FERTILIZATION EFFECTS ON SOIL AND FOLIAR NUTRIENT STATUS IN RELATION TO DECLINING SUGAR MAPLE (*ACER SACCHARUM* MARSH.)

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the Degree of Master of Science

Department of Renewable Resources
McGill University
February 1990

Suggested short title

FERTILIZATION OF DECLINING SUGAR MAPLE STANDS

ABSTRACT

M.Sc. Heather A. Spankie Renewable Resources

Eight fertilization treatments were applied in May 1987 to two sugar maple stands in the Lower Laurentians of Quebec, one located in the Entrelacs area and the other located in the St-Hippolyte area. This was followed by soil and foliar sampling and decline evaluation in mid-summer 1987 and foliar sampling and decline evaluation in mid-summer 1988.

Although the complete range of decline was in evidence at both sites, trees selected for sampling purposes on average showed evidence of light to moderate decline. Foliar nutrient status was found to be poor at both sites, with Ca, Mg, K and P at or very near to deficiency levels although foliar molar ratios for Ca/K, Ca/Mg and Ca/Al were well within their respective critical ranges.

Fertilization had significant effects on several elemental concentrations of the soil and foliage at the Entrelacs site. Effects in general showed an increase in base cation concentrations when those elements were supplied in high enough quantities in the fertilizers. Fertilization had no significant effect on decline levels, perhaps due to the relatively short duration of this project or to the tree having had a critical degree of damage from which no revitalization would have been possible.

Positive correlations were obtained between soil B horizon levels and foliar Ca, Mg and K and between soil FH horizon levels and foliar K

and Al when analyses were carried out on data obtained from Entrelacs and St-Hippolyte. This indicated that the fertilization treatments did have an effect on both the soil and foliage and that the nutrient status of the soil did influence the nutrient status of the foliage. When the control plots only were analysed for the two sites, the only element that gave a significant negative correlation to tree decline level was foliar Mg.

RESUME

M.Sc. Heather A. Spankie Ressources Renouvelables

Huit traitements de fertilisation ont été appliqués au mois de mai 1987 dans deux érablières situées dans les Basses Laurentides au Québec, soit dans la région d'Entrelacs et dans la région de St-Hippolyte. L'échantillonnage du sol, des feuilles ainsi que l'évaluation visuelle du degré de dépérissement ont été effectués vers le milieu de l'été 1987. L'échantillonnage des feuilles et l'évaluation visuelle du dépérissement ont été répetés à l'été 1988.

Les arbres aux deux stations montraient des niveaux très variés de dépérissement. Cependant, seuls les arbres montrant des degrés de dépérissement léger à modéré ont été sélectionnés pour l'étude. Le statut nutritif des feuilles s'avérait pauvre en Ca, Mg, K et P et ce, même si les ratios molaires Ca/K, Ca/Mg et Ca/Al du feuillage étaient bien en-deça de leur limite critique.

La fertilisation a eu des effets significatifs sur les concentrations en éléments nutritifs du sol et du feuillage à la station d'Entrelacs. On a observé ces effets par une augmentation de la concentration des cations basiques lorsque ces éléments étaient fournis en quantité suffisante par les fertilisants. La fertilisation n'a eu aucun effet significatif sur les degrés de dépérissement. Cela peut être dû au fait que le projet était de trop courte durée ou que certains arbres avaient atteint un degré de dépérissement tel que la revitalisation n'était plus possible.

En combinant les données d'Entrelacs et de St-Hippolyte, des corrélations positives ont été obtenues entre les niveaux de Ca, Mg et K du feuillage et ceux de l'horizon minéral B du sol ainsi qu'entre les niveaux de K et d'Al des feuilles et ceux de l'horizon FH. Ceci démontre que les traitements de fertilisation ont eu un effet significatif sur le sol et le feuillage et que la fertilité du sol a effectivement influencé le statut nutritif des feuilles. Lorsque seules les parcelles témoins sont utilisees pour l'analyse, seule la concentration en Mg des feuilles est corrélée negativement avec le degré de dépérissement.

PREFACE

The purpose of this study was to examine the influence of fertilization on soil nutrient concentrations, foliar nutrient concentrations and decline levels in a sugar maple stand located in the Entrelacs area of the Lower Laurentians of Quebec. The relationship between foliar and soil nutrient concentrations and decline was also assessed using data collected from the Entrelacs area as well as the St-Hippolyte area, also located in the Lower Laurentians. The first section of this thesis provides a general introduction to the study and its objectives. Chapter One is a review of the literature concerning recent forest decline. Chapter Two deals with the effects of fertilization treatments on soil and foliar nutrient concentrations and sugar maple decline in the Entrelacs area. Chapter Three is concerned with the assessment of possible relationships among soil and foliar nutrient concentrations and decline in the Entrelacs and St-Hippolyte areas. These two latter chapters are presented in paper format and are followed by an overall summary of the project in Chapter Four. The Appendix contains complete foliar and soil data sets for both the Entrelacs and St-Hippolyte areas under study.

ACKNOWLEDGEMENTS

I would like to express my thanks to my advisor, Professor Ivan O'Halloran, whose patience, guidance and constant availability were sincerely appreciated.

To the numerous people who helped in the field work for this project I also wish to express my gratitude: Judy Brisson, Michel Champagne, Michael Gee, Barbara Kishchuk, Denyse Lajeunesse, Hélène Lalande, Catherine Leduc and Jackie Meier. I am also grateful for the interest, support and availability shown by Professor William Hendershot.

I especially would like to acknowledge the patient instruction and assistance given to me by Hélène Lalande. Her helpful advice over the past three years, both in and out of the laboratory, was most appreciated.

I wish to express special thanks to my friend Maureen Wolfenden and to all my sisters. Their constant encouragement and interest were much-needed sources of motivation at times.

I dedicate this work to my husband, Ron, whose love, patience, understanding and friendship have been so evident throughout these years.

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INTRODUCTION

Forest decline is far from being a modern-day occurrence. Some forests of Europe experienced decline more than 200 years ago while in North America declining trees were a phenomenon nearly 100 years ago. Parts of Mexico, Hawaii, Papua-New Guinea, New Zealand and Australia have also been affected by declining forests in the past (Dessureault 1986). These declines have involved many different species over the years with only one or two species in a particular region being affected at a specific time. This can be contrasted with the new type of forest decline which has been taking place within the past ten years particularly in central Europe and northeastern North America. Recently, development of decline symptoms has been rapid and several species at the same time over an extended area have been affected. While in Europe and northeastern United States the majority of trees affected have been coniferous, forest decline in Canada appears to be more severely affecting the deciduous trees, especially the sugar maple (Acer saccharum Marsh.) stands located throughout their entire range in Quebec (Lachance 1985) and the sugar maple of northeastern Ontario (McLaughlin et al. 1985).

There have been numerous theories proposed to explain the occurrences of declining forests but none has been unanimously accepted by researchers as totally satisfactory. Current theories which have merited attention recently regarding the possible cause(s) of decline include the multiple-stress hypothesis, the climate hypothesis, gaseous pollutant effects, the excess nitrogen hypothesis and the acid deposition/soil acidification/nutrient imbalance theory. Interestingly, one factor which forms an integral part of each theory is common to all five theories. Nutrient deficiencies or imbalances in the soil or foliage appear to be pervasive where declines occur. Fertilization to improve or correct such nutrient deficiencies or imbalances has been shown by some researchers to have positive effects on nutrient concentrations in the past (Mader and Thompson 1969; Zoettl and Huettl 198ˢ).

In this study several fertilizers were applied, composed mainly of various combinations of basic cations which in the past have been found to be at deficiency levels in declining sites. The fertilizer treatments were used in order to study:

a) the effects of fertilizer treatments on the nutrient status of the soil and of the foliage in a declining sugar maple stand; and

b) the effects of fertilizer treatments on the decline levels of the trees as evidenced by visual examination.

Poor availability of soil nutrients has often been linked to foliar deficiencies which in turn is demonstrated by poor tree health (Mader and Thompson 1969; Huettl and Wisniewski 1987; Bernier and Brazeau 1988a). Predictions possibly could be made therefore of deficient nutrients in the foliage by examination of the soil alone if there is a strong relationship between soil and foliar nutrient status. Also it may be of interest to know if a specific element is correlated to decline so that the deficiency (or excess) may possibly be corrected through fertilization. Therefore, other aspects of this study included:

a) the examination of the relationship(s) between foliar and soil nutrient concentrations in sugar maple stands; and

b) the examination of the relationship(s) between decline levels of the tree and foliar nutrient concentrations.

The following section, Chapter 1, reviews the current literature on forest decline and nutrient imbalances. Chapter 2 discusses the effects of various fertilizer treatments on foliar nutrient concentrations, soil nutrient concentrations and tree decline levels in a sugar maple stand. Chapter 3 deals with the relationships between foliar and soil nutrient concentrations and tree decline levels and Chapter 4 gives an overall summary of the study.

CHAPTER ONE

REVIEW OF LITERATURE

1. REVIEW OF LITERATURE

1.1 INTRODUCTION

Declines have been defined as complex diseases which interact to produce an effect that no single agent can do alone. This effect is evidenced by a progressive loss of vigor and weakening of the tree together with increased susceptibility to secondary biotic and abiotic stresses. Dieback of portions of the canopy can follow and ultimately death of the tree can result (Manion 1985; McLaughlin 1985).

Declines have been observed for at least two hundred years in Europe and nearly a hundred years in North America (Dessureault 1986) but forest damage was not as systematic and widespread nor as intensive as it has been seen recently (Prinz 1987). The fact that the declines are affecting conifers and deciduous trees growing under a wide range of soil, site and climatic conditions in both Europe and North America has led researchers to classify these recent declines as a "new type" of forest decline or "Waldsterben" meaning forest death (Schutt and Cowling 1985) which is not due to natural and silvicultural factors alone (Krause et al. 1986).

More specific symptoms associated with declining coniferous trees include diameter growth reduction, needle discoloration, premature senescence of older needles, crown thinning, decreased root/shoot ratios, adventitious branching and eventual death. Deciduous trees experience many of the same symptoms as well as smaller and paler leaves, premature fall coloring, abscission of green leaves and shoots, the dying back of branches from the outermost twigs inwards, a loosening of the bark on the smaller branches and perhaps on the trunk and, with sugar maple, a slower rate of taphole closure. An important non-visual symptom which has been observed in declining stands through foliar, root and/or soil analyses is nutrient imbalances in the system (Schutt and Cowling 1985; Gagnon 1988).

Krause et al. (1986), Nilsson and Duinker (1987) and Pitelka and Raynal (1989) present comprehensive reviews on the background and extent of new forest decline in Europe and North America. In Europe, from White fir (Abies alba Mill.) in the 1970's to spruce (Picea spp), pine (Pinus spp), European beech (Fagus sylvatica) and oak (Quercus spp) throughout the 1980's, the declines seem to be getting progressively worse (Schutt and Cowling 1985). In eastern United States red spruce (Picea rubens Sarg.), several pine species (Siccama et al. 1982) and sugar maple are affected, with sugar maple decline being detected in Michigan in the late 1950's (Kessler 1963). Sugar maple is also undergoing decline in Quebec and Ontario (Pitelka and Raynal 1989). Since the late 1970's sugar maple decline has increased to the point where it is now present throughout its range in Quebec (Lachance 1985).

1.2 CAUSES OF DECLINE

Although the effects of decline can easily be seen, the cause(s) is (are) still under debate. For any explanation offered for the present decline syndrome Prinz (1983) (as cited by Krause et al. 1986) has postulated three criteria which must be met before its acceptance:

1. It must be possible to relate specific symptoms of injury to the causal factor in question;

2. Temporal development of injury must coincide with temporal development of the causal factor in question, including accumulation effects and delayed action of the factor; and
3. Spatial distribution of injury must largely coincide with spatial distribution of the factor in question.

The following discussion will examine the five major hypotheses currently proposed in the literature regarding the causal factor(s) for this new type of forest decline. These hypotheses tend to overlap in some way with one another, but each considers a different mechanism to be the driving force behind the decline.

1.2.1 The Multiple-Stress Hypothesis

The multiple-stress hypothesis, which is quite widely accepted (Dessureault 1985; Roy et al. 1985), postulates that the new declines are not just caused by one factor but by competitional, physical climate, biotic pathogen and chemical stresses which can occur at the same time or one after another in any order. They can be either long-term or short-term and either increase or decrease with age of the forest stand. They can act independently, additively, synergistically or antagonistically (Cowling 1985). Manion (1981) groups these various stresses into three sets of factors maintaining that at least one factor from each set must appear in order for decline to occur:

a) Predisposing factors - those that are generally static or nonchanging such as climate, soil moisture, genotype of host, soil nutrients, air pollutants;

b) Inciting factors - those that are short in duration and may be physical or biological in nature such as insect defoliators, early frost, drought, salt spray, air pollutants, mechanical injury; and

c) Contributing factors - those that produce noticeable symptoms and signs on the weakened host and are often blamed for the tree's death such as bark beetles, canker fungi, viruses, root-decay fungi and competition (McLaughlin 1985; Krause et al. 1986; Rehfuess 1987).

The areas with the most severe sugar maple decline in Quebec could be considered to have marginal climate and poor soils as predisposing factors (Hendershot and Jones 1989), drought and/or spring thaws in the early 1980's as inciting factors (Roy et al. 1985), and finally shoestring root rot (Armillaria mellea) as a contributing factor (Lachance 1985).

1.2.2 The Climate Hypothesis

Climate can be looked at in terms of an overall global warming trend or in terms of short-term climatic episodes, such as summer droughts, early spring thaws or late frosts, which have been previously classified as inciting factors but which some consider to be more like primary causes. Regarding global warming, since the mid-1800's the temperature has increased by about 0.5°C and is expected to increase an additional 0.5°C by the year 2000, this being at least in part due to increasing concentrations of CO_2 in the atmosphere. Warming may enhance forest growth because of an increase in growing season but other detrimental effects could also take place because of physiological processes such as photosynthesis, transpiration, respiration and reproduction capabilities being affected. Decomposition and pathogen and pest ranges may also be altered (Hepting 1963; Smith 1985). Auclair (1987) related the onset of widespread crown dieback in 1925, 1937 and 1981 on some northern hardwood species in eastern Canada to episodes of rapid increase in global temperature and theorized that long-term global warming and associated variability in weather is a primary factor inciting forest decline in the northern hardwoods of eastern Canada and the northeastern United States. Manion (1981) also related the birch (Betula spp) dieback between 1930 and 1950 in northeastern North America to an increase in average summer temperatures of 1°C over a 10-20 year period. He considered this increase a predisposing factor.

Short-term climate events such as drought and frost damage have been shown to be important inciting factors in decline. In Europe the experience of dry summers of 1976, 1980, 1982 and 1983 coinciding with a considerable increase in the development of forest decline has led many to believe that climate does have a triggering or synchronizing role to play (Johnson and Siccama 1983; Schutt and Cowling 1985; Smith 1985; Krause et al. 1986; Prinz 1987; Rehfuess 1987). From 1964 to 1966 the United States experienced the most severe drought in the northeast in the past 250 years (LeBlanc et al. 1987). Johnson and Siccama (1983) suggested that subsequent growth reductions in red spruce represented the initiation of dieback and decline in these trees. Scots pine (Pinus sylvestris L.), red pine (Pinus resinosa Ait.) and Norway spruce (Picea abies (L.) Karst.) all exhibited periods of diminished growth as well during the decades after 1960 with decreases in growth being larger in those groups assumed to be more susceptible to acidic deposition effects

(LeBlanc et al. 1987). But McLaughlin (1985) argued against drought as a primary causal agent, stating that initiation of the downward growth trend occurred prior to the driest years (1964 and 1965) in many northeast sites and occurred at some southern sites where droughts were not apparent or where droughts could not be obviously correlated to the onset of growth reductions.

Quebec has experienced unusual weather events in the 1980's which Roy et al. (1985) suggest could be a probable factor in sugar maple decline. In the winter of 1979-80 there was little snow cover on the soil, possibly resulting in deep frost penetration which would seriously injure the root system (Lachance 1985). Another damaging climatic event occurred in June 1980 when a late frost severely damaged maple in early leaf over an area of 1300 km^2 (Hendershot and Jones 1989). In early 1981 a thaw took place where for 25 days (February 15-March 2, March 5-13) maximum daily air temperatures exceeded 0°C. Sapflow and premature bud-break resulted on some trees. Physiological changes that probably resulted included rehydration of tissues and subsequent decrease in frost resistance. The freezing temperatures of March 3 and March 14-17 which followed this thaw, together with the little amount of snow cover once again, probably resulted in severe frost damage and mortality to the roots (Auclair 1987). In May 1982 there was a drought at early leaf period followed by another drought in July of that year (Roy et al. 1985). These inciting factors could all have had a devastating effect on the trees.

1.2.3 Gaseous Pollutants

The major gaseous pollutants that are considered by some to be primary factors in forest decline are sulphur dioxide and ozone.

Sulphur dioxide is more important on a regional scale as one of the precursor pollutants leading to the formation of acid rain, but it is also capable of causing more direct damage to forests for distances of over 100 km from major point sources (Linzon 1986). For example, in the Ore Mountains of northeastern Bavaria and the northern mountains of Czechoslovakia where about 30,000 ha of spruce forests have been killed, classical sulphur dioxide damage to the foliage was considered the most prominent stress factor, disturbing mainly the photosynthesis and transpiration of the trees. Frost shocks were also considered to contribute to the decline of these forests (Rehfuess 1987). However, Krause et al. (1986) have stated that in general in Europe, where sulphur dioxide concentrations have been decreasing since 1970, there is neither the necessary spatial nor temporal correlation between areas of forest decline and sulphur dioxide concentrations. As Johnson and Siccama (1983) pointed out, red pine growing on exposed ridges of the Green Mountains in the United States showed no abnormal growth or mortality and since red pine is a very sensitive species to sulphur dioxide it should therefore be a good indicator of the effects of sulphur dioxide pollution.

Ozone, which is found in higher concentrations in areas of greater altitudes (500 to 1500 m above sea level), has been increasing steadily in concentrations since 1967 in many parts of Europe (Krause et al. 1986). Ozone can cause cell membranes and cuticular waxes to deteriorate, making them more permeable to cations. Leaching of essential nutrients is even more enhanced in combination with acid rain and fog (Prinz 1987). This can lead to a decrease in net photosynthesis with subsequent poorer development of the root system and foliar decline symptoms which can in turn increase the tree's susceptibility to other stress factors (Schutt and Cowling 1985). Prinz (1987) and Krause et al. (1986) believe that temporal and spatial development of forest decline can be related to distribution and formation of O_3 in the atmosphere, leading them to conclude that ozone is the major contributing factor of all air pollutants involved. Some researchers do not believe, however, the ozone hypothesis adequately explains many symptoms seen on, for example, declining red spruce stands in the northeastern United States. Also, since conducive conditions to forming ozone would be more frequent in the southern than northern Appalachians but mortality is prevalent in the north and not the south, Johnson and Siccama (1983) suggest it would be surprising if ozone were the leading cause of decline. Much more detailed knowledge is necessary of all facets of weather conditions and events that could have any bearing on secondary air pollutants in order to make a strong link between air pollutants and forest decline (Manion 1985).

In southern Quebec, relatively low levels of ozone exist, seasonal mean values being between 20 ppb and 40 ppb (Schemenauer and Anlauf 1987), and the concentrations of sulphur dioxide in ambient air are probably well below the phytotoxicity thresholds except for isolated emission sources which are of negligible importance to the region as a whole (Bernier and Brazeau 1986). Therefore air pollutants, although possibly contributing, are probably not major factors relating to the serious decline of sugar maple, a species which has been classified as "tolerant" to both sulphur dioxide and ozone (Davis and Gerhold 1976, as cited by Kozlowski and Constantinidou 1986).

1.2.4 The Excess Nitrogen Hypothesis

The excess nitrogen or "ammonium hypothesis" postulates that ever-increasing amounts of nitrogen compounds in wet and dry deposition are contributing to declining forests (Nihlgard 1985). Several mechanisms may be involved:

a) Nitrogen may be taken up in the form of ammonia, ammonium and nitrous oxides by the leaves through dry and wet deposition. During the natural metabolism of nitrogen, ammonium is oxidized and nitrate reduced to ammonia before assimilation to amines, amides, amino acids and proteins takes place (Raven and Smith 1976). This process results in soluble carbohydrates being consumed. Volume production of the tree is stimulated to produce more carbohydrates in order to utilize the additional nitrogen. The production of assimilation waste products is also therefore increased and toxic concentrations of an increasing amount of waste substances in the leaves may be reached when they cannot be exuded in dry periods. The tree may then just "shed" the leaves;

b) Decreased amounts of soluble carbohydrates caused by increased amounts of leaf nitrogen will result in decreased root growth, changes in root/shoot ratios and decreases in frost hardiness, for conifers in particular. Friedland et al. (1984), studying winter damage to foliage as a factor in red spruce decline in the Appalachians suggested that nitrogen supplied (37-44 kg N $ha^{-1}yr^{-1}$) to the foliage and/or soil induced growth later in the season and delayed cuticularization of the epidermis. This, along with incomplete starch to sugar conversions, caused the plants to be more susceptible to damage from early frost or dessication;

c) Leaf damage such as decreased leaf resistance, leaf chlorosis, necrosis and turgor loss can take place after direct uptake of ammonium. The uptake will, in turn, cause cations such as K or Mg to be exchanged;

d) Excess nitrogen may also stimulate fungal diseases as well as insect attacks and algal growth on leaf surfaces;

e) Excess nitrogen will cause initial increased growth, resulting in a greater demand for other nutrients and water. In low fertility soils deficiencies of other essential nutrients can result. Mohren et al. (1986) concluded when studying Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) in the Netherlands that the increased nitrogen availability due to atmospheric nitrogen input resulted in the development of phosphorus deficiency;

f) A high deposition of ammonium and nitrate may cause an increase in the rate of nitrification, resulting in a more acidic soil environment with subsequent increases of leaching of base cations and Al solubilization;

g) Soil leaching of Mg, Ca and K is increased due to soil acidification, and high ammonium concentrations in the soil suppresses Mg uptake, potentially causing a deficiency in Mg which is necessary in the formation of chlorophyll and for protein synthesis;

h) Mycorrhizal activity, which is very important in phosphorus nutrition for the tree, may be adversely affected. Mycorrhizal root infection has been reduced in some nitrate-rich soils, and the decreased supply of carbohydrates being exuded from the roots due to their increased consumption because of excess ammonium may also inhibit activity (Nihlgard 1985).

Although the excess nitrogen hypothesis can explain decline in many areas receiving large deposition, such as the Netherlands where deposition can exceed 50 kg N ha^{-1} yr^{-1}, some consider the link not too strong in areas of decline at higher altitudes in central and southern Germany where deposition rates are less than 25 kg N ha^{-1} yr^{-1} (Blank et al. 1988).

1.2.5 Acid Deposition, Soil Acidification and Nutrient Imbalances

A final hypothesis on the cause of the present forest decline is the soil acidification and nutrient imbalance theory. The natural acidification of some forest soils is accelerated when the input of acidity in the forest ecosystem exceeds the buffering capacity of the soil and when cation losses due to leaching are not sufficiently replaced by cation weathering of primary minerals (Johnson et al. 1982). During this period of acidification and depending on various soil chemical properties, replacement on the exchange sites with H^+ and Al^{3+} ions and subsequent leaching of nutrient cations such as Ca, Mg, K and Na will take place causing a potential nutrient deficiency situation for the trees (Huttermann and Ulrich 1984; Johnson et al. 1985). Huettl (1986a) and Zoettl and Huettl (1986) consider this deficient nutrient supply as the dominant predisposing stress factor for the new type of forest decline. Acid deposition and nutrient imbalances have been suggested as the reasons for changes in the rates of K, Ca and Mg cycling in deciduous forests of

Tennessee (Johnson et al. 1985). Hauhs and Dise (1989) reported as well that Ca and Mg depletion in the soil at Lange Bramke in West Germany was caused by acid deposition and that soil acidification was involved in the Mg deficiency symptoms seen since 1982 in about one-third of the tree population in the area. This mechanism also has been used to explain why declining sugar maple forests in Quebec have shown low foliar concentrations of K, Ca, Mg and in some cases P (Bernier and Brazeau 1988bc; Gagnon 1988) as well as a major decrease in exchangeable cations in the soil of K, Mg and Ca over the past 17 years (Gagnon et al. 1986).

Acid deposition can also cause increased foliar leaching. Using acidified artificial mist with sugar maple seedlings, Wood and Bormann (1975) demonstrated that foliar losses of K, Mg and Ca increased as the acidity of the artificial mist was raised. Although leaching will involve an exchange of H^+ from the acidic deposition with cations such as Ca, Mg or K from the foliage, the total H^+ load to the soil will not be decreased. The amount buffered in the crown canopy is released through the root system to the soil when the base cations that were previously leached from the foliage are replaced by base cations from the soil solution. In this way, electroneutrality in the tree is maintained. It is also maintained during ion uptake by the tree. Since trees will often take up more cations than anions, especially in acid soils where conditions for reduced nitrification exist, there will be an additional proton flux from the root to the soil which, combined with the proton flux resulting from canopy buffering, will acidify the rhizosphere (Ulrich 1983; Matzner and Ulrich 1985).

Aluminum concentration in the soil solution will be increased as pH decreases and may reach the point where it is damaging or even toxic to the roots (Ulrich et al. 1980; Godbold et al. 1988). Also, while studying spruce trees in North America and Europe, Joslin et al. (1988) found that sites with higher levels of plant-available Al supported trees with correspondingly lower foliar levels of Ca and Mg providing circumstantial evidence that Al may be interfering with Ca and Mg uptake and transport. This has been shown to occur in other studies in Europe as well (Huttermann and Ulrich 1984; Godbold et al. 1988). Low foliar levels of Mg in particular have been evident in many species in declining forests in Germany and this has been related to acid deposition (Zech et al. 1985). Rehfuess (1987) found that some ozone-damaged spruce trees had extreme Ca and Mg deficiencies while growing on sites with a potential for adequate amounts of available Mg. He concluded that the ozone-damaged needles, when subjected to acid mists, allowed much leaching to occur. In addition, acid deposition could accelerate leaching of Mg from the soil and increase Al solubilization resulting in negative root uptake effects on Mg. As base cations are lost from the system, nutrient imbalances may result and subsequently affect the roots. For example, adequate Ca is needed to maintain the selective ion uptake processes in roots. Deficiency in Ca or Mg can result in damaged roots and may be expressed in above-ground symptoms (Epstein 1961; Meyer et al. 1985). Also, increased Al concentration in the soil and less Ca due to leaching losses decreases the Ca/Al molar ratio. It is believed that this ratio, which should be greater than one (Rost-Siebert 1983 as cited by Eldhuset et al 1987), and not the absolute amounts of Ca or Al is the important factor for the manifestation of Al-toxicity since even at low pH values and high Al-concentrations a high Ca-concentration can counteract the detrimental effect of Al ions (Huttermann and Ulrich 1984; Godbold et al. 1988).

The acidification-nutrient imbalance theory has received criticism however. Rehfuess (1987) found much spruce decline in the high altitudes of the calcareous Alps and felt that soil acidification could not be a stress factor under conditions where Ca and Mg were plentiful but available K and Mn were lacking in the soil. Eldhuset et al. (1987) in experimenting with Norway spruce, European bi ch (Betula pendula Roth.) and Scots pine seedlings with nutrient solutions found that the Ca/Al ratio in the root medium was probably not in itself important but rather that a sufficient amount of Ca in relation to plant requirement must be available to the roots. They suggested that Al was not an important factor in connection with forest dieback in Europe. Other experiments have shown that declining red spruce in northeastern United States could have low (<500 ppm) Al concentrations in the fine roots and healthy spruce roots could have high Al concentrations (>2000 ppm) (Johnson and Siccama 1983). The Ca/Al ratios followed a similar pattern. Zoettl and Huettl (1986) when examining Norway spruce in the southern Black Forest Region observed significant differences in the Ca and Mg needle contents of healthy and declining trees but no significant differences in the Al content in either the needles or roots and no differences in root growth.

Of the several hypotheses that have been discussed, no single hypothesis has yet been fully accepted to explain the new forest declines in evidence in Europe and North America. However, there is a factor common to all forest decline areas and that is nutrient deficiencies or imbalances for which fertilization may possibly be used as a means to restore nutrients to the deficient soil or to correct the present imbalances. This would not deal with the cause of the decline, which may never be known, but it may be an effective means to treat at least the symptoms.

1.3 FERTILIZATION TO CORRECT NUTRIENT DEFICIENCIES

Because a deficient nutrient supply is considered by some to be the dominant predisposing stress factor for the new type of forest decline it is hypothesized that fertilization could be a useful tool to possibly mitigate this decline (Huettl 1986b; Zoettl and Huettl 1986; Huettl and Wisniewski 1987). "Diagnostic fertilizer trials" were conducted in southwestern Germany at different sites with different deficiency symptoms, parent materials and soils. Analyses of needle and root tissue and soils were done, the atmospheric deposition load was taken into account and when the nutrient deficiencies were "diagnosed" appropriate fertilizer treatments were given to the stands. Results after application showed a substantial visible and chemical improvement even after only one year (Huettl 1986b; Huettl and Wisniewski 1987). Matzner et al. (1983) in studying the effects of N-K fertilization and liming on the fluxes of chemical elements for a beech and spruce stand in Germany stated that the addition of easily soluble-salt fertilizers would cause an acidification push leading to high concentrations of Al in the soil and subsequent root stress due to Al-toxicity. They concluded liming should be used to improve the chemical state of the soil before additions of soluble-salt fertilizer or at least liming should be used in conjunction with a low dose salt fertilizer. They also found an increase in the Ca/Al ratio and concluded that the beneficial effects of liming of acid forest soils outweigh those being possibly detrimental. Ulrich et al. (1980) also stated that large scale liming is recommended for forest protection as an intermediate measure if a site is subjected to substantial dry deposition of SO_2. However Tomlinson (1987) cautioned that Ca in high concentrations in the soil solution can act antagonistically to K, inhibiting its uptake by the roots and causing a K deficiency in the tree.

Mader and Thompson (1969) also used fertilizer as a means to improve low foliar N levels in declining sugar maple in northeastern United States during the mid-1960's. After fertilizing at the rate of 224 kg N ha^{-1}, N levels increased resulting in improved foliage color and condition, leading to the conclusion that foliar nitrogen deficiencies were a critical factor in sugar maple decline. Drought, they thought, could also be a major factor in the decline. With increased emissions of nitrous oxides since that time, however, insufficient nitrogen nutrition is generally not a problem, in central Europe especially. On the contrary, atmospheric nitrogen overfertilization is considered more a problem as was previously discussed.

Hendershot et al. (1989) also found that fertilization resulted in positive responses from declining sugar maple trees in Quebec after initial foliar analyses indicated they were low in base cation nutrients. They attributed this response to a relationship between forest decline and nutrient deficiencies or imbalances.

Although fertilization may not help the tree once a critical degree of damage has occurred, it has helped foliage return to a green color after being yellow and improved height growth, lateral shoot elongation as well as the quality of foliar wax. Also, healthy and vigorous stands are less likely to succumb to secondary pathogens (Huettl and Wisniewski 1987).

1.4 CONCLUSION

The impacts of many of the stresses that declining trees are subjected to are often related to the nutritional status of the stand - frost susceptibility and N, decrease in photosynthesis and Mg, possible root necrosis and Ca and Al, increased transpiration and K. This situation may possibly be improved if nutrient imbalances did not exist in the system to exacerbate the effects of other stresses such as those imposed by acidic deposition, climate or biotic attacks.

It has been shown that trees suffering from nutrient deficiencies attempt to compensate through increased nutrient uptake by roots. This reaction can occur only if the root system is still functional and if sufficient nutrient elements are supplied in a plant-available form (Huettl and Wisniewski 1987). Fertilization may be able to prolong the life of the trees up until the time where the as-yet-unknown cause of decline can be determined, and the most appropriate steps in preserving these forests taken.

CHAPTER TWO

EFFECTS OF FERTILIZATION ON SOIL NUTRIENT CONCENTRATIONS, FOLIAR NUTRIENT CONCENTRATIONS AND DECLINE LEVELS

2. EFFECTS OF FERTILIZATION ON SOIL NUTRIENT CONCENTRATIONS, FOLIAR NUTRIENT CONCENTRATIONS AND DECLINE LEVELS

2.1 INTRODUCTION

Deciduous forests in Quebec, especially those in the Appalachian Uplands but also including those in the Lower Laurentians, have been showing symptoms of severe decline since the early 1980's. This situation is of great concern because the dominant species of this forest, sugar maple, is particularly affected. It has been determined that the present decline is not only decreasing the volume of wood fibre in recent years (Carrier 1986) but also threatening the maple syrup industry which generates annual revenues of approximately $40 million in Quebec to sugarbush owners who, in most cases, depend on this extra income to make their farm a viable operation (Robitaille 1986).

There is yet to be a concensus reached on the exact causes of the present decline. However, many researchers have concluded that disturbances in mineral nutrition appear to be involved (Mader and Thompson 1969; Carrier 1986; Zoettl and Huettl 1986; Bernier and Brazeau 1988a;1988b;1988c). Although only considered a palliative solution, fertilization has been used with some success in the past as a tool to mitigate forest decline in central Europe (Zoettl and Huettl 1986; Huettl and Wisniewski 1987) and to alter or improve nutritional status of declining maple stands in northeastern North America (Mader and Thompson 1969; Hendershot and Jones 1989; Hendershot et al. 1989). This may have been accomplished either directly through an increased supply of the deficient nutrients to the trees or indirectly through the creation of a more favourable milieu in which mineralization could be increased resulting in a greater availability of nutrients for the trees.

In this study, then, fertilizers were applied in order to study their effects on soil nutrient concentrations, foliar nutrient concentrations and decline levels of sugar maple trees. It is important to note here that although foliar nutrient concentrations are often directly linked to tree health, research has shown that in many cases after fertilization a "dilution effect" will take place whereby, because the biomass of the tree has been increased, the concentrations of certain nutrients within the foliage may actually decrease (Jarrell and Beverly 1981). Visual examination of the tree regarding decline level is therefore necessary to preclude this possibility of a dilution effect and give, together with soil and foliar analysis, a more accurate portrayal of the state of the tree decline.

2.2 MATERIALS AND METHODS

2.2.1 Study Area

The study was conducted in the Entrelacs area of the Lower Laurentians of Quebec (approximately 110 km northeast of Montreal) in part of a managed sugarbush which was dominated by 100-130 year old sugar maple but also included some American beech (<u>Fagus grandifolia</u> Ehrh.) and yellow birch (<u>Betula alleghaniensis</u> Britton). These species are typical of those found in the Great Lakes - St. Lawrence forest region of Canada in which the site is located. Soils in the area were derived from glacial till and had a mor type of humus. They were predominantly humo-ferric or ferro-humic podzols (Canada Soil Survey Committee 1978) and were well- to imperfectly-drained. Some poorly drained organic soils were also found in depressions. The site was located on an easterly facing slope and contained some rock outcrops.

While the complete range of decline levels from a normal, healthy tree to a dead tree could be seen, in general the site was one of moderate decline with the vast majority of sugar maple showing evidence of some decline.

2.2.2 Plot Establishment

In May 1987, 24 sample plots (20 m x 20 m) were established with buffer strips of at least 5 m left between plots. One of eight treatments, replicated three times, was then assigned randomly to each plot (Table 2.1). Fertilizer was applied by hand to quadrants of the plots to ensure uniformity of application. Eight sugar maple trees (dying or small trees excluded) per plot, located at least 3 m inside the plot boundaries, were tagged and measured for diameter at breast height (average diameter = 25.5 cm).

2.2.3 Soil Sampling and Analyses

In July 1987, each plot was divided into four equal sections and a composite of four samples collected from each section for both the organic

Table 2.1. List of treatments applied to Entrelacs site (3 replicates)

Treatment	Fertilizer Rate	Element Rate
1. Control	-	-
2. K_2SO_4	400 kg ha^{-1}	166 kg ha^{-1} K
3. $CaCO_3$	400 kg ha^{-1}	160 kg ha^{-1} Ca
4. $Ca,Mg(CO_3)_2$	400 kg ha^{-1}	87 kg ha^{-1} Ca 53 kg ha^{-1} Mg
5. K_2SO_4 + $CaCO_3$	(400+400) kg ha^{-1}	166 kg ha^{-1} K 160 kg ha^{-1} Ca
6. K_2SO_4 + $Ca,Mg(CO_3)_2$	(400+400) kg ha^{-1}	166 kg ha^{-1} K 87 kg ha^{-1} Ca 53 kg ha^{-1} Mg
7. $(NH_4)_2SO_4$	400 kg ha^{-1}	80 kg ha^{-1} N
8. 4-4-8	400 kg ha^{-1}	16 kg ha^{-1} N 7 kg ha^{-1} P 27 kg ha^{-1} K 48 kg ha^{-1} Ca 16 kg ha^{-1} Mg

FH horizon (4-7 cm thick with L layer removed and not sampled) and the top 15-20 cm of the mineral B horizon. Air dried soil samples were sieved (2 mm) and subsamples extracted (in duplicate) using 0.1 M $BaCl_2$ (Hendershot and Duquette 1986). Exchangeable cations were determined using atomic absorption spectrophotometry (AAS) with an air/acetylene gas mixture for Ca, Mg, K, Na, Fe and Mn determination and with a nitrous oxide/acetylene gas mixture for Al determination, and cation exchange capacities calculated. Quality control samples were routinely analysed to ensure reliability of laboratory procedures. Soil pH was determined in water with a ratio of soil to water of 1:2 for the mineral soils and 1:10 for the organic soils.

2.2.4 Foliar Sampling and Analyses

Because foliar nutrient composition varies over the growing season, leaf sampling must take place when trees are subject to the least amount of variability in foliar nutrient concentrations. For temperate deciduous trees such as sugar maple the month of August has been recommended for sampling (Leaf 1973; Lea et al. 1979; Morrison 1985). It is thought, however, this period of stability throughout August may be shortened if the tree is subject to nutrient or air pollution stresses. In such cases late July or early August would be the better period of time to sample before leaf growth has ceased with its subsequent changing of foliar nutrient concentrations (Bernier and Brazeau 1988a). Therefore leaf sampling took place in early August 1987 and late July 1988. Four of the eight tagged trees in each plot were sampled. Since it has been suggested that once a tree has reached a certain level of decline fertilization may not have a positive impact on that tree (Huettl and Wisniewski 1987), severely declining trees were not sampled. Two branches were cut from different sections of the lower one-third of the crown of the tree in an attempt to reduce variations in foliar concentrations caused by crown position (Morrison 1985). Fifteen leaves from each branch were combined, placed in a paper bag and oven-dried at 65°C for 24 hours. The leaves were then ground (petioles removed) and duplicate subsamples acid-peroxide digested for chemical analysis (Thomas et al. 1967). Concentrations of foliar elements were determined as follows: N and P by using a Technicon autoanalyser; K, Ca, Mg, Fe, Mn and Zn by AAS using an air/acetylene gas mixture; Al by AAS using a graphite furnace with argon gas. Molar ratios of Ca/K, Ca/Mg and Ca/Al were calculated. Quality control samples were routinely analysed to ensure reliability of laboratory procedures.

2.2.5 Tree Evaluation

Visual evaluations of the tagged trees in relation to decline symptoms were performed in early August 1987 and late July 1988. In both years, a rating was assigned to each tree based on a scale developed by Mader and Thompson (1969) which follows:

1. Normal trees. Foliage full size and rich in color. No dead twigs or branches.
2. Foliage abnormally small, curled, thin, yellowish, or otherwise weak in appearance, but not conspicuously so. No dead twigs or branches.
3. A tree similar to 2, except that it has a number of dead, that is, bare twigs in the top of the crown. Such bare twigs number less than 25% of the crown and perhaps are in a dying state, and hence represent one of the early symptoms of dieback.

3.5. Same as 3 except the number of bare twigs will be greater than 25% but less than half the crown.

4. Trees with dead branches for no apparent reason but such branches to constitute less than half the crown. A "branch" should be at least three or four feet long and there should

be two or three dead branches before the tree is placed in this class.

5. Trees with over half the crown dead.

6. Crown dead except for small adventitious branches usually to be found at the base of the crown.

In 1988 more specific criteria which gave a more accurate portrayal of the state of decline were added to the visual examination incorporating some of the procedures developed by a Canada-USA task force on hardwood decline (Millers and Lachance 1988). These included estimates of:

1. Branch dieback - percentage of crown volume that has died from the outside in;

2. Foliage transparency - percentage of skylight visible through the foliated portion of the branches when looking upwards from near the trunk; and

3. Foliage discoloration - percentage of the foliage that is discolored, e.g. pale green, yellow, brown leaves.

When using this evaluation scheme, trees were assigned a decline index (DI), the mean of these three criteria, with a rating of 0 representing a perfectly healthy looking tree and 100 representing a dead tree.

2.2.6 Statistical Analyses

Soil data

The experiment was conducted as a completely randomized design and the mean (four samples) data of each plot were analysed using the general linear model (GLM) and analysis of variance (ANOVA) programs of SAS software (SAS Institute Inc. 1979). Single degree of freedom contrasts were used according to the procedures of Steel and Torrie (1980) to detect treatment differences when analysis of variance indicated significant ($p < 0.05$) treatment effects.

Foliar data

The foliar data were statistically analysed in a similar manner as the soil data except for the inclusion of a year effect (1987 and 1988) in the model statement. Thus, the foliar data analysis was conducted using a factorial model.

Decline data

The data collected (1987 and 1988) using the Mader and Thompson scale were analysed in a similar manner as the foliar data, while the decline index data (1988) were analysed using the same procedures as for the soil parameters.

2.3 RESULTS AND DISCUSSION

2.3.1 Overall Site Evaluation

It is assumed that the unfertilized control plots represent the natural nutritional and decline status of the site.

Evaluation of tree decline for the control plots indicated that levels ranged from 2 to 4 with a mean of 3.2 by using the Mader and

Thompson scale and from 2 to 33 with a mean of 10 by using the decline index parameters. The site, therefore, was one of light to moderate decline with the average level being evidenced by trees having a number of dead twigs at the top of the crown numbering approximately 25% of the total crown area.

Soil analyses of the FH and B horizons indicated that the pH values, while acidic, were not abnormally low for soils of this region (Tables 2.2 and 2.3). (Complete data sets for both the soil LH and B horizons are given in Appendix Tables A.1 and A.2, respectively.) Calcium values for both horizons (15.34 and 1.46 cmol(+)kg^{-1} for FH and B horizons, respectively) were generally higher than those found by Bernier and Brazeau (1988c) at similar sites in the Lower Laurentians (10.56 and 0.22 cmol(+)kg^{-1} for H and Bhf horizons, respectively). This was reflected by the higher proportion of Ca on the exchange sites (Tables 2.2 and 2.3). However, Mg and K were not abundant in either soil horizon. Low Mg values were not surprising as soils in the Lower Laurentians at elevations above 200 m are predominantly derived from Mg-poor granite and syenite (Raymond et al. 1976 as cited by Bernier and Brazeau 1988c). Since surface mineral soils in New York were considered Mg-deficient when they measured 0.12-0.22 cmol(+)kg^{-1} (Stone 1953), Mg values of 0.12 cmol(+)kg^{-1} in the B horizon (Table 2.3) would be considered quite low. Potassium values of 0.86 and 0.07 cmol(+)kg^{-1} for the FH and B horizons, respectively, were also much lower than K concentrations reported for other K-deficient sites in the Lower Laurentians (1.51 and 0.11 cmol(+)kg^{-1} for the H and Bhf horizons, respectively) (Bernier and Brazeau 1988c).

Table 2.2. Influence of treatments on selected soil chemical properties of FH horizons at Entrelacs

Treatment	pH H_2O^+	Ca	Mg	K	Al	CEC	%Ca	%Mg	%K	%Al
		----------- cmol(+) kg^{-1} ----------					------- of CEC --------			
1.Control	4.49 (0.14)	15.34 (1.25)	1.53 (0.15)	0.86 (0.10)	5.54 (3.09)	24.19 (2.04)	64.1 (9.2)	6.4 (1.0)	3.6 (0.7)	22.0 (11.2)
2.K_2SO_4	4.54 (0.35)	16.44 (1.48)	1.59 (0.26)	1.34 (0.50)	3.46 (1.76)	23.94 (2.01)	68.6 (3.5)	6.7 (1.0)	5.8 (2.4)	14.1 (6.8)
3.$CaCO_3$	4.73 (0.37)	20.68 (5.76)	1.96 (0.30)	0.95 (0.11)	2.30 (0.79)	26.93 (6.76)	76.4 (2.2)	7.5 (1.3)	3.7 (1.3)	8.5 (1.3)
4.$Ca,Mg(CO_3)_2$	4.33 (0.01)	17.53 (1.62)	2.62 (0.11)	1.10 (0.03)	2.03 (1.33)	24.10 (0.88)	72.9 (4.7)	11.0 (0.7)	4.6 (0.1)	8.1 (4.8)
5.K_2SO_4 + $CaCO_3$	4.43 (0.35)	24.85 (1.85)	2.13 (0.04)	1.45 (0.37)	1.95 (1.02)	31.16 (2.10)	79.7 (2.4)	6.9 (0.4)	4.7 (1.2)	6.3 (2.9)
6.K_2SO_4 + $Ca,Mg(CO_3)_2$	4.36 (0.14)	18.20 (1.48)	2.97 (1.17)	1.50 (0.23)	2.45 (1.61)	26.03 (0.67)	69.9 (14.4)	11.4 (4.2)	5.8 (0.8)	9.5 (6.5)
7.$(NH_4)_2SO_4$	4.33 (0.39)	18.02 (5.47)	1.76 (0.63)	1.02 (0.19)	3.71 (2.24)	25.64 (4.21)	69.4 (11.6)	6.9 (1.9)	4.1 (0.1)	15.2 (11.4)
8.4-4-8	4.27 (0.07)	18.76 (4.72)	2.37 (0.48)	1.18 (0.06)	1.61 (0.41)	24.84 (4.72)	74.9 (4.7)	9.6 (0.3)	4.9 (1.1)	6.9 (2.9)

$^+$ soil-water ratio, 1:10
Note: Standard deviations of means are given in parentheses

Table 2.3. Influence of treatments on selected soil chemical properties of B horizons at Entrelacs

Treatment	pH H_2O^+	Ca	Mg	K	Al	CEC	%Ca	%Mg	%K	%Al
		----------- cmol(+) kg^{-1} ----------					------- of CEC --------			
1.Control	5.01 (0.08)	1.46 (0.46)	0.12 (0.04)	0.07 (0.02)	3.55 (0.13)	5.34 (0.53)	25.4 (5.9)	2.1 (0.6)	1.3 (0.3)	68.7 (6.1)
2.K_2SO_4	5.02 (0.16)	1.43 (0.50)	0.15 (0.06)	0.13 (0.02)	3.34 (0.56)	5.24 (0.50)	27.6 (9.4)	2.8 (1.0)	2.4 (0.5)	63.4 (12.1)
3.$CaCO_3$	5.07 (0.16)	1.32 (0.57)	0.15 (0.06)	0.07 (0.01)	3.24 (1.41)	4.94 (1.07)	28.1 (13.1)	3.1 (1.3)	1.4 (0.4)	64.2 (15.0)
4.$Ca,Mg(CO_3)_2$	4.97 (0.11)	1.16 (0.10)	0.11 (0.02)	0.06 (0.02)	3.69 (0.87)	5.17 (0.98)	22.8 (3.1)	2.1 (0.6)	1.3 (0.7)	71.2 (3.7)
5.K_2SO_4 + $CaCO_3$	4.94 (0.19)	1.66 (0.25)	0.16 (0.05)	0.13 (0.01)	3.88 (1.21)	6.02 (0.93)	27.8 (8.1)	2.6 (1.1)	2.1 (0.4)	64.5 (10.7)
6.K_2SO_4 + $Ca,Mg(CO_3)_2$	4.96 (0.05)	1.10 (0.36)	0.10 (0.02)	0.11 (0.01)	3.93 (0.39)	5.42 (0.76)	19.6 (4.0)	1.9 (0.2)	2.0 (0.3)	73.4 (4.5)
7.$(NH_4)_2SO_4$	4.82 (0.18)	1.63 (0.12)	0.17 (0.02)	0.10 (0.04)	3.76 (1.19)	5.80 (1.19)	28.6 (7.2)	3.0 (0.8)	1.8 (0.9)	64.3 (8.1)
8.4-4-8	4.85 (0.08)	1.11 (0.52)	0.11 (0.04)	0.07 (0.01)	4.64 (0.93)	6.10 (1.59)	17.4 (3.7)	1.7 (0.2)	1.1 (0.1)	77.1 (4.2)

$^+$ soil-water ratio, 1:2
Note: Standard deviations of means are given in parentheses

Percentage of Al on the exchange sites was also quite high for the B horizon (68.7% - Table 2.3) resulting in a low base saturation of the soil. Increasing acidification due to acidic deposition would increase the amount of Al and H on the exchange complex and promote the leaching of base cations such as K and Mg from the soil profile. Because of the poor buffering capacity of the soil the cations leached from the profile are not easily replaced. This has been the suggested mechanism responsible for the lowering of pH and drop in exchangeable base cation levels in the soil that have been taking place in many areas of Quebec over the past twenty years (Gagnon et al. 1986).

Analyses of the foliar nutrient data indicated that there were no significant year*treatment interactions and therefore the 1987 and 1988 foliar data were combined for each treatment. (A complete data set of foliar elemental concentrations for 1987 and 1988 is given in Appendix Tables A.3A and A.3B, respectively.) Control concentrations of Mg and K were both below the published range for those elements (Table 2.4). However, when comparisons were made to the critical limit values for sugar maple, Mg, K and P were at the critical level with Ca only slightly above the critical limit. The low levels of Mg and K reflected the soil nutrient status where both elements were seen previously to have been at low levels perhaps due to base cation leaching, and/or low parent material concentration.

Nitrogen concentrations were at the upper limit of reported values. Increased N availability in the soil due to atmospheric nitrogen input can cause increased growth initially. However, this may result in a greater demand for other nutrients and water which cannot always be met due to

Table 2.4. Influence of treatments on foliar concentrations at Entrelacs, published ranges and critical limits for each element

Treatment	Ca	Mg	K	N	P	Al
	mg g^{-1}					ug g^{-1}
1. Control	7.14 (0.91)	0.90 (0.07)	6.04 (0.66)	22.27 (3.55)	1.01 (0.04)	35.68 (8.26)
2. K_2SO_4	8.16 (2.04)	1.08 (0.23)	7.92 (1.02)	20.72 (2.30)	1.03 (0.09)	35.12 (4.82)
3. $CaCO_3$	8.64 (1.32)	0.99 (0.07)	5.82 (1.51)	19.21 (1.81)	0.98 (0.07)	27.11 (3.48)
4. $Ca,Mg(CO_3)_2$	7.16 (0.28)	1.01 (0.16)	5.16 (0.75)	19.61 (1.37)	0.98 (0.11)	25.84 (3.19)
5. K_2SO_4 + $CaCO_3$	8.62 (2.31)	1.17 (0.09)	8.26 (0.84)	21.35 (2.66)	1.02 (0.07)	28.71 (5.90)
6. K_2SO_4 + $Ca,Mg(CO_3)_2$	6.66 (1.81)	0.98 (0.15)	8.51 (0.82)	20.49 (1.20)	1.02 (0.09)	28.48 (4.20)
7. $(NH_4)_2SO_4$	8.06 (0.92)	1.11 (0.07)	6.19 (1.53)	22.48 (3.87)	1.12 (0.06)	34.30 (5.23)
8. 4-4-8	6.92 (1.14)	0.98 (0.14)	6.21 (0.92)	20.09 (1.19)	1.01 (0.08)	28.21 (5.90)
Published Range+	6.0-14.3	1.1-1.8	8.0-10.1	16.6-22.8	1.0 2.4	60.0
Critical Limit++	7.0	0.9	6.0	15.0	1.0	

+ adapted from Bernier and Brazeau 1988a

++ adapted from Hendershot and Lalande 1988. It should be noted that these values are not necessarily correct or absolute.

Note: Standard deviations of means are given in parentheses

the short supply in the soil. This greater demand then may have been partly responsible for the nutrient deficiencies seen. The high N foliar concentrations found may also be indicative of direct leaf uptake of atmospheric ammonium. This can result in leaf damage such as decreased leaf resistance, chlorosis, necrosis and turgor loss which can in turn lead to leaching of susceptible mobile cations such as K and Mg. This mechanism may partially explain the very low values of K and Mg but high values of N found in the foliage.

Even though N was abundant, P was at the critical level. It has been suggested that excess N in the tree or excess nitrate in the soil can adversely affect ectomycorrhizal associations, and thus P nutrition of the tree (Nihlgard 1985). Although sugar maple trees form endomycorrhizae, it is possible that excess N may also adversely affect these associations.

Molar ratios are also often used in foliar analysis to determine if proper nutrient balances exist. However, the molar ratios of Ca/K, Ca/Mg and Ca/Al all fell well within the range considered acceptable (Table 2.5). For this site, then, specific individual elements at the absolute critical level of concentration were found to exist rather than nutrient imbalances. This was an important observation as sufficiency in concentration of each element is vital for the proper health and functioning of the tree.

2.3.2 Fertilization Effects on Soils

Fertilization significantly affected the concentration of Mg and K as well as the % Mg of the CEC in the FH horizon (Table 2.6). All other

Table 2.5. Foliar molar ratios and critical ranges for Entrelacs (n=6)

Treatment	Ca/K	Ca/Mg	Ca/Al
1. Control	1.15 (0.09)	4.89 (0.87)	143 (47)
2. K_2SO_4	0.99 (0.18)	4.61 (0.87)	163 (58)
3. $CaCO_3$	1.50 (0.27)	5.32 (0.87)	221 (58)
4. $Ca,Mg(CO_3)_2$	1.37 (0.15)	4.39 (0.64)	189 (23)
5. K_2SO_4 + $CaCO_3$	1.02 (0.28)	4.47 (1.04)	212 (72)
6. K_2SO_4 + $Ca,Mg(CO_3)_2$	0.76 (0.15)	4.10 (0.83)	160 (40)
7. $(NH_4)_2SO_4$	1.32 (0.27)	4.43 (0.61)	161 (26)
8. 4-4-8	1.09 (0.09)	4.33 (0.69)	172 (48)
Critical Range+	0.5-2.0	2.5-8.0	>100

+ adapted from Hendershot and Lalande 1988
Note: Standard deviations of means are given in parentheses

measured FH horizon soil parameters were not significantly affected by fertilization.

Table 2.6. Partial analysis of variance of FH soil parameters

Parameter	DF	MS	F Value
Mg (cmol(+) kg^{-1})	7	0.78	2.86*
% Mg of CEC	7	12.46	3.84*
K (cmol(+) kg^{-1})	7	0.17	2.65*

* significant at the .05 level

Application of dolomitic limestone (Treatments 4 and 6) significantly increased Mg concentration and % Mg of CEC in the FH horizon compared to the appropriate controls (Treatments 1 and 2) and those treatments containing calcitic limestone (Treatments 3 and 5) (Tables 2.2 and 2.7). However, this effect was not observed in the B horizon, where Mg concentrations or % Mg of CEC were not significantly affected by treatment (Appendix Table A.2). This may indicate that in the relatively short period of time between fertilization and soil sampling in this study the majority of the applied dolomite has remained in the upper horizons of the profile.

Table 2.7. Influence of treatments on significant FH horizon soil parameters

Parameter	Contrast[+]	MS	F Value
Mg (cmol(+) kg^{-1})	4,6 vs 1,2	4.58	16.77**
	4,6 vs 3,5	1.69	6.19*
	1 vs 8	1.08	3.94
% Mg of CEC	4,6 vs 1,2	63.89	19.71**
	4,6 vs 3,5	47.68	14.71**
	1 vs 8	15.30	4.72*
K (cmol(+) kg^{-1})	2,5,6 vs 1,3,4	0.96	15.32**

[+] single degree of freedom contrast
*,** significant at the 0.05 and 0.01 levels

Note: Contrast numbers correspond to treatment numbers as follows: 1.Control 2.K_2SO_4 3.$CaCO_3$ 4.Ca,Mg$(CO_3)_2$ 5.K_2SO_4+$CaCO_3$ 6.K_2SO_4+Ca,Mg$(CO_3)_2$ 7.$(NH_4)_2SO_4$ 8. 4-4-8

The other Mg-containing treatment, 4-4-8, also tended to increase the Mg concentration in the FH horizon relative to the control (p=0.065) (Treatment 8 vs 1, Table 2.2). As would be expected with such an increase in Mg concentration, there was a corresponding significant increase in the % Mg of CEC (Table 2.7).

Application of treatments which contained K (Treatments 2, 5 and 6) significantly increased K concentration in the FH horizon compared to the appropriate controls (Treatments 1, 3 and 4) (Tables 2.2 and 2.7). Potassium was also applied in the 4-4-8 fertilizer (Treatment 8) but only at a rate of 27 kg ha^{-1} compared to 166 kg ha^{-1} K for the other K-containing fertilizers. This may account for the slightly elevated level of K for the 4-4-8 treatment when compared to other non-K containing treatments (Treatments 1, 3 and 4, Table 2.2), but this difference was not significant.

The data indicated that those treatments containing the highest rates of Ca fertilizers (Treatments 3 and 5) tended to increase the Ca levels in the FH horizon (Table 2.2). However, due to the variable nature of the Ca concentrations in the soil, the overall treatment effect was only significant at the 0.101 level.

Although no treatments significantly reduced the concentration of Al or % Al on the exchange sites, the general trend in the FH horizon was for Al to decrease when base cations were applied (Table 2.2). The lack of significant results for this possibly may be due to the high variability associated with Al. A greater number of samples would be required if a better estimate of Al is to be obtained.

For the B horizon soil parameters, the only significant treatment effect was found for K concentration ($p = 0.004$). When single degree of freedom contrasts were used to test treatment effects it was found that application of K_2SO_4-containing treatments (Treatments 2, 5 and 6) significantly increased the K concentration ($p = 0.001$) compared to appropriate controls (Treatments 1, 3 and 4, Table 2.3), indicating that K may have moved down the soil profile, unlike Mg or Ca. In the case of the 4-4-8 treatment, although as mentioned before the amount of K in this treatment (27 kg ha^{-1}) may have slightly elevated the value in the FH horizon, in the B horizon the K concentration was the same as for those treatments containing no K additions (Table 2.3). The elevated K concentrations for those treatments receiving higher rates of K

(Treatments 2, 5 and 6) tended ($p = 0.059$) to correspond to an elevation in the amount of K on the exchange sites.

2.3.3 Fertilization Effects on Foliage

Fertilization significantly affected the foliar concentrations of Ca, Mg, K, N and Al (Tables 2.4 and 2.8). Molar ratios of Ca/K, Ca/Mg and Ca/Al were also all significantly affected by at least one treatment but all ratios for every treatment were well within the critical range (Tables 2.5 and 2.8).

Year effect was significant for Ca, K, N, P and Al concentrations with lower mean values for Ca, K, N and P and higher mean values for Al in 1988 when compared with those of 1987 (Table 2.8, Appendix Tables A.3A and A.3B). It is unlikely that these differences could be attributed to the well-known within-season variations in nutrient concentrations as trees were sampled at approximately the same time of year in both years. Nor could laboratory error be the cause as quality control checks were used in all laboratory analyses for both years. Fertilization as well was probably not a factor in the differences in concentration levels from the fertilized year (1987) to the second year (1988) as the control plots also experienced a decrease in nutrient concentration of Ca, K, N and P and an increase in Al. Perhaps climatic differences from one year to the next have played a role in the variation in nutrient concentration. In any event for purposes of analysis samples of both years were combined since there were no significant year*treatment interactions.

Table 2.8. Partial analysis of variance table for foliar concentrations and molar ratios

Element	Source	DF	MS	F Value
Ca	Year	1	39.024	36.68**
	Treatment	7	3.734	3.51**
	Treatment*Year	7	2.129	2.00
Mg	Year	1	0.007	0.38
	Treatment	7	0.045	2.51*
	Treatment*Year	7	0.019	1.05
K	Year	1	11.291	11.81**
	Treatment	7	9.645	10.09**
	Treatment*Year	7	0.362	0.38
N	Year	1	105.910	32.96**
	Treatment	7	8.438	2.63*
	Treatment*Year	7	4.450	1.38
P	Year	1	0.041	6.65*
	Treatment	7	0.011	1.70
	Treatment*Year	7	0.002	0.38
Al	Year	1	188.417	7.88**
	Treatment	7	92.857	3.88**
	Treatment*Year	7	26.937	1.13
Ca/K	Year	1	0.058	1.49
	Treatment	7	0.340	8.73**
	Treatment*Year	7	0.041	1.06
Ca/Mg	Year	1	17.521	69.93**
	Treatment	7	0.860	3.43**
	Treatment*Year	7	0.127	0.51
Ca/Al	Year	1	41132.546	29.03**
	Treatment	7	4445.472	3.14*
	Treatment*Year	7	1357.883	0.96

*, ** significant at the 0.05 and 0.01 levels, respectively

Application of calcitic limestone (Treatments 3 and 5) significantly increased Ca concentration compared to dolomitic limestone (Treatments 4 and 6) (Tables 2.4 and 2.9). This was expected as the Ca contained in the calcitic limestone (160 kg ha^{-1} Ca) was much higher than that contained in the dolomitic limestone (87 kg ha^{-1} Ca). Application of calcitic limestone by itself (Treatment 3) and with added K_2SO_4 (Treatment 5) also significantly increased Ca concentration when compared to the control treatment (Treatment 1) and the K_2SO_4 treatment by itself (Treatment 4). It is interesting, however, that the latter two treatments had no significant difference from the dolomitic limestone treatments with respect to increasing the Ca foliar concentration. This indicates that the higher rates of Ca application are required to observe significant increases in foliar concentrations.

Application of dolomitic limestone (Treatments 4 and 6) did not result in significantly different foliar Mg values. As mentioned previously, the Mg appeared to remain in the FH horizon yet the uptake did not increase. This may imply that Mg uptake occurs mainly from the B horizon. If this were the case then for these two treatments, a very high percentage of the cation exchange capacity was occupied by Al - 71.2% for the $Ca,Mg(CO_3)_2$ treatment and 73.4% for the K_2SO_4 + $Ca,Mg(CO_3)_2$ treatment (Table 2.3). It is known that aluminum saturation percentages of 65-70% are often associated with Mg nutritional problems because high levels of exchangeable aluminum in acid soils can impair plant uptake of Mg (Tisdale et al. 1985) and perhaps this may have accounted in part for no significant increases in foliar Mg concentration due to dolomitic limestone application.

Table 2.9. Influence of treatments on significant foliar nutrient concentrations

Element	Contrast[+]	MS	F Value
Ca	3,5 vs 4,6	17.75	16.68**
	3,5 vs 1,2	5.80	5.45*
Mg	1 vs 2	0.10	5.31*
	1 vs 5	0.22	12.18**
	1 vs 7	0.14	7.72**
K	2,5,6 vs 1,3,4	58.91	61.61**
N	7 vs 8	17.18	5.35*
	1 vs 8	14.28	4.44*
	1 vs 3	28.09	8.74**
	1 vs 4	21.23	6.61*
Al	1 vs 3,4,5,6	318.24	13.31**
	1 vs 8	167.40	7.00*

[+] single degree of freedom contrast
*,** significant at the 0.05 and 0.01 levels, respectively

Note: Contrast numbers correspond to treatment numbers as follows: 1.Control 2.K_2SO_4 3.$CaCO_3$ 4.Ca,Mg$(CO_3)_2$ 5.K_2SO_4+$CaCO_3$ 6.K_2SO_4+Ca,Mg$(CO_3)_2$ 7.$(NH_4)_2SO_4$ 8. 4-4-8

However, application of three non-Mg containing treatments (Treatments 2, 5 and 7) significantly increased Mg concentrations compared to the control (Treatment 1) (Tables 2.4 and 2.9). Although not significantly different, the highest Mg concentrations in the B horizon were found for these three fertilizer treatments (Table 2.3). Perhaps the relatively abundant K and NH_4 cations from the fertilizers displaced some of the Mg on the exchange sites of the FH horizon, thus making Mg more available for uptake by the roots and thereby increasing foliar Mg concentrations. Leaching processes in the soil profile may also have been taking place,leading to a higher concentration of Mg in the B horizon.

Application of K-containing fertilizers (Treatments 2, 5 and 6) significantly increased foliar K concentrations when compared to treatments without K additions (Treatments 1, 3 and 4)(Tables 2.4 and 2.9) and corresponds to the soil analyses whereby K-containing fertilizers increased soil K (Tables 2.2, 2.3 and 2.7). There was no significant difference regarding K concentration between the control (Treatment 1) and the 4-4-8 treatment (Treatment 8), the only other treatment to have contained K, but since the 4-4-8 fertilizer rate was only 27 kg ha^{-1} K compared to 166 kg ha^{-1} K for the K_2SO_4 fertilizers, it is not surprising there was no effect.

It has been reported that there is an antagonism between Ca and K such that when Ca is in good supply in the soil it may act antagonistically toward K, restraining its uptake by the roots and thereby promoting a nutrient deficiency in the tree (Tomlinson 1969; Tisdale et al. 1985). In those treatments where Ca was applied without K (Treatments 3 and 4) there was a reduction in foliar K concentrations relative to the control (Treatment 1) (Table 2.4) although not significant.

The two N-containing treatments that were applied, the $(NH_4)_2SO_4$ fertilizer (Treatment 7) with 80 kg ha^{-1} N and the 4-4-8 fertilizer (Treatment 8) with only 16 kg ha^{-1} N, gave significantly different values for N from each other and, as expected, the N concentration due to the $(NH_4)_2SO_4$ treatment was higher although not significantly different from that of the control treatment (Tables 2.4 and 2.9). These latter two treatments, resulting in higher N concentrations than all other treatments, produced values which were at the uppermost levels of the published foliar N range for sugar maple. This elevated nutritional status of N for both the control and $(NH_4)_2SO_4$ treatments may reflect an unhealthy nutritional status in the tree. Excess nitrogen in the foliage has been shown to stimulate fungal diseases, insect attacks and algal growth on leaf surfaces and to cause decreases in frost hardiness (Nihlgard 1985) all of which could manifest itself by demonstrating symptoms of dieback. Treatments which contained more of a balance of basic cations, however, resulted in lower N concentrations and the 4-4-8, the $CaCO_3$ and the $Ca,Mg(CO_3)_2$ treatments (Treatments 8, 3 and 4) significantly decreased the foliar N concentrations when compared to those of the control (Tables 2.4 and 2.9).

There were no treatment effects observed on foliar P concentration including the only treatment which did contain some P, the 4-4-8 treatment (Treatment 8, Table 2.8). Most of the foliar concentrations were either below or at the critical limit indicating that P nutrition may be a problem (Table 2.4).

Aluminum foliar concentrations were significantly higher for the control treatment (Treatment 1) in comparison with all those treatments which contained some liming ingredient (Treatments 3, 4, 5, 6 and 8) (Tables 2.4 and 2.9). This was reflected in the FH horizon where the highest Al levels were found for the control treatment (1) and those treatments which contained no liming materials (Treatments 2 and 7) (Table 2.2). The B horizon, however, showed no similar pattern regarding treatments (Table 2.3). Although pH did not appear to be influenced by the addition of liming materials, perhaps Al concentration in the solution was reduced thereby causing uptake by the roots to decrease somewhat. This may then have been reflected in the lowering of the foliar Al content for those lime-containing treatments. In all treatment cases, though, the Ca/Al molar ratios were well above the critical minimum value of 100, with the control treatment being closest to the minimum at a value of 143 (Table 2.5).

2.3.4 Fertilization Effects on Decline Levels

Decline level values obtained over two years following the Mader and Thompson procedure outlined in Section 2.2.5 were found to have no significant differences from each other due to any treatment. Analysis of the Decline Index data which incorporated branch dieback, foliage transparency and foliage discoloration from the 1988 season gave the same result. This was not surprising as it is reasonable to assume that a quite general visual examination of a tree over the space of two years may not reveal any subtle changes in the health of the tree which may be taking place over that time period. It was because of this reasoning that the Mader and Thompson scale was "improved upon" for the second year of visual examination as it was considered not specific enough in describing the extent of decline. Although more parameters were used for the second season, the Decline Index probably still gave too general a portrayal of the state of decline. Trees would have had to experience a fairly radical change in dieback condition in order for comparisons made from one year to the next to have shown a difference.

Although there were no significant treatment effects then in decline, trends may possibly be looked at by comparing fertilizer effects.

Decline levels found according to the Mader and Thompson scale for each treatment and each year were on average of light to moderate severity (Figure 2.1). For Treatments 1 through 4 the decline values remained about the same between 1987 and 1988, neither improving nor deteriorating to a great extent. While Treatment 5 seems to have resulted in an increase in decline level, for Treatments 6, 7 and 8 decline seems to have improved somewhat from 1987 to 1988. This is interesting because as mentioned before, the foliar concentration values on average decreased from 1987 to 1988. The dilution effect described in section 2.1 may explain the apparent decrease in decline with decrease in nutrient concentrations. With treatments 2, 7 and 8 the decline levels for 1988 indicated improvement over that of the control plot for that year. However, treatment 2 did not seem to improve the decline from one year to the next. Also, treatment 6, although not improving in decline level when compared to control, had a higher initial decline level in 1987.

Decline Index values for 1988 for each treatment ranged for the selected trees from 10.7% to 14%, indicating again a light to moderate level of decline (Figure 2.2). Although change in decline from one year to another could not be examined using the Decline Index, it did serve as confirmation of the Mader and Thompson levels as the decline index values in the second year reflected the levels of decline found by the Mader and Thompson scale for that year.

It is difficult to interpret the decline results with respect to fertilization effect since decline level itself is not a very precise

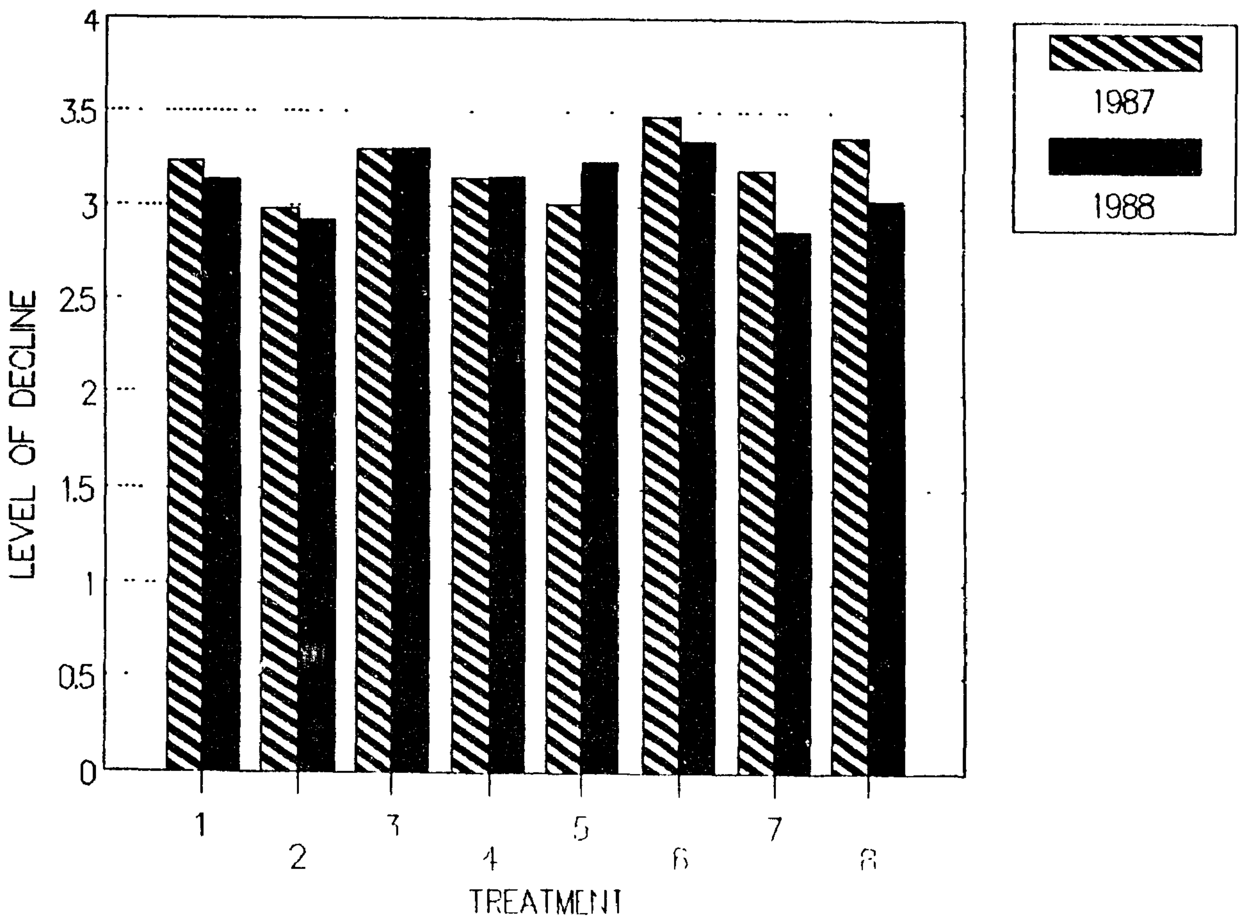

Figure 2.1. Mean decline levels per treatment per year at Entrelacs (for Mader and Thompson scale description see Section 2.2.5) Note: Treatment numbers represent the following: 1.Control 2.K_2SO_4 3.$CaCO_3$ 4.$Ca,Mg(CO_3)_2$ 5.K_2SO_4+$CaCO_3$ 6.K_2SO_4+$Ca,Mg(CO_3)_2$ 7.$(NH_4)_2SO_4$ 8.4-4-8

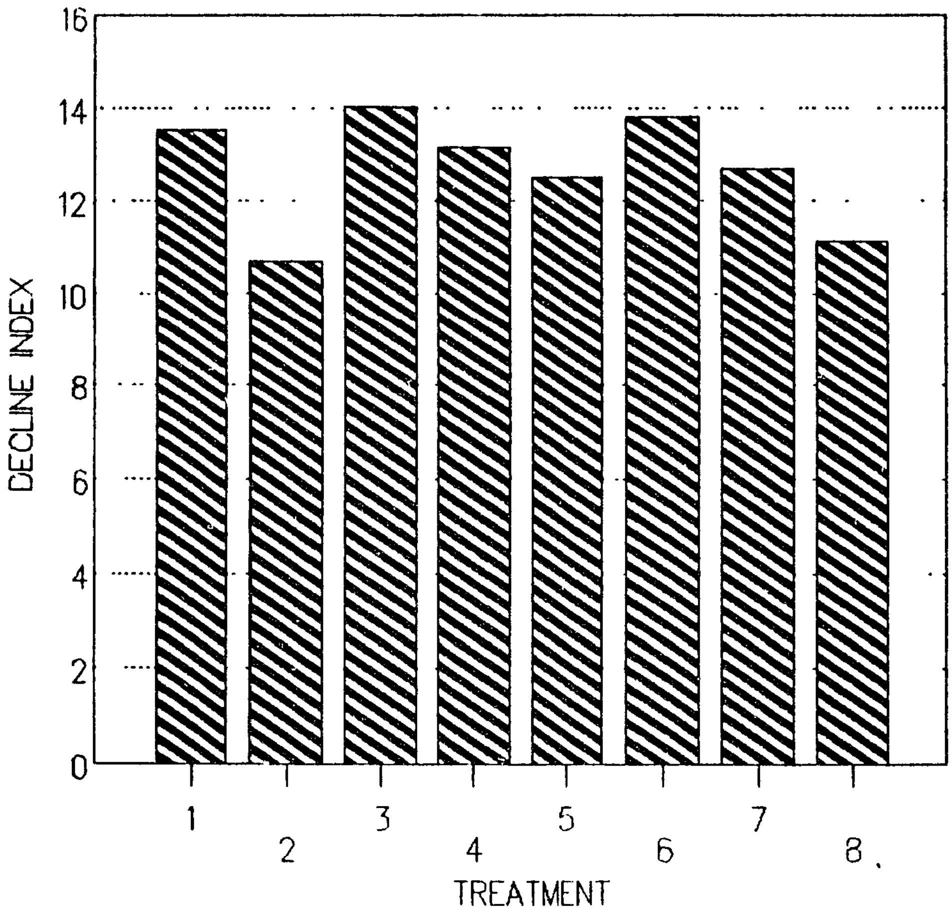

Figure 2.2. Mean decline index levels per treatment at Entrelacs for 1988 (for criteria used see Section 2.2.5) Note: Treatment numbers represent the following: 1.Control 2.K_2SO_4 3.$CaCO_3$ 4.$Ca,Mg(CO_3)_2$ 5.K_2SO_4+$CaCO_3$ 6.K_2SO_4+$Ca,Mg(CO_3)_2$ 7.$(NH_4)_2SO_4$ 8.4-4-8

measurement. To better understand what improvement, if any, was taking place after a treatment had been applied, decline levels should have been obtained on all trees prior to fertilization and visual evaluations made for a period of time longer than two years. Decline levels of trees in treated plots would not then be compared to the decline levels of control treatments but to the level of decline within the specific fertilized treatment. Perhaps by extending the period of time in which the trees were evaluated, the differences in decline levels would also become more apparent. Analyses showed that there was no significant difference on decline level due to any treatment but perhaps, because of the foregoing reasons, this conclusion may be a bit premature.

2.4 CONCLUSION

The study area was one in which sugar maple trees, from a visual examination, were only moderately affected by decline. However, when chemical soil and foliar analyses were carried out nutrient deficiencies were quite apparent. Soil Mg and K in both the FH and B horizons were found to be at very low levels in comparison to concentrations seen at other sites of sugar maple stands in the Lower Laurentians. Similarly, foliar Mg, K and P concentrations were found to be at critical levels and foliar Ca was only slightly above the critical level, indicating nutritional deficiencies in the forest ecosystem.

Fertilization could replenish some of the deficient nutrients in the soil to a certain extent and subsequently improve some of the foliar deficiencies as well. But it has been seen that not all fertilizers had a positive effect on those foliar nutrient levels. Not only was rate of application an important factor to consider but also combinations of elements within the fertilizers. There are antagonisms which develop when too much of one element (e.g. Ca) will outcompete another element (e.g. K) for root uptake and this may have been demonstrated with the liming treatments of $CaCO_3$ and $Ca,Mg(CO_3)_2$. Elements behaved in different ways in the soil as well where K was seen to move down the soil profile after application whereas Mg tended to remain in the upper LH horizon. Soil variability has accounted in part for some degree of uncertainty with respect to the interpretation of some results. As discussed previously in relation to decline levels, had sampling of the soil as well as the leaves taken place before fertilization, perhaps a more accurate portrayal of fertilization effects on soils and foliage could have been made.

The results of part of this research were inconclusive insofar as determining a fertilization treatment that would bring about a significant difference in the decline levels of sugar maple. However, it can be concluded that significant differences in nutrient levels in both soil and foliage did occur with the application of certain fertilizers. Some appeared to be somewhat detrimental to overall nutrient balance of the tree such as the $CaCO_3$ and $Ca,Mg(CO_3)_2$ treatments which resulted in a slight lowering of the K concentration in particular to levels below the critical limit. However, all other treatments, while not visually improving decline level significantly, did appear to have a positive effect on the base cation nutrient levels in the foliage when compared to the critical levels that existed for Ca, Mg and K exhibited by the control treatment plots.

The research carried out at the study site took place over a period of time of only two years. What may be necessary to determine the long-term impact of fertilization on decline and nutrient levels is to continue the examination, evaluation and analysis of the soil, foliage and tree decline levels for the next few years to ascertain which, if any, fertilization treatments may improve sugar maple decline.

CHAPTER THREE

CORRELATIONS BETWEEN SOIL AND FOLIAR CONCENTRATIONS AND BETWEEN FOLIAR CONCENTRATIONS AND DECLINE LEVELS

3. CORRELATIONS BETWEEN SOIL AND FOLIAR CONCENTRATIONS AND BETWEEN FOLIAR CONCENTRATIONS AND DECLINE LEVELS

3.1 INTRODUCTION

The nutritional status of the soil has often served to reflect that of the foliage. Both soil fertility and foliar nutrient concentration have also been shown in the past to have a relationship with the state of decline of the sugar maple (Mader and Thompson 1969; Gagnon et al. 1986; Bernier and Brazeau 1988a;1988c). In order to better predict specific deficiencies in the foliage from sampling the soil it is necessary to know if a strong correlation exists between the concentration of that element in the leaves, soil mineral horizon (B) and soil organic horizon (FH) of sugar maple stands. Also, it would be a useful tool to know if strong correlations existed between specific elements and the state of decline of the tree. In this way predictions could be made as to the susceptibility of an area to decline and preventive measures such as fertilization taken to possibly inhibit the onset or continuation of decline.

In this study the relationships between soil fertility, foliar nutrient concentrations and decline of the sugar maple were examined.

3.2 MATERIALS AND METHODS

3.2.1 Study Area

This study was conducted at two sites in the Lower Laurentians of Quebec. Site 1, previously described in Section 2.2.1, was located in the Entrelacs area. Site 2 was located in the St-Hippolyte area 80 km north of Montreal and formed part of the 14 km² comprising the Station de Biologie de l'Université de Montréal. This unmanaged site, also located in the Great Lakes - St. Lawrence forest region of Canada, was dominated by 80-100 year old sugar maple but included some American beech. Soils at Site 2 were also derived from glacial till, having a mor type humus, were predominantly humo-ferric or ferro-humic podzols (Canada Soil Survey Committee 1978) and were well- to imperfectly-drained. The LH Horizon averaged 4-6 cm in thickness and organic soils were found in a few depressional areas. The southwesterly facing site was located in a slightly sloping area and decline levels encompassed the complete range but, as at Site 1, Site 2 was one of moderate decline with most trees showing some evidence of dieback.

3.2.2 Plot Establishment

Methods regarding plot establishment at Site 1 were described in Section 2.2.2. In May 1987 at the St-Hippolyte site, eight sample plots (15 m x 15 m) were established with buffer strips of at least 5 m left between plots. Eight fertilizer treatments as set out in Table 2.1 were assigned randomly to the plots. Fertilizer was applied by hand to the soil surface of each plot as at Site 1 ensuring uniformity of application. When possible a total of eight sugar maple trees (dying or small trees excluded) per plot, each located at least 3 m inside the plot boundaries, were tagged and measured for diameter at breast height (average diameter = 26.5 cm).

3.2.3 Soil Sampling, Foliar Sampling and Tree Evaluation

These procedures were all carried out in the same manner for the eight plots at Site 2 as for the 24 plots at Site 1 and were described in detail in Sections 2.2.3 to 2.2.5, inclusive. For Site 1, complete data sets for the soil LH and B horizons and 1987 and 1988 foliar concentrations are presented in Appendix Tables A.1, A.2, A.3A and A.3B, respectively. Site 2 data sets for the soil LH and B horizons and 1987 and 1988 foliar concentrations are given in Appendix Tables A.4, A.5, A.6A and A.6B, respectively.

3.2.4 Statistical Analyses

In determining if relationships existed between Ca, Mg, K and Al in soil mineral horizons (B), soil organic horizons (FH) and foliage, plot means were determined for organic soil elements, mineral soil elements and foliar elements from a total of four values per parameter per plot. Since soil sampling was done for one year only, the 1987 data were used for all parameters analysed. When the data of two sites were combined this resulted in a total of 32 plot values for each soil LH, soil B and foliar sample - 24 from Site 1 and 8 from Site 2. The data could be combined for analysis of Ca, Mg and K as values between sites were very similar. However, for Al, only Site 1 data were used (a total of 24 plot values). A preliminary analysis indicated that the average Site 2 foliar Al concentration was quite a bit higher than that of Site 1 and that correlation coefficients were of the opposite sign, thus combining the two sites in this case eliminated significant correlations. SAS software using the Pearson Correlation Coefficient procedure was employed to determine if correlations between soil FH values, soil B values and leaf concentrations of Ca, Mg, K and Al were significant ($p < 0.05$) (SAS Institute Inc. 1979).

In determining a possible relationship between decline and foliar nutrient concentrations, only the data obtained from the sampled trees of the control plots were used as foliar nutrient concentrations after fertilization may have been altered without causing a change in decline status in the relatively short time period of this study. The decline level for each tree was related to that tree's foliar nutrient concentration values. Data for two years from the control plots of Site 1 (24 samples) and Site 2 (8 samples) were combined and correlations were determined between the Mader and Thompson decline levels and each foliar nutrient concentration using the Pearson Correlation Coefficient procedure. Analysis of the decline index data, using percentages of branch dieback, discoloration and transparency as parameters was also performed in an attempt to determine if a relationship existed between this measure of decline and foliar concentrations. The decline index analysis was based on only 16 samples since this parameter was only measured in 1988.

3.3 RESULTS AND DISCUSSION

3.3.1 Soil and Foliar Correlations

Potassium, Ca, Mg and Al foliar levels were all correlated to levels of those elements in the soil although only one partial correlation coefficient exceeded 0.5 (Table 3.1). Calcium and Mg levels in the leaves were positively correlated to B horizon levels but not significantly correlated to FH horizon levels. This result is somewhat surprising since it is expected that the majority of nutrient uptake would occur from the FH horizon and thus foliar nutrient levels should be correlated to the soil levels in the FH horizon. This lack of correlation may be due to foliar nutrient concentrations not being truly indicative of nutrient uptake, i.e. possible dilution effects. This finding could also reflect some other condition in the FH horizon affecting nutrient absorption other than the absolute concentration of that nutrient. Aluminum foliar levels were positively correlated to the Al levels in the LH horizon. This may suggest that in this horizon Al is more available for plant uptake thus competing with base cation uptake. Perhaps the roots themselves have been damaged to a point where uptake or transport of base cations has been interfered with (Epstein 1961; Meyer et al. 1985). However, the positive correlation between soil B horizon and foliar levels at Sites 1 and 2 seems to indicate that the roots of the sugar maple were in a functional

Table 3.1. Partial correlation coefficients between foliar and soil concentrations of Ca, Mg, K (Sites 1 and 2) and Al (Site 1)

	Foliar Ca	Soil B Ca	Soil FH Ca
Foliar Ca	1.00	0.49**	0.26
Soil B Ca		1.00	0.36*

	Foliar Mg	Soil B Mg	Soil FH Mg
Foliar Mg	1.00	0.41*	-0.12
Soil B Mg		1.00	-0.14

	Foliar K	Soil B K	Soil FH K
Foliar K	1.00	0.57**	0.45**
Soil B K		1.00	0.51**

	Foliar Al	Soil B Al	Soil FH Al
Foliar Al	1.00	0.04	0.48*
Soil B Al		1.00	-0.43*

*, ** significant at the 0.05 and 0.01 levels, respectively

state to absorb or transport available soil nutrients. Potassium foliar levels were positively correlated to both the FH and B horizon levels with the highest correlation occurring with the B horizon.

To an extent these results reflected the findings of Mader and Thompson (1969) concerning Ca and Mg. They concluded that foliar nutrient levels in general appear to reflect those available in the soil profile.

3.3.2 Foliar and Decline Correlations

The combined foliar and decline data from the control plots of Sites 1 and 2 are presented in Table 3.2. It should be emphasized that the project was initially set up so that trees exhibiting extremely severe decline symptoms would not be selected. The range of decline levels, therefore, is fairly narrow.

Calcium, Mg, K and P all had mean values at or very close to their respective critical limits (Table 3.2). The trees selected had decline levels ranging from level 2, characterized by discolored or small leaves being evident, to level 4, characterized by trees having dead branches constituting less than half the crown, with the mean level of decline being evidenced by trees having dead twigs at the top of the crown accounting for less than 25% of the crown (level 3). When decline index parameters were used decline was also seen to be light to moderate in severity (Table 3.2). So it would seem that even though the sites were at very critical levels nutritionally, their level of decline was still only moderate. This may be a bit misleading, however, in that a level of moderate decline throughout most of Sites 1 and 2 could lead in a relatively short period of time to a more severe level of decline owing to the very poor nutrient status of the areas. The short two-year duration of this project unfortunately can only allow speculation.

Table 3.2. Mean foliar elemental concentrations and decline level of sugar maple for samples taken from control plots of two sites for two years (n=32)

Variable	Mean	Range	Critical Limit[+]
Ca	7.11 mg g^{-1} (1.52)	4.16-10.69	7.0
Mg	0.93 (0.19)	0.59-1.34	0.9
K	6.16 (1.22)	4.08-8.87	6.0
N	21.56 (3.72)	16.90-31.22	15.0
P	1.02 (0.13)	0.81-1.29	1.0
Al	34.12 ug g^{-1} (9.92)	23.06-70.50	
Decline Level Mader & Thompson	3.06 (0.77)	2-4	
Decline Index[++]	8.23 (3.87)	1.67-16.67	

[+] adapted from Hendershot and Lalande 1988
[++] used in 1988 only (n=16)
Note: Standard deviations are given in parentheses

Analysis of the decline index data indicated that there were no significant correlations between decline and foliar concentrations (Table 3.3). This may have been due, however, to the small sample size that was used. When the Mader and Thompson scale was used the only foliar element significantly correlated with decline was Mg (Table 3.3). Since the range of decline levels was fairly narrow, this correlation (r=-.40, p=0.022) may have been even more pronounced had sugar maple trees encompassing a greater range of decline levels been sampled.

Table 3.3. Partial correlation coefficients between foliar elemental concentrations and sugar maple decline for the control plots of Sites 1 and 2 for two years (n=32)

	Mg	K	N	P	Al	DEC+	DI++
Ca	0.52**	0.30	0.44**	0.32	-0.05	-0.05	-0.19
Mg		-0.00	-0.20	0.14	0.21	-0.40*	-0.23
K			0.30	0.38*	-0.23	0.18	-0.07
N				0.44**	-0.24	0.08	-0.00
P					-0.13	-0.14	-0.34
Al						-0.01	-0.04

*,** significant at the 0.05 and 0.01 levels, respectively
\+ based on Mader and Thompson scale
++ based on Decline Index parameters (n=16)

This decline correlation is interesting as Bernier and Brazeau (1988c) found acute Mg deficiency symptoms occurring in severely declining sugar maple at various sites in the Lower Laurentians of southeastern Quebec. Because the forest is detrimentally affected by a severe Mg deficiency, it was thought that there may be a direct relationship between tree dieback and Mg deficiency. There have been many studies done in central Europe where lack of Mg has been implicated in the recent forest declines of that area (Zech et al. 1985; Huettl 1986). Mader and Thompson (1969) as well found that reduced growth of sugar maple and an increase in decline level were associated with low Mg as well as low N levels in the foliage. These observations were made in declining sugar maple stands of western Massachusetts with soil also developed from glacial till.

Acidic deposition and resulting base cation leaching has been suggested by many researchers to be the underlying cause of Mg deficiencies in areas such as the Lower Laurentians of Quebec (Bernier and Brazeau 1988c), the Lange Bramke basin area in West Germany (Hauhs and Dise 1989) and northeastern Bavaria (Zech et al. 1985). The study areas in question in the Lower Laurentians were located on nutrient deficient soils which received a fairly high input of acid deposition. Decline symptoms, although not severe, were in evidence and statistical analyses demonstrated a negative correlation between foliar Mg and decline. These factors considered, it may be suggested that here, as in Europe, acidic deposition has been accelerating base cation leaching losses leading to acute nutrient deficiencies within the forest ecosystem followed by decline symptoms in the sugar maple trees.

Although Bernier and Brazeau (1988b) found that sugar maple decline was negatively correlated to K in the Quebec Appalachians, in this study it was found that Mg was negatively correlated to decline. This indicates that the nutrient(s) most closely associated with decline are site specific.

3.4 CONCLUSION

Foliar base cation nutrient levels correlated to B horizon levels although K was also correlated to the FH horizon levels while Al foliar concentrations were correlated to the FH horizon only. The data suggests that there was a possible interaction occurring between the Al and the base cation uptake in the FH horizon. Although some foliar nutrient concentrations were correlated with some soil levels the highest correlation found was 0.54 for K between the foliar concentration and the level in the B horizon indicating that many other factors are affecting nutrient uptake other than just the element itself.

Foliar concentration and decline level relationships indicated that only Mg was negatively correlated to decline for these sites, which might be attributable to the low Mg content of the parent material coupled with leaching due to acidic inputs. Foliar analysis demonstrated that Ca, Mg, K and P were at their critical limits indicating that the sole addition of Mg may not be adequate to alleviate nutritional imbalances at these sites. It is suggested that the prevalent foliar Mg deficiency together with the other deficiencies in Ca, K and P in the foliage may be playing a significant role in the current sugar maple decline being experienced in the study areas.

CHAPTER FOUR

SUMMARY

4. SUMMARY

Foliar nutrient status was found to be poor at both sites in this study. Foliar elements such as Ca, Mg, K and P were found to be at or very near to deficiency levels. Although the decline levels were in general not severe for most trees at this point in time, this had to be considered in light of the sampling method employed at the onset of the project. Trees that were visibly severely damaged were not considered for the purposes of the experiment. This may have undervalued the overall level of decline for the two sites.

Fertilization was shown to have significant effects both in elemental concentrations of the soil and foliage. Effects in general showed an increase in base cation concentrations when those elements were supplied in high enough quantities. Although there was no significant effect on the decline levels following treatment by fertilization, this may in part be due to the short duration of this particular project. For example, in the cases where a tree is rated at level 4 of decline one year (i.e. containing large dead branches in the crown) it is not conceivable that, even with perhaps an increase in healthy foliage due to fertilization, those dead branches will have disappeared from the crown. Therefore the tree rating would have remained the same in both years. Another possibility of why there was no significant effect on some tree decline levels following fertilization could be perhaps because no revitalization was even possible due to a critical degree of damage having been reached in the tree prior to fertilization (Huettl and Wisniewski

1987). It is known that sometimes deficiency symptoms can develop slowly in a tree with the tree not exhibiting dieback symptoms until an element has been deficient for some time. It follows that when elements are increased to a point where they are no longer deficient, the amount of dieback that exists may not disappear in one or two seasons. Therefore actual differences in decline levels due to fertilization treatments over a relatively short period of time is quite difficult to measure.

Positive correlations were obtained between soil B horizon levels and foliar concentrations of Ca, Mg and K and between soil FH horizon levels and foliar concentrations of K and Al which indicated once again that the fertilization treatments did have an effect on both the soil and foliage and that the nutrient status of the soil did influence the nutrient status of the foliage. The only element that gave a significant negative correlation to tree decline level was foliar Mg.

This study indicated that the sites examined formed part of a forest ecosystem experiencing light to moderate sugar maple decline but acute nutrient deficiencies. These deficiencies could be somewhat alleviated through various fertilization applications thereby enabling the trees to better withstand other biotic or abiotic stresses. However, fertilization is just a tool to temporarily overcome nutritional deficiencies brought about by some cause or causes. Many researchers have suggested acidic deposition as the underlying cause of the new forest decline that is being experienced in many parts of the world. Observations have shown in the Lower Laurentians of Quebec that declining sugar maple with deficient foliar nutrient levels are growing on acidic nutrient-poor soils which receive fairly heavy acidic deposition. These facts suggest that the acidification and nutrient imbalance theory of sugar maple decline may be applicable to this situation. If such is the case then fertilization may be instrumental in slowing or stopping the decline taking place and restoring the tree to health. But unless this fertilization is carried out on a regular basis the symptoms may only be temporarily alleviated while the actual cause of nutrient deficiencies in the forest ecosystem continues.

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APPENDIX

Table A.1. 1987 soil chemical properties of FH Horizons of Entrelacs for 8 treatments (n=4) and partial analysis of variance

Treatment	Plot	pH	Ca	Mg	K	Na	Fe	Mn	Al	CEC	%Ca	%Mg	%K	%Al
			cmol(+) kg⁻¹								% of CEC			
1.Control	9	4.60	14.98	[illegible]	0.97	0.07	0.11	0.86	3.95	22.46	67.15	6.88	4.38	16.99
	20	4.53	14.31	1.38	0.79	0.16	0.13	0.56	9.11	26.44	53.78	5.19	2.98	34.80
	22	4.33	16.73	1.67	0.81	0.11	0.10	0.67	3.57	23.66	71.46	7.08	3.48	14.23
2.K_2SO_4	3	4.37	16.30	1.73	1.90	0.14	0.13	1.01	.43	22.65	71.60	7.55	8.52	6.58
	4	4.95	15.03	1.29	0.95	0.18	0.05	0.96	4.47	22.92	64.70	5.66	4.21	19.92
	23	4.31	17.98	1.76	1.18	0.12	0.13	0.61	4.48	26.26	69.43	6.91	4.54	15.92
3.$CaCO_3$	2	4.31	16.23	1.92	1.07	0.08	0.21	0.34	1.49	21.34	76.03	8.96	4.99	7.06
	8	5.02	18.61	1.69	0.92	0.16	0.01	1.25	2.36	25.01	74.33	6.82	3.72	9.43
	11	4.86	27.19	2.28	0.86	0.15	0.07	0.84	3.06	34.45	78.78	6.60	2.49	8.99
4.$Ca.Mg(CO_3)_2$	6	4.34	19.22	2.58	1.13	0.11	0.12	0.74	1.13	25.03	76.63	10.36	4.60	4.51
	10	4.32	17.40	2.74	1.08	0.08	0.14	0.44	1.39	23.29	74.50	11.73	4.68	6.22
	15	4.34	15.98	2.54	1.08	0.12	0.13	0.57	3.56	23.99	67.62	10.83	4.50	13.57
5.K_2SO_4 + $CaCO_3$	12	4.14	22.76	2.09	1.35	0.12	0.17	0.41	1.92	28.62	79.03	7.25	4.69	6.58
	18	4.82	25.52	2.12	1.13	0.23	0.05	0.86	2.98	32.89	77.64	6.47	3.43	8.98
	24	4.34	26.28	2.17	1.86	0.09	0.08	0.35	0.94	31.78	82.31	6.94	5.87	3.19
6.K_2SO_4 + $Ca.Mg(CO_3)_2$	1	4.46	18.38	4.27	1.71	0.13	0.16	0.51	1.40	26.56	69.17	16.04	6.45	5.30
	13	4.41	16.64	2.00	1.26	0.40	0.16	0.51	4.31	25.18	65.87	7.90	4.96	17.04
	16	4.20	19.58	2.64	1.52	0.15	0.17	0.53	1.65	26.24	74.52	10.10	5.86	6.26
7.$(NH_4)_2SO_4$	14	4.77	12.05	[illegible]	0.85	0.11	0.08	1.29	6.20	21.63	56.00	4.98	4.13	28.26
	19	4.19	22.80	2.00	1.23	0.13	0.11	0.69	3.06	30.02	76.23	6.72	4.11	9.87
	21	4.04	19.21	2.25	0.99	0.12	0.18	0.65	1.87	25.26	75.91	8.85	3.98	7.48
8.4-4-8	5	4.35	13.90	1.85	1.24	0.10	0.10	0.77	2.06	20.03	69.71	9.23	6.17	10.14
	7	4.25	19.06	2.48	1.12	0.12	0.17	0.53	1.52	25.01	76.08	9.88	4.48	6.26
	17	4.22	23.32	2.79	1.19	0.14	0.10	0.65	1.26	29.47	78.83	9.62	4.16	4.41

Statistics

	Ca	Mg	K	Na	Fe	Mn	Al	CEC	%Ca	%Mg	%K	%Al
Treatment SS	180.762	5.460	1.160	0.032	0.010	0.431	35.511	119.884	516.235	87.212	14.345	611.116
F Value'	2.12	2.86*	3.65*	1.07	0.53	0.94	1.70	1.38	1.93	3.84*	1.48	1.81

* significant at the 0.05 level

' degrees of freedom are 7 for treatment and 16 for the error

Table A.2. 1987 soil chemical properties of B Horizons of Entrelacs for 8 treatments (n=4) and partial analysis of variance

	Plot	pH	Ca	Mg	K	Na	Fe	Mn	Al	CEC	%Ca	%Mg	%K	%Al
Treatment			cmol(+) kg^{-1}								of CEC			
1.Control	9	5.09	1.68	0.10	0.06	0.06	0.05	0.07	3.70	5.71	27.61	1.75	1.03	66.43
	20	4.94	0.93	0.09	0.05	0.04	0.08	0.03	3.52	4.73	18.61	1.90	1.23	75.63
	22	5.00	1.78	0.16	0.09	0.04	0.05	0.01	3.44	5.57	29.84	2.76	1.65	64.18
2.K_2SO_4	3	4.96	0.88	0.09	0.14	0.03	0.07	0.02	3.54	4.77	18.26	1.88	2.90	74.46
	4	5.20	1.84	0.20	0.13	0.05	0.04	0.23	2.71	5.19	37.03	3.95	2.47	50.50
	23	4.91	1.57	0.15	0.11	0.04	0.10	0.03	3.77	5.77	27.48	2.68	1.97	65.31
3.$CaCO_3$	2	4.89	0.79	0.10	0.06	0.03	0.14	0.02	4.84	5.96	13.29	1.62	0.99	81.33
	8	5.18	1.24	0.14	0.07	0.06	0.02	0.11	2.19	3.83	32.47	3.66	1.87	57.37
	11	5.14	1.93	0.21	0.07	0.06	0.04	0.02	2.70	5.03	38.46	4.12	1.48	53.82
4.$Ca.Mg(CO_3)_2$	6	5.09	1.23	0.09	0.05	0.05	0.08	0.01	3.54	5.05	24.20	1.74	0.90	70.76
	10	4.88	1.21	0.12	0.06	0.05	0.14	0.01	4.63	6.20	19.24	1.84	0.92	75.16
	15	4.96	1.04	0.12	0.08	0.03	0.07	0.02	2.91	4.26	24.89	2.83	2.09	67.82
5.K_2SO_4 + $CaCO_3$	12	4.85	1.62	0.14	0.12	0.06	0.11	0.01	4.79	6.85	23.60	2.33	1.66	70.37
	18	5.16	1.93	0.21	0.12	0.06	0.02	0.18	2.51	5.02	37.13	3.92	2.22	52.22
	24	4.81	1.44	0.12	0.14	0.02	0.13	0.01	4.31	6.18	22.74	1.88	2.33	70.95
6.K_2SO_4 + $Ca.Mg(CO_3)_2$	1	4.97	0.68	0.09	0.11	0.04	0.07	0.02	3.54	4.55	15.09	1.89	2.37	78.11
	13	5.00	1.31	0.12	0.10	0.16	0.09	0.01	3.93	5.73	22.47	2.16	1.84	69.16
	16	4.91	1.30	0.10	0.11	0.04	0.09	0.01	4.32	5.98	21.38	1.74	1.30	72.98
7.$(NH_4)_2SO_4$	14	4.99	1.74	0.19	0.14	0.04	0.02	0.01	2.60	4.74	36.67	3.94	2.91	55.24
	19	4.84	1.51	0.15	0.07	0.04	0.08	0.04	3.69	5.58	26.42	2.74	1.23	66.87
	21	4.63	1.64	0.17	0.10	0.04	0.13	0.02	4.98	7.09	22.82	2.37	1.35	70.93
8.4-4-8	5	4.93	0.65	0.07	0.06	0.03	0.08	0.02	3.81	4.71	13.63	1.48	1.24	81.08
	7	4.76	1.68	0.15	0.08	0.07	0.14	0.01	5.65	7.83	21.07	1.90	1.05	72.70
	17	4.85	1.01	0.10	0.06	0.03	0.09	0.01	4.45	5.76	17.30	1.77	0.99	77.77
Statistics														
Treatment SS			1.057	0.014	0.016	0.004	0.008	0.018	3.921	3.721	381.747	5.860	4.647	549.550
F Value'			0.94	1.32	7.62**	0.63	0.52	0.75	0.64	0.53	0.96	1.20	2.53	0.38

** significant at the 0.01 level

' degrees of freedom are 7 for treatment and 16 for the error

Table A.3A. 1987 foliar elemental concentrations of Entrelacs for 8 treatments (n=4)

Treatment	Plot	Ca	Mg	K	N	P	Fe	Mn	Zn	Al
		mg g^{-1}								ug g^{-1}
1.Control	9	8.59	0.91	7.03	21.89	1.04	0.05	1.36	0.02	27.24
	20	7.48	0.88	5.88	25.78	1.06	0.05	0.76	0.01	32.65
	22	7.60	0.78	6.36	27.47	1.02	0.04	0.90	0.02	29.58
2.K_2SO_4	3	8.65	0.98	7.92	20.78	1.05	0.04	1.20	0.02	35.27
	4	9.51	0.98	9.45	20.28	0.94	0.04	0.74	0.02	27.43
	23	10.11	1.30	8.43	25.09	1.15	0.06	0.66	0.03	32.19
3.$CaCO_3$	2	7.41	0.89	5.57	19.05	1.07	0.03	1.19	0.02	32.54
	8	10.35	0.96	6.03	20.71	1.02	0.04	0.81	0.02	22.34
	11	10.01	0.98	8.19	21.78	1.02	0.05	0.49	0.02	26.78
4.$Ca,Mg(CO_3)_2$	6	6.96	0.96	4.87	20.10	1.03	0.03	1.28	0.02	21.26
	10	7.27	0.97	6.09	21.39	1.05	0.05	1.00	0.02	27.38
	15	7.10	0.79	4.59	18.91	0.89	0.05	1.24	0.01	25.22
5.K_2SO_4 +	12	10.52	1.10	9.01	21.62	0.99	0.05	1.37	0.03	28.27
$CaCO_3$	18	11.92	1.33	7.90	20.90	1.11	0.04	0.52	0.02	26.93
	24	8.67	1.23	9.35	26.29	1.11	0.05	0.94	0.03	24.35
6.K_2SO_4 +	1	7.13	0.83	8.61	20.43	1.04	0.04	1.31	0.03	27.72
$Ca,Mg(CO_3)_2$	13	9.10	1.23	9.39	21.82	1.04	0.05	1.22	0.03	31.67
	16	8.34	1.06	9.33	21.66	1.12	0.04	1.26	0.02	28.85
7.$(NH_4)_2SO_4$	14	9.79	1.11	8.06	21.37	1.23	0.05	1.00	0.02	37.08
	19	8.05	0.99	6.26	28.33	1.06	0.07	0.86	0.02	31.57
	21	7.63	1.09	5.07	25.98	1.12	0.05	1.35	0.02	29.77
8.4-4-8	5	7.40	0.89	6.29	20.90	0.91	0.04	1.34	0.02	27.36
	7	8.06	1.21	7.77	20.85	1.12	0.04	1.02	0.02	27.59
	17	8.05	0.92	6.46	20.87	1.00	0.04	0.80	0.02	21.77
OVERALL MEAN FOR ALL TREATMENTS		8.57	1.02	7.25	22.26	1.05	0.05	1.03	0.02	28.45

Table A.3B. 1988 foliar elemental concentrations of Entrelacs for 8 treatments (n=4)

Treatment	Plot	Ca	Mg	K	N	P	Al
		mg g^{-1}					ug g^{-1}
1. Control	9	6.35	1.01	6.06	19.24	0.96	32.62
	20	6.30	0.92	5.01	19.37	1.03	46.85
	22	6.50	0.89	5.87	19.85	0.96	45.13
2. K_2SO_4	3	5.11	0.80	6.36	19.03	1.00	39.11
	4	6.15	1.00	7.58	18.64	0.93	40.76
	23	9.40	1.40	7.77	20.47	1.11	35.96
3. $CaCO_3$	2	7.09	0.99	3.65	17.12	0.90	27.58
	8	8.40	1.08	5.02	17.42	0.90	24.77
	11	8.60	1.05	6.44	19.16	0.99	28.66
4. $Ca,Mg(CO_3)_2$	6	6.91	1.18	4.34	20.18	1.07	30.68
	10	7.66	1.20	6.07	19.72	1.05	26.46
	15	7.04	0.94	4.98	17.34	0.79	24.02
5. K_2SO_4 + $CaCO_3$	12	7.10	1.11	7.66	20.89	0.99	28.10
	18	7.93	1.11	7.16	18.40	0.95	24.40
	24	5.55	1.14	8.48	20.01	0.96	40.23
6. K_2SO_4 + $Ca,Mg(CO_3)_2$	1	4.63	0.82	8.24	18.56	0.88	33.97
	13	5.55	0.98	7.16	19.88	0.93	21.79
	16	5.22	0.97	8.30	20.59	1.09	26.89
7. $(NH_4)_2SO_4$	14	7.79	1.12	7.29	18.73	1.10	31.11
	19	8.06	1.20	6.59	21.45	1.13	32.61
	21	7.05	1.17	3.84	19.01	1.05	43.68
8. 4-4-8	5	6.64	1.03	6.14	20.09	0.99	36.62
	7	6.24	1.02	5.55	19.99	1.07	33.47
	17	5.14	0.80	5.07	17.81	0.94	22.44
OVERALL MEAN FOR ALL TREATMENTS		6.77	1.04	6.28	19.29	0.99	32.41

Table A.4. 1987 soil chemical properties of FH Horizons of St-Hippolyte for 8 treatments (n=4)

Treatment	pH	Ca	Mg	K	Na	Fe	Mn	Al	CEC	%Ca	%Mg	%K	%Al
		------- cmol(+) kg^{-1} -------								------- % of CEC -------			
1.Control	4.34	14.84 (4.20)	1.61 (0.54)	0.92 (0.24)	0.09 (0.04)	0.18 (0.06)	0.69 (0.26)	2.03 (1.35)	20.36 (4.12)	72.11 (6.08)	7.80 (1.40)	4.51 (0.55)	10.88 (7.72)
2.K_2SO_4	4.64	14.04 (2.02)	1.42 (0.17)	1.34 (0.44)	0.11 (0.05)	0.14 (0.02)	1.15 (0.28)	4.62 (1.99)	22.81 (3.29)	61.73 (6.64)	6.27 (0.49)	5.85 (1.71)	19.85 (6.21)
3.$CaCO_3$	4.33	18.40 (2.63)	1.98 (0.23)	0.91 (0.15)	0.06 (0.03)	0.23 (0.01)	0.39 (0.07)	1.81 (0.46)	23.77 (2.75)	77.25 (2.83)	8.35 (0.14)	3.81 (0.34)	7.74 (2.40)
4.$Ca,Mg(CO_3)_2$	4.44	12.14 (2.75)	1.70 (0.16)	0.71 (0.12)	0.07 (0.05)	0.21 (0.06)	0.66 (0.44)	4.68 (1.30)	20.17 (3.55)	59.87 (4.51)	8.66 (2.00)	3.54 (0.17)	23.22 (5.34)
5.K_2SO_4 + $CaCO_3$	4.54	22.85 (3.82)	1.79 (0.16)	1.85 (0.49)	0.11 (0.05)	0.10 (0.06)	0.86 (0.66)	2.78 (3.62)	30.33 (2.29)	75.22 (9.91)	5.93 (0.79)	6.13 (1.69)	9.27 (12.09)
6.K_2SO_4 + $Ca,Mg(CO_3)_2$	4.54	17.03 (4.55)	1.84 (0.50)	1.11 (0.21)	0.06 (0.05)	0.09 (0.04)	0.96 (0.30)	2.64 (1.24)	23.73 (4.74)	71.19 (5.49)	7.69 (0.80)	4.72 (0.69)	11.77 (5.82)
7.$(NH_4)_2SO_4$	4.38	21.02 (1.63)	1.63 (0.08)	1.20 (0.18)	0.07 (0.03)	0.10 (0.02)	1.54 (0.51)	1.35 (0.41)	26.90 (1.39)	78.04 (2.21)	6.07 (0.45)	4.44 (0.62)	5.07 (1.74)
8.4-4-8	4.37	17.29 (2.98)	1.82 (0.32)	1.16 (0.33)	0.11 (0.03)	0.12 (0.02)	0.95 (0.28)	2.03 (0.80)	23.47 (3.42)	73.45 (2.98)	7.78 (1.25)	4.89 (1.02)	8.83 (3.99)

Note: Standard deviations of means are given in parentheses.

Table A.5. 1987 soil chemical properties of B Horizons of St-Hippolyte for 8 treatments (n=4)

Treatment	pH	Ca	Mg	K	Na	Fe	Mn	Al	CEC	%Ca	%Mg	%K	%Al
		cmol(+) kg^{-1}								% of CEC			
1.Control	5.02	0.76 (0.15)	0.06 (0.02)	0.04 (0.02)	0.03 (0.02)	0.03 (0.01)	0.02 (0.02)	3.06 (0.55)	4.00 (0.75)	18.98 (0.57)	1.53 (0.51)	1.11 (0.14)	76.48 (1.15)
2.K_2SO_4	5.05	1.18 (0.21)	0.08 (0.02)	0.08 (0.02)	0.02 (0.01)	0.02 (0.01)	0.03 (0.03)	2.58 (0.38)	3.98 (0.37)	29.87 (5.69)	2.15 (0.30)	1.84 (0.34)	64.53 (4.94)
3.$CaCO_3$	4.92	1.29 (0.54)	0.11 (0.05)	0.06 (0.02)	0.02 (0.01)	0.08 (0.06)	0.01 (0.01)	4.01 (1.03)	5.58 (1.68)	22.52 (3.25)	1.88 (0.33)	0.99 (0.02)	72.65 (3.86)
4.$Ca,Mg(CO_3)_2$	5.00	0.74 (0.16)	0.07 (0.01)	0.05 (0.01)	0.02 (0.01)	0.03 (0.01)	0.03 (0.02)	2.91 (0.28)	3.85 (0.43)	19.15 (2.97)	1.88 (0.06)	1.40 (0.18)	75.63 (2.74)
5.K_2SO_4 + $CaCO_3$	4.86	1.08 (0.39)	0.11 (0.04)	0.11 (0.04)	0.02 (0.01)	0.06 (0.04)	0.02 (0.01)	3.27 (0.73)	4.68 (1.18)	22.67 (3.84)	2.23 (0.37)	2.32 (0.80)	70.55 (5.01)
6.K_2SO_4 + $Ca,Mg(CO_3)_2$	4.97	1.44 (0.46)	0.13 (0.04)	0.09 (0.02)	0.02 (0.01)	0.05 (0.02)	0.02 (0.01)	2.50 (0.93)	4.24 (1.19)	34.40 (11.11)	3.03 (0.69)	2.34 (0.76)	58.06 (12.00)
7.$(NH_4)_2SO_4$	4.82	1.41 (0.41)	0.12 (0.03)	0.15 (0.07)	0.04 (0.02)	0.07 (0.06)	0.03 (0.01)	3.37 (0.68)	5.19 (1.20)	27.05 (2.33)	2.25 (0.17)	2.78 (1.23)	65.39 (3.50)
8.4-4-8	4.94	1.87 (0.92)	0.14 (0.05)	0.07 (0.04)	0.03 (0.01)	0.06 (0.04)	0.03 (0.01)	2.88 (1.13)	5.07 (1.72)	36.23 (14.04)	2.68 (0.28)	1.24 (0.38)	57.48 (13.50)

Note: Standard deviations of means are given in parentheses.

Table A.6A. 1987 foliar elemental concentrations of St-Hippolyte for 8 treatments (n=4)

Treatment	Ca	Mg	K	N	P	Al
	mg g^{-1}					ug g^{-1}
1. Control	7.88 (2.69)	1.00 (0.30)	7.06 (1.30)	20.39 (2.08)	1.04 (0.15)	31.28 (6.14)
2. K_2SO_4	10.46 (2.86)	1.05 (0.20)	9.93 (0.66)	24.79 (3.79)	0.85 (0.14)	22.70 (4.85)
3. $CaCO_3$	8.96 (1.13)	0.94 (0.30)	7.37 (2.34)	21.59 (1.86)	0.98 (0.18)	37.51 (15.06)
4. $Ca,Mg(CO_3)_2$	8.54 (0.83)	0.90 (0.12)	6.85 (1.65)	21.18 (1.53)	1.06 (0.14)	37.32 (4.64)
5. $K_2SO_4 + CaCO_3$	9.87 (2.04)	1.00 (0.27)	8.31 (0.36)	20.71 (1.11)	0.87 (0.06)	40.77 (10.21)
6. $K_2SO_4 + Ca,Mg(CO_3)_2$	10.91 (2.92)	1.04 (0.24)	7.97 (1.29)	20.33 (1.09)	0.91 (0.03)	40.00 (8.55)
7. $(NH_4)_2SO_4$	8.33 (1.37)	0.93 (0.15)	7.73 (0.58)	22.34 (1.90)	1.06 (0.16)	43.24 (8.31)
8. 4-4-8	8.96 (0.92)	1.08 (0.14)	7.53 (1.06)	22.99 (1.62)	1.06 (0.14)	45.77 (6.16)

Note: Standard deviations are given in parentheses.

Table A.6B. 1988 foliar elemental concentrations of St-Hippolyte for 8 treatments (n=4)

Treatment	Ca	Mg	K	N	P	Al
	-------	-------	mg g^{-1}	-------	-------	ug g^{-1}
1. Control	6.20 (1.62)	1.03 (0.32)	6.04 (0.91)	18.51 (1.55)	1.07 (0.17)	27.63 (3.92)
2. K_2SO_4	5.89 (1.24)	1.06 (0.22)	9.39 (1.07)	19.47 (1.65)	0.95 (0.18)	30.63 (5.34)
3. $CaCO_3$	6.67 (0.58)	1.02 (0.14)	6.11 (1.56)	19.04 (0.94)	0.95 (0.04)	39.97 (13.72)
4. $Ca,Mg(CO_3)_2$	6.72 ((0.75)	1.07 (0.12)	7.76 (2.66)	18.99 (1.34)	1.21 (0.09)	32.73 (8.68)
5. K_2SO_4 + $CaCO_3$	5.38 (1.02)	0.92 (0.09)	8.18 (1.12)	17.37 (1.01)	0.90 (0.03)	25.50 (2.52)
6. K_2SO_4 + $Ca,Mg(CO_3)_2$	7.11 (0.70)	1.04 (0.18)	7.34 (1.27)	16.96 (1.91)	0.85 (0.09)	23.81 (4.39)
7. $(NH_4)_2SO_4$	6.02 (0.32)	0.97 (0.15)	9.00 (2.39)	19.36 (1.96)	1.20 (0.19)	23.67 (3.52)
8. 4-4-8	8.03 (0.90)	1.08 (0.15)	8.13 (0.95)	20.32 (0.79)	1.21 (0.08)	23.53 (3.02)

Note: Standard deviations are given in parentheses.