-2.55277	0.58443

SIMPLE CONTRASTS FOR HEIGHT X DIAMETER

LEVEL 12 AND LEVEL 2

COMPARISON = -0.98571 SUM OF SQUARES = 6.27824 F = 0.834

SIGNIFICANCE LEVEL = 0.36140

LEVEL 10 AND LEVEL 2

COMPARISON = -2.30333 SUM OF SQUARES = 35.36896 F = 4.696

SIGNIFICANCE LEVEL = 0.03042 *

LEVEL 13 AND LEVEL 12

COMPARISON = -1.63029 SUM OF SQUARES = 15.50402 F = 2.059

SIGNIFICANCE LEVEL = 0.15160

LEVEL 4 AND LEVEL 12

COMPARISON = -1.70262 SUM OF SQUARES = 18.73143 F = 2.487

SIGNIFICANCE LEVEL = 0.11503

LEVEL 11 AND LEVEL 12

COMPARISON = -1.78659 SUM OF SQUARES = 21.51588 F = 2.857

SIGNIFICANCE LEVEL =0.09123

LEVEL 5 AND LEVEL 12

COMPARISON = -2.10071 SUM OF SQUARES = 30.89100 F = 4.102

SIGNIFICANCE LEVEL = 0.04305 *

SAMPLE CALCULATION - Conservative Approach to Multiple Comparisons

Treatments 1, 3, 9, and 14 had negative means to their confidence intervals. The remainder were positive. A negative mean indicates these treatments had poorer growth than would have been expected in an untreated stand. Only treatment 2 and 12 had positive lower limits to their confidence intervals. All others were negative. A negative lower confidence limit indicates there is greater than a 5% probability that that treatment had no significant growth enhancement. An entirely positive confidence interval indicates there is less than a 5% probability that that treatment had no significant positive effect on growth. As a result we cannot be sure treatments other than 2 and 12 were significantly different from the controls.

Treatments 2 and 12 were successful insofar as trees in these plots are significantly taller than their controls.

However, with 14 treatments there is a chance these results could have been obtained even if the fertilizers were ineffective. Therefore, to be more positive of these results and to test their significance in relation to the other treatments, a conservative approach to multiple comparisons (Bonferroni's Inequality) was utilized (Fisher 1978).

The desired level of significance in this study is = *des = 0.5

There are k treatments (where k = 14).

To test the significance of 2 and 12 we set * (which equals our new conservative level of significance) =

*des/k = 0.5/14 = 0.0036 = 0.36%

If 2 and 12 are still significant at this level of significance (0.36%) then we can accept, at the much more conservative 5% level of significance, that treatments 2 and 12 are significant. For illustrative purposes the details of this test are shown for treatment 2 height data.

Mean = 0.58667

Standard error = 0.13401

* = 0.0036 = 0.36% conservative level of significance

1 - * = 0.9964 = 99.64% confidence level

Since 3 standard errors equals a 0.997 confidence level which is greater than 0.9964 confidence level we can multiply

3 x 0.13401 = 0.40203

and subtract this from the mean to simplify calculations. In fact, this puts treatment 2 results for height to an even more rigorous test of validity for we are now testing to see if treatment 2 produced significantly taller trees than untreated trees at the 99.7% level of probability. The lower limit for a confidence interval at the 0.003 level of significance is

0.58667 - 0.40203 = 0.18464

Since this lower limit is still positive at this significance level treatment 2 is accepted as being significant at *des = 0.05

Table 5 lists the results of the conservative approach to multiple comparisons for treatments 2 and 12 height and diameter data. From these results we can confidently say that both treatments significantly boosted height and diameter growth within the treatment plots.

TABLE 5

Acceptance Or Rejection Of The C.I. For 2 And 12

Treatment	Height	Diameter	Ht. x Dia.
2	accept	accept	accept
12	accept	accept	accept

Appendix G

FOLLOW-UP TESTING

Firstly, an average growth site should be chosen using the same selection criteria as was used in this study. By studying only one site a more intensive analysis can be undertaken. The chosen stand should be young, preferably between 5-10 years of age. Such stands have less windfall, are relatively easy to work in and the trees are most susceptible to toxic effects of high fertilizer concentration.

Once the site has been selected, thorough site documentation must be made so the site and plots can be easily relocated. Following this a soil and foliar nutrient content analysis should be carried out to determine what fertilizer applications are best suited for improving stand growth on this site. Results from the present study may also be used to provide some of the fertilizer treatments to be tested (i.e., concentrations around treatment 2 and 12 levels could be incorporated into the design as well). The range of treatments should be narrowed to three. The site should then be divided into four equal sections, one being set up as a control, of sufficient size to study the effects of each treatment in isolation (perhaps 20 X 50 m each with a 5 m buffer zone between each section).

Before fertilization is undertaken the following measurements can be made if a complete record of spot fertilization effects over time is desired:

1. Measurement (1). A randomly selected stem count should be done on the entire site to get a figure for average stem density before fertilization;
2. Measurement (2). The heights and diameters of randomly selected trees from anywhere on the site should be measured in order to get an average figure for height and diameter before fertilization.

During late spring each section (except the control) should be spot fertilized with one treatment in a similar manner to that carried out in this study. This season has been shown to be advantageous for the application of fertilizer in fertilization trials (Morrison 1981). It is recommended that, while fertilizing, a numbered marking peg be placed in the center of each fertilized spot so the plots can be relocated at a later date. The peg numbers and treatment applied to each section must be documented.

Ten years after fertilization the site should be relocated and the following measurements taken:

1. Measurement (3). A randomly selected stem count on each fertilized section to get a figure for average stem density 10 years after fertilization.
2. Measurement (4). A randomly selected stem count in the control section to get a figure for average stem density 10 years after fertilization.

3. Measurement (5). A stem count within randomly selected fertilized spots in each fertilized section to get a figure for average stem density in the fertilized area of each section.
4. Measurement (6). A randomly selected sample of tree heights and diameters within the ring of "enhanced" growth surrounding randomly selected fertilized spots (fertile ring) in each treated section.
5. Measurement (7). A randomly selected sample of tree heights and diameters of trees immediately surrounding the randomly selected fertile rings (i.e., in the suppressed ring) within each fertilized section. [Note: to be able to compare results of measurement (7) with measurement (6) and to simplify sampling it is suggested that the suppressed ring should equal twice the area of the fertile ring and that one-half of this be randomly selected and measured. A pole marked at the radius of each ring can assist in determining which ring the trees are located in.]
6. Measurement (8). A randomly selected sample of control tree heights and diameters to get a figure for "natural" growth.
7. Measurement (9). A randomly selected sample of tree heights and diameters in each fertilized section to get a figure for growth in a managed stand.

These measurements may be analyzed comparitively. The following describes some of the comparisons that may be made:

9 - 8 = the growth difference attributable to overalll improved stand growth in that fertilized section due to that particular spot fertilization treatment.

6 - 7 = the growth difference produced between fertile ring and suppressed ring over 10 years due to the fertilizer treatment in each section.

3 - 4 = the amount of mortality attributable to the thinning effects of each treatment.

5 - 4 = the amount of mortality due to fertilizer toxicity in the fertilized spots.

To test whether dominance is being expressed a technique designed by Duff and Nolan (1953) and later used by Stark and Cook (1957) -- which measures cambium growth rates within each internode from the apex downward -- is suggested. This technique requires that a jack pine stand containing trees which have begun to express dominance characteristics be located after growth has slowed in the autumn. Selecting a series of dominant and codominant trees, the internode lengths along the main axis are measured back to the point where the dominant and codominant trees had similar heights and height increments. Additionally, a section of the main axis is taken from the center of each internode and the mean widths of all the annual rings determined in each section. From this data it may be possible to determine through comparitive analysis of dominant and codominant tree information at what age the dominant tree began exerting an increased suppressive influence upon the codominant and also how much more annual ring width and height increment was required by the dominant tree before it began expressing dominance. Comparing these difference figures with the spot fertilization differences produced in each section between tree heights and diameters in the fertile ring (representing dominants) and suppressed ring (representing codominants) (i.e., measurement 6 - 7) it should be possible to determine whether the differences produced by spot fertilization are sufficient to prompt early dominance establishment.

As far as the author is aware this technique has not been used for analyzing dominance establishment; consequently, to successfully carry out such a project (which is substantial enough in itself to be considered a separate study of great potential value to forest ecology) reference should be made to the aforementioned works and refinement of the experimental design made.

Alternative studies to those being proposed which may be of interest/value to researchers wishing to investigate spot fertilization are the following:

1. replication of this testing over the 3 prairie provinces in order to examine response on a variety of sites,
2. study the spot fertilization of various stand ages,
3. modification of the treatment plot size,
4. applying spot fertilization in conjunction with thinning,
5. study slow-releasing fertilizers to determine what effect a longer influence of fertilization has, and
6. a greenhouse study to measure spot fertilization effects under laboratory conditions.