THE EFFECTS OF SUGAR MAPLE (<u>ACER</u> <u>SACCHARUM</u> MARSH.) AND BLACK WALNUT (<u>JUGLANS</u> <u>NIGRA</u> L.) ON SOIL FERTILITY: PRELIMINARY ASSESSMENT OF THEIR AGROFORESTRY POTENTIAL

by

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ABSTRACT

Two studies were carried out in the Morgan Arboretum of McGill University to explore the agroforestry potential of some native tree species of Southern Quebec. In the first study, soil chemical characteristics under basswood (*Tilia americana* L.), white ash (*Fraxinus americana* L.) and bitternut hickory (*Carya cordiformis* Wang. K. Koch) in relation to sugar maple (*Acer saccharum* Marsh.) were assessed in natural stands. Soil pH was highest under white ash and was lowest under bitternut hickory. Soil NO_3^- was low under basswood compared to white ash. Soil pH and exchangeable soil Ca^{2+} and Mn^{2+} decreased with an increase in basal area and exchangeable soil K^+ decreased ($p=0.07$) with an increase in the proportion of sugar maple relative to total basal area.

In the second study, the effects of black walnut (*Juglans nigra* L.) on growth and nutrient content of lettuce (*Lactuca sativa* L.), kale (*Brassica oleracea* L.), parsley (*Petroselinum crispum*) and Swiss chard (*Beta vulgaris* L.) in an alley cropping system were determined. The experiment was carried out in a randomized complete block design with repeated measures. All vegetables survived in the black walnut plantation and in the open field. The order of sensitivity to growth under black walnut was Swiss chard > kale > lettuce > parsley. Low light intensity in the plantation likely decreased plant dry weights and nutrient contents. Generally plant N, P and K concentrations were higher in the plantation while Ca, Mg and Mn concentrations were higher in the open field, possibly due to an antagonistic effect of high soil K^+ content in the plantation and to inhibitory effects of black walnut.

RÉSUMÉ

Deux études ont été conduites dans l'Arboretum Morgan de l'Université McGill pour explorer le potentiel agroforestier de quelques essences forestières indigènes. Dans la première, les caractéristiques chimiques des sols sous le tilleul (*Tilia americana* L.), le frêne d'Amérique (*Fraxinus americana* L.) et le caryer cordiforme (*Carya cordiformis* Wang. K. Koch) en relation avec l'érable à sucre (*Acer saccharum* L.) Le pH du sol était plus élevé sous les couples d'érable à sucre et de frêne d'amérique et était le plus bas sous l'érable à sucre et le caryer cordiforme. Les nitrates échangeables du sol étaient en plus faible concentration sous les couples d'érable et de tilleul que sous les couples d'érable et de frêne. Le pH et le Ca^{2+} et Mn^{2+} échangeable diminuaient avec l'augmentation de la surface terrière alors que le K^{+} diminuait ($p=0.07$) avec l'augmentation de la contribution de l'érable à sucre à la surface terrière totale.

Dans la deuxième étude, l'effet du noyer noir sur la croissance et le contenu en nutriments de la laitue (*Lactuca sativa* L.), du chou frisé (*Brassica oleracea* L.), du persil (*Petroselinum crispum*) et de la bette à carde (*Beta vulgaris* L.) dans un système d'alley cropping a été déterminé. Le dispositif expérimental était un plan à bloc complet aléatoire avec mesures répétées. Tous les légumes ont survécu dans la plantation et le champ. L'effet négatif du noyer noir sur la croissance a été établi comme suit: Bette à carde > chou frisé > laitue > persil. La faible intensité lumineuse dans la plantation a probablement diminué le poids sec et le contenu en nutriments des plantes. En général, les concentrations en N, P et K des plantes étaient plus élevées en plantation alors que

Ca, Mg et Mn étaient plus élevés au champ, probalement dû à l'effet antagoniste de la concentration élevée en K^+ du sol en plantation et de l'effet inhibiteur du noyer noir.

PREFACE

The purpose of this study was to examine the influence on soil chemical characteristics of different tree species in relation to sugar maple, and the effect of black walnut on growth and nutrient uptake of vegetable crops under an alley cropping system. Essentially, the two studies are of exploratory nature regarding agroforestry systems in Southern Quebec. A general introduction is presented at the beginning of the thesis. The two studies are presented separately. There are three chapters in this work; chapters one and two contain each experiment respectively with specific introduction, literature review, material and methods, results and discussion sections. A connecting paragraph is inserted between chapter one and chapter two. Chapter three contains the general conclusions.

The following remark concerning the authorship of papers is excerpted according to the Guidelines Concerning Thesis Preparation from Faculty of Graduate Studies and Research, McGill University 1995:

> "The candidate have the option of including, as part of the thesis, the text of one or more papers submitted or to be submitted for publication, or the clearly-duplicated text of one or more published papers. These texts must be bound as an integral part of the thesis.
>
> If this option is chosen, **connecting texts that provide logical bridges between the different papers are mandatory.** The thesis must be written in such a way that it is more than a mere collection of manuscripts; in other words, results of a series of papers must be integrated.
>
> The thesis must still conform to all other requirements of the "Guidelines for Thesis Preparation". **The thesis must include:** A Table of Contents, an abstract in English and French, an introduction which clearly states the rationale and objectives of the study, a comprehensive review of the literature, a final conclusion and summary, and a thorough bibliography or reference list.

Additional material must be provided where appropriate (e.g. in appendices) and in sufficient detail to allow a clear and precise judgement to be made of the importance and originality of the research reported in the thesis.

In the case of manuscripts co-authored by the candidate and others, **the candidate is required to make an explicit statement in the thesis as to who contributed to such work and to what extent.** Supervisors must attest to the accuracy of such statements at the doctoral oral defense. Since the task of the examiners is made more difficult in these cases, it is in the candidate's interest to make perfectly clear the responsibilities of all the authors of the co-authored papers. **Under no circumstances can a co-author of any component of such a thesis serve as an examiner for that thesis".**

Therefore, the two papers in this thesis will be co-authored by the candidate and his supervisor, Dr. B. Côté. The candidate has been responsible for both conducting the studies and preparing the manuscripts. Guidance and assistance were provided by Dr. B. Côté.

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GENERAL INTRODUCTION:

In a forest ecosystem individual trees can affect the chemical properties of the soil in their vicinity (Riha et al. 1986a). Alban (1982) and Binkley and Valentine (1991) found that many tree species influenced soil pH and cation concentrations, especially in the surface horizons. Soil acidification under forest trees is quite variable. Such variation is due to differential nutrient accumulation or uptake, especially of calcium (Alban 1982, Binkley and Richter 1987), and acid litter and leachates from decomposing leaves (Lutwick et al. 1952, Gilliam 1991). In studying long-term soil chemistry changes in aggrading forest ecosystems, Knoepp and Swank (1994) indicated that the younger and more vigorous white pine (*Pinus strobus* L.) stand accumulated about 80% more calcium, potassium and magnesium than the mixed hardwood forest. Such plant nutrient uptake affects soil pH and amounts of exchangeable cations, and overall soil fertility.

The variation in soil chemical nutrients and changes in pH levels influence survival and growth of the understorey canopy. The understorey canopy is also influenced by the amount of light reaching ground level (Yocum et al. 1964, Vezina and Boulter 1966, Holmes and Smith 1977a,b, Tasker and Smith 1977), variation in soil and air temperatures (Wild 1993) and plant phytotoxic substances (Massey 1925, Davis 1928, Gordon and Williams 1988). With increasing demand for integrated forestry-farming or agroforestry in the tropics and in temperate regions (Smith 1942, Garrett and Kurtz 1983a) there is a need to understand various tree-crop relations such as shading effects, phytotoxicity and competition for various nutrients in these systems.

This study was carried out in two parts. First, comparison of soil chemical properties under different tree species in relation to sugar maple (*Acer saccharum* Marsh.) was examined in order to assess the potential of different high value hardwoods for their soil ameliorating properties for agroforestry systems. The relationship with sugar maple was chosen due to its omnipresence in the hardwood forest of southern Quebec and to its potential for soil acidification (Jones 1962). Secondly, a study on the effects of black walnut (*Juglans nigra* L.) on growth and nutrient content of vegetable crops grown under an alley cropping system was carried out. Black walnut is a tree species suitable for agroforestry systems due to its high economic value and growth habits (Bolar 1973, Garrett et al. 1991). It also produces an allelopathic substance that inhibits the growth of various crops. The two studies were carried out to establish how different tree species influenced soil fertility, especially of the top soil horizon that is mainly utilized by crops.

The main aim of this study was to study the effects of sugar maple and black walnut, two economically important trees species in Northeastern America, on soil fertility in order to assess their potential for agroforestry.

CHAPTER 1

COMPARISON OF SOIL CHEMICAL PROPERTIES UNDER DIFFERENT TREE SPECIES IN RELATION TO SUGAR MAPLE

1.1 INTRODUCTION:

The variability in soil properties and distribution of plant species can be attributed to variation in climate, topography, parent materials, disturbance history and biological processes within the soil (Beckett and Webster 1971, Yin et al. 1992) as well as to interactions between these factors (Gilliam 1991). In a forest ecosystem individual trees and different species of trees affect the chemical properties of the soil in their vicinity (Riha et al. 1986a). The soil, under the influence of the forest, develops properties that vary spatially with relation to the location of the trees (Zinke 1962). Trees influence soil properties through the return of various residues in the form of bark debris, leaf litter, twig and branch materials which decompose and form soil carbon, nitrogen and exchangeable cations (Zinke and Crocker 1962). Individual trees in a forest community can control the soil properties in a very systematic way (Lodhi 1977) such as the development of radial or lateral gradients in soil properties with distance from the tree (Zinke and Crocker 1962), and development of concentric zones. For example, Crampton (1984) observed that under western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and red cedar (*Thuja plicata* Donn.) there was a limited flow of very acidic water from precipitation down the stem and a much greater flow of less acidic water from the periphery of the canopy. Zinke (1962) reported that tree influence is maximal under the crown canopy and increases or decreases outward from the tree crown.

Soil acidification under forest trees has been studied through analysis of soil pH and vegetation data (Zinke 1962, Alban 1982, Crampton 1984, Riha et al. 1986a,b, Tamm and Hallbacken 1986). For example, in a study of four tree species in southern Ontario, France et al. (1989) reported that the acidity of forest floor differed greatly among species (white pine pH 5.3, white spruce (*Picea gluca* (Moench) Voss) 5.9, paper birch (*Betula papyrifera* Marsh.) 4.8, and sugar maple 3.7). Alban (1982) suggested that such variation is probably due to differential nutrient accumulation or uptake, especially of calcium. He also stated that tree species alteration of the soil calcium status with consequent changes in soil pH contributes to major changes in soil cation exchange capacity. Several other factors contribute to forest soil acidification. These factors include precipitation amounts, soil age, tree nutrient uptake (Binkley and Richter 1987), leachates from decomposing leaves (Lutwick et al. 1952), stemflow water (Carlisle et al. 1967, Mina 1967) and in many coniferous forests, through inputs of acid litter to the forest floor (Gilliam 1991).

Most of the research on the forest soil has involved chemical and physical soil properties under different tree species in relation to similar or different soil types. In this study, the aim was to find out whether there is variation of soil chemical properties under and between sugar maple and three other tree species on two soil types in the Morgan Arboretum. The other tree species were basswood (*Tilia americana* L.), white ash (*Fraxinus americana* L.), and bitternut hickory (*Carya cordiformis* Wang. K. Koch). These tree species are found growing naturally with sugar maple and their leaf litter is characterized by low acidity, high directly titratable bases and ash bases (Howard and Howard 1990, Côté and Fyles 1994). They could therefore significantly influence the soil cation-exchange capacity, exchangeable cations and soil pH as well as act as soil ameliorators in presence of acidifying sugar maple (Côté and Fyles 1994).

1.2 LITERATURE REVIEW:

1.2.1 Throughfall and stemflow:

Within a forest stand, individual trees can influence soil development by affecting microclimate, litter quality and by having differential nutrient absorption and accumulation (Aluko 1993). Such influence varies spatially with relation to the location, size, age or shape of the tree crown (Zinke 1962). The quality of rain water entering the soil may differ depending on whether the source is stemflow, drip or throughfall (Zinke 1962), including wash off of deposited particles and gases as well as uptake and release of substances by plants and microflora (Carlisle et al. 1966, Alban 1982, Lovett and Lindberg 1984). Acid stemflow affects markedly the area near the trunk. These were established in several studies on sessile oak (*Quercus petraea*) (Carlisle et al. 1967) pine, spruce, birch, basswood and ash (Mina 1967) and in American beech (*Fagus grandifolia* Ehrh.), red oak (*Quercus rubra* L.) and sugar maple (Gersper and Holowaychuk 1971). Stemflow also contribute small but appreciable quantities of bases to the soil which influence the soil pH (Carlisle et al. 1967). The percentage of intercepted precipitation which reaches the ground surface as stemflow varies with tree species and is mainly related to bark characteristics and branching pattern, with smooth, dense bark trees usually having a large amount of stemflow while rough, corky bark trees have considerably less (Mina 1965, Gersper and Holowaychuk 1970b, 1971). The influence of stemflow on soil is localized about the trunk and extends radially 30-50 cm outward from the trunk and to a depth of 1 m in loamy sand soils (Mina 1967). However, Beniamino et al. (1991) reported that the relation between stemflow and acidification of the soil around the trunk may be questionable in the case of oak trees since most of the rain water reaching the soil as stemflow is only 0.62% of the incident rain in an oak stand of similar age and in the same geographic region.

In studying precipitation in spruce (*Picea abies* L.) and beech (*Fagus sylvatica* L.) stands, Nilhgard (1970) reported that in spite of a higher interception and lower rainfall reaching the ground, the amounts of nutrients are higher in the rain-water of the spruce forest than in that of the beech forest and that the rain water is more acid in the spruce forest, especially the stemflow derived from the leaching processes of the canopy. Leachates from decomposing leaves of different forest trees have been shown to cause relatively low soil pH (Lutwick et al. 1952, Alban 1982, France et al. 1989). Alban (1982) reported that soil pH and cation exchange capacity were higher under the pine species than under aspen (*Populus tremuloides* Michx.) and spruce species, and calcium was higher under pines than spruce and aspen. He also noted that the high pH was directly related to high soil calcium under the pines. Coldwell and Delong (1950) reported that natural rain water leachates from maple leaf litter were strongly acidic until the following spring. The leachates of birch species were least acidic and those of beech and poplar species were intermediate, the leachates becoming progressively more alkaline as the time and extent of decomposition increased. France et al. (1989) in studying soil chemistry of forest floor among different species of trees reported that the low pH associated with maple and higher pH with white pine appear to indicate that the biogeochemistry of the maple is rapidly altering the ability of the soil to withstand acidification.

Miles (1985) stated that nutrient enriched throughfall and stemflow can modify the soil under plants' canopy. For example, when an individual of one species is replaced by a plant of a different species, changes in labile soil properties such as top-soil pH, organic matter and exchangeable base content are detected. Under large woody plants, such changes in the soil occur as a radial gradient from main stems and with depth (Zinke 1962, Grubb et al. 1969, Lodhi 1977). Zinke (1962) indicated that soil pH increased away from the tree trunk and soil nitrogen content was lowest at the tree trunk increasing to maximum at 1.22-1.83 m out and declining or increasing with distance outward depending upon the nature of the adjacent vegetation while exchangeable cations Ca^{2+}, Mg^{2+}, K^+ and Na^+ decreased away from the tree trunk.

1.2.2 Leaf litter and nutrient availability:

Lodhi (1977) suggested that variable tree litter under different species plays an important role in controlling the soil pH, nitrification, and mineralization. As a result of leaf litter acidity of maples, Côté and Fyles (1994) suggested that the gradual transformation of mixed to pure stands of sugar and red maple (*Acer rubrum* L.) in eastern Canada may have resulted in soil acidification with an accompanying decrease in base cation availability and soil fertility. Boerner (1984b), Perry et al. (1987), Boerner and Koslowsky (1989) and Côté and Fyles (1994) suggested that nutrient cycling of certain species may vary as a function of the site conditions. In studying surface soil acidification under red pine (*Pinus resinosa* Ait.) and Norway spruce (*Picea abies* [L.] Karst) in natural stands and plantations on varying soil types, Pallant and Riha (1990) found a significant decrease in soil pH from the edges of the tree canopies to the bases of the trees in both species in the upper mineral soil and organic horizons, but this pattern varied according to soil type. The soil pH under a natural stand of red pine growing in sandy soil was lower than those grown in a coarse-loam (Pallant and Riha 1990) suggesting that the sandy soil was low in exchangeable bases and more poorly buffered against soil acidification and that the lower availability of base cations also resulted in lower concentrations in the leaf litter. Beniamino et al. (1991) also pointed out that trees growing on soil containing more clay do not acidify and accumulate organic matter as much as trees growing on a soil poorer in clay content, due to the high buffering capacity of clay soils.

In a study on the pedological influence of spruce planted on a former beech forest soil, Nihlgard (1971) reported that the quantity of exchangeable elements varied even within the profiles of the same stand, with a decrease of potassium and calcium and an increase of iron and phosphates in the upper horizon and an increase of potassium in the lower horizon. Soil nutrient levels may also change if tree nutrient uptake is greater than the replenishment ability of the soil (Heirberg et al. 1959). Alban (1982) reported that the relatively greater increase in H^+ activity under spruce plantation can be attributed to the greater demand for base cations such as calcium and magnesium by this species. He stated further that redistribution of soil minerals such as calcium by vegetation uptake and return to forest floor via litter fall is strongly dependent on tree species and may affect many soil properties such as pH and cation exchange capacity. Among the species he studied (sycamore (*Platanus occidentalis*), hackberry (*Celtis occidentalis*), red oak (*Quercus borealis*), white oak (*Q. alba*), and American elm (*Ulmus americana*)), Lodhi (1977) reported that white oak had the lowest soil pH and the lowes mean amount of all minerals except zinc and ammonium nitrogen. But Klemmedson (1987) reported that P, S, Ca and K concentration under gambel oak (*Quercus gambelii* Nutt.) were significantly increased by increased oak basal area. Gersper and Holowaychuk (1971) reported that the chemical variation in the soil under beech and red oak were attributed mainly to effects of stemflow water, whereas those under sugar maple, pignut hickory (*Carya glabra*) and white oak were attributed mainly to effects of organic litter or to the combination of the two effects. Although decomposing litter is a source of nutrients to the soil, it has been suggested in some cases to temporarily accumulate some elements. Rustad and Cronan (1988) reported that although decomposing litter was an important source of P, Mg, and Mn, the litter acted as a sink for Al, Fe, and N through abiotic adsorption on humified litter. Aluko (1993), who studied soil properties and nutrient distribution under *Terminalia superba* stands, found that at one site, the organic matter and potassium concentration increased with plantation age and the values of nitrogen, phosphorus and magnesium in the soils of 15 year-old stands were significantly lower than in soils of 11 year-old stands.

Satchell (1980) reported that birch litter increased the nitrogen and calcium contents and slightly raised the pH of the soil.

1.2.3 Forest allelochemicals:

Allelopathic effects of trees on understorey plants have been documented for some time now (Massey 1925 and Davis 1928). Patrick and Koch (1958) reported that toxic substances are likely to be produced in localized areas where environmental factors such as the concentration of plant residues, water content, and pH are favourable for toxic substance formation. The toxicity level of these substances can decrease or eventually disappear because they may be metabolized or oxidized through soil-plant processes, microbial activity, leaching and several other environmental factors (Lodhi 1975).

Most of the chemicals produced by plants are secondary metabolites and are produced as offshoots of primary metabolic pathways (Rizvi and Rizvi 1992). Rice (1984) classified the chemical compounds identified as allelopathic agents produced by higher plants and microorganisms into several major categories ranging from aliphatic aldehydes, naphthaquinones, complex quinones, benzoic acids, cinnamic acids, flavonoids to tannins. Lodhi (1975), in studying soil-plant phytotoxicity and its possible significance in patterning of herbaceous vegetation in a bottomland forest, isolated phytotoxic compounds such as ferulic, caffeic and p-coumaric acids that were toxic or inhibitors of herbaceous plants growing under hackberry (*Celtis laevigata*). Phenolic compounds including tannins are usually considered a major component of carbon-based defenses against herbivory attack on trees or plants (Coley 1986, Rossister et al. 1988). Plant-induced changes in the soil environment for forest species have been shown to regulate the availability of nitrogen forms by affecting the soil microbial processes governing mineralization (Zinke 1962, Lodhi 1977). Rice and Pancholy (1972) suggested that climax vegetation inhibits nitrification and, earlier, Basaraba (1964), Rice (1965 and 1969) provided evidence that inhibitors of nitrification are basically polyphenols which are released from the vegetation. Lodhi and Killingbeck (1980) stated that inhibition of nitrification is often attributed to low soil pH in coniferous forest. However, in their study on allelopathic inhibition under ponderosa pine (*Pinus ponderosa* Dougl.), they found the pH to be slightly alkaline and they suggested that another factor caused the low nitrification which was evidenced by their isolation of chemical inhibitors such as caffeic and chlorogenic acids and condensed tannins toxic to *Nitrosomonas* bacteria which are involved in nitrate synthesis. Lodhi and Ruess (1988) reported that *Nitrosomonas* and *Nitrobacter* counts were higher under basswood than under red oak, hemlock, sugar maple and beech and also found no relationship between soil pH and *Nitrobacter*. Inhibition of nitrification in natural ecosystems increases the amount of ammonium nitrogen thus resulting in a conservation of energy (Lodhi 1978b) by increasing retention of nitrogen in upper soil horizons and decreased leaching (Lodhi and Killingbeck 1980).

1.3 MATERIALS AND METHODS:

1.3.1 Study site and soil sampling:

The study was conducted in the Morgan Arboretum of Macdonald Campus of McGill University on the West Island of Montreal in southern Quebec (45°25'N, 73°57'W; 30 m above sea level). Two stands were chosen in the Morgan Arboretum on two soil types. The first site was a St.Bernard loam (Lajoie and Baril 1952) and the second site was a Farmington loam (Jones 1962); the two sites were half a kilometre apart. St. Bernard soils consist of till derived from sandy magnesian limestone and dolomite of the Beekmantown formation. The soils are well drained, have a moderate moisture-holding capacity, and are mainly of a loam texture with some fine sandy loams and clay soils. Soil pH of the 0-15 cm soil depth ranges from 6.7 to 7.8. The Farmington soils are derived partly from a thin sheet of till over calcareous bedrock and partly from the weathered limestone bedrock itself. The soils are generally well drained and have limited water holding-capacity. The texture varies from fine sandy loam to loam. Soil pH of the 0-15 cm soil depth ranges from 6.8 to 7.5 (Lajoie and Baril 1952). The two sites were chosen based on their similarity in terms of soil type and the prevalence of the four tree species under study although the second site (Farmington loam) had a higher diversity of tree species than the first site (St. Bernard loam).

Selection of trees was done on the two sites based on prevailing wind direction and tree size. Wind influences distribution and redistribution of leaf litter. The prevailing wind in the Morgan Arboretum blow from NE to SW and SW to NE. Therefore soil sampling was restricted to a linear transect between any two trees whose alignment relative to the

North fell between 30°-90° or 210°-270°. In addition, to minimize variation in tree size, the two trees had to be closely similar in diameter at breast height (DBH) (e.g sugar maple:basswood 23:20 or 45:50 cm). Tree pairs were combination of sugar maple-basswood (sm-ba), sugar maple-bitternut hickory (sm-bh), sugar maple-white ash (sm-wa) and sugar maple-sugar maple (sm-sm). Each combination of tree species was replicated five times on each site for a total of 40 tree pairs. Trees were measured for DBH and the distance between trees recorded. The distances between trees ranged from 3.3 and 11.0 m. A preliminary analysis of the data revealed that the distance between the trees had no significant effect on soil chemical characteristics. To account for the effect of roots which is not affected by the prevailing wind direction, the closest tree on each side of the transect was also measured for DBH. Three soil samples were collected along the linear transect between the two trees. To avoid stemflow effect, the area (radius = 1 m) surrounding tree trunk was not considered for sampling. Soil samples were collected at distance D/4, D/2 and 3D/4 from one of the two trees at a depth of 10 cm (Ah horizon) (Figure 1.1). Sampling was done between October 20 and 26, 1993. Soil samples were stored in polyethylene bags at 4°C for a maximum of one week during sampling until taken to laboratory where they were air dried.

1.3.2 Soil laboratory analyses:

Soil samples were air dried at room temperature for three weeks and were gently ground to pass through a 2 mm sieve. Soils (2.5 g sub-samples) were extracted using 25 ml Mehlich III solution (Mehlich 1984). The solution was shaken for 5 minutes and

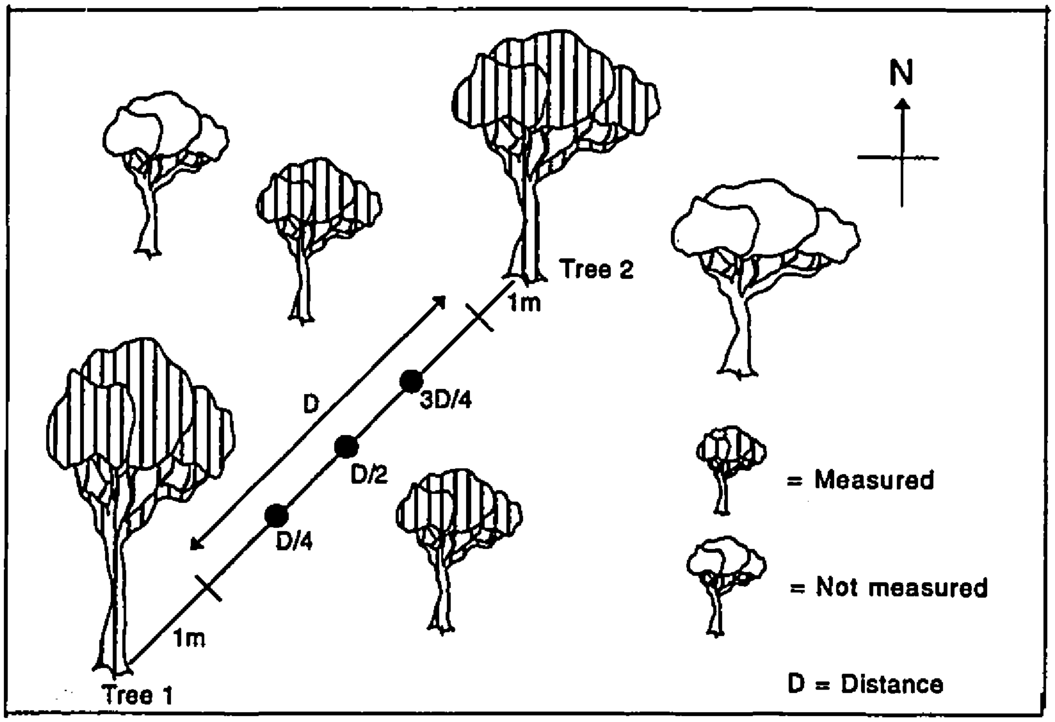


Fig 1.1. Positions in which soil samples were collected along a linear transect in the forest canopy study; example between two trees.

filtered through Whatman no.5 filter paper. The filtrate was measured for calcium, magnesium and manganese by atomic absorption spectrophotometry (Beaty 1978). Phosphorus and potassium were determined using a Lachat Automated Ion Analyzer (Lachat Instruments 1992). Nitrate and ammonium were extracted using 10 g soil sub-samples with 100 ml 1 M KCl (Bremner 1965). The samples were mechanically shaken for one hour and filtered. The filtrate was analyzed automatically for nitrate and ammonium using a Technicon Automated Analysis Instrument (Technicon Instruments 1976). Soil nutrient contents are reported in $kg \cdot ha^{-1}$ (to a 0.2 m depth).

Soil pH in water was determined in a 1:2 ratio of air dried soil and de-ionized distilled water (5 g soil and 10 ml water) (McLean 1982). The solution was shaken for 5 minutes and left to settle for 10 minutes; pH was then measured using a Fisher Scientific pH meter.

1.3.3 Statistical analyses:

The experimental design was a completely randomized design with two covariates: tree total basal area (sum of stem cross section) and the ratio of sugar maple basal area (stem cross section) to tree total basal area (sum of stem cross section). The total basal area is the basal area of both trees in the pair and the two closest adjacent trees opposite the transect. The effect of distance and sampling position between trees was tested and no significant effect was detected. Therefore results for the three positions for each pair of trees were pooled for statistical analysis. Analysis of covariance was carried out on the soil chemical data to determine significant difference between sites, species and the covariates. Where significant differences were detected between sites, the least significant difference method at $p<0.05$ was used to separate their means. For comparison of species means, least square means were determined. Soil pH data was log transformed before analysis was carried out due to heteroscedasticity, thus stabilizing the variance. The data is presented in non-transformed form. Partial correlation coefficients were used to assess relationships between soil chemical characteristics and total basal area and sugar maple basal area to total basal area ratio. The data was analyzed using procedures of Statistical Analysis Systems (SAS) from the SAS Institute Inc. (SAS 1987).

1.4 RESULTS:

1.4.1 Site and tree species influence on soil chemical characteristics:

The effect of tree species on soil chemical characteristics are presented in Table 1.1. Soil pH and exchangeable soil NO_3^--N were significantly different ($p<0.05$) among the tree species pairs. Soil pH under SM-BH was lower than under SM-BA although the difference was small, about 0.3 units. Soil NO_3^--N was higher under SM-WA than under SM-BA tree pair. The other exchangeable elements (Ca^{2+}, Mg^{2+}, Mn^{2+}, P, K^+ and NH_4^+-N) did not differ significantly among tree species pairs. Although not statistically significant, the SM-SM tree pair consistently had among the lowest soil nutrient contents for all elements compared to the other three tree species pairs (Table 1.1).

Soil chemical characteristics of the two sites (Table 1.2) were very similar except for exchangeable soil Mg^{2+} and P content that were higher in site 1 and site 2, respectively.

Table 1.1 Overall means of the soil chemical properties of the Ah horizon under tree species pairs (n=30).

Tree species	pH	NO_3^--N	NH_4^+-N	P	K^+	Ca^{2+}	Mg^{2+}	Mn^{2+}
		($kg \cdot ha^{-1}$)						
SM-BH	5.8b	40ab	15a	41a	200a	5000a	570a	70a
	(0.1)	(4.2)	(1.6)	(6.3)	(20)	(400)	(47)	(8)
SM-BA	6.1a	25c	12a	43a	200a	4900a	580a	70a
	(0.1)	(4.2)	(1.6)	(6.4)	(20)	(400)	(48)	(8)
SM-SM	6.0ab	29b	13a	37a	150a	4500a	570a	60a
	(0.1)	(4.6)	(1.8)	(6.8)	(22)	(440)	(51)	(9)
SM-WA	6.0ab	45a	15a	50a	190a	4400a	530a	80a
	(0.1)	(4.3)	(1.7)	(6.4)	(20)	(420)	(48)	(8)

Standard errors of means are given in parentheses.
Within each column, values followed by the same letter are not significantly different at $p<0.05$.

Table 1.2 Overall means of the soil chemical properties of the Ah horizon of the two sites in the Morgan Arboretum (n=60).

Site	pH	NO_3^--N	NH_4^+-N	P	K^+	Ca^{2+}	Mg^{2+}	Mn^{2+}
		(kg·ha^{-1})						
Site 1 St. Bernard Loam	6.0a (0.05)	37a (2.5)	13a (0.7)	34b (2.3)	200a (11)	4500a (211)	660a (22)	68a (3.6)
Site 2 Farmington Loam	5.9a (0.07)	32a (2.9)	14a (0.96)	51a (3.5)	180a (10)	5000a (260)	470b (23)	73a (4.3)

Standard errors of means are given in parentheses.
Within each column, values followed by the same letter are not significantly different at $p<0.05$.

1.4.2 Influence of tree basal area and the contribution of sugar maple to basal area on soil chemical characteristics:

Soil pH (Table 1.3 and Figure 1.2a) and soil Ca^{2+} and Mn^{2+} (Table 1.3 and Figures 1.2b and 1.2c) decreased with increasing total basal area. Although total basal area did not correlate significantly with other soil nutrient contents (Mg^{2+}, P, K^+, NH_4^+-N and NO_3^--N), all coefficients were negative, suggesting a general decrease in soil nutrient content with an increase in total tree basal area (Table 1.3).

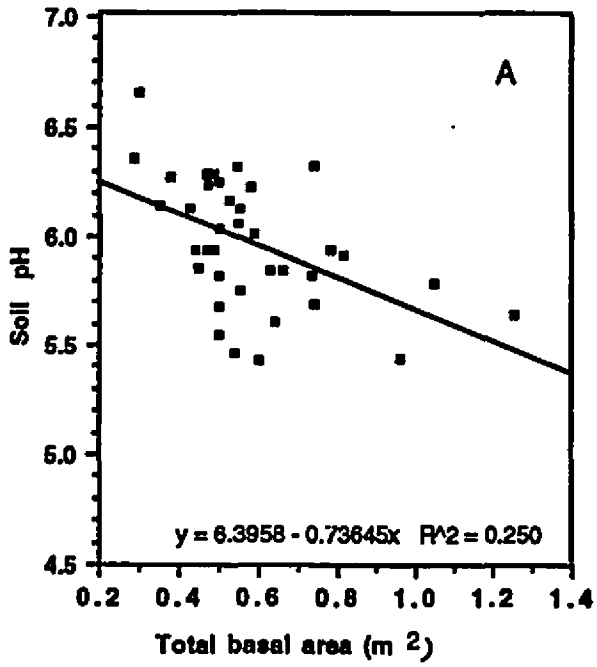
Though not significant, soil K^+ content tended to decrease (p=0.07) with increasing sugar maple contribution to total basal area (sugar maple basal area : total basal area) (Table 1.3 and Figure 1.3).

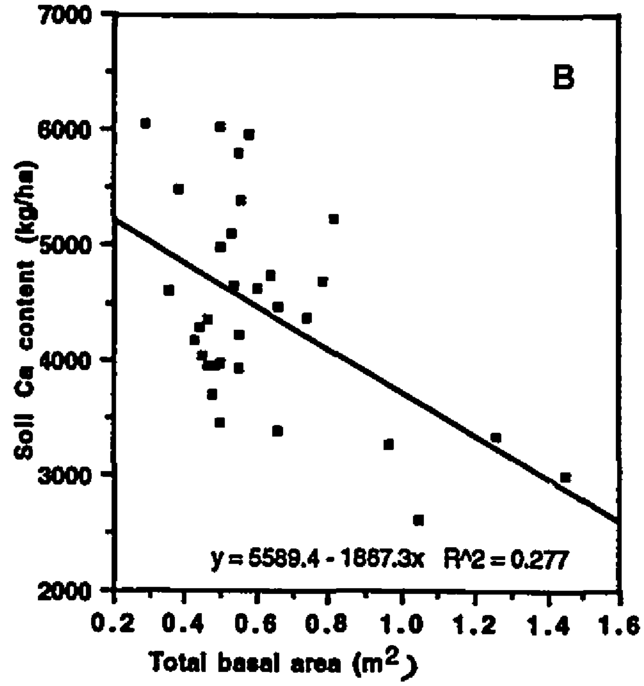
Table 1.3 Partial correlation coefficients of total basal area and ratio of sugar maple to total basal area with soil chemical characteristics (n=40).

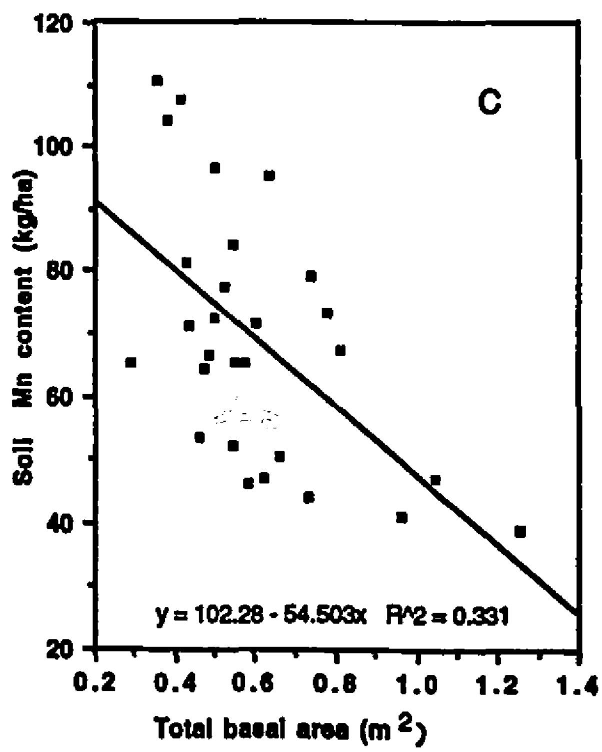
	pH	NO_3^--N	NH_4^+-N	P	K^+	Ca^{2+}	Mg^{2+}	Mn^{2+}
Total basal area	-0.310 0.05*	-0.153 0.35	-0.064 0.69	-0.178 0.28	-0.105 0.53	-0.442 0.005	-0.16 0.34	-0.381 0.017
Sugar maple / total basal area	0.008 0.96	0.055 0.74	-0.006 0.97	0.068 0.68	-0.296 0.0675	0.065 0.69	-0.082 0.62	0.062 0.71

* Probability level.

Fig. 1.2, (A) soil pH, (B) soil Ca and (C) soil Mn respectively
in relation to total basal area.


A
7.0
6.5
6.0
5.5
5.0
4.5
Soil pH
0.2 0.4 0.6 0.8 1.0 1.2 1.4
Total basal area (m 2)
y = 6.3958 - 0.73645x R^2 = 0.250


B
7000
6000
5000
4000
3000
2000
Soil Ca content (kg/ha)
0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6
Total basal area (m2)
y = 5589.4 - 1867.3x R^2 = 0.277


C
120
100
80
60
40
20
Soil Mn content (kg/ha)
0.2 0.4 0.6 0.8 1.0 1.2 1.4
Total basal area (m 2)
y = 102.28 - 54.503x R^2 = 0.331

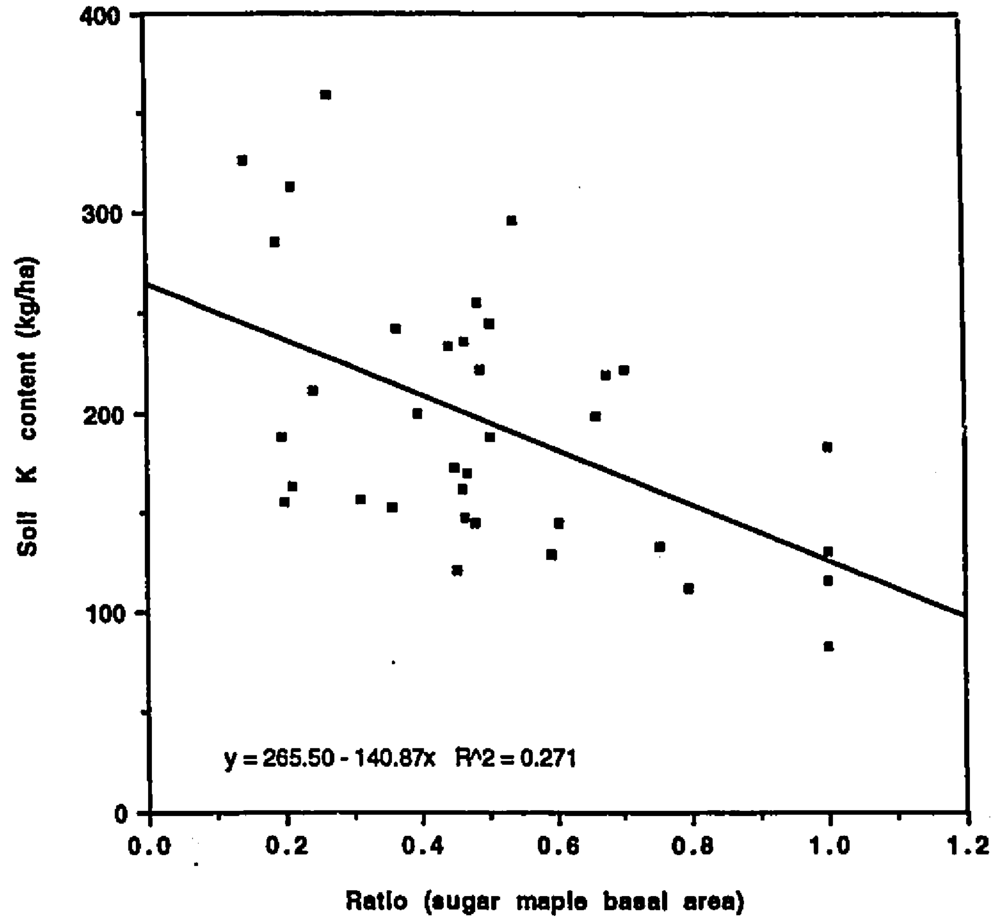


Fig 1.3 Soil K content in relation to the ratio of sugar maple basal area to total basal area

1.5 DISCUSSION:

1.5.1 Site and tree species influence on soil chemical characteristics:

Among the eight soil chemical characteristics studied between the tree species pairs, only soil pH and exchangeable NO_3^--N showed significant differences. The low soil pH under SM-BH tree pairs compared with SM-BA tree pairs could be attributed to high and intermediate acidity of the leaf litter of these two respective species (Howard and Howard 1990 and Côté and Fyles 1994). Although the SM-SM tree pair was expected to show lower soil pH than other tree pairs, it gave an intermediate soil pH compared to other tree species, indicating less sugar maple influence away from the tree trunk. This could be associated with interspecific differences in seasonal nutrient flux during leaf fall in October when soil samples were collected. Sykes and Bunce (1970) indicated that up to 81% of annual total litter-fall, fall between September and November. With leaf litter comes the release of large amounts of organic acids. The timing of soil sampling versus leaf fall of each species was likely the main factor plus the timing of rain that could have decreased the acidification effect of sugar maple.

The lower exchangeable soil NO_3^--N level observed under SM-BA compared to SM-WA tree pairs may be as a result of earlier leaf fall and litter decomposition in basswood and therefore, an earlier peak in nitrate leaching or mineralization than in the other tree species. Although, leaf fall of trees and shrubs mainly occurs between September and November, there are differences in their peak among tree species. The main leaf fall peak period for most of the hardwoods in the Morgan Arboretum occurs between September 15 and October 20 (Djalilvand, pers. comm.). Holmes and Zak (1994) indicated a peak in net N mineralization following a period of increased carbon availability between October and November in northern hardwood ecosystems dominated by sugar maple, basswood and red oak. Sykes and Bunce (1970) reported that oak (*Quercus petraea* (Mattuschka) Liebl.), ash (*Fraxinus excelsior* L.) and birch (*Betula pubescens* Ehrh.) consistently over a three year period, reached their litter fall peak in October with gradual decline through November while hazel (*Corylus avellana* L.) reached its peak in November. Litter of deciduous trees usually decomposes more rapidly than those of coniferous trees especially those rich in nitrogen and soluble carbohydrates and poor in polyphenols although considerable variation occurs between different species. Bocock and Gilbert (1957) observed that leaves of birch (*Betula verrucosa* Ehrh.) and lime (*Tilia cordata* Mill.) were more rapidly decomposed than those of oak. Lodhi and Ruess (1988) reported that basswood had the highest total leaf N and a higher count of *Nitrosomonas* and *Nitrobacter* bacteria under it than under red oak, hemlock, sugar maple and beech trees. Holmes and Zak (1994) reported that under sugar maple-basswood stands there was higher microbial biomass carbon and nitrogen than under sugar maple-red oak stands although the differences were not statistically significant. Possible early leaf fall and influence of microbial activities under basswood may have led to earlier nitrate immobilization.

Although it was not statistically significant, the SM-SM tree pairs consistently had among the lowest soil nutrient content for all elements compared with the other three tree species pairs. The lower nutrient availability under SM-SM tree pairs could indicate a depletion of soil chemical nutrients in sites with pure sugar maple trees compared with sites with mixture of sugar maple and other species.

The lack of significant differences between the sites for most of the soil chemical characteristics studied (soil pH, exchangeable Ca^{2+}, K^{+}, Mn^{2+}, NH_4^{+}-N and NO_3^{-}-N) indicates a strong similarity in soil chemistry under the two forest floors, especially at distances that eliminate stemflow effects. The significant site difference observed for exchangeable soil Mg^{2+} could be due to the high content of this element in the parent material of site 1 (Lajoie and Baril 1952, Côté and Fyles 1994). The high soil P content of site 2 compared to site 1 could be the result of different tree species composition. Site 1 was dominated by sugar maple and hickory while site 2 was dominated by sugar maple, basswood and white ash (Jones 1962). Pastor et al. (1984) indicated that stands with increased proportion of such species as sugar maple, basswood and ash had greater P concentration in their leaf litter which also correlated with enhanced P mineralization.

1.5.2 Influence of total tree basal area and the contribution of sugar maple to basal area on soil chemical characteristics:

The decrease in soil pH with an increase in total basal area could be the result of a decrease in soil exchangeable cations, especially soil calcium. Indeed, both soil pH and exchangeable soil Ca^{2+} decreased significantly as total basal area increased. Alban (1982) indicated that the lower the level of Ca^{2+} in the forest floor or the mineral soil, the lower the soil pH.

Although total basal area did not correlate significantly with exchangeable soil Mg^{2+}, P, NH_4^+-N and NO_3^--N, all of their coefficients were negative indicating a general decreasing trend in soil nutrient contents with an increase in total basal area. The decrease in content of these soil nutrients could be due to leaching, accumulation in soil organic matter or in plant tissues through nutrient uptake as plant biomass increased. Alban (1982) reported that differential Ca^{2+} uptake by vegetation rather than by leaching was the probable cause of changes in forest floor and exchangeable soil Ca^{2+} status. Johnson and Todd (1990) showed that in forests of the Walker Branch Watershed, Tennessee, sub-soil exchangeable Ca^{2+} and Mg^{2+} decreased over the period of 1971 to 1982. They had hypothesized that wood accumulation was the dominant cause of the decrease in exchangeable Ca^{2+} and that atmospheric deposition-induced leaching was the dominant cause of the exchangeable Mg^{2+} decrease. They found that wood accumulation far exceeded leaching of Ca^{2+} in those plots where soil exchangeable Ca^{2+} decreased. They also reported a decrease in exchangeable P, K^+ and total N but all were mostly inconsistent. The decrease in exchangeable Mn^{2+} content with an increase in total basal area could also be attributed to an accumulation in tree biomass or leaching into deeper soil horizons. However, Jokela et al. (1990) indicated that in *Rubus spp*, a dominant understorey plant especially common in pine plantations, showed considerably higher Ca, Mn, B, and Cu concentrations than in pine foliage, indicating that understorey species can also compete and accumulate substantial soil nutrients from forest soils, hence causing decreases.

Among the soil chemical characteristics studied, only exchangeable soil K^+ decreased with an increase in the ratio of sugar maple to total basal area. This indicated that sugar maple may have immobilized more K in its perennial tissues than other tree species. The lack of significant differences for other soil chemical characteristics could indicate that under such tree pairing as in this study, where sugar maple did not occupy a large proportion of the total basal area relative to the other species, spatial variation in soil fertility was minimal. This could be due to the interactivity of various tree species through varying leaf litter content, deposition, redistribution, decomposition and nutrient uptake under the mixed forest canopy. Côté and Fyles (1994) indicated that many species typical of sugar maple climax may have better soil ameliorating potential than sugar and red maple. Côté and Fyles (1994) reported a higher concentrations of N, P, K, Ca, and Mg in leaf litter of basswood, butternut (*juglans cinerea* L.), eastern cottonwood (*populus deltoides* Marsh.) white ash and bitternut hickory compared to those of oak, white pine and maple species

CONNECTING PARAGRAPH

Black walnut has been identified as the species of choice for agroforestry purposes in Northeastern America. However, other species such as sugar maple (maple syrup) and basswood (honey), which are not usually considered for use in agroforestry systems, could meet the needs of some producers. In the preceding study, soil chemical characteristics under three commercially important tree species in relation to sugar maple were determined. Before designing agroforestry systems adapted to Quebec conditions, I felt that it was important to assess the ameliorating soil potential of some tree species non-commonly used in agroforestry. In the second part of this study, I explored the potential of some cash crops also not commonly considered or used in agroforestry. In an already established black walnut plantation I assessed the potential of leafy vegetables (kale, lettuce, parsley and Swiss chard) in an alley cropping system. Both growth and nutrient content of the vegetables were measured.

CHAPTER 2

EFFECTS OF BLACK WALNUT ON GROWTH AND NUTRIENT CONTENT OF VEGETABLE CROPS IN AN ALLEY CROPPING SYSTEM

2.1 INTRODUCTION:

Black walnut (*Juglans nigra L.*) is a very valuable tree to the economy of North America (Lassoie et al. 1991, Garrett et al. 1991). It has received considerable attention in various fields of research due to the economic value of its lumber, logs, veneer and nuts (Bolar 1973, Gordon and Williams 1990, Garrett et al. 1991), and its allelopathic effects on plant community relationships (Massey 1925, Davis 1928, Gabriel 1975). The concept of integrated forestry-farming or agroforestry is not new in North America and has been proposed on numerous occasions using black walnut (Smith 1942, Garrett and Kurtz 1983a). Agroforestry is a term derived from "agriculture" and "forestry". It is a land-use system which involves the combined production and utilization of forest and agricultural crops on a given tract of land (Mendoza et al. 1986), and is popular in developing countries in the tropics.

In the past, agricultural policy has relegated trees to small, over-utilized farm woodlots and shelterbelts where soils are poor and sites marginal for agriculture. Such policies have caused the general public to criticize agricultural policy makers and the farming community for past agricultural practices that have increased soil and wind erosion, degraded soil structure, lowered water quality and reduced wildlife habitat

(Gordon and Williams 1990, Lassoie et al. 1991). As a result, cropping systems are being sought that will maintain or increase food production while at the same time, minimizing environmental degradation. Garrett et al. (1991) suggested that agroforestry is a viable land use option that has the potential for increasing crop yield and for improving soil quality while reducing soil and wind erosion and alleviating these problems on a long-term basis.

Gold and Hanover (1987) illustrated three kinds of agroforestry systems that appear to offer particular promise for wide spread implementation. These are 1) grazing of livestock and intercropping under managed conifer stands 2) multicropping of agricultural crops under intensively managed, high value hardwood plantations and 3) growing trees for energy, chemicals, fibre, forage and soil conservation. Black walnut is suitable for the above second category. In North America many tree species including maple, ash, oak, birch, black walnut, chinese nut, heartnut, and hickory (Lassoie et al. 1991) have been investigated for their potential in intercropping. However, the best returns for intercropping with forest trees have been demonstrated for black walnut, a valuable hardwood tree which produces edible nuts, the shells of which are sold for use as abrasives and filter agents and as a filler in a number of products (Gordon and Williams 1988).

Black walnut is a suitable agroforestry tree because it has foliage characteristics which allow the penetration of sufficient light to support plant growth in the understorey (Bolar 1973, Garrett et al. 1991). This is important since most vegetables for example, require full or partial sunlight (Splittstoesser 1990). Although black walnut is suitable for agroforestry practices, it also produces a phytotoxic substance called juglone that eliminates or inhibits the growth of plants that grow close to it (Massey 1925, Davis 1928, Gordon and Williams 1988). The inhibitory or allelopathic effect of black walnut affects various plants differently and, therefore, a better understanding of its effects on a wide range of crops, especially on vegetables, is needed.

The aims of this study were 1) to assess the potential (survival and growth) of four vegetable crops (lettuce (*Lactuca sativa L.*) cv. romaine, kale (*Brassica oleracea* L.) var. acephala, parsley (*Petroselinum crispum*) cv. plain and Swiss chard (*Beta vulgaris* L.) var. cicla mog) for alley cropping with black walnut and 2) to determine the most limiting factors (e.g soil fertility, light and temperature) for vegetables growing under black walnut in an intercropped scenario.

2.2 LITERATURE REVIEW:

2.2.1 Allelopathic effects of black walnut:

Allelopathy is a term which was coined by Molisch (1937) (cited in Rice 1974) that refers to the biochemical interactions between all types of plants including microorganisms. Rice (1974), however, defined it as any direct or indirect harmful effect by one plant on another through the production of chemical compounds that escape into the environment. In essence, allelopathy is the production of phytotoxic compounds and the influence of those toxins on other plants. Cook (1921) reported wilting of potato (*Solanum tuberosum*) and tomato (*Lycopersicum esculentum*) plants due to black walnut that were growing in their vicinity. The range of wilting coincided with the spread of the black walnut root system. He also observed that other crops and some other trees were not affected. Massey (1925) similarly showed that tomato grown close to black walnut wilted while other crops such as beet (*Beta vulgaris* L.), snap beans (*Phaseolus vulgaris* L.) and corn (*Zea mays* L.), which also grew close to the black walnut root invaded area, showed no sign of wilting. This demonstrates the variation in effect of black walnut toxicity on plants, indicating that some plants are tolerant or alter the toxicity of the compound produced by black walnut in their metabolism and, thus, grow unaffected. Massey (1925) concluded that toxic substances are not generally distributed around the black walnut tree but localized within the vicinity of the walnut roots.

Davis (1928) isolated the toxic substance from black walnut hulls and roots and determined and identified its chemical nature as juglone (5-hydroxy 1,4 napthaquinone). Juglone was first isolated from fresh walnut hulls by chemists in search of dye bases (Wheeler and Scott 1919). Most of the compounds that contribute to allelopathic effects as well as defensive role against herbivory in plants are simple phenolic compounds such as phloroglucinol, gentisic, vanillin, caffeic and ferulic acids and the more complex phenolics such as coumarins (e.g scopoletin), phenolic quinones (e.g juglone), lignins (e.g coniferyl alcohol), tannins (e.g ellagic acid) and flavonoids (Levin 1971). These substances reach the soil through various means apart from root exudates such as the fall of senescing leaves, leaf and bark leachates, stemflow and throughfall of water into the soil (Carlisle et al. 1967). Juglone is known to be allelopathic or phytotoxic to some plants growing in its vicinity, affecting the growth and survival of tomatoes, raspberries and most legumes (Gordon and Williams 1988, Gordon and Williams 1990). Gabriel

(1975) reported that black walnuts grown in the vicinity of white birches were detrimental to the growth and survival of the birches, causing death, and that birch vigour increased as distance away from the black walnut trees increased. He also noted that birches were susceptible to the residual effect of black walnuts that had died prior to the establishment of the birch trees. The death of the birches was suggested to be due to the allelopathic effects of the dead black walnut trees.

Juglone has been found to interfere in various processes. In their studies cited by Fisher (1978) (Jensen and Welbourne 1962, Perry 1967 and Ruzincke and Crane 1970) reported that juglone inhibits mitosis, inhibits oxygen uptake in tomato and bean leaf discs, and functions as an electron acceptor for NADH dehydrogenase. Koeppe (1972) using excised corn roots and corn mitochondria, showed that juglone inhibited respiration through an inhibition of coupled intermediates of oxidative phosphorylation.

The concentration of juglone in the soil depends on the age of the black walnut trees, possible degradation of the juglone and juglone precursors in the soil (Fisher 1978, Coder 1983) and the soil moisture content (Fisher 1978, Gordon and Williams 1988). Gordon and Williams (1988) suggested that in early years of black walnut establishment, before the trees are five to eight inches in diameter, there is less of an effect of juglone on crops. After that, however, crop selection is limited to certain grasses and grains that tolerate high juglone concentrations. Fisher (1978) has shown that juglone is more problematic on poorly drained sites. In research on juglone inhibition of red pine (*Pinus resinosa* Ait.) and white pine growth under certain moisture regimes in Southwestern Ontario on a Brant-Tuscola-Colwood Catena (series) of fine sandy loam soils, he found that juglone persisted longer in soils which remained wet for long periods of time than in those which were drier, suggesting that soil conditions play an important role in the interaction between black walnut and other plant species.

Allelopathic effects of other plant species are widespread. Tubbs (1973) found that the growth of yellow birch seedlings was inhibited by sugar maple and that the inhibition was associated with a chemical exuded from sugar maple roots. In examining roots of dead and dying cinquefoil (*Potentilla fructicosa L.*) Massey (1925) found that in every case, there was a close association between the roots of the weed and those of butternut (*Juglans cinerea*) growing in its vicinity, and attributed this to antagonistic action or allelopathic effects from the butternut. While studying lettuce, Junttila (1975) found that extracts from fruits or seeds of *Heracleum sp.* inhibited growth of lettuce seedlings. Chou and Waller (1980) also reported that 5% aqueous extracts of dried fallen leaves and roots of coffee plants markedly inhibited radicle growth of lettuce, rye grass (*Lolium multiflorum*) and fescue due to caffeine which is a strong growth inhibitor (Evenari 1949).

Rizvi and Rizvi (1992) concluded that in any agroforestry programme, consideration of allelopathic interactions could prove to be beneficial in many ways since 1) the best suited companion crop/variety could be selected 2) production could be increased either by minimizing losses due to negative allelopathic effects or exploiting the positive allelopathic interactions among the trees and companion crops and 3) reduction in loss or increase in production due to allelopathic interactions could be made without increasing the farm input.

Weed management in agricultural systems is of great concern. Most intercropping treatments result in less weed biomass compared to sole crops due to crop combination, row arrangement and fast-growing crops with an early establishment advantage over weeds (Sharaiha and Gliessman 1992). Gliessman (1983) and Rizvi and Rizvi (1992) suggested the use of crops with an allelopathic potential in multiple cropping systems for weed control. Thus allelopathy might effectively be combined with an array of weed management practices to suppress weeds (Gliessman 1983).

2.2.2 Shade effect on understorey canopy:

When agricultural crops and trees are intercropped, they compete for light, moisture, nutrients and space (Danso and Morgan 1993). Shading is a result of partial or whole exclusion of light reaching lower plant canopy. Plant canopies act as selective absorption filters. As sunlight filters through the canopy, its spectral distribution is changed because of selective spectral absorption of leaves. The altered spectral distribution may influence understorey photosynthesis and growth, germination, and photoperiod response (Federer and Tanner 1966). Plants growing beneath are, therefore, subjected to a light environment with low photosynthetically active radiation due to an increase in crown cover (Sequeira and Gholz 1991).

Characteristically mature and established black walnut trees have foliage characteristics which allow penetration of sufficient light (i.e not dense shaders) to support plant growth in the understorey (Bolar 1973, Garrett et al. 1991). This may make it compatible with some crops that require minimum shade such as some vegetables e.g

Swiss chard, spinach (*Spinacia oleracea*), lettuce, parsley and kale (White 1981, Schneck 1992). Splittstoesser (1990) indicated that leafy vegetables can be grown in partial shade but vegetables producing fruits need full sun. Garrett et al. (1991) stated that for many cool season species, black walnut shade enhances forage yield and quality. This has been demonstrated with Kentucky 31 tall fescue (*Festuca arundinacea* Schreb.), orchard grass (*Dactylis glomerata* L.) and Reed Canary grass (*Phalaris arundinacea* L.) when grown under walnut as compared to open field.

There is potential growth enhancement of black walnut through alley cropping management. Cutter and Garrett (1993) reported a marked increase in growth rate (mean annual radial increment) of black walnut when intercropped with winter wheat (*Triticum aestivum* L.) and soybean (*Glycine max* [L.] Merr.) due to improved weed control and fertilization of the intercrop.

In two separate experiments on plants of *Chenopodium album* L. grown beneath a range of tobacco canopies and beneath natural canopies (woodland, grass-sward and day light control), Morgan and Smith (1981) reported that the above ground dry weight and leaf dry weight : stem dry weight ratio decreased with increasing canopy density for plants growing beneath the tobacco canopy; specific leaf area increased with increasing canopy density for plants growing beneath both tobacco and natural canopies. An increase in specific leaf area for plants growing beneath vegetational canopies has also been observed in *Circaea lutetiana* (Frankland and Letendre 1978) grown beneath an oak woodland and in *Veronica persica* and *V. montana* (Fitter and Ashmore 1974) grown beneath a tobacco canopy. Frankland and Letendre (1978) also observed that the final height in *Circaea lutetiana* was reduced for plants grown in the shade.

Boardman (1977) reported that plants grown in the shade have thinner leaves. Further, in an elaborate study on the photosynthetic responses of black walnut seedlings to shading, Dean et al. (1982) reported that shading resulted in plants that possessed leaves that were thinner, had less palisade mesophyll, lower stomatal density and more chlorophyll per unit of leaf area. Bensink (1971) cited by Gray and Steckel (1981) showed that a reduction in irradiance increases leaf length without corresponding increase in leaf width of lettuce (crisp head and butter head cultivars). In a similar study on lettuce, Gray (1978) suggested that the variation in mature head, size and density of field grown lettuce was associated with a difference in temperature and irradiance during later stages of growth. In studying hearting and mature head characteristics of lettuce as affected by shading, Gray and Steckel (1981) stated that in lettuce the ground area covered by shaded plants was greater than that covered by unshaded plants because shading increased the length of the outer non-hearting leaves. Plant density and biomass production of mustard (*Brassica campestris*) cultivated under *Acacia nilotica* declined with increasing tree canopy depth (shade) towards the tree trunk (Yadav et al. 1993). In studying the growth of taro (*Colocasia esculenta*), a staple crop in a variety of traditional agroforestry systems in certain Pacific Islands grown under artificial shade, Roger and Losefa (1993) found that the height and leaf area of the taro plant and the total plant biomass (dry weight) were increased under shade compared with full sunlight, but the percentage of biomass in corms was reduced.

2.2.3 Temperature regime under tree canopy:

Soil and air temperatures are mainly influenced by (1) incoming solar radiation and soil reflection, (2) heat loss through radiation, convection, conduction, and latent heat of vaporization of water and (3) by thermal conductivity and heat capacity of the soil (Wild 1993). The temperature regime of the soil is strongly influenced by vegetation. Bare soils have high mean temperatures and greater temperature amplitudes than vegetated soils because they are more exposed to incident radiation and they lack any surface layer which can reduce radiation and decrease wind movement (Burrows 1963, Liddle and Moore 1974, Wild 1993).

Soil microorganisms play an integral function in the cycling of nitrogen within terrestrial ecosystems. The temporal variation in rates of N transformations results from seasonal changes in factors controlling microbial activity, like soil temperature, water potential and carbon availability (Holmes and Zak 1994). Soil temperature optimum for nitrification is between 25-30°C (Wild 1993).

Soil temperature has been found to influence seed germination, seedling emergence, root growth and nutrient uptake (Kabu and Toop 1970, Kaspar and Bland 1992, Wild 1993). In studying the response of seedlings of Halford and Siberian C rootstocks of peach (*Prunus persica* (L.) Batsch) to soil temperature, Young (1980) reported that the height, and root and shoot dry weights of Halford seedlings were less at 10°C and 30°C than at 20°C, and Siberian C height and dry weights were reduced at 30°C. Also, the foliage N content was low at 10°C and high at 30°C. Costigan (1985), in studying nutrient concentration and early shoot and root growth of lettuce, reported that variation in total root length was explained largely by differences in plant weight but the root length/plant weight ratio decreased with increasing average air temperature. However, in studying effects of air and soil temperature on growth and yield of sugar-beets, Sibma (1983) reported that increasing the soil temperature alone did not increase the growth or the yield of the sugar-beet but when higher soil temperatures were combined with higher ambient air temperatures, plant growth and dry matter production increased.

Soil temperature can also influence nutrient uptake by plants. Kabu and Toop (1970) reported that magnesium concentration in tomato plants was increased when plant root-medium temperature increased to a maximum of 23.9°C but decreased at higher soil temperatures. The reduction in plant magnesium was attributed to increased plant growth and a resultant dilution of the nutrient element in the plant tissue. Mackay and Barber (1984) reported that corn yield, root growth and P uptake were increased between 3 and 5-fold at 25°C compared with 18°C soil temperature. However, in studying phosphorus and temperature effects on magnesium, calcium and potassium in wheat and tall fescue leaves, Reinbott and Blevins (1994) found that leaf concentration and total uptake of magnesium and calcium were more dependent on phosphorus nutrition than root temperature.

2.3 MATERIALS AND METHODS:

2.3.1 Field site:

This study was carried out in the Morgan Arboretum of the Macdonald Campus of McGill University. The soil of the experimental sites is of a Chateauguay series and is a clay loam deposited over calcareous till (Lajoie and Baril 1952). The soil is moderately well drained, has good moisture-holding capacity and has a well developed granular structure (Lajoie and Baril 1952, Jones 1962). Two sites were chosen, one within a black walnut plantation aged between 40-45 years, and the other in an open field. The two sites were 30 metres apart. Before the start of this experiment, a thick undergrowth of mainly white ash was present in the black walnut plantation. The open field had been fallow for several years though covered by various grasses that were cut and removed periodically during the summer. Also no pesticides had ever been used in the open field.

2.3.2 Plot establishment:

In May 1993, four plots in the alleys of the black walnut plantation and four plots in the open field were established. The field was prepared manually using shovels, forks and pruning knives to minimize soil disturbance and damage to tree root systems. The plots were fenced using 2.5 cm mesh chicken wire. Each plot measured 2 x 2 m. The crops were assigned randomly to each of the four rows in each of the four plots at each site. Four vegetable crops (lettuce, kale, parsley and Swiss chard) were planted every 30 cm within rows and 60 cm between rows. Each crop appeared in a row of four plants in each plot giving 16 plants per plot. The plots were one metre apart. In the plantation, black walnut trees were spaced 3.4 x 3.1 m between and within rows respectively.

2.3.3 Pot experiment:

In the summer of 1994, a pot experiment was incorporated to establish whether the decrease in plant dry weights in the plantation observed in 1993 was due to inherent soil effects, possibly as a result of contact with root exudates from black walnut trees, or due to lower light intensity in the plantation. Both plantation and open field soils were used. The vegetables were transplanted into pots and the pots were buried in the soil to ground level in the open field and in the plantation according to the following three treatments: A) potted plants with plantation soil and placed in the plantation. B) potted plants with open field soil and placed in the plantation. C) potted plants with open field soil and placed in the open field. There were two plots for each treatment in both plantation and open field. Plot dimensions, planting arrangements and experimental design were as in the field experiment described above. Pots measured 15 cm in diameter and 20 cm in depth and were tapered and perforated at the bottom.

Two week old vegetable seedlings were transplanted to the field during the last week of May 1993 and the second week of May 1994. Weeding was done manually in the two fields. Each year, one weeding was done in the plantation plots four weeks after transplanting, and two weedings were done in the open field plots, four and six weeks after transplanting. Weed proliferation in the open field was greater than in the plantation.

2.3.4 Soil sampling and laboratory analyses:

Five soil samples (0-10 cm) were collected randomly within each plot in the plantation and in the open field on 27 October 1993 using a soil auger. The soils were placed in polyethene bags and kept at 4°C for two days during sampling before being taken to laboratory for analyses. Soil samples were first air dried and then were analyzed for pH and extractable Ca^{2+}, Mg^{2+}, Mn^{2+}, P, K^+, NO_3^--N and NH_4^+-N as indicated in the Materials and Methods Section of Chapter One.

2.3.5 Light intensity (P.A.R):

Photosynthetically Active Radiation (P.A.R) reaching the crop canopy in the plots was measured using a datalogger LI-1000 LI-COR (1987) fitted with a quantum sensor model LI-190SA SR.No. Q8140. The sensor was placed on ten spots randomly chosen within the black walnut plantation and the open field plots. Light intensity (instantaneous) was measured at 1300 hours on a cloudless day on a weekly basis for seven weeks during the second growing season of 1994 from transplantation to harvest starting in early May. PAR was measured as μmol s^{-1} m^{-2}. Light intercepted by trees was converted into percentage of the light (P.A.R) received in the open field.

2.3.6 Soil and air temperature:

A datalogger (LI-1000 LI-COR) was installed in the black walnut plantation to record soil temperatures at 10 cm and 25 cm depth (by using sensor cables buried in the soil), and air temperature twice a day at 0400 and 1600 hours for one year starting October 1993 to September 1994. The data recorded was retrieved from the datalogger monthly. Similar data for the open field were obtained from the Ste-Anne-de-Bellevue Meteorological Station which is 1.2 kilometres from the experimental sites. The data from this station is reliable and is routinely used to characterize experimental plots around the weather station. Mean monthly temperatures are reported in this study.

Temperature and precipitation data for the two crop seasons of 1993 and 1994 were also obtained from the Ste-Anne-de-Bellevue Meteorological Station (Table 2.1). Twice as much total precipitation was received during the 1994 crop season (months of May and June) compared to the 1993 crop season. The maximum average air temperature reached in the two seasons was 21°C both in July.

Table 2.1 Average temperature and total precipitation for the two growing seasons of 1993 and 1994 in Ste-Anne-de-Bellevue.[1]

	May	June	July	August
Temperature (°C)				
1993	13.0	17.2	21.0	20.1
1994	12.1	18.9	21.3	18.0
Precipitation (mm)				
1993	79.1	74.8	94.8	57.5
1994	148.9	194	61.3	99.9

[1] Temperature and precipitation data was obtained from Ste-Anne-de-Bellevue Meteorological Station.

2.3.7 Plant measurements and analyses:

Over the growing season, observations and monitoring of crop performance were made. In 1994, plant heights were recorded on a weekly basis starting one week after transplanting. Vegetables were harvested on July 14, 1993 and July 6, 1994, respectively, as above ground material and roots. Plant height and root length were measured. Soil was carefully washed off the roots and then the fresh plant material (above ground parts and roots) were oven dried at 65°C for 48 hours and their dry weights determined. The above ground dry plant material was ground to pass a 40-mesh screen. A wet digestion method (Parkinson and Allen, 1975) was used to determine N, P, K, Ca, Mg and Mn content in the plant material. Sub-samples of 0.20 g were digested with concentrated H_2SO_4 and H_2O_2 at 340°C in a fume-hood and diluted to 100 ml. Total nitrogen and phosphorus were determined with a Technicon Automated Analysis Instrument and K, Ca, Mg, and Mn were determined by Atomic Absorption Spectrophotometry. The results are reported as concentration ($mg \cdot g^{-1}$ D.W.) and content ($mg \cdot plant^{-1}$ D.W.).

2.3.8 Statistical analyses:

The experimental design was a randomized complete block design with repeated measures. Plant dry matter, total nutrient content and calcium concentration data for kale were log transformed before analysis of variance was carried out due to lack of homogeneity of variance. Data are presented in non-transformed form. Analyses of variance were performed for each crop individually. When site-year interactions were significant, means were separated by year for interpretation purposes. Multiple comparison of means was made using the least significant difference method (lsd $p<0.05$). The General Linear Model (GLM) procedure of Statistical Analysis Systems (SAS) from the SAS Institute Inc. (SAS, 1987) was used for all data analyses to determine significant effects.

2.4 RESULTS:

2.4.1 Soil chemical characteristics:

Soil pH and exchangeable P, K^+, Ca^{2+}, and Mg^{2+} content were higher in the plantation soil while exchangeable NO_3^--N and Mn were higher in the open field (Table 2.2). Exchangeable NH_4^+-N was not significantly different between the two sites.

2.4.2 Soil and air temperature:

Soil and air temperatures were lowest in January and highest in July in both the plantation and open field (Figure 2.1). The temperature varied by 1°C or less at 10 cm and 25 cm soil depth, and for air temperature in both plantation and open field conditions. With the exception of slightly lower soil temperature at 10 cm depth in the open field compared to plantation over winter (December-February), the temperature regime under black walnut plantation was similar to that of the open field (Figure 2.1).

2.4.3 Light intensity (P.A.R) at crop level:

The light intensity (P.A.R) observed in the plantation from the beginning of the cropping season to crop harvest ranged from 1730 to 732 µmol s^{-1} m^{-2} and from 1982 to

Table 2.2 Soil chemical characteristics of Ah horizon of the two experimental sites (n=5) before the cropping season of 1993.

Site	pH	NO_3^--N	NH_4^+-N	P	K^+	Ca^{2+}	Mg^{2+}	Mn^{2+}
		($kg \cdot ha^{-1}$)						
Black walnut plantation	6.4a (0.01)	10.1b (0.4)	4.7a (0.2)	19.4a (0.9)	181a (8)	2330a (90)	360a (10)	28.4b (1)
Open field	5.6b (0.1)	13.4a (0.7)	4.8a (0.3)	16.3b (0.8)	11b (4.9)	2050b (56)	249b (6.7)	34.3a (0.5)

Standard errors of means are given in parentheses.
Within each column, values followed by the same letter are not significantly different at $p<0.05$.

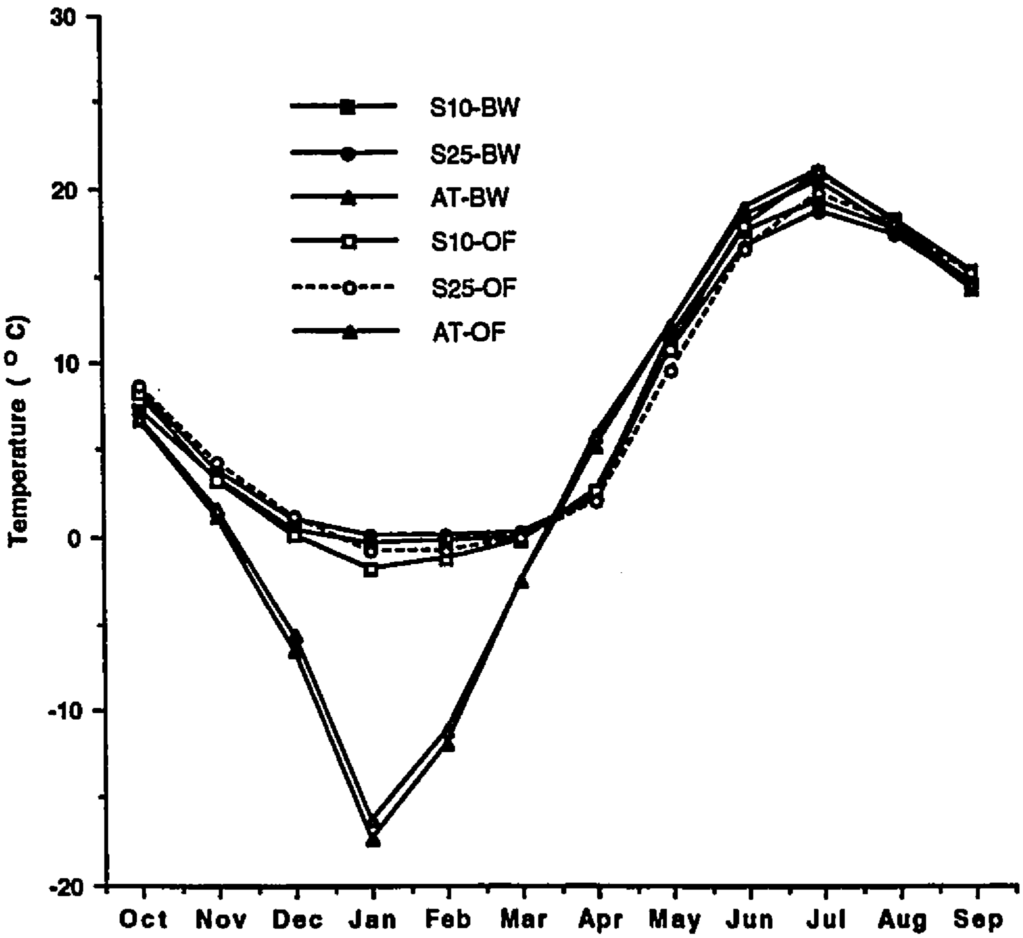


Fig 2.1 Soil temperature at 10 cm (S10) and 25 cm (S25) depth and air temperature (AT) under black walnut (BW) and for open field (OF) obtained from Ste-Anne-de-Bellevue meteorological station from Oct. 93 to sept. 94

1852 μmol s^{-1} m^{-2} in the open field. On percentage of open field light, the plantation light intensity decreased from 87% at planting to 39.5% by the time the vegetables were harvested (Figure 2.2) reflecting the increase in the amount of foliage of black walnut until the end of June.

2.4.4 Visual observations:

All the seedlings survived except for a few plants that were uprooted in the plantation by wild animals, but these were replaced. In mid June of 1993 and 1994, some lettuce and kale planted directly into the soil in the plantation showed wilting and symptoms of desiccation although the soil was moist as a result of previous rains, but these symptoms disappeared after a few days. Swiss chard planted directly into the soil showed yellow discoloration on leaf edges and circular spots appeared soon after plantation. The affected leaves started to rot or wilt. Potted plants in the plantation and open field as well as plants planted directly into the soil in the open field did not show any of the above symptoms.

2.4.5 Plant dry matter, nutrient content and concentration:

In both years, plant dry weight and plant nutrient content (mg·$plant^{-1}$) of all vegetables were significantly decreased in plantation compared to open field grown vegetables (Table 2.3 and 2.4). Plant dry weights and plant nutrient contents in all vegetables except parsley increased in 1994 compared with 1993 (Table 2.3 and 2.4). The shoot : root ratio based on plant dry weight was high for plantation grown lettuce, parsley and Swiss chard compared to open field but it was not significantly different for kale (Figure 2.3).

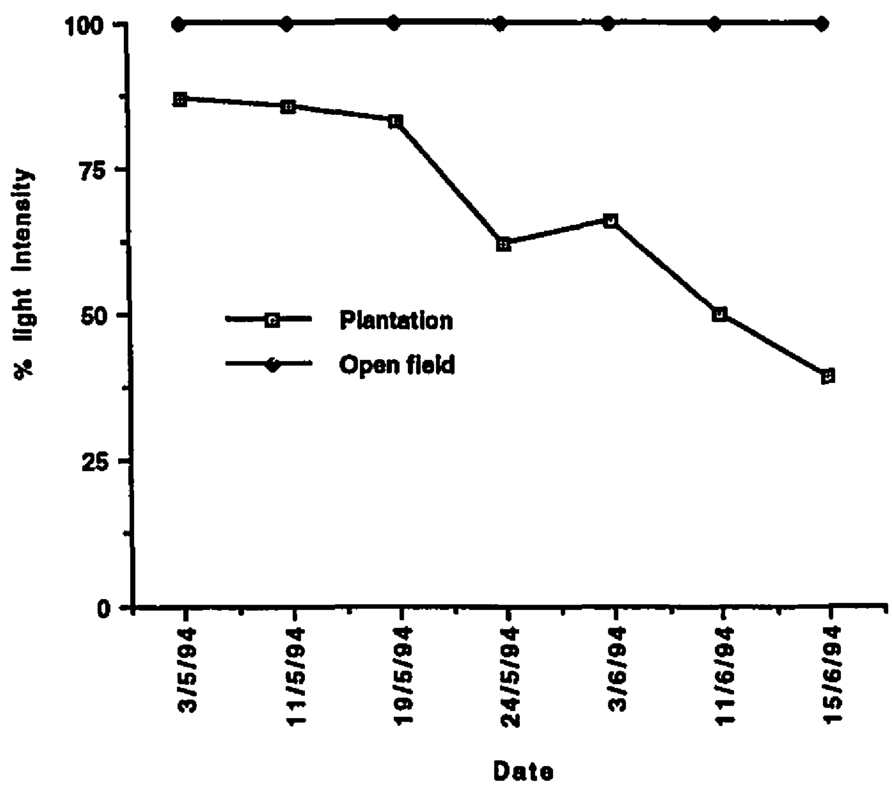


Fig 2.2 Light Intensity reaching crop canopy as percentage of open field light (P.A.R).

Table 2.3 Mean plant dry weight (DW) and total plant nutrient content in the four crops in the black walnut plantation and open field in 1993.

Crop	Site	DW ($g \cdot plant^{-1}$)	N	P	K	Ca	Mg	Mn
			($mg \cdot plant^{-1}$)					
Kale	Plantation	1.6b (0.4)	57b (11)	4.6b (0.8)	86b (21)	53b (13)	9b (2.2)	0.06b (0.02)
	Open field	7.6a (3.2)	245a (115)	21.4a (11)	260a (120)	227a (108)	39a (16)	0.8a (0.37)
Lettuce	Plantation	0.9b (0.12)	24b (2.6)	2.3b (0.3)	59b (5.5)	13b (1.3)	4b (0.4)	0.13b (0.03)
	Open field	3.4a (0.6)	80a (16)	9.3a (1.8)	113a (10)	43a (6.4)	17a (2.5)	0.6a (0.06)
Parsley	Plantation	2.3b (0.4)	60b (11)	6b (1)	170b (32)	38b (7.6)	8b (1.6)	0.09b (0.02)
	Open field	12a (1.7)	310a (63)	35a (5.6)	340a (63)	226a (41)	64a (10)	1.2a (0.26)
Swiss chard	Plantation	2b (0.3)	62b (11)	5b (0.7)	170b (35)	21b (3.8)	15b (2.6)	0.16b (0.03)
	Open field	8.4a (1)	200a (28)	11.6a (1.2)	440a (67)	200a (20)	93a (15)	5.3a (1.1)

Within each column, values followed by the same letter for the same crop are not significantly different at $p<0.05$.
Standard errors of means are given in parentheses.

Table 2.4 Mean plant dry weight (DW) and total plant nutrient content in the four crops in the black walnut plantation and in the open field in 1994.

Crop	Site	DW ($g \cdot plant^{-1}$)	N	P	Ca	K	Mg	Mn
			($mg \cdot plant^{-1}$)					
Kale	Plantation	5.2b (1.3)	160b (37)	15b (3)	270b (93)	160b (53)	23b (7)	0.3b (0.09)
	Open field	37a (6.5)	1200a (222)	80a (14)	1090a (227)	680a (80)	125a (15)	2.8a (0.5)
Lettuce	Plantation	4.2b (0.9)	115b (26)	12b (2.6)	300b (69)	27b (5.9)	14b (2.9)	0.45b (0.08)
	Open field	30a (2.2)	846a (79)	116a (8.3)	1430a (219)	200a (14)	160a (15)	4.9a (0.2)
Parsley	Plantation	0.65b (0.1)	14.3b (2.6)	1.4b (0.2)	38b (12)	5b (0.8)	1.8b (0.2)	0.05b (0.01)
	Open field	6.3a (0.4)	180a (13)	20a (1.5)	170a (41)	57a (3)	31a (2.5)	0.7a (0.05)
Swiss chard	Plantation	8.5b (0.7)	260b (25)	22b (2.3)	645b (88)	68b (9)	70b (11)	1.4b (0.06)
	Open field	35a (5)	1030a (140)	60a (8)	1530a (308)	616a (108)	540a (90)	20a (3.6)

Within each column, values followed by the same letter for the same crop are not significantly different at $p<0.05$.
Standard errors of means are given in parentheses.

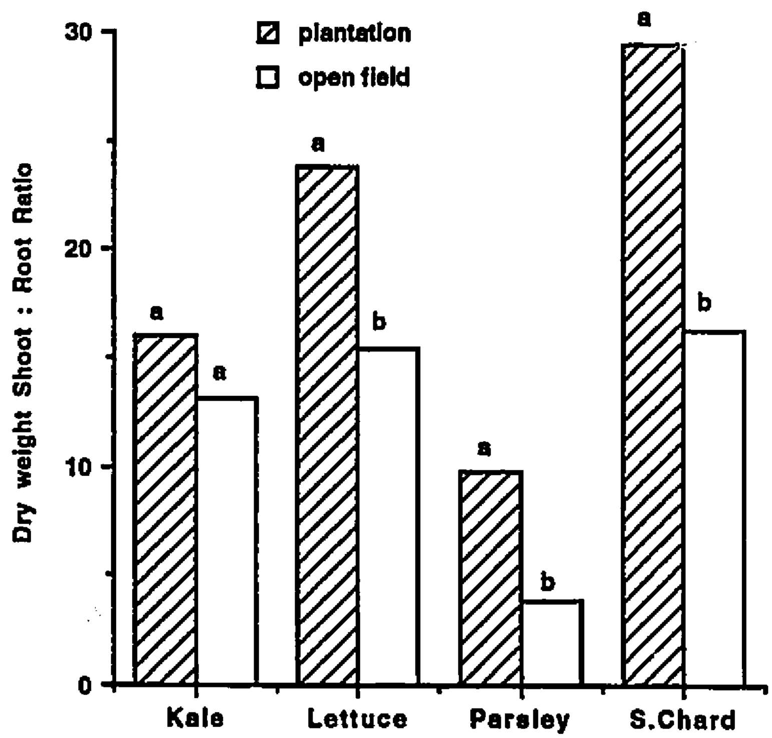


Fig 2.3 Shoot : root ratio based on plant dry weights of the four crops in the plantation and in the open field.

Nitrogen concentration in above ground plant parts in 1993 was significantly higher in the plantation compared with the open field for all crops except parsley (Table 2.5). In 1994, N concentration in kale, lettuce and Swiss chard did not differ significantly between sites while parsley had higher N concentration in open field compared to plantation (Table 2.6). Phosphorus concentration in Swiss chard was higher in plantation in 1993 but was not significantly different for lettuce, parsley and kale (Table 2.5). In 1994, P concentration was significantly higher in the open field compared to plantation for lettuce, parsley and Swiss chard, but kale had higher P concentration in the plantation (Table 2.6). Potassium concentration in the plantation grown vegetables was significantly higher in both years for all crops compared to that of open field (Table 2.5 and 2.6). Parsley and Swiss chard had high Ca concentration in the open field compared to plantation in both seasons, although the difference was not significant for parsley in 1993. Kale had a higher Ca concentration in the plantation in both years while lettuce did not show significant differences between sites in both years (Table 2.5 and 2.6). Magnesium and manganese concentrations were significantly higher in the open field than in plantation for each of the two seasons for lettuce, parsley and Swiss chard. Mg concentration in kale at both sites was not significantly different in both years while Mn concentration was higher in the open field in 1993 but not in 1994 (Table 2.5 and 2.6).

Table 2.5 Mean plant nutrient concentration in the four crops in the black walnut plantation and in the open field in 1993.

Crop	Site	N	P	K	Ca	Mg	Mn
		(mg g^{-1})					
Kale	Plantation	36a (1.6)	3.1a (0.2)	50a (1)	31a (0.8)	5.4a (0.1)	0.03b (0.003)
	Open field	30b (1.8)	2.4a (0.3)	32b (2.7)	27a (2.5)	5a (0.3)	0.09a (0.01)
Lettuce	Plantation	28a (0.6)	2.8a (0.15)	69a (5.2)	16a (0.9)	4.7a (0.2)	0.15a (0.01)
	Open field	24b (0.5)	2.8a (0.16)	36a (4)	13a (1.4)	5.2a (0.4)	0.18a (0.02)
Parsley	Plantation	26a (0.9)	2.6a (0.1)	76a (1.9)	16a (0.7)	3.6b (0.6)	0.04b (0.002)
	Open field	25a (2.4)	3a (0.1)	28b (2.4)	19a (1.3)	5.4a (0.4)	0.1a (0.01)
Swiss chard	Plantation	33a (0.9)	3.1a (0.3)	93a (5.2)	12b (0.7)	8.2b (0.16)	0.08b (0.01)
	Open field	24b (0.9)	1.4b (0.1)	52b (3.6)	24a (1.8)	11a (0.6)	0.6a (0.06)

Within each column, values followed by the same letter for the same crop are not significantly different at $p<0.05$. Standard errors of means are given in parentheses.

Table 2.6 Mean plant nutrient concentration in the four crops in the black walnut plantation and in the open field in 1994.

Crop	Site	N	P	K	Ca	Mg	Mn
					($mg\,g^{-1}$)		
Kale	Plantation	32a (1.4)	3a (0.3)	48a (6)	29a (3.9)	4.2a (0.4)	0.06a (0.002)
	Open field	32a (0.8)	2b (0.01)	29b (3.3)	19b (1.6)	3.5a (0.3)	0.08a (0.006)
Lettuce	Plantation	27a (0.8)	2.9b (0.03)	71a (2.4)	6.6a (0.1)	3.3b (0.01)	0.1b (0.007)
	Open field	28a (0.9)	3.9a (0.1)	47b (5.5)	6.7a (0.1)	5.2a (0.3)	0.16a (0.01)
Parsley	Plantation	22b (0.6)	2.2b (0.04)	65a (1.9)	7.6b (0.4)	2.8b (0.2)	0.08b (0.01)
	Open field	28a (1)	3.2a (0.1)	26b (5.3)	9a (0.3)	5a (0.7)	0.12a (0.005)
Swiss chard	Plantation	31a (0.8)	1.8b (0.07)	74a (5.8)	8b (0.7)	8b (0.8)	0.2b (0.01)
	Open field	30a (1.1)	2.6a (0.1)	43b (3.3)	17.6a (1)	15.5a (0.5)	0.6a (0.05)

Within each column, values followed by the same letter for the same crop are not significantly different at $p<0.05$. Standard errors of means are given in parentheses.

2.4.6 Potted plants:

Plant dry weight in treatment A and B were not significantly different for all crops but were significantly lower compared with treatment C (Table 2.7). Generally, plant N and P concentrations for all crops in treatment A and B were not significantly different although they differed from treatment C in most cases. Plant K concentration varied significantly among treatments with treatment A having the highest concentration in all vegetables with the exception of kale in which treatment A and B were not significantly different. Plants in treatment B had a relatively high K concentration despite the low availability of soil K^+ in the potted soil used (Table 2.7). Results for plant Ca concentration differed among treatments. In lettuce and parsley, treatment A and B were not significantly different but were both higher compared with treatment C in lettuce and lower compared with treatment C in parsley. Kale had a significantly higher Ca concentration in treatment B compared with both treatment A and C which were similar. Swiss chard showed a significant difference in all treatments in terms of Ca concentration with treatment C having the highest concentration (Table 2.7). Both plant Mg and Mn concentrations showed a general similarity in pattern with increased concentrations in treatment C compared with both treatment A and B especially in Swiss chard. Both Mg and Mn concentrations were lower in treatment A for all vegetables except kale which was not significantly different (Table 2.7). Swiss chard had consistently a high N, P, and K concentrations in the plantation and a high Ca, Mg and Mn concentrations in the open field.

Table 2.7 Mean potted plant dry weight (DW) and nutrient concentration in the four crops within the three treatments (TRT) in the black walnut plantation and in the open field.

Crop	TRT	DW ($g \cdot plant^{-1}$)	N	P	K	Ca	Mg	Mn
			($mg \cdot g^{-1}$)					
Kale	A	3.2b	30b	2.6a	60a	23b	5.2a	0.07a
		(0.4)	(1)	(0.2)	(1.4)	(2)	(0.1)	(0.004)
	B	3.5b	31b	2.7a	58a	31a	5.3a	0.08a
		(0.4)	(0.6)	(0.1)	(2.3)	(0.6)	(0.2)	(0.003)
	C	28a	38a	2.2b	36b	23b	5.3a	0.07a
		(4.4)	(1)	(0.1)	(2.4)	(1)	(0.4)	(0.005)
Lettuce	A	1.8b	25b	3a	70a	8.7a	3.5c	0.11a
		(0.2)	(0.5)	(0.1)	(2.7)	(0.4)	(0.1)	(0.008)
	B	1.6b	28a	3.2a	60b	9a	4.2b	0.13a
		(0.3)	(0.6)	(0.1)	(2.1)	(0.2)	(0.1)	(0.006)
	C	15a	26b	3.3a	39c	5.9b	5.4a	0.13a
		(1.7)	(0.6)	(0.1)	(1.4)	(0.2)	(0.2)	(0.006)
Parsley	A	0.7b	23b	2.3b	62a	9.4b	3c	0.12b
		(0.2)	(0.5)	(0.1)	(1.8)	(0.6)	(0.1)	(0.007)
	B	0.6b	25b	2.4b	52b	9.1b	3.8b	0.14a
		(0.1)	(0.5)	(1)	(1.4)	(0.3)	(0.1)	(0.01)
	C	4.4a	28a	3.3a	27c	14a	6a	0.12ab
		(0.9)	(1.2)	(0.2)	(1.7)	(2)	(0.3)	(0.005)
Swiss chard	A	1.8b	26a	2.1a	94a	7.6c	6.9c	0.18c
		(0.3)	(0.7)	(0.1)	(1.7)	(0.5)	(0.3)	(0.008)
	B	1.5b	28a	2.2a	81b	11.5b	10.3b	0.33b
		(0.2)	(0.5)	(0.1)	(1.5)	(1.3)	(0.9)	(0.02)
	C	10.3a	27a	1.5b	49c	19a	17.5a	0.48a
		(1.5)	(2.1)	(0.1)	(2.4)	(1.5)	(0.6)	(0.04)

A) plantation soil in pots placed in the plantation, B) open field soil in pots placed in the plantation and C) open field soil in pots placed in the open field.
Within each column, values followed by the same letter for the same crop are not significantly different at $p<0.05$.
Standard errors of means are given in parentheses.

2.5 DISCUSSION:

2.5.1 Soil chemical characteristics:

The two sites differed in soil chemical properties (Table 2.2) although they have a similar soil classification (Lajoie and Baril 1952). The differences are likely due to vegetative cover and its associated nutrient cycling. Past agricultural practices and removal of grasses from the open field may have led to export of nutrients that could have replenished the soil nutrient pools hence depletion of soil nutrients, especially K^+ (Tappeiner and Alm 1975 and Boerner and Koslowsky 1989).

The high soil pH, P and exchangeable K^+, Ca^{2+}, and Mg^{2+} in the plantation compared to the open field soil (Table 2.2) indicates that the plantation soils are more fertile and suitable for vegetable growth than the open field. The pH requirement for all the vegetables used in this study ranges between pH 6.0 - 7.0 (Schneck 1992) and thus the plantation with a pH of 6.4 is suitable unlike the open field with a pH of 5.6. With high pH and high availability of soil nutrients in the plantation, the decreased plant dry matter for all crops in the plantation compared to the open field as well as the similarity in the potted plant dry weight for treatment A and treatment B for all vegetables in the plantation (Table 2.7) was likely due to factors other than pH or low nutrient availability.

2.5.2 Temperature and precipitation:

The observed difference in temperature in this study is likely negligible in terms of effect on nutrient uptake by plants. Kabu and Toop (1970) Reinbott and Blevins (1994) suggested that root zone temperature differences of 5 - 10°C were required to affect significantly leaf nutrient concentration in wheat, tall fescue and tomato plants. The slightly higher mean temperature and greater temperature amplitude in the open field could have resulted from higher incident radiation since it lacks the upper canopy layer which can reduce radiation and decrease wind movement (Burrows, 1963 and Liddle and Moore, 1974). All plant dry weights of both plantation and open field grown vegetables increased in 1994 when total precipitation increased compared to 1993 (Table 2.1).

2.5.3 Light intensity (P.A.R) at crop canopy level:

The smaller plant dry weights observed in the plantation could be attributed mainly to low light intensity received in the plantation. In a three year study on performance of conifer-seedling success and microclimate at different levels of herb and shrub cover, Coates et al. (1991) suggested that low soil and air temperatures and low light levels were primary factors that inhibited conifer seedling performance and that light levels beneath the undisturbed vegetation were sufficiently low to impair photosynthesis. In similar studies, several authors (Fitter and Ashmore 1974, Frankland and Letendre 1978, Morgan and Smith 1981, Sanchez and Allen 1989, Stoneman and Dell 1993 and Yadav et al. 1993) have observed a decrease in photosynthesis and in plant dry weight, and an increase in specific leaf area with an increase in canopy shading.

2.5.4 Visual observations:

The observed wilting and desiccation symptoms shown by some kale and lettuce and leaf damage in Swiss chard planted directly into the soil in the plantation compared to potted plants suggest an effect of black walnut roots and that these crops are susceptible to black walnut allelochemicals. These effects could be attributed to inhibitory effects of black walnut through production of juglone from root exudates or from direct contact from throughfall (Fisher 1978 and Coder 1983).

The single weeding done in the black walnut plantation, unlike the two done in the open field, demonstrated the potential of suppression of weed regeneration under black walnut plantation, possibly through reduced P.A.R and / or allelopathic effects (Gliessman 1983 and Rizvi and Rizvi 1992).

2.5.5 Plant nutrient concentration:

The results of plant N and P in the plantation suggested a slightly higher concentration in 1993 when the soil was relatively dry but decreased or were similar in 1994 when precipitation was higher (Table 2.5 and 2.6). Although the amount of plant dry weights and plant nutrients were higher in 1994 than in 1993, the amount of K, Ca, Mg and Mn concentrations were slightly decreased in 1994 when precipitation was higher (Table 2.1). The differences in amounts of nutrient concentrations among years could be attributed to increased plant growth in 1994 with subsequent dilution of the nutrient elements in plant tissue (Kabu and Toop 1970).

Kale had consistently higher N and P concentrations in the plantation compared to open field in both years (Table 2.5 and 2.6). Similarly the N and P concentrations in the potted plants were generally higher in the plantation compared to the open field grown vegetables, though not consistent (Table 2.7). In studying the effects of light, nitrogen and phosphorus on red pine seedlings under full light and shade conditions, Elliott and White (1994) reported similar findings, in that N and P concentrations were higher in shade than in full light but were not associated with a faster rate of growth of the seedlings. But unlike vegetables, pine seedlings are slow growing plants and may accumulate more nutrients. Also Bjorkman (1981), cited by Elliott and White (1994) and Evans (1989), reported that shade plants invest large quantities of N in light-harvesting pigments but make only small investments in proteins, for example, rubisco and other CO_2-processing enzymes. The decreased concentration of P in the plantation grown vegetables in 1994, except for kale, could be due to the inhibitory effect of black walnut. Glass (1973) reported inhibition of phosphate uptake in barley (*Hordeum vulgare* L.) roots by natural occurring phenolic acids. Since black walnut produces phenolic juglone and the plantation soil was wetter in 1994 than in 1993, this could have provided a favourable condition for juglone retention (Fisher 1978) and thus reduced uptake of P from the soil and subsequent decrease of P concentration in the plantation grown vegetables.

The plant K nutrient concentration was high in the plantation for all the vegetables studied as compared to those grown in the open field (Table 2.5, 2.6 and 2.7). The high K concentration in plant tissues could be due to the high availability of K^+ in the plantation soil (Table 2.2). Plant Ca, Mg and Mn concentration was higher in all the open field grown vegetables compared to plantation with the exception of kale which had higher Ca concentration in the plantation compared to the open field (Table 2.5 and 2.6) and with similar Ca, Mg and Mn concentrations in the three potted treatments (Table 2.7). The lower Ca, Mg and Mn in the plantation grown vegetables could be the result of the antagonism of uptake of these elements by high soil K^+ in the plantation. Competition or inhibition from high levels of soil K^+ and or NH_4^+-N decreased Ca^{2+} and Mg^{2+} uptake in corn (*Zea mays* L.) (Claassen and Wilcox 1974, and Brauer 1994) and in winter wheat (*Triticum eastivum* L.) (Reinbott and Blevins 1994), but the high levels of K^+ in the soil did not affect either N or P concentration in corn tissue (Claassen and Wilcox 1974).

The high shoot : root ratios for all plants grown in the plantation compared to those grown in the open field indicate that the root systems were poorly developed for those vegetables grown in the black walnut plantation. This could seriously have affected nutrient uptake and general growth of the plants. Although the shoot : root ratio for kale was high in the plantation, the difference was not significant, indicating a proportional root system development such that though the plants were small in plantation, their root system was proportional to the above ground plant material. This could explain the general similarity of Ca, Mg and Mn concentrations in Kale in both plantation and open field conditions. *Brassica* species have been shown to compete more effectively for plant nutrients than other vegetables. Qasem and Hill (1993) reported that cabbage and lettuce accumulated similar amounts of K, while cabbage being of the same family as kale, accumulated twice the amount of Mg, P and N and five times more Ca than lettuce.

CHAPTER 3.

3. CONCLUSIONS:

The soil fertility under the different tree species pairs did not vary significantly. Although some soil chemical characteristics indicated a significant decrease with increase in total basal area, their relationships were weak suggesting factors other than total basal area could be more important in influencing forest soil fertility. The association of lower exchangeable soil K^+ with higher sugar maple basal area to total basal area could suggest a depletion of soil K^+ under sugar maple compared with the other tree species studied. White ash appears to favour soil N and P availability and could have the best soil ameliorating potential among the species studied.

Vegetable growth was not increased in the plantation. High soil K^+ content in the plantation consistently resulted in high K concentration in vegetables. The order of sensitivity of the vegetables in the alley cropping system with black walnut was Swiss chard > kale > lettuce > parsley. The high shoot : root ratio of vegetables under black walnut plantation could suggest a poor development of plant root system under black walnut. Low light intensity in the plantation appeared to be the most limiting factor for vegetable growth under black walnut. Understanding the competition for light and soil nutrients between trees and crops is of great importance in an agroforestry system. The observed decrease in soil nutrients with increase in tree total basal area could be minimized by using a wider tree spacing which would also increase light intensity at crop level and, thus, could improve crop production. Other vegetable species or grains, could have a better growth potential than those used in this study. More studies are needed to assess the potential of black walnut or other commercially important tree species for alley cropping as well as other agroforestry systems in Southern Quebec.

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