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Forest Research Branch

HARDWOOD PLANTING PROBLEMS AND POSSIBILITIES IN EASTERN CANADA

by

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Conclusions en français.

DEPARTMENT OF FORESTRY PUBLICATION No. 1043

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ABSTRACT

All hardwood timber, which accounts for twenty-one per cent of the total value of annual lumber production in eastern Canada, is presently cut from virgin forests or from forest stands regenerated naturally after logging. Artificial regeneration of many hardwood species has often been attempted in eastern Canada, but few records are available and most of these report failures.

This paper summarizes the results of a review of North American and European literature of hardwood planting of those species most commonly grown in eastern Canada.

Emphasis is placed on the general problems of planting site selection, site preparation and cultivation, selection of planting stock and seeding practices.

Information on planting practices, cultivation methods, fertilization and general plantation development is discussed individually for each species and all information is combined in a table of recommendation for hardwood plantation establishment in eastern Canada.

Published under the authority of
The Honourable Maurice Sauvé, P.C., M.P.
Minister of Forestry
Ottawa, 1964

ROGER DUHAMEL, F.R.S.C.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1964

Catalogue No. Fo 47-1043

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PREFACE

This technical note is based on a review of hardwood planting literature and its aim is to assist the forester, tree farmer and woodlot owner in the planning of hardwood planting operations. No single planting practice exists which leads invariably to successful plantation establishment, but a review of present knowledge can prevent the repetition of past mistakes and may lead to improved planting practices.

The report is divided into three parts. The first deals with general aspects of artificial hardwood regeneration, the second with specific information relating to individual tree species, while the third combines all information in the form of recommendation for future hardwood planting operations.

HARDWOOD PLANTING PROBLEMS AND POSSIBILITIES IN EASTERN CANADA[1]

by

F. W. von Althen[2]

INTRODUCTION

Hardwood stands cover 23 million acres of forest land in eastern Canada and supply 405 million board feet of lumber annually (Anon. 1956). Most of this timber is cut from virgin stands or forests regenerated naturally after an initial light cut : Natural regenaration is the most important and most widely used method of hardwood regeneration.

Artificial seeding or planting, on the other hand, is the only means of regenerating forest areas where poor harvesting practices have resulted in the destruction of the original stand with no potential for future growth, where overcutting has eliminated individual, highly valuable tree species or where the introduction of new species appears desirable. Reforestation of river valleys or other productive forests areas formerly cleared for agriculture and later abandoned, or establishment of shelterbelts and rehabilitation of eroded land can also only be accomplished by artificial regeneration.

Millions of hardwood seedlings have been planted in eastern Canada, but very few of the numerous attempts to establish hardwood plantations have been recorded and most of these must be called failures. As a result, successful hardwood planting has often been regarded as impossible.

However, hardwood plantations in other countries have been successful, resulting in excellent stands of the most highly valued timber species.

Present knowledge of site requirements and suitable planting practices is still limited for most hardwood species, but great advances have been made in the United States and Europe during the last three decades.

The purpose of this report is a review of North American and European literature of hardwood regeneration of those species most commonly grown in Canada. While much of this information will not be directly applicable to Canadian forest conditions, the basic principles of species reaction to site conditions and planting practices will also apply in Canada.

For example, some of the most intensive hardwood plantation research was undertaken for the reforestation of strip-mined land in the United States. There are no such areas in eastern Canada, but the research results in regard to species mixture, age of planting stock or suitability for under-planting are important and may hold true for many planting sites in Canada. Another example is black locust which has been planted only sparingly in Canada, but

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information from other countries indicates the great potential of this species in the reforestation of poor, eroded land. The very intensive cultivation of European poplar plantations, on the other hand, may suggest new approaches to poplar planting in this country.

A comparison of costs and expected returns of artificial softwood and hardwood regeneration indicates that under *extensive* forest management the softwoods will probably produce the higher returns, since they are generally tolerant to a wide range of planting sites, are easily planted, need little attention after planting and produce large quantities of wood, suitable for a wide variety of products. Hardwoods, on the other hand, are generally very sensitive to variations in site conditions, are difficult to plant, need constant attention during the early years after planting and produce wood suitable for only a limited range of products.

But under *intensive* management hardwoods grown on suitable sites and properly cared for, will produce the highest returns. With the diminishing supply of high quality timber and the ever increasing cost of making accessible new virgin stands, the prospect of successful plantations of desirable species, grown close to markets, make artificial hardwood regeneration steadily more attractive.

MAJOR FACTORS IN ARTIFICIAL REGENERATION

Selection of the Planting Site

Selection of a suitable planting site is the most important single factor in the establishment of successful hardwood plantations. The failure of many plantings can be traced directly to poor judgement in site evaluation and selection. When hardwoods are grown for timber production, as compared to planting of ornamental trees or for erosion control and shelterbelts, they should be planted exclusively on the most fertile sites where the type of soil and its physical condition are excellent (Hicks *et al* 1938; Stevens 1944). For satisfactory growth, most broad-leaf trees demand deep, uneroded, fertile, moist but well-drained soil, and even land which may raise fair farm crops is not always suited for good hardwood growth (Locke 1931). The best sites will usually be found in bottomlands, along streams or creeks, and on fertile lower slopes. Hardwoods will never produce high quality timber when grown on dry, exposed slopes and ridges or in areas where the topsoil is shallow and the sub-soil consists of heavy compacted clay (Minckler 1948, 1952; Hassenkamp 1958).

Knowledge of the site requirements of most hardwood species is rather limited. However, hardwoods appear to be much more exacting in their requirements than most of the commonly planted softwood species, especially the pines (Hansen and McComb 1955). Changes in soil-site factors will nearly always have a marked effect on the growth of hardwood seedlings, and the mere removal of the forest cover can often alter the site adversely for their establishment (Chapman 1940). Many observations have shown that seedlings failed to grow well because they were not planted under a stand of hardwoods, and site conditions of the planting site had changed since the removal of the original stand (Haasis 1930).

The most serious change in site conditions is usually found in old fields. In the past, tree planters have been told that it is usually safe to plant native trees which formerly occupied the site or which grow well on nearby lands of similar character (Auten 1933). Following this rule, hardwood seedlings were often planted on abandoned fields or pasture land, formerly occupied by these same species. But since the removal of the original stand the site factors have often been seriously changed by denudation and cultivation (Bedwell 1937), resulting in the depletion of nutrients and erosion of the top soil and humus, compaction of the surface and clogging of the soil pores by rain, so that the land was actually very different from what it had been prior to clearing (Den Uyl 1951; Minckler 1952; Ryker 1958). With the known sensitivity of the hardwood species to changes in site conditions it is not surprising that most of the plantations failed (Hansen and McComb 1958).

Several individual site factors are probably responsible for the inability of the hardwood seedlings to grow at a satisfactory rate. Hansen and McComb (1958) concluded on the basis of their observations that chemical conditions were probably most important, followed by soil physical factors and microclimate. Chapman and Lane (1951) rated soil compaction and moisture conditions, together with poor aeration, as the most important factors, followed by mineral deficiency and harmful exposure of seedlings to extreme microclimatic conditions. Mitchell and Chandler (1939) found that increased nitrogen supply through fertilization resulted in increased growth of various species from 10 to 300 per cent. Fast growth and high leaf nitrogen were nearly always associated with uncultivated and uneroded sites generally found around old farmsteads. Armson (1959) observed that Norway spruce reflected the difference in soil quality 39 years after destruction of a cowshed and despite the agricultural use of the land during this period of time.

The reason for the withdrawal of land from agriculture has generally been low fertility, and it must be recognized that poor farm land is also poor hardwood forest land. On the uncultivated and uneroded sites the height growth of many broadleaf species may exceed that of the fastest growing pines, whereas hardwood growth is generally poor in old fields, and pine growth is rapid, or at least satisfactory (Hansen and McComb 1955). Due to their much greater range in tolerance to changes in site conditions, it seems more logical, therefore, to plant the pioneering species first on these old abandoned lands than to try to leap the succession by planting the climax hardwood trees (Bedwell 1937; Allen 1953).

On lands unfavourable to direct hardwood planting the desired species will often establish themselves naturally under stands of conifers planted as pioneering species, provided there is a seed source. In areas where even a slight doubt exists as to the suitability of the site to hardwood planting, costly failures may be avoided through conifer planting in the first rotation and the subsequent regeneration of hardwoods under the protection of the conifer nurse crop (Haasis 1930).

Site Preparation and Cultivation

The second most important factor in the successful establishment of hardwood plantations is the preparation of the planting site and control of herbaceous vegetation during the early life of the seedlings (George 1939; Hilf 1940; Schreiner 1945, a,b; Anon 1947; Roe 1955; Jenks 1958; Chapman 1961). While seedlings of many hardwood species grow best under the protection of a partial overhead cover, they are at the same time very sensitive to competition from grasses and weeds (Wallihan 1949; Lane and McComb 1953; Aird 1956; 1958; Dimbleby 1958; Green and Green 1959).

Herbaceous plants may adversely influence the growth and survival of young hardwood seedlings by the following means: (1) The faster growing weeds will compete intensively with the young trees for light, moisture and soil nutrients; (2) seedlings may be deformed or smothered through the accumulation of dead stems and leaves; (3) heavy weed growth provides an ideal habitat for mice and rabbits, and (4) weeds will compete for soil oxygen and may also have a toxic effect on the root growth of the planted seedlings (Roe 1955; Aird 1958; Hensel 1961).

In order to compete successfully, the planted species must either be capable of fast initital growth, or some supplementary treatment must reduce the competition from grasses and weeds (Green and Green 1959; Anon. 1960). The main objectives of cultivation before planting are therefore good initial establishment of seedlings and reduction in the number of weeding operations. Even if grass and weeds grow again, the transplants have had a little time without any competition (Jenks 1958; Wood and Nimmo 1962).

Site preparation may be in the form of partial or complete cultivation, or mulching, and the choice of method will depend on the condition of the soil, the topography, the density of existing cover, and the cost of the various methods under consideration. While complete cultivation is most expensive and does not generally reduce the planting costs, it may later reduce the cost of weeding. Establishment costs may be high but if it has been worth planting it should certainly be worth doing the work well and initial high costs may prove to be the cheapest in the long run (Gaskill 1906).

Mulching will benefit the planted seedlings by reducing (1) surface evaporation, (2) transpirational drain by competitive vegetation, (3) soil temperature extremes and (4) soil surface movement. The decomposition of mulch materials will also improve soil structure and fertility and increase biological activities. One disadvantage of mulching is the furnishing of ideal nesting conditions for mice and other rodents (Pruett 1959).

Recent developments in the field of chemical herbicides have resulted in faster, easier and cheaper methods of weed control in forest plantings (Seymour 1960; Brown and Carvell 1961). Pruett (1960) and Pruett and Gatherum (1961) studied the effect of three mechanical and six chemical weed control treatments on the height growth and survival of white and jack pine, black walnut and eastern cottonwood. Seedling survival and height growth varied with treatments and soils types, but were generally greatest on the cultivated plots. Tree survival and height growth varied directly with the effectiveness of weed control as reflected in available water and light intensities. Hensel (1961) reported a successful first year control of weeds through one application of Simazine 80W. A Lowther tree-planting machine was adapted to hold two tanks from which the herbicide was sprayed at a rate of 2.5 lb. per acre in a 12-inch wide band on either side of the planting furrow, thereby allowing the planting and spraying to be combined into one operation.

Planting Stock

Planting success will largely depend on the quality and suitability of the planting stock. To sacrifice quality for low initial costs is bound to be highly expensive in the long run. Good hardwood planting stock should be hardy, sturdy, have a well branched root system and a well balanced top to root ratio (Rudolf 1937; George 1939).

Improved nursery techniques and grading of seedlings will result in better growth and survival of the young trees. (Iimstrom *et al* 1953, 1955).

The most commonly used planting stock, with the exception of poplars, is 1-0 or 2-0 stock (Winch 1937). Larger seedlings require greater handling care, and planting costs increase considerably due to the necessity of larger planting holes. In areas where the density of ground cover makes full cultivation excessively expensive, larger stock may be planted to shorten the time of active competition (Westveld and van Camp 1935). Tap-rooted species, however, may be subject to planting injury, resulting in reduction of growth (Seidel 1961), while survival and form development is generally not influenced by method of regeneration (Boyce and Merz 1959; Boyce and Neebe 1959).

Direct Seeding

Hardwood establishment by direct seeding has been investigated as an alternate method to planting of nursery-grown seedlings. Advantages of direct seeding are the reduction in planting costs and the elimination of planting injury. The greatest disadvantage is the uncertainty of satisfactory establishment. Hardwood species with relatively small seeds such as the ash species and yellow poplar were generally found to be unsuitable for direct seeding and only the oaks and black walnut showed any promise of success (Winch 1937; Plass 1952; Renshaw and Doolittle 1958). The most important factors affecting germination and survival after seeding are rodents and insects which destroy the seeds or newly germinated seedlings (Korstian 1927; Plass 1952; Nichols 1954; Krajicek 1955; Engle and Clark 1959; Sluder *et al* 1961).

SELECTION OF SPECIES

Black Locust

Black locust is probably the most extensively planted hardwood species (Meade 1951; Roach 1958; Funk and Roach 1961). This popularity is founded on the ability of the species to grow on a wide variety of sites and to improve the soil through the agency of nitrogen fixing bacteria found in nodules on the roots. The greatest disadvantage is the susceptibility to attack by the locust borer (*Cyllene robinae*), which causes severe damage in many plantations.

Black locust has often been classified as a species very indifferent to site quality. This is true from the standpoint of its ability to establish itself and exist, but it is not the case from the standpoint of rapid growth, profitable yield of wood products and resistance to locust borer attack (Auten 1933; 1936; Gibbs and Ligon 1942; Minckler 1946). For optimum growth black locust demands a fertile, moist but well drained loamy soil, preferably of limestone origin (Pfandkuch and Duncan 1956). Growth appears to be closely correlated with those properties of the subsoil which influence drainage and aeration, namely plasticity, compactness and structure (Auten 1933). Within a range of 4.6 to 8.2, no apparent relationship seems to exist between pH and growth. Compactness of the soil, particularly a tight sub-soil and excessively dry or very poorly drained soils appear to be detrimental to good growth (Minckler 1948). Experiments on many types of soil have shown that tree vigour is the important factor in resistance to locust borer attack and that fast growing trees on the best soils exhibit the greatest resistance (Hall 1933).

Black locust is the only hardwood species which is well adapted to erosion control planting. (Kellogg 1933; Ligon 1940; Stevens 1944; Minckler and Chapman 1948; Meade 1951; Allen 1953; Hansen and McComb 1955). It may also be planted as a pioneering species on poor, dry sites as found on abandoned fields and strip-mined land. (Chapman 1936; Afanasiev 1947; Deitschman 1950; Clark 1954; Boyce and Merz 1959; Boyce and Neebe 1959; Hart and Byrnes 1960; Limstrom 1960). In such an environment, locust may not be expected to make good growth but even if it has no other value than to improve the site and thereby provide an opportunity for the establishment of other trees, the cost of its planting may be fully justifiable. After initial establishment it maintains itself well by means of numerous root suckers and stump sprouts.

Improvement of site condition through black locust planting was observed by Hart and Byrnes (1960) who reported that 10 years after establishment on strip-mined land, leaf litter two inches in depth had accumulated on the bare sites and a luxuriant growth of herbs and grasses as well as naturally established seedlings was present. Boyce and Neebe (1959) found that soil horizons and soil structure had begun to form on strip-mined land 20 years after planting.

While black locust may be planted for the production of posts or for erosion control, it seems to find its greatest usefulness as a nurse crop for other more valuable timber producing hardwoods (Chapman 1935; Chapman and Lane 1951; Deitschman 1956). When various hardwood species were underplanted in 8- to 9-year-old shortleaf pine and black locust plantations on strip-mined land in Illinois, they were, after eight growing seasons, generally two to three times taller under the locust than under pine. Yellow poplar and black walnut showed by far the best growth response (Deitschman 1956). The comparative planting of various hardwood species in an old field and underplanting under the cover of sassafras, planted pine and planted black locust proved that the last was greatly superior as a nurse crop, both in survival and growth (Chapman and Lane 1951). In plantings of catalpa, white ash, tulip poplar and black oak adjacent to black locust plantations, appreciable decreases in the height and diameters of trees were found with increasing distance from the locust (Chapman 1935).

Boyce and Neebe (1959) recommended underplanting of hardwoods at the beginning of a locust borer attack. At this time full advantage can be taken of the beneficial effects of black locust while the ground cover is usually still sparse and seedlings can take advantage of the maximum period of light. Chapman and Lane (1951) suggested the planting of hardwoods in association with the locust in one operation, rather than underplanting at a later date. Advantages would be the elimination of two separate planting operations and the reduction of competition and mechanical damage from the older locust trees.

The percentage of locust in mixed plantations with other hardwoods should not be more than 25 per cent according to Boyce and Neebe (1959), but

Chapman and Lane (1951) recommended two-thirds to three-fourths black locust. None of the conifers was found suitable for interplanting with black locust.

Cultivation after planting will greatly improve the growth. Cultivation will be most beneficial on the marginal sites and may be the deciding factor between success or failure of the plantation (Gaskill 1906). Meginnis (1934) reported that a single cultivation by either ploughing two furrows with a small furrowing plough on each side of the row, or hoeing to a distance of about 18 inches around each tree showed striking results in the following summer. The terminal leader growth had increased from 3.1 to 12.7 inches, the colour of foliage and size of leaves showed improvement and at the end of the first growing season the cultivated trees had a 17 per cent higher survival than the control.

The use of complete fertilizers in black locust plantations on eroded or impoverished sites was recommended by Chapman (1940). On severely eroded pasture land the fertilization with 4 ounces of 4-12-4 fertilizer, placed 6 inches below the surface, resulted in an annual height growth of more than twice the growth of check trees (Holsoe 1941). Cummings (1942) reported that a marked increase in height growth was evident for two years after fertilization of black locust seedlings with complete fertilizer on soils of low fertility, old fields or spoil banks. The continued superiority in the rate of development of fertilized trees after the initial 2-year period was ascribed largely to their better establishment.

Den Uyl (1944) applied ½, 1 and 2 tablespoons of complete fertilizer 2-12-6 in the planting hole at time of planting. One tablespoon per tree treated 30 trees per pound and amounted therefore to nearly 1 ounce per spoonful. The planting site was heavily eroded silt loam with a compact sub-soil. One and two tablespoons gave the same good growth response, while the application of ½ tablespoon showed no response. Great improvement was observed in the size and colour of foliage and increased height growth continued for four years. Most significant was the increase in diameter growth at one foot above the root collar where the diameter of the fertilized trees was 2.1 inches as compared with 1.2 inches for the control. The number of roots of the fertilized trees was three to five times that of unfertilized and the roots extended 20 feet from the base versus 5 feet for the control.

Fertilization experiments with nitrogen, phosphorus and potassium on several Iowa soils showed a black locust response to phosphorus only (McComb and Kapel 1940; McComb 1949). Allen (1953) recommended an application of phosphate fertilizer on moderately eroded sites to increase the growth of newly planted black locust seedlings. But applications of 150 and 250 pounds of phosphorus per acre failed to result in significant increases in growth or vigour of already stagnant plantations (Walker 1955).

Yellow Birch

Yellow birch is not a plantation tree, but is included in this report because it is the most important hardwood tree in eastern Canada. It grows on a wide range of sites from rich, moist bottom lands to the drier soils of hilltops and ridges (Anon 1961b). It seldom grows in pure stands but is generally found in association with sugar maple, red maple, American beech, eastern hemlock, white and red spruce, balsam fir and eastern white pine.

Yellow birch is a prolific seeder, producing some seed each year and very large crops at irregular intervals (Harlow and Harrar 1950). But successful seedling establishment is largely dependent on favourable seedbed conditions. Germination and early survival is always very poor on the thick litter of undisturbed forest floors (Jarvis 1957; Fayle 1961a). Without some disturbance of the soil surface, regeneration is restricted mostly to cracks in boulders and to rotted logs and stumps (Gilbert 1960). In Quebec, with artificial seedings under forest conditions, Linteau (1948) observed that first-year germination was highest under partial shade, almost as high under full canopy, but much lower in the open. On the other hand, seedling survival on mineral soil after two years, in per cent of total germination, was highest in the open and next under partial shade. Survival, therefore, depends on a combination of temperature, moisture and light. The seedlings require overhead light, but the seedbed must be cool and moist (Gilbert 1960).

Since young yellow birch seedlings are very susceptible to browsing damage from deer and hare, wildlife control is an absolute necessity (Jarvis 1957; Fayle 1961b).

To ensure satisfactory regeneration after logging, Zillgitt and Eyre (1945) proposed moderate selection cuttings with openings of one-tenth acre by removing small groups of decadent trees. Linteau (1948) recommended either a selection cut of thirty to fifty per cent of stand volume to allow at least thirty per cent of sunlight to reach the forest floor, or a clear-cutting in small patches of not more than one-half acre.[3]

Black Walnut

Black walnut is one of the most highly valued timber species. Due to the sustained demand for high quality lumber and veneer logs, this species has been widely planted throughout its range, often with variable success (Brinkman 1957). Plantations established on poor agricultural land have invariably failed to produce high quality timber (Auten 1936; Prichard 1941; Afanasiev 1947; Meade 1951; Minckler 1952; Hansen and McComb 1955; Ryker 1958). The species is very sensitive to soil conditions and for satisfactory growth demands a rich, moist, deep fertile soil of alluvial origin with a pH range from 7.1 to 8.0 (Wilde 1934). Chapman (1961) recommended the planting in undisturbed hardwood forest soils with at least two feet of loam, sandy loam or silt loam, ranging downward through a layer no finer in texture than silty, clay loam. Acceptable sites may be found most frequently in valley bottoms and along small streams where the flood water does not stand for long periods, in coves and on lower north- or east-facing slopes.

Hansen and McComb (1958) stated that black walnut growth in plantations of southeastern Iowa appeared to be closely correlated with texture and depth of the rooting zone, internal drainage and aeration, the content of organic matter and soil nutrients. However, later studies by Thomson and McComb (1962) indicated that chemical, rather than physical soil conditions

3. When D. H. Burton and others of the Ontario Dept., of Lands and Forests planted yellow birch seedlings under similar conditions, the results were unsatisfactory.

were limiting growth in these plantations. Potassium and calcium were especially limiting and pH was a good indicator of site index.

Black walnut appears to grow better in association with other hardwood species than in pure stands (Haasis 1930; Locke 1931; Boyce and Neebe 1959). Species suggested for such mixtures are yellow poplar, red oak and white ash.

In plantations of the Syracuse Forest Experiment Station, black walnut was found to be unable to compete with sugar maple and northern red oak (Prichard 1941). Planting of black walnut under a cover of decadent black locust and shortleaf pine on strip-mined land resulted in height growth two to three times better under the locust than under the pine (Deitschman 1956). Walnut planted with black locust in alternate rows may become overtopped and suppressed by the locust (Hart and Byrnes 1960) and mechanical damage may result from whipping by the thorny branches (Boyce and Merz 1959). Chapman (1961) therefore recommended a black locust component of only 20 to 25 per cent of the planted seedlings, and in order to obtain a good distribution of walnut in any hardwood mixture, alternate rows in which every other tree is a walnut might be alternated with rows composed entirely of other hardwoods.

Regeneration may be either by direct seeding of the nuts or by planting of nursery-grown seedlings of 1-0 or 2-0 stock. Seeded walnuts often show better growth than planted stock, but survival and form seem to be less influenced by method of planting (Boyce and Merz 1959; Boyce and Neebe 1959; Seidel 1961). The inferior growth of the seedling stock is generally attributed to transplanting damage of the tap roots. A disadvantage of seeding is the danger of nut pilferage by squirrels and rodents. Rodent control is therefore an absolute necessity to satisfactory seedling establishment. Engle and Clark (1959) found that the rodent repellents, Endrin and Thiram failed to reduce rodent pilferage.

The season of planting largely depends on the climatic and soil conditions of the region. In areas of extended frost periods and where heavy soils may result in extensive forest heaving, spring planting will give better results. Nuts may be sown in fall or in spring but autumn seeding generally increases the danger of loss from rodent pilferage during the winter. Spring-sown nuts require stratification which may be done by placing the nuts over winter in moist sand or peat, but the stratification pit must also be protected against pilferage by animals (Chapman 1961). Stratified seeds must be planted early in spring before visible germination.

To ensure satisfactory stocking it is generally safest to plant 2 to 3 nuts per seed spot. The nuts should be placed in the ground and covered with 1 to 2 inches of soil.

Black walnut will tolerate herbaceous competition (Clark 1954), but cultivation or mulching during the first two growing seasons will result in better survival and growth due to increased moisture and nutrient supply.

Plantations must be protected from damage by livestock or browsing by deer or rabbits (McLeod 1956).

Poplar Species

Poplar plantations, established on suitable sites and properly cared for will produce the greatest volume of wood in the shortest period of time of any native broadleaf species (Hansen and McComb 1955). Beside the native poplar species a large variety of hybrids and different clones of poplars have been planted (Blow 1948), of which the most commonly known hybrid is the Carolina poplar. No attempt has been made to distinguish between the species and only the genus Poplar is discussed here.

Poplars are very intolerant and should only be planted in the open and in pure stands (Maisenhelder 1960). Since poplars are exacting in their site requirements, selection of the right planting site is most important and plantation establishment on unsuitable sites will invariably lead to poor growth and eventual plantation failure (Den Uyl 1962). For optimum growth poplars demand a soil rich in minerals, especially lime, moist but well-drained, well-aerated and with a pH not lower than 5 (Bull and Muntz 1943; Hesmer 1951; Ulrich 1962). Unsuitable sites include : heavy, compacted, impermeable, poorly aerated, dry, shallow and minerally depleted soils; swampy areas with stagnant water or with a very high water table (Graves *et al* 1958; Kriebel *et al* 1958).

Poplars are very sensitive to competition from grass, weeds or brush. Controlled experiments have shown that the presence of herbage significantly decreased root, shoot and volume growth, number of leaves and weight, and foliar composition (Aird 1962). Planting without site preparation and subsequent cultivation is almost always futile and may be regarded as money wasted (Schreiner 1945, a,b; Rudolf 1948; Cunningham 1954; Eschner 1960; Maisenhelder 1960). Preparation of the planting site may be in the form of complete cultivation, which will eliminate all existing vegetation and will facilitate future weeding operations (Aird 1958) or in the form of planting spot preparation through the scalping of small areas around each individual seedling. Planting spots should be at least two feet square (Hesmer 1951; Ulrich 1962) and Lane and McComb (1953) found in a study of planting-spot sizes that maximum growth was always obtained on the 48-inch scalps, the largest size used in the experiment. After the initial site preparation the planting spots must be kept clear from invading ground vegetation for at least two years. The requirement to maintain clean cultivation is generally not economically attractive in North America, but recent advances in the use of herbicides may reduce costs. Kuntz and Riker (1957) controlled weeds and most grasses without injury to cottonwood cuttings by spraying Diuron (Karmex DW) at 2 and 4 lb. per acre on sandy loams and 4 lb. per acre on muck soils. KDW at 2 lb. per acre in combination with 20 pounds of C.I.P.C. also controlled weeds well with no injury to poplar cuttings. Aird (1962) reported highly significant increases in first year leader length, volume and leaf weight of one-year-old rooted cuttings of Carolina poplar resulting from good weed control during the early part of the growing season after pre-planting treatment of the site with a herbicide mixture of one pound acid equivalent of 2,4-D (Esteron ten-ten) and ten pounds of acid equivalent of Radapon. But before herbicides can be recommended for extensive use, more must be known about their effects on growth and survival of the young seedlings. Close planting has also been advocated as an alternative to continued cultivation with the purpose of complete canopy closure within two to three years after planting (Schreiner 1940). However, thinning will be necessary in these plantations at an early age when the removed trees are still of unmerchantable size and postponement of thinnings will very seriously affect the growth rate of such plantations (Rohmeder 1961).

The most commonly used planting stock in North America are cuttings or rooted cuttings. These are cut during the dormant season from previous years, shoots and are easily planted with the help of a planting stick, having a slightly larger diameter than the cuttings (Hesmer 1951).

The most common European practice is the planting of 2-year-old plants, grown in the nursery from cuttings (Heimburger 1952). Such plants have well-developed root systems and planting holes of relatively large size, mostly 2 x 2 x 2 feet (Ulrich 1962) are required for good establishment. While this planting method results in very high survival and much better early growth than the planting of cuttings, costs are also much higher due to high manual labour requirements.

The use of explosives has recently been investigated in the search for a cheaper method of planting hole preparation (Anon 1961a; Jobling 1961). Charges of 1.6, 4 and 5.6 ounces of polar Ammon Gelignite were exploded at depths of 15 and 18 inches. The 1.6 ounce charge produced a cylindrical hole 15 inches in diameter and 18 inches in depth, while the 4 ounce charge produced a conical hole 42 inches in diameter and 24 inches deep. The 5.6 ounce charge did not differ markedly from the 4 ounce charge (Jobling 1961).

Heid (1961) also investigated the use of Ammon Gelignite in the preparation of planting holes. For best results, one stick was used per hole and exploded at a depth of 51 inches below surface. A good indication for proper depth of explosion was the loosening of the ground without loss of soil due to flying particles during the blast.

Sufficient disturbance occurred at the base of the hole to allow soil to be removed easily before planting. Differences in vigour between the trees planted in "exploded" holes and the controls were only slight after the first growing season but became very pronounced after four years. Trees planted in the "exploded" holes were appreciably taller (Jobling 1961). Heid (1961) found an increased height growth of 68 per cent of trees planted in the "exploded" holes. This better growth is believed to be the result of loosening of the soil at the bottom of the hole and thereby providing for better penetration by the growing roots.

For stabilization planting of sand dunes in Italy the following planting methods were used successfully and may be noted as an indication of the versatility of planting methods according to local requirements. The first method involved the boring of 12-foot deep planting holes to the water table with an auger five inches in diameter. Young trees 25 feet high were inserted into these holes after their roots had been pruned to fit the holes (Jobling 1961). The trees have survived and grown well. Subsequent examination revealed a strong root system near the base of the trees at the level of the water table with another very dense system for support in the upper horizon at a depth of two feet below the surface, separated by a bare section of the originally buried stem. A second method involved the hammering of three-year-old fresh poplar poles into the sand dunes until the sharpened point was buried in the water-carrying zone. The top was then cleared of splits and abrasions and the poles soon started to sprout and have survived well. (Anon 1961a).

Poplar planting stock will withstand considerable exposure of the roots without markedly influencing survival and growth. Jobling (1960a) reported that periods up to 40 days are unlikely to result in failure. Health and early rate of growth may be poorer but the effects were found only to be temporary.

Fertilization with nitrogen, applied as a surface soil dressing, and if possible worked into the soil, will considerably improve growth during the first growing season and results may be noticed within two weeks after application (Jobling 1960b; Ulrich 1962). Phosphate and potassium applied at planting time did not give the same response as nitrogen during the first two seasons but resulted in a lasting effect until the fourth season. Fertilization is most beneficial on the marginal sites.

Application of 1 ounce of 10-10-10 fertilizer per seedling showed a small effect when applied to the surface only, but when worked into the upper soil the response was significantly better (Aird 1956; 1962).

White Ash

White ash is the most abundant and important of the American ashes. In natural stands it is found scattered or in small groups among other hardwoods and never forms pure stands. It has been planted frequently but is not regarded as a common plantation tree (Wright 1959b). It is a demanding species in regard to soil fertility and soil moisture (Wallihan 1949). Mitchell and Chandler (1939) found that white ash responded to additional nitrogen supply with an increased growth rate of 250 to 300 per cent. No apparent response was observed to phosphorus and potassium fertilization (Cummings 1941). A soil survey of the species natural distribution area showed that white ash was infrequent or absent on the poor sites, made slow growth in nitrogen-deficient soils and approached maximum growth only at very high levels of nitrogen availability.

Minckler (1946) evaluated the site requirements for white ash in southwest Virginia and the Tennessee Valley, and recommended plantation establishment on sites with the following characteristics: on well-drained bottom soils and those showing no apparent erosion and having a top layer of dark coloured soil at least 6 inches deep; in areas with some topsoil and at least 12 inches of non-compacted sub-oil. The pH range of the species lies between 5.0 and 7.5.

When white ash is planted on abandoned, infertile fields or pastures, on eroded land or dry exposed ridges, it will never produce a stand of high quality timber (Stoeckler and Limstrom 1950; Minckler 1952; Ryker 1958; Hart and Byrnes 1960).

On strip-mined land, Boyce and Neebe (1959) recommended the planting of white ash on lower slopes and bottoms and in areas with a pH greater than 5.5. Except on very acid soils, white ash seedlings showed good to excellent survival, but the form was poor on infertile soils while on the better sites many stems of good form were found.

In plantations of the Biltmore Estate, white ash grew only 20 feet in 20 years when planted in pure stands, but in association with white oak, the height growth increased to 30 feet during the same period on a similar site. This growth equalled that of pines of the same age, the diameter, however, was still only half that of the pines (Haasis 1930). In plantations in Arkansas the growth was generally slow, except on soils of excellent fertility and moisture conditions (Meade 1951). One of the best and oldest plantations, in Tioga County, Penn., was described by Cope (1948). White ash was planted as two-year-old stock at a spacing of 5 x 5 feet on first class agricultural land. At age 35 the trees were 56 feet tall and the diameters ranged from 4 to 13 inches. When planted adjacent to black locust, white ash showed appreciable decreases in height and diameters with increasing distance from the locust, indicating the favourable effect of locust on the nitrogen supply of the soil (Chapman 1935).

One of the outstanding characteristics of white ash is its ability to withstand shade in its juvenile stage (Cope 1948). Protection from a nurse crop and seeded rye reduced the damage from late frost by over 50 per cent (Stoeckeler 1955). It also shows a high ability to recover from browsing or extended suppression.

Seedlings are mostly planted as 1-0 or 2-0 stock. Since the seedlings can withstand more mishandling in the nursery than seedlings of almost any other commonly planted tree, ash generally recovers quickly from top and root pruning. However, seedlings with a large, well-developed root system and good lateral root development will grow faster initially and are less subject to frost heaving (Bramble 1952).

Site preparation in the form of cultivation or scalping of the planting spots as well as cultivation during the first two growing seasons will result in increased growth and better establishment of the trees (Cope 1948).

Green Ash

Green ash occurs naturally over a very wide range but has also been planted extensively since it is easily grown in the nursery, is relatively easy to plant and generally survives well (Hansen and McComb 1955). Its major fault is poor form. It is one of the most successful and commonly planted hardwoods in the shelterbelts of the Great Plains and the Canadian Prairies (Munns and Ctoeckeler 1946; Cram and Morgan 1961). It grows best on uncultivated, uneroded soils and on moist bottom sites, but has also been successfully planted on moist upland soils (Wright 1959a). The species demands a high soil moisture (Shear and Stewart 1934) and while Pfandkuch and Duncan (1956) reported best annual growth on fine-textured soils in Minnesota, the best shelterbelt plantings were found on coarse-textured soils. The species may survive on drier sites but will not thrive. It is very tolerant to water saturated soil conditions (Hosner and Boyce 1962).

When planed in old fields, on pasture land or on soils with a tight claypan at a depth of 12 to 24 inches, green ash growth has generally been inadequate (Hansen and McComb 1958). The mean annual height growth was found to be closely correlated with the per cent of leaf nitrogen, and fast tree growth and high leaf nitrogen content were closely associated with the uncultivated sites. Survival, however, was not influenced by site. The species is also very sensitive to site deterioration associated with erosion and height and diameter growth were found to be inversely correlated with the degree of erosion of the A horizon.

On strip-mined land the best growth was found on lower slopes and bottoms and in areas with a pH greater than 5.5 (Boyce and Neebe 1959).

Planted in association with black walnut and black cherry in the Syracuse Forest Experiment Station, green ash showed very poor form (Prichard 1941). In mixed plantations, planted in alternate rows with Norway spruce, the ash was overtopped after 25 years and again showed very poor form. When planted in an old field and under the cover of sassafras, planted pine and planted black locust, green ash responded very well to the nurse crop of black locust and growth was second only to that of yellow poplar (Chapman and Lane 1951).

Green ash is generally regarded as an exceedingly hardy species to climatic extremes (Harlow and Harrar 1950), but Wallihan (1949) found that the species suffered from severe frost injury in a plantation where red oak and basswood made excellent growth.

Green ash seedlings are tolerant to herbaceous vegetation and survival is generally very good on such sites. However, the height growth and especially the form is very poor on sites with heavy competition (Hart and Byrnes 1960). Cultivation for one or two growing seasons will help the young transplants to get established and to compete more successfully with the surrounding vegetation.

Yellow Poplar

Yellow poplar is a valuable timber species and has been widely planted in the Central States forest regions (Renshaw and Doolittle 1958), but in Canada it is of little economic importance due to its limited natural range. Survival and growth of planted seedlings has been extremely variable and most plantation failures seem to have been the result of planting on unsuitable sites. For optimum growth yellow poplar demands a moist but well-drained soil of loose texture (Allen 1953) and satisfactory growth was found to be highly correlated with a high nitrogen content of the soil (Prichard 1941). Plantings on dry, exposed slopes and ridges and abandoned old fields or pasture land with an infertile, shallow top soil or a heavy compact under-layer have invariably failed (Haasis 1930; Minckler 1946, 1952; Green and Neebe 1957; Ryker 1958; Jones 1959).

The species is well suited for underplanting, especially under decadent stands of black locust (Boyce and Neebe 1959), but release will be necessary after approximately 5 years to maintain satisfactory survival and height growth (Williston and Huckenpahler 1957). When planted in mixture with black locust, yellow poplar should constitute at least 75 per cent of the stand to avoid domination by the locust.

Quality of planting stock has a marked effect on the success of planting (Limstrom *et al* 1955; Limstrom and Finn 1956; Rodenbach and Olsen 1960). Weed suppression through cultivation should be maintained for at least the first two growing seasons after planting (Prichard 1941).

Fertilization with 250, 500 and 1,000 pounds of diammonium phosphate (20-52-0) per acre resulted in a definite increase in height growth with increasing rates of application (McAlpine 1959; Ike 1962). Two years after fertilization with phosphorus and potassium, Cummings (1941) found no marked effect in height growth of fertilized over untreated trees.

Northern Red Oak

Northern red oak has been planted widely due to its quality as a timber tree, its fairly rapid growth and its tolerance to a variety of growing sites. The species grows best in association with other hardwoods on deep, moist but well drained soils of medium texture with a silt-plus-clay content of 20 per cent or more (Stoeckeler and Limstrom 1950; Sander 1957). A growth survey of the natural stands in the Northeast indicated that the species can grow satisfactorily in nitrogen-deficient soils (Mitchell and Chandler 1939).

In southeastern Iowa plantations of red oak grew moderately fast on uncultivated sites, but the majority of the trees, even in the best stands, were crooked, forked and coarsely limbed (Hansen and McComb 1955) and the maximum height growth on good sites only approximated that of last growing pines. In a mixed plantation of red oak, basswood, burr oak and green ash, established on deep silt loam with limestone fragments, the growth of red oak was good with a height of 12.6 feet in 12 years. (Wallihan 1949). Best growth was recorded in a plantation on a 5 per cent northeast slope on stony, clay soil with a pH of 5.0. The average height was 40.5 feet in 23 years with individuals reaching a height of 47 feet and a diameter of 4.8 inches while the average diameter was 4.1 inches (Winch 1937). A survey of eight plantations in Arkansas showed a generally low survival and poor growth which was partly due to grazing damage (Meade 1951).

Red oak is the most tolerant of the oaks and in early youth prefers a protective overstorey (Stoeckeler and Limstrom 1950). When 1-0 red oak seedlings were planted under a stand of 4-year-old aspen, the complete removal of the overstorey at the end of eight years was very harmful to the young oak trees, while the retention of a moderate overstorey doubled or trebled survival, partly due to lessened frost injury. The average height growth was also markedly better in areas where some overstorey was retained. On strip-mined land more oak survived in mixed plantings with 75 per cent locust than in pure stands, but best height growth was always obtained in mixture with 25 to 50 per cent black locust (Boyce and Merz 1959).

In the search for cheaper methods of regeneration, direct seeding of acorns has been investigated by several foresters, but regeneration establishment is still uncertain and direct seeding must be regarded as a gamble (Engle and Clark 1959). The most important factors affecting seedling establishment from acorns are rodents and insects (Korstian 1927). In North Carolina and Connecticut 90 to 100 per cent of the sown acorns were destroyed by animals and insects. A cover of leaf litter or soil resulted in better survival while screens were of little benefit. Acorns not covered with hardware cloth were almost completely destroyed by rodents (Krajicek 1955). All of the unprotected acorns placed on top of the leaves and 99 per cent of those covered with leaves were taken. Sixty-eight per cent of the acorns planted in the soil were destroyed. When the screens were removed shortly after germination, all acorns placed on top of the leaves and beneath the leaves were taken and 75 per cent of those planted in the soil were lost.

In a seeding experiment in North Carolina planting depth was found to be the most important factor in acorn survival, with the highest survival at a seeding depth of one or two inches (Sluder *et al* 1961). Spring-sown acorns were taken more readily by the rodents than those sown in fall. In an old field seeding in southeastern Ohio, neither ground preparation nor aspect of the planting site was found to affect seeding survival (Plass 1952). However, seeding in fall was more successful than spring seeding.

All red oak plantations must be protected from damage by rabbits, deer and cattle. The grazing of cattle in plantations will always be detrimental to satisfactory growth (Meade 1951).

White Oak

White oak in the most important member of its genus, since it produces nearly three-fourths of the timber marketed as oak. As a plantation species, however, it has fallen into disfavour because most of the plantations have been complete failures (Hansen and McComb 1955). In natural stands it generally occurs in association with other hardwoods and while it will grow on a wide range of soils and sites, it reaches its best development in coves or on the higher bottomlands where the soil is deep and moist, with good drainage (Harlow and Harrar 1950). When planted on old field sites survival and growth have always been poor.

In plantations of the Biltmore Estate the trees have nearly always grown poorly (Haasis 1930). When planted in mixtures with pines, the oaks have not been able to equal the pine growth. In forest plantations in Arkansas all white oak plantations showed an extremely wide variation in the height growth of individual trees (Meade 1951). Mean annual height growth for all plantations was 0.8 feet, and the survival was 52 to 69 per cent.

On strip-mined land white oak survival was best in mixed plantings where 75 per cent of the trees were black locust, but best growth occurred in mixtures of 25 to 50 per cent black locust (Boyce and Merz 1959). Chapman and Lane (1951) reported that white and red oak showed the least response to the effects of locust on the site and Mitchell and Chandler (1939) found that increased nitrogen supply failed to result in a pronounced growth response.

White oak may be planted as nursery-grown seedlings or by direct seeding of the acorns. Since white oak acorns are sweeter than those of black and red oak, they are the preferred food for wildlife including deer, birds, and rodents (Minckler 1957). Seeding without complete control of wildlife and particularly rodents offers very little scope for successful plantation establishment.

Burr Oak

Burr oak is a timber species of minor importance but its ability to make satisfactory growth, even on dry clay soils, and its resistance to smoke and gas injury recommends it for plantation establishment in areas where most other hardwood species will not grow well (Harlow and Harrar 1950; Deitschman 1958). In natural stands it is commonly associated with the soft maples, American elm, red and green ash, and other moderately tolerant species. While it grows best in bottomlands, it will tolerate poor soil aeration and from this standpoint is probably a desirable species to plant on the heavy textured and poorly drained prairies soils (Hansen and McComb 1955). Because of its extreme drought hardiness, the species may be planted in shelterbelts, provided the rabbit damage can be held to reasonable limits (Munns and Stoeckeler 1946).

In plantations of the northern hardwood region, burr oak showed very high survival (Wallihan 1949). The average first year survival was 84 per cent and after 6 to 12 years it was 77 per cent. The mean annual height growth ranged from 3.4 to 10.7 inches.

Burr oak plantations established on old field sites generally showed poor growth and form, but when planted on an exposed upland ridge in uncultivated prairie soils, growth was satisfactory and form was good (Hansen and McComb 1955). On strip-mined land burr oak will grow in most locations and tolerates heavy competition from herbaceous cover (Clark 1954). It grows well in mixture with black locust and other species.

Black Cherry

Black cherry is of relatively minor importance as a plantation tree but has been planted in many localities and appears to have potentialities, but too little is yet known about its requirements for successful planting (Hansen and McComb 1955). In natural forests, the species is seldom found in pure stands, but generally occurs in mixture with sugar and red maple, beech, yellow and sweet birches, basswood, white ash, and hemlock (Hough 1960). It grows best on rich, deep, moist soils and while very young seedlings are shade tolerant, they soon demand good light conditions and are sensitive to root competition.

Planting has generally been recommended in mixture with other hardwoods (Haasis 1930). However, pure plantations have been established successfully. In a plantation on the Biltmore Estate, black cherry was planted on a small patch of good soil near the site of an old farmhouse. This pure plantation has developed into a good stand, which at 25 years of age averaged 35 feet in height and 7 inches in diameter. But many other plantations in the same forest have been marked failures. When planted in mixture with pines, only a few seedlings have grown into acceptable trees and often the pines have outgrown the cherry trees which were planted 10 years earlier.

A survey of 26 hardwood plantations in New York State revealed that the survival of black cherry was generally very good after the first growing season (90.9 per cent) but 8 to 9 years later survival was only 65.5 per cent. The mean annual height growth for nine growing seasons varied from 2.9 to 18.4 inches. The growth was found to be closely correlated with moisture and fertility of the soil, the lateness of spring frosts and the control of damage by mice and rabbits (Wallihan 1949).

When black cherry seedlings were planted under the cover of sassafras, planted black locust, planted pine and in an old field, it was found that best growth was associated with the cover crop of black locust (Chapman and Lane 1951). While the mean height was 14.1 feet under the locust, it was 6.9 feet under the pine and only 2.7 and 2.5 feet, respectively, under sassafras and in the old field. Since stems were found to be somewhat crooked as a result of whipping of the tops by the locust, planting of cherry and locust at the same time may be advantageous, rather than underplanting. On strip-mined land, planted black cherry grew best on moist sites (Clark 1954) and under the cover of deteriorated black locust.

The most commonly used planting stock are 1-0 seedlings which may be root pruned (Winch 1937). Seedlings with a "bushy" root system were superior in resisting frost heaving on heavier soils (Bramble 1952).

The sensitivity of black cherry seedlings to competition makes cultivation necessary for at least one or two growing seasons. The seedlings must also be protected from browsing by deer and rabbits since excessive populations of these animals can practically destroy all regeneration (Hough 1960).

Sugar Maple

Sugar maple is one of the most valuable commercial hardwoods in eastern North America. Regeneration is generally abundant on sites where the tree occurs naturally and planting has therefore been restricted to former agricultural land or strip-mined areas. Such plantations have generally been unsuccessful, since sugar maple does not compete well with grass, demands a good soil and grows best under the cover of an overstorey nurse crop (Stoeckeler and Limstrom 1950; Godman 1957).

For optimum growth the trees demand a moist, rich, well-drained soil. For planting in Wisconsin, Wilde *et al* (1949) recommended soils with a minimum depth to water table of 3.5 feet, at least 35 per cent of silt and clay particle content, not less than 3 per cent of organic matter in the upper seven inches of the soil and a pH range between 5.5 and 7.3. Rudolf (1950) also recommended a pH range of 5.7 to 7.3 for suitable planting sites in the Lake States.

Sugar maple seedlings planted in the forests of the Biltmore Estate have generally grown slower than white and shortleaf pines planted at the same time (Haasis 1930), and even when height growth was equal, the trees were characteristically more slender than the pines, having a diameter an inch or two less at 25 or 30 years of age. Maple planted in mixture with the pines have generally been suppressed and have reached a height only half that of the pines.

In plantations of the Syracuse Experiment Station, red oak and sugar maple planted in mixture seemed to have been evenly matched in the rate of height growth (Prichard 1941).

On strip-mined land sugar maple planted on ridges, upper slopes and in pure plantations showed poor growth with more than half of the trees having multiple stems (Boyce and Merz 1959). Best growth was found in well-drained bottoms and on lower north - or east - facing slopes, and when grown in mixture with black locust.

The seedlings are highly susceptible to frost damage, rabbit and deer browsing, and to heavy competition from herbaceous vegetation (Stoeckeler and Limstrom 1950). A cover crop of rye, planted the previous fall furnished 100 per cent protection against frost damage to new foliage (Stoeckeler 1955). Cultivation for the first one or two growing seasons will help the seedlings to compete more successfully with the ground vegetation. Control of the deer and rabbit populations are essential for satisfactory growth.

Silver Maple

Silver maple is a minor species in plantation establishment and few planting records have been published. Hansen and McComb (1955) reported that silver maple grew rapidly when planted on moist uncultivated upland sites in southeastern Iowa. Its natural pruning was good, but the seedlings tended to form sprout clumps which required thinning to one good stem per clump. Boles were often crooked and leaning. The maximum annual height growth was 3.4 feet, while the mean annual height growth was 3.0 feet.

On strip-mined land silver maple was found to be suitable for planting in mixture with other hardwoods and for underplanting in decadent black locust stands (Boyce and Neebe 1959). Survival was generally good and growth was best on calcareous sands in valleys and on lower slopes. Heavy sprouting at the base and poor form were the major faults of the species.

American Basswood

American basswood is a valuable timber tree, generally growing as scattered individuals in mixture with other hardwoods. It attains its optimum development on rich, moist, well-drained soils (Scholz 1958). It demands a very high nitrogen supply in the soil, and a survey of the forest sites of the Northeast revealed that only 15 per cent of the area could be classed as good to excellent for basswood growth in regard to nitrogen supply (Mitchell and Chandler 1939).

Basswood has been planted frequently, but few reports have been published. Hansen and McComb (1955) recommended the species as a plantation tree with great potential, but noticed that at present little is known about the exact site requirements. Also, planting stock is often difficult to obtain due to the difficulty of germinating and growing basswood in the nursery.

A plantation survey of northern hardwoods revealed that the most successful plantation had been established on a soil of silt loam, several feet deep with limestone fragments. The dominant trees had attained a height of 9.2 feet after 12 growing seasons (Wallihan 1949). In nearly all of the sampled plantations, first year survival was very high with an average of 82 per cent. However, 6 to 12 years later the average was only 51 per cent. Mean annual height growth for 8 to 12 growing seasons ranged from 1.1 to 9.9 inches.

In the Syracuse Forest Experiment Station trees in a 20-year-old basswood plantation were 10 to 33 feet high and 1 to 4 inches in diameter. (Prichard 1941). Best growth was found in an area where topsoil had been deposited from the surrounding hillsides and the trees had been protected by surrounding forests from drying winds and the hot afternoon sun. Leaf litter, blown in from the woods, helped overcome the grass competition in the field.

Protection of young seedlings from browsing by cottontail rabbits, deer and cattle, is a prerequisite to successful plantation establishment (Scholz 1958). Cultivation during the first one or two growing seasons will help the young seedlings to compete successfully with the surrounding herbaceous vegetation.

American Sycamore

The American sycamore is a timber tree of minor importance. The species occurs as single trees or in small groups in mixture with other hardwoods in the northern part of its range, but may be found in pure stands of up to 100 acres in the Mississippi bottomlands (Merz 1958). Best growing sites are found along stream banks and in moist bottomlands where periods of flooding do not exceed one week. On eroded old fields sycamore may become established but will seldom make good growth.

The species has been recommended as one of the best trees for planting on strip-mined land having a pH range from 4.5 to 8.0 (Boyce and Neebe 1959; Den Uyl 1962). It grows best in pure stands where its form is mostly good, but branches are generally very persistent (Boyce and Merz 1959). It will not grow when planted under a cover of black locust.

Preparation of the planting site has resulted in better survival and growth than on uncultivated sites (Huppach 1960). Application of 1.5 ounces of 8-8-8 fertilizer placed in two dibble holes four inches away on opposite sides of the seedlings increased height growth, but when placed in the planting hole and covered with 3 to 4 inches of sand prior to insertion of the seedlings, survival was poor.

CONCLUSIONS

Hardwoods have been planted frequently but a review of the plantation literature reveals many failures and few successes. Knowledge of site, climatic, or nutritional requirements of most hardwood species is still limited and softwood planting practices have therefore often been applied to hardwood planting, generally with poor results. The ability of most hardwood species to sprout makes it possible for them to persist for long periods of time even on unfavourable sites. But these seedlings can hardly be expected to produce timber of acceptable quality and since most hardwoods are grown for their timber value, small or poorly shaped trees are generally unacceptable.

To avoid costly failures, hardwood planting should be restricted to forest sites of the highest quality. With the exception of black locust, green ash and burr oak, Canadian hardwood species are unsuitable for reforestation of abandoned agricultural lands or areas which have not supported a stand of hardwood trees just prior to reforestation. Under these conditions most hardwood species can only be regenerated as a secondary crop, growing under the protection of a nurse crop.

The establishment of hardwood plantations is generally more costly than softwood planting, since most hardwood seedlings require a thorough preparation of the planting site, are often difficult to plant and must be tended for the first few years after planting.

However, planting of selected hardwood species will be well justified on suitable forest sites because the present high value of good quality timber is expected to increase further with the diminishing supply of high quality hardwood trees cut at present from virgin forest stands.

CONCLUSIONS

On a planté, fréquemment, toutes sortes d'essences feuillues, mais l'étude des ouvrages qui se rapportent à ces plantations révèle de nombreux échecs et bien peu de réussites. On ne connaît pas grand chose encore des besoins de la plupart des essences feuillues en matière de terrain, climat et alimentation; c'est pourquoi, la plantation de feuillus a été accomplie de la même façon qu'on plante les essences résineuses, ce qui n'a donné la plupart du temps que de piètres résultats. La propriété commune à presque toutes les essences feuillues de rejetonner leur permet de persister pendant longtemps, même en terrain défavorable. Toutefois, on ne peut s'attendre à ce que des rejets produisent du bois de qualité convenable; puisque la plupart des essences feuillues se plantent en raison de la valeur de leur bois. les arbres de petite taille et rabougris ne peuvent convenir.

Si l'on veut éviter des échecs onéreux, il faut s'appliquer à ne planter les essences feuillues que dans les stations forestières de grande fertilité. Hormis le faux-acacia, le frêne vert et le chêne à gros glands, les essences feuillues indigènes ne conviennent pas au reboisement des terres agricoles abandonnées ou des terrains qui ne supportaient pas un peuplement de feuillus peu de temps avant le reboisement. Dans de telles conditions, on ne pourra régénérer des peuplements de la plupart des essences feuillues que comme peuplements secondaires, croissant sous la protection d'un peuplement d'abri.

En général, il est plus onéreux de planter des essences feuillues que des essences résineuses, parce que les semis de feuillus exigent un terrain soigneusement préparé; ils sont d'ailleurs difficiles à planter et demandent des soins attentifs durant les premières années de leur croissance.

Malgré tout, il vaut la peine de planter des feuillus judicieusement choisis et dans des stations forestières convenables, vu qu'on prévoit que la valeur déjà grande du bois dur de bonne qualité ira croissant, en raison du rendement décroissant des arbres d'espèces feuillues de bonne qualité que l'on coupe présentement dans les peuplements vierges.

APPENDIX 1

Botanical Names of Species Mentioned.

English Name	Botanical Name
Green ash	*Fraxinus pennsylvanica* Marsh.
White ash	*Fraxinus americana* L.
Basswood	*Tilia americana* L.
American beech	*Fagus grandifolia* Ehrh.
Sweet birch	*Betula lenta* L.
Yellow birch	*Betula alleghaniensis* Britt.
Butternut	*Juglans cinerea* L.
Northern catalpa	*Catalpa speciosa* Ward.
Black cherry	*Prunus serotina* Ehrh.
Eastern cottonwood	*Populus deltoides* Marsh.
American elm	*Ulmus americana* L.
Black gum	*Nyssa sylvatica* Marsh.
Black locust	*Robinia pseudoacacia* L.
Red maple	*Acer rubrum* L.
Sugar maple	*Acer saccharum* Marsh.
Silver maple	*Acer saccharum* L.
Black oak	*Quercus velutina* Lam.
Burr oak	*Quercus macrocarpa* Michx.
Northern red oak	*Quercus rubra* L.
White oak	*Quercus alba* L.
Poplar spp.	*Populus* L.
Yellow poplar	*Liriodendron tulipifera* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees.
American sycamore	*Platanus occidentalis* L.
Black walnut	*Juglans nigra* L.
Eastern hemlock	*Tsuga canadensis* (L.) Carr.
Eastern white pine	*Pinus strobus* L.
Jack pine	*Pinus banksiana* Lamb.
Red pine	*Pinus resinosa* Ait.
Shortleaf pine	*Pinus echinata* Mill.
Virginia pine	*Pinus virginiana* Mill.
Norway spruce	*Picea abies* (L.) Karst.

APPENDIX 2

TABLE 1. Average Annual Hardwood Lumber Production by Provinces and 1956 to 1960

Species	Newfoundland		Prince Edward Island		Nova Scotia		New Brunswick		Quebec		Ontario		Total	
	M ft.b.m.	Value $'000	M ft.b.m.	Value $'000	M ft.b.m.	Value $'000	M ft.b.m.	Value $'000	M ft.b.m.	Value $'000	M ft.b.m.	Value $'000	M ft. b.m.	Value $'000
White birch	530	35	41	3	1,017	72	461	29	12,259	932	6,415	623	20,723	1,694
Poplar	12	1	10	1	127	7	499	26	15,335	766	18,591	896	34,574	1,697
Yellow Birch	52	4	23	2	5,319	411	6,508	587	121,223	11,076	25,670	2,777	158,795	14,857
Maple			50	3	5,556	362	18,146	1,460	36,610	2,825	59,009	6,043	119,371	10,693
Beech			4*	—	69	4	2,711	161	2,651	160	4,837	309	10,272	634
Oak			1*	—	229*	19*	7*	—	1,978	161	5,632	531	7,847	711
Ash					21*	1*	359*	28*	1,815	160	3,099	268	5,294	457
Elm					1*	—	15*	1*	4,053	270	17,857	1,286	21,926	1,557
Basswood					88*	5*	217*	14*	13,248	1,101	11,546	1,016	25,099	2,136
Butternut							4*	—	95*	7*	78*	6*	177	13
Hickory									44*	3*	179*	14*	223	17
Cherry									58*	4*	605*	64*	663	68
Walnut									5*	—	63*	8*	68	8
Sycamore											3*	—	3	—
Yellow Poplar											2*	—	2	—
Chestnut									4*	—	2*	—	6	—
Willow									174*	7*	51*	3*	225	12
Unspecified	2**		8**		597**	46**	394**	30**	366**	24**	900**	87**	2,267	187

* Average of 1956 to 1958   ** Average of 1959 and 1960

TABLE 2. Average Annual Quantity and Value of Total Softwood and Hardwood Lumber Production by Provinces 1956 to 1960

Province	Softwood M ft.b. m.	Percentage of total	Hardwood M ft.b. m.	Percentage of total	Softwood Value $'000	Percentage of total	Hardwood Value $'000	Percentage of total
Newfoundland	32,419	98	596	2	1,969	98	40	2
Prince Edward Island	7,854	98	131	2	459	98	9	2
Nova Scotia	225,966	95	12,530	5	13,737	94	889	6
New Brunswick	241,788	89	28,843	11	15,629	87	2,302	13
Quebec	851,728	80	209,547	20	56,892	76	17,495	24
Ontario	502,608	77	153,660	23	38,467	74	13,845	26
Total	1,862,363	82	405,307	18	127,153	79	34,580	21

TABLE 3. Species Requirements for Successful Planting

Tree Species	Trees Suitable for Planting on						Planting Stock				Stand Composition			Site Preparation		Planting Method		Cultivation After Planting	
	Eroded Land	Shelterbelts	Abandoned Agricultural Land	Poorly Drained Areas	Intermed-iate Soils	Undisturbed Hardwood Soils	Seeds	Cuttings	1-0 Nursery Stock	2-0 Nursery Stock	Pure Plantations	In Mixture with other Hardwoods	Suitable for Underplanting	Essential	Beneficial	Machine Planting	Hand Planting	Essential	Beneficial
Black Locust	x	x	x		x	x			x	x	x	x			x	x	x		x
Black Walnut						x	x		x	x		x		x			x	x	
Poplar spp.						x		x			x			x			x	x	
White Ash						x			x	x		x	x		x	x	x		x
Green Ash		x		x	x	x			x	x	x	x			x	x	x		x
Yellow Poplar						x			x	x		x		x			x	x	
Red Oak					x	x	x		x	x	x	x			x	x	x		x
White Oak						x	x		x	x		x			x	x	x		x
Bur Oak		x	x		x	x	x		x	x		x			x	x	x		x
Black Cherry					x	x			x	x		x		x		x	x	x	
Sugar Maple					x	x			x	x		x	x	x		x	x	x	
Silver Maple				x	x	x			x	x		x	x		x	x	x		x
Basswood					x	x			x	x		x	x		x	x	x		x
Sycamore				x	x	x			x	x		x			x	x	x		x

TABLE 4. PLANTING GUIDE

Tree Species	Purpose of Planting	Climatic Range in Canada	Where to Plant	Where *not* to Plant	Age of Planting Stock
Black Locust	Erosion control or pioneer planting.	Not a native tree in Canada but has been been planted successfully from southern Quebec to southern Manitoba.	May be planted anywhere; trees will not grow well, but will persist and improve the site for subsequent plantings.	On excessively dry or very wet sites.	1-0 or 2-0 seedlings.
	Fencepost and timber production.	Same as above	For optimum growth plant only deep, fertile, moist but well drained loamy soils, preferably of limestone origin.	On dry or very wet, poorly aerated compacted sites.	1-0 or 2-0 seedlings.
Burr Oak	Shelterbelts, reforestation of poor dry sites.	Southwestern New Brunswick to southern Saskatchewan.	Best growth is found in bottomlands, but will grow on heavy textured, poorly aerated and drained prairie soils.	On exposed, stoney ridges and very wet areas.	Stratified acorns or 1-0 or 2-0 seedlings.
Green Ash	Shelterbelts, reforestation of wet areas.	Southwestern Quebec to eastern Alberta	Along rivers and creeks and areas which may be flooded up to 40 percent of time during the growing season. On moist uplands soils with neutral to alkaline reactions.	On exposed dry ridges and soils with a light claypan at depth of less than 24 inches.	1-0 or 2-0 seedlings.
American Sycamore	Reforestation of areas of wet muck land, shallow peat soils and river banks.	Native in southern Ontario but has been planted successfully as far north as Ottawa.	For optimum growth plant in rich bottomland soils, along creeks and rivers. Will also grow in wet muck land, shallow peat soils and moist upland sites. Is tolerant to wet soil conditions and flooding.	On exposed or excessively dry ridges or dry sand plains.	1-0 or 2-0 seedlings.
Northern Red Oak	Timber production.	Cape Breton to southwestern Ontario.	For optimum growth plant in deep, moist, well drained soils of medium texture. Will also grow on soils ranging from clay to loamy sands to shallow, rocky soils, but tree growth and form will be poor on these sites.	In open fields or abandoned pastures. On excessively dry or wet soils. Young seedlings prefer protective overstorey.	Seeding acorns in fall or spring or 1-0 or 2-0 seedlings.

How to Plant				Evaluation
Species Composition	Site Preparation	Method of Planting	Cultivation after Planting	
Pure plantations.	Ploughed strips or preparation of planting spots by spading and elimination of weeds.	Machine planting or manual planting by spade.	Ploughing between rows or hoeing around each tree for at least the first two years.	A very valuable tree for erosion control planting and soil improvement through nitrification.
Pure plantation or in mixture with other hardwoods.	Same as above	Same as above	Same as above.	The most vigorous trees develop highest resistance to locust borer attack.
In mixture with black locust and green ash.	Ploughed strips of preparation of planting spots 12 × 12 inches.	Machine plating or manual planting by spade.	Will tolerate heavy competition but ploughing or hoeing will be beneficial.	Very drought hardy, good resistance to smoke and gas injury. Of minor value as a wood producing tree.
In mixture with black locust, silver maple, poplar spp., and aspen.	Ploughed strips or planting spots at least 12 × 12 inches.	Machine planting or manual planting by spade.	Will tolerate heavy competition but cultivation for the first two growing seasons is benefical.	Very hardy to climatic extremes. Major fault is poor form. Good tree for reforestation of wet areas and shelterbelts.
Always in mixture with green ash, poplar spp. red maple, silver maple and Manitoba maple.	Ploughed strips or planting spots at least 12 × 12 inches.	Generally manual planting by spade.	Will tolerate moderate competition but cultivation for the first two growing seasons will be beneficial.	Not a valuable timber tree but preferred for reforestation of wet, poorly drained areas. Planted extensively as an ornamental.
In pure stands or in mixture with white ash basswood American beech, black cherry hickory and maple spp.	Ploughed strips or planting spots at least 12 × 12 inches.	Machine planting or manual planting by spade.	Will tolerate moderate competition but cultivation for the first two growing seasons will be beneficial.	An important timber tree, grows rapidly on a wide variety of sites and is also planted extensively as an ornamental.

TABLE 4. PLANTING GUIDE (Continued)

Tree Species	Purpose of Planting	Climatic Range in Canada	Where to Plant	Where *not* to Plant	Age of Planting Stock
Black Cherry	Timber production.	Western Nova Scotia to Lake Superior.	For optimum growth plant on rich, deep, moist, but well drained soils as found in river valleys and on lower slopes. It will grow on drier upland soils, but growth is generally slow.	In abandoned, infertile, open fields or pastures on eroded land or dry, exposed ridges or on swampy ground.	1-0 or 2-0 seedlings.
Basswood	Timber production, source of honey.	Western New Brunswick to southern Manitoba.	For optimum growth plant on deep, moist but well drained soils with a high nitrogen content as found in river valleys and on lower slopes. On drier upland soils the growth is generally slow.	In abandoned infertile, open fields or pastures, on eroded land or dry, exposed ridges or on swampy ground.	1-0 or 2-0 seedlings.
Yellow Poplar	Timber production.	Southern Ontario.	For optimum growth plant on deep, moist but well drained soils with a high nitrogen content and a loose texture as found in river valleys and on lower slopes.	In abandoned, infertile, open fields or pastures, on eroded land or dry, exposed ridges or on swampy ground.	1-0 or 2-0 seedlings.
Black Walnut	Timber production.	Southern Ontario on protected sites as far north as Ottawa.	For optimum growth plant only on deep, fertile, moist but well drained soils of alluvial origin as found in river valleys, protected coves and lower slopes.	In abandoned, infertile, open fields or pastures, on even slightly eroded land or dry exposed ridges.	Seeds or 1-0 or 2-0 seedlings.

How to Plant				Evaluation
Species Composition	Site Preparation	Method of Planting	Cultivation after Planting	
In mixture with black locust, sugar and red maple, white ash and basswood.	Complete cultivation or preparation of planting spots at least 18 × 18 inches.	Manual planting by spade.	Clear cultivation must be maintained around the seedlings for at least the first two growing seasons.	A valuable timber tree in mixed hardwood stands. At present little is known about best planting procedures.
In mixture with white ash, black cherry, hickory spp. and black walnut.	In ploughed strips, or planting spots at least 18 × 18 inches.	Manual planting by spade.	Will tolerate moderate competition but cultivation for the first two growing seasons will be beneficial.	A valuable timber tree and an important source of honey. At present little is known about best planting procedures.
In mixture with black locust, black walnut basswood and black cherry Suitable for underplanting.	Complete deep cultivation or preparation of planting spots at least 18 × 18 inches.	Manual planting by spade. Fleshy roots are susceptible to planting injury.	Clear cultivation must be maintained around the seedlings for at least the first two growing seasons.	A valuable timber tree but of little economic importance in Canada due to small range. Planted frequently as an ornamental.
In mixture with black locust, yellow poplar, white ash and basswood.	Complete deep cultivation or preparation of planting sports at least 18 × 18 inches.	Manual planting by spade.	Clear cultivation must be maintained around the seedlings for at least the first two growing seasons.	One of the most valuable timber trees, but difficult to grow due to its very high soil requirements.

TABLE 4. PLANTING GUIDE (Continued)

Tree Species	Purpose of Planting	Climatic Range in Canada	Where to Plant	Where *not* to Plant	Age of Planting Stock
White Oak	Timber production.	Southern Ontario to southern Quebec.	On higher bottomland where the soil is deep and moist with good drainage.	In open fields or abandoned pastures, on very dry or very wet sites, or in mixture with softwoods.	Seeding of acorns in fall or spring or 1-0 or 2-0 seedlings.
Silver Maple	Timber production.	Southwestern New Brunswick to southwestern Ontario.	For optimum growth plant in bottomland with a moist, deep soil and along borders of swamps and rivers. Will also grow on poorer sites, but requires high soil moisture.	In open fields or abandoned pastures, on shallow, dry soils or exposed ridges. In mixture with softwoods.	1-0 or 2-0 seedlings.
Sugar Maple	Timber production and source of maple syrup and maple sugar.	Nova Scotia to western Ontario.	For optimum growth plant on moist, rich, well drained soils as found on lower slopes and in valley bottoms. On poor, dry soils the growth is generally slow and the form is poor.	In open fields or abandoned pastures, on shallow, dry soils, or on exposed ridges.	1-0 or 2-0 seedlings.
Poplar spp.	Maximum wood production for timber or pulpwood.	Wide distribution over nearly all parts of Canada.	For optimum growth plant only on soils rich in minerals, especially lime, moist but well drained and well aerated soils as found in valley bottoms, along creeks and rivers and moist, but well drained fields.	On sites with heavy, compacted, poorly aerated, dry, shallow or minerally depleted soils, and in swampy areas with stagnant water.	Cuttings or rooted cuttings.
White Ash	Timber production.	Cape Breton Island to the lower end of Lake Superior	For optimum growth plant on deep, moist, well drained soils which have a high nitrogen content. These soils are generally found on bench lands in river valleys and on lower slopes.	On abandoned, infertile, open fields or pastures on eroded land or dry, exposed ridges.	1-0 or 2-0 seedlings.

How to Plant				Evaluation
Species Composition	Site Preparation	Method of Planting	Cultivation after Planting	
In mixture with basswood, white ash, black cherry, hickories and northern red oak.	In ploughed strips or planting spots at least 12 × 12 inches.	Manual planting by spade.	Will tolerate moderate competition but cultivation for the first two growing seasons will be beneficial.	An important timber tree, but very difficult to plant.
In mixture with white ash, red maple, American Sycamore, and green ash.	In ploughed strips or planting spots at least 12 × 12 inches.	Manual planting by spade.	Will tolerate moderate competition but cultivation for the first two growing seasons will be benefical.	A very rapidly growing tree. Its greatest disadvantage is poor form due to heavy sprouting at the base. Used extensively as an ornamental.
In mixture with black locust, beech, red oak, red maple and hickories.	In ploughed strips or planting spots at least 18 × 18 inches.	Manual planting by spade.	Clear cultivation must be maintained for at least the first two growing seasons.	A valuable timber tree. Seedlings are highly susceptible to frost damage and browsing. At present llittle is known about best plating procedures.
In pure plantations only.	Complete, deep cultivation or preparation of planting spots at least 4 × 4 feet.	Cuttings are planted by planting stick. Rooted cuttings by spade in holes of 2 × 2 × 2 feet.	Clear cultivation must be maintained for at least the first two growing seasons.	When planted on proper site and properly cared for, poplar will produce the greatest volume of wood in the shortest period of time.
In mixutre with black locust, basswood, oak, beech and maple spp.	In ploughed strips or planting spots at least 18 × 18 inches.	Machine planting or manual planting by spade. May be planted under protection of nurse crop.	Will tolerate moderate competition but cultivation for the first two growing seasons will be beneficial.	An excellent timber tree of high value. Suitable for underplanting if released later.

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