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AGRONOMIC METHODS FOR GROWING BLACK LOCUST (ROBINIA PSEUDOACACIA L.) AS A PERENNIAL FORAGE CROP presented by

Robert P. Barrett

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AGRONOMIC METHODS FOR GROWING BLACK LOCUST (ROBINIA PSEUDOACACIA L.) AS A PERENNIAL FORAGE CROP

By

Robert P. Barrett

A DISSERTATION

Submitted to Michigan State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Forestry

ABSTRACT

AGRONOMIC METHODS FOR GROWING BLACK LOCUST (ROBINIA PSEUDOACACIA L.) AS A PERENNIAL FORAGE CROP

By

Robert P. Barrett

The nitrogen-fixing black locust tree (Robinia pseudoacacia L.) is extremely high yielding, rapid growing, and adaptable, widely naturalized, and has potential for use in agroforestry systems, including forage production, short rotation biomass, fuelwood, beekeeping, soil improvement, and alley cropping. Wildlife and livestock will consume it, although it has tannins which reduce protein digestibility, and stipular spines. Despite these faults, genetic diversity is great and the reproductive age is low, allowing rapid selective breeding. The concept of ideotype breeding is examined, and black locust is evaluated in terms of an ideal model forage tree.

Field trial treatments involving five spacings, two harvest heights, two years of first harvest, and eight harvest dates during the growing season were applied to plots of black locust planted in 1988, during the years 1988 to 1991. Effects on yields per plot and per plant, the dry weight percentage, and survival are reported.

Harvesting two times a year was found unsatisfactory. Harvest dates early in the season were unfavorable because of low regrowth productivity, while those in July or August were rejected because of low survival. A single harvest date as late in the growing season as possible was advised. Harvesting the first season reduced future productivity and survival, often severely. For every aspect of growth, yield, and survival, the harvest height of 30 cm was superior compared to 5 cm. Continued improvement with establishment periods longer than one season and heights above 30 cm was projected.

The narrowest spacing tested (10 cm) gave superior yields the first season only. The widest (50 cm) gave yields which were lower the first and second seasons, equal the third, and superior the fourth. Four year total yields did not vary with density. Survival was highest at 50 cm.

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INTRODUCTION TO BLACK LOCUST

BLACK LOCUST IN AGROFORESTRY

Agroforestry is the science of including trees in farming systems to obtain more favorable results than are possible with trees, crops, or livestock alone. The main techniques include alley cropping, with annual crops grown between hedges of trees, taungya, with crops grown in forest plantations while the trees are young, silvopasture, with timber trees grown on grazing land, tropical gardens, with a wide variety of shade tolerant food, medicinal, and ornamental crops grown under large fruit or timber trees, and fodder trees, which are cultivated and periodically trimmed to feed livestock. Scientific research on alley cropping has concentrated on tropical nitrogen fixing leguminous trees, primarily leucaena (Leucaena leucocephala (Lam.) de Wit), but other species in the genera <u>Acacia</u>, <u>Calliandra</u>, <u>Erythrina</u>, <u>Gliricidia</u>, <u>Leucaena</u>, and <u>Sesbania</u> have also been investigated. Because of their high-protein foliage, these same genera have been researched as fodder trees. These and other multi-purpose trees, which are useful for fuelwood, soil enrichment or conservation, fodder, shading coffee or cacao plantations, and sometimes for food, have been promoted throughout the tropics for use in agroforestry systems that are intended to be more sustainable and are sometimes more profitable than growing annual crops or timber trees alone.

Agroforestry systems have received less attention in the temperate zone than in the tropics because there is little room for trees in mechanized cash crop monocultures. Industrialized countries also have readily available chemical fertilizers and pesticides, no major crops that require shade, and few subsistence farmers. In addition to these economic factors, there are few nitrogen fixing plants that grow to tree size that can survive freezing temperatures. The black locust

(Robinia pseudoacacia L.) is a frost tolerant, productive, and adaptable nitrogen fixing tree. Thus, it is the most likely species to play the multi-purpose role in temperate climates that leucaena has in the tropics. Both leucaena and black locust have rapid growth from seed or coppice, rhizobial nitrogen fixation, dense wood, high protein forage, and a reputation for adaptability (Barrett and Hanover 1991).

INTERDISCIPLINARY NATURE OF THE RESEARCH

It should be recognized that the treatments applied to black locust in these experiments were more typical of those employed in the science of agronomy than in forestry. The product under consideration was not wood but livestock feed, and it was harvested annually. The only element of conventional forestry involved was the species, which grows as a tree in nature but can also be cultivated as field crop. The emerging scientific discipline of agroforestry involves growing trees as part of a diversified farming system, in conjunction with livestock and field crops. The cultivation of woody species as crops to produce commodities other than wood could be considered a branch of agroforestry, or of agronomy. It could also be considered an extension of the forestry technique known as short rotation intensive culture, which has been developed to produce high yields of woody biomass for fuel and fiber. Then again, perennial leaf crops such as tea, qat, betel, coca, and yerba mate are claimed by the discipline of horticulture. The easiest solution would be to designate black locust as a "new crop" (Barrett et al. 1990) and leave it at that. Because my chosen area of study lies at the intersection of several established disciplines, I propose the name "dendro-agronomy" to specify the practice of growing woody species under agronomic conditions.

FEATURES OF BLACK LOCUST

Adaptations and range

Black locust is a multi-purpose leguminous tree noted for rapid juvenile growth. It is adaptable to a wide range of growing conditions, and has a tendency to escape from cultivation. Although it requires full sunlight and grows best on limestone soils, deep taproots and symbiotic nitrogen fixation enable it to thrive on difficult sites, including acidic mine spoil banks and sand dunes (Fowells 1965; Miller <u>et al</u>. 1987; Barrett and Hanover 1991). Black locust tolerates more acidic soil than most other North American deciduous tree species, and is recommended for planting at pH levels as low as 4.0 (Sutton and Dick 1987).

Native to southeastern North America, black locust has become naturalized in temperate regions around the world. In the early 1600's it was imported to France and England, and rapidly spread through Europe (Peabody 1982; Barrett and Hanover 1991). By 1880 it had become naturalized in New Zealand, and it has been grown as an ornamental in the Australian states of Tasmania and Victoria, and used for soil conservation and ornamental purposes in both Israel and Zimbabwe. It was introduced to Kenya in 1913, and in 1962 specimens were reported as growing well in the Nairobi Arboretum (Streets 1962).

Black locust appears to reach the limit of its productive range where the frost-free growing season is under 100 days (Miller et al. 1987). In India black locust grows best from 1500 - 2000 m altitude with 1150 - 1750 mm annual rainfall (Gupta 1986). The National Research Council (1983) asserts that it has been successfully grown with 300 - 400 mm rainfall. It avoids drought stress by deep taproots, leaflet folding, and leaf abscission. It will root sprout or coppice if cut down or damaged by fire (Gustafson 1935; Fowells 1965).

Insect Pests

In North America, the major pest attacking black locust is the locust stem borer beetle <u>Megacyllene robiniae</u> Forster. The larvae tunnel through the heartwood, often causing the trunks

to break in high winds and generally making the lumber unattractive (Hoffard and Anderson 1982; Galford 1984; Barrett and Hanover 1991). In Hungary, where the beetle is not present, black locust is a major timber tree (Keresztesi 1988). The locust twig borer <u>Ecdytolopha insiticiana</u> Zeller, a moth larva, forms galls in the new growth and can cause undesirable crooked trunks. In addition to the locust stem and twig borers, black locust is sometimes damaged by cowpea aphids <u>Aphis craccivora</u> Koch., two leaf beetles, the leaf mining larvae of the moth <u>Parectopa robinella</u>, and the leaf-miner beetle <u>Odontota dorsalis</u> Thunberg (Meginnis 1934; Hoffard and Anderson 1982; Genys and Harman 1990; Hoffard 1992).

Genetics and cultivars

Hopp (1941) classified black locust trees into three major groups: spreading, palmate, and pinnate growth forms, with the crooked spreading form by far the most common. Bongarten (1992) reported a system for uniquely describing 40 black locust clones growing on the same site, by classifying four characteristics of juvenile growth: branch sinuosity, branch angle, frequency of lateral branching, and degree of apical dominance. The shipmast locust, <u>Robinia pseudoacacia</u> var. <u>rectissima</u> (L.) Raber, is a well-known example of the pinnate form. Huang <u>et al</u>. (1975) called it an ecological variant, not a genetic variety, based on soluble protein gel-electrophoresis data. Several researchers have noted that the characteristics of shipmast locust change when clones are planted in other regions (Bongarten 1992). Many special-purpose black locust cultivars have been bred in Hungary from the diverse naturalized gene pool (Keresztesi 1977, 1983, 1988). Rehder (1940) described 24 ornamental varieties of black locust, mostly from Europe and cultivated since the 19th century, with unusual flowering habits or morphology. Four varieties have been grown in Europe, only three to four dozen of them were being cultivated at the Kew Gardens near London.

Because black locust is cross-pollinated by bees, desired clones must be reproduced vegetatively. Major germplasm collections include over 900 accessions at Michigan State

University, over 100 at the University of Georgia, and hundreds in Hungary (Barrett and Hanover 1991). Range-wide provenance/progeny tests of over 400 accessions in Michigan showed highly significant variation in five traits (height, diameter, number of leaders, spine length, and winter dieback), but no differences due to region of origin (Mebrahtu and Hanover 1989; Barrett et al. 1990). Two prostrate mutants have been described which sometimes retained their horizontal habit when vegetatively propagated (Kriebel 1960; Davis and Keathley 1988). Spineless seedlings have been observed, but they are shrubby and grow slowly (Barrett and Hanover 1991). A mutant spineless shoot described by Kim and Lee (1974) grew slowly when grafted. In plantation 92.13 at Michigan State University's Sandhill Research Area, 24 spineless clones have been planted by the author in a permanent archive (19 survived to 1993), together with other unusual phenotypes and hybrids that vary in leaf form, leaf color, flower color, and flowering time.

Flowering

Depending on growing conditions, black locust will bloom within two to five years from sowing. Flowering time in Michigan is in late May and early June. The fragrant white beepollinated pea-like flowers grow in clusters 10 - 20 cm long and supply much nectar which makes excellent honey. Bencat (1986) found the average dimensions of black locust inflorescences to be 10.7 cm long by 5.5 cm wide, with a peduncle length of 2.4 cm and a fresh weight of 3.0 g. Total floral biomass fresh and dry weights were calculated at up to 12.7 and 1.5 tons/ha, respectively.

Use as bee forage

Black locust has many positive features as a bee forage, but the time of bloom is too early for domestic honey bees to take full advantage of (Ayers 1992). Keresztesi (1977) noted that in good flowering years, black locust honey accounts for about 75% of the market in Hungary.

Uses of wood

The heavy, hard wood is useful for fuel, charcoal, parquet flooring, posts, poles, and pulp. Because of black locust's adaptability, inexpensive propagation by seed, rapid juvenile growth, high heat content of the wood, and prolific regrowth after cutting, it is ideally suited for woody biomass plantings. Commercial energy production may eventually become one of its primary uses in the U.S. (Miller <u>et al.</u> 1987).

Black locust wood has a specific gravity of 0.66 to 0.71, a caloric content of 4.7 kcal/g, an extractives content of 6-9% of dry weight, and a very low volumetric shrinkage value of 10-11%. It is far easier to dry without warping than other commercial high density woods such as oak (Stringer 1992). The durability of black locust wood makes it suitable for railroad ties, mine timbers, and structures in contact with the soil. Heartwood extracts have conferred decay resistance on other woods equivalent to the effect of commercial wood preservatives (Smith <u>et al.</u> 1989; Smith 1992).

Uses for soil conservation

At present, surface mine reclamation is probably the main use for which black locust is planted (Bridgen 1992). In the past it has been widely employed for erosion control, windbreaks and shelterbelts, and to increase soil fertility for other species. Black locust will thrive in sand and has been used extensively for stabilizing coastal dunes in the U.S. (Gustafson 1935; Kroodsma 1937), southern France, Romania, Cyprus, and Japan (Streets 1962). Estimates of black locust's annual nitrogen input per hectare range from 30 kg (Boring and Swank 1984) to 109 kg (Dawson et al. 1982), with 56 kg (Ike and Stone 1958) and 70 kg (Haines 1978) also reported. Bridgen (1992) cited five authors who reported average nitrogen fixation rates ranging from 26 to 274 kg/ha/year. Soil in a 36-year-old Indiana plantation had an average annual nitrogen input of 19 kg per hectare. From peak acetylene reduction rates of individual nodules, it was estimated that with the most efficient Rhizobium strains the nitrogen fixation rate could be increased over five times to above 100 kg/ha/year (Reinsvold and Pope 1985).

Black locust has been interplanted to improve growing conditions for high value timber trees such as Sitka spruce (<u>Picea sitchensis</u> (Bong.) Carr.) (Streets 1962) and black walnut (<u>Juglans nigra L.</u>) (Fowells 1965). Schlesinger and Williams (1984) concluded that the rapid

growth of black locust becomes detrimental to walnuts, unless competition is controlled by locust borers, poisoning, or other silvicultural interventions. Timely girdling of interplanted black locust improved walnut growth by up to 135%, but only on the poorest sites.

Black locust is being tested as the hedge component in an alley cropping system with maize, in Ohio. Year-old seedlings were transplanted 150 cm apart in hedges 540 cm apart, with five rows of maize between. The alley cropping arrangement had 28% fewer maize plants than a solid stand, but yielded 18% less. This was attributed to better access to light for the rows adjacent to the young trees. Soil moisture was adequate throughout the growing season, but competition for light and water was anticipated as the trees grew larger (Ssekabembe and Henderlong 1991).

Uses for animal feed

A wide variety of wildlife and livestock consume the high-protein foliage, although it is not suitable as a sole feed. In a listing of 19 Indian tree fodders containing over 15% crude protein (CP), black locust rated third at 20.45% average CP (Singh and Negi 1987). CP content and protein digestion inhibitors decline with the age of the leaves, so the content of digestible protein remains relatively constant at around 10% (Singh and Negi 1987; Barrett and Hanover 1991).

Black locust has tannins which reduce protein digestibility, and stipular spines on the stems which are flexible when green but rigid when mature. Processing can separate the leaflets for a higher protein feed component, or grind the spines and woody stems into digestible fragments (Barrett and Hanover 1991). Black locust leaves are used for livestock feed in the Republic of Korea and in Bulgaria (Keresztesi 1983, 1988) and for commercial angora rabbit production in China (Cheeke 1992). In the highlands of northern India it is a common fodder tree. Branches above the reach of livestock are cut when other green forages are scarce, and the wood is used later for fuel (Barrett et al. 1990). Black locust leaf meal is exported from China for use in Japan as a xanthophyll pigment source for poultry feed. It is used in small amounts (3 - 5%) for coloring only, and not for its nutrient content (Cheeke 1992).

In one laboratory test, ground black locust foliage and woody stems were found chemically comparable to alfalfa (Medicago sativa L.), with 22 - 24% CP, 7% lignin, and 4.2 kcal/g (Baertsche et al. 1986). In published feeding trials, black locust has always been found inferior to alfalfa. Horton and Christensen (1981) compared black locust leaf meal with alfalfa meal in a feeding trial with lambs. Both contained 20% CP and 4.5 kcal/g; CP digestibility was 27.0% in black locust and 69.6% in alfalfa, and caloric utilization was 42.5% and 61.7%, respectively. They deduced that in black locust leaf meal only the hemicellulose component of the cell walls was digested.

No adverse effects of feeding black locust to rabbits were observed by Harris <u>et al.</u> (1984), but the apparent CP digestibility of 54.6% was significantly lower than the 78% measured for alfalfa. Black locust leaf meal fed to growing chicks reduced growth, but not as much after autoclaving. Lectins were suspected of inhibiting digestion (Cheeke <u>et al.</u> 1983). Singh and Negi (1987) stressed the role of condensed tannins in binding protein, and suspected the alkaloid robin of additional inhibitory effects. Cheeke (1992) blamed low protein digestibility on tannins and other phenolic compounds, but noted that the low dry matter digestibility of black locust compared to alfalfa was not directly due to tannins. Tannins could act indirectly, however, by inhibiting digestive enzymes of herbivores or their rumen microflora.

EXPERIMENTAL OBJECTIVES

The nitrogen-fixing black locust tree is extremely high yielding, rapid growing, and adaptable, being widely naturalized in temperate regions. It has potential for use in agroforestry systems, including forage production, short rotation biomass, fuelwood, beekeeping, soil improvement, and alley cropping. Cultivars for specific purposes have long been used in Hungary, and hold great promise for the future, considering the existing genetic diversity and the relatively short generation time of the species. Current problems involving spines, crooked trunks, locust borer damage, and protein digestion inhibitors can be addressed by selective breeding and improved

at a much faster rate than is possible with other temperate zone tree species. Together, these features make black locust an attractive subject for scientific research in general and for agricultural evaluation in particular.

A set of experiments was designed to obtain basic agronomic data on black locust as a crop plant. Field trials were conducted on monoculture plantings to identify the optimal agronomic management practices for producing green leafy material. Treatments involving five spacings, two harvest heights, two years of first harvest, and eight harvest dates during the growing season were applied to plots of black locust planted in 1988. Two trials to compare seed sources were also established, but they will be discussed here only in regard to spacing and year effects. The effects of seed sources were rarely statistically significant, and have been reported elsewhere (Barrett 1992).

Harvest operations were done by hand on small plots to simulate mechanical harvesting at a constant height. Fresh weight, dry weight, and number of plants cut were recorded at each harvest, from 1988 to 1991. Records were also kept for height, number of stems, diameter, fresh and dry weight, and survival for a set of individual seedlings harvested at different dates in 1989 and 1990. Numbers of harvested branches were counted in 1988-1990 in one of the seed source trials.

The results of these experiments have direct applicability for the production of livestock feed and short rotation woody biomass from black locust. The findings also have implications for other species, and other uses of black locust, including direct grazing, alley cropping, and soil conservation.

ORGANIZATION OF THIS DISSERTATION

This dissertation is organized into seven chapters. This introductory chapter described the unusual features and multiple uses of black locust, explains what experiments were done, and why.

Details of where, when, and how field trials were conducted are contained in a separate materials and methods section for each experiment.

The next four chapters cover agronomic treatments involving variations in time of harvest, harvest height, spacing, and year of first harvest. The effects of these treatments over three or four years upon yields per plot and per plant, the dry weight percentage, and survival are reported. The year treatments interacted with spacing and harvest height, and spacing interacted with harvest height. These interactions are mentioned where statistically significant. Chapter two reports the effects of eight harvest dates during the growing season. Six of the harvest dates were compared over two years (1989 - 1990) for yields and over three years (1989 - 1991) for survival. Chapter three reports the effects of the height of harvest above the ground. Two heights were compared over three growing seasons (1988 - 1990). Chapter four reports the effects of spacing or initial population density. A square grid planting system was employed to give a single distance between plants at each spacing. Five spacings were tested over three years (1988 - 1990), and two over four years (1988 - 1991). Chapter five reports the effects of the year of first harvest upon sets of plots that were also used to investigate seed sources, harvest heights, and the spacing between plants. First harvests were taken in 1988 or 1989, and the effects were recorded through 1990 or 1991.

Chapter six contains a literature review on ideotype breeding, and explains how it relates to selecting and improving trees for use as crop plants. Desirable features for for a woody species grown as a perennial forage crop are combined from published lists into a detailed ideotype, or ideal model. The characteristics of black locust are then compared with this ideotype and evaluated.

Chapter seven is a forward-looking conclusion. It briefly summarizes the main findings of the experiments, and then examines a host of unanswered questions. As is typical in scientific investigation, many more questions have been raised than answered. These include some of the original hypotheses where the data are inconclusive, new mysteries that appeared during the field trials, and ideas investigated by others using other species. Because the ideas and results of previous researchers were cited in previous chapters, and the conclusion is a synthesis, it does not contain citations. Next, I present a short list of priorities for future research on black locust as a perennial forage crop. Finally, I offer a few insights for future researchers on working with black locust. I offer both my conclusive results and my subjective opinions to those who will continue research on multi-purpose nitrogen fixing tree species, in the hope that such plants can make a greater contribution to human needs on this increasingly crowded planet.

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EFFECTS OF HARVEST DATE ON SURVIVAL AND FORAGE YIELD OF BLACK LOCUST

ABSTRACT

A harvest date trial was conducted over two years on plots of black locust trees planted at 25 - 35/m², cut at 25 - 30 cm height on eight dates 46 - 156 days after bud break. Green biomass yield increased at about 12 g dry weight/m²/day from late June to late September, even after height growth ceased. Plots harvested early and cut a second time had low regrowth productivity, under 3 g dry weight/m²/day. Only September harvest dates were comparable between years, because of reduced vigor and survival the second year. Dry weight increased from about 20% of fresh weight in June to about 50% in September. Survival steadily decreased over three years, but was highest with September harvests. To obtain the highest green biomass yields each year and maintain adequate survival, a stand of black locust seedlings should be harvested as late in the growing season as possible, but before the leaves are killed by frost. Physiological reasons for this recommendation are discussed.

INTRODUCTION

Black locust is a very rapid growing nitrogen fixing tree which is useful for a variety of products. Because of its high yields of high protein foliage it is being investigated as a perennial forage crop. To grow black locust for green biomass or forage, optimal harvest times must be determined. The relation of yield to height growth and to survival rates needs to be clarified. Field trials must be repeated on the same dates for more than one season, to determine how weather

conditions and any variation in survival affect yields. The dry weight percentage, important for utilization as silage, is known to increase with age during the season, but may vary between years.

PREVIOUS RESEARCH

Seasonal effects have been observed for many species, where survival, coppice shoot numbers, or growth rates were highest when cut while dormant and lowest when cut in midsummer (Blake 1983).

Black locust

Meginnis (1940) transplanted year-old black locust seedlings to the field and decapitated them at four dates, three during dormancy. Cutting back the tops in May, one month after planting, gave the lowest survival and heights at two years after transplanting. Bencat (1992) measured the change in mineral content of black locust leaves from late spring to late autumn. Ca content increased 139%, K content decreased 41%, and little variation was found in the contents of Fe, Mg, Na, Pb, or Zn. The leaves were collected from trees 10 - 15 years old.

No other information on the effect of harvest date on black locust is available. Therefore, reports on other nitrogen-fixing leguminous trees must be consulted. All such research has been done with tropical species.

<u>Leucaena</u>

Yields of leucaena (Leucaena leucocephala (Lam.) deWit) usually increase with harvest interval length (Guevarra et al. 1978; Krishnamurthy and Mune Gowda 1982, 1983; Jeyaraman et al. 1989; Field and OeMatan 1990; de Lucena Costa et al. 1991), though not always significantly (Topark-Ngarm 1983; Evensen 1985). In all trials, 20 - 50 day intervals gave the lowest yields. Lower yields with frequent cutting may follow high mortality from stress (Osman 1986), and have also been attributed to relatively more time spent in slow growth while recovering from cutting (Guevarra et al. 1978; Horne et al. 1985). Some results showed a peak around 60 days, while other trials gave a peak at 90 days. All intervals over 90 days gave declining yields (Takahashi and Ripperton 1949; Osman 1981a, 1986), except for one with a unique bimodal pattern. Mendoza et al. (1983) found a decline at about 84 days, compared with 56 and 112 days.

Horne <u>et al</u>. (1985) noted a strong interaction between harvest frequency and planting density in leucaena. To maximize leaf yields, harvesting should be done on closed canopies with the highest possible leaf area index, just before shading causes lower leaves to abscise. At higher densities where the canopy closes earlier, shorter harvest intervals should raise leaf yields.

When expressed by weight, the yield of dry forage gives no indication of the proportion of woody material present. Lignification affects the protein and fiber contents, and thus the nutritive value of the forage. By defining the age of the material, harvest interval exerts a major effect on wood content. Factors such as cultivars, fertilization, and season can also affect wood proportion (Osman 1981b). Leucaena yield data should be assumed to include woody stems unless specified otherwise.

From a review of early leucaena data, Hill (1971) concluded that the optimum harvest frequency for maximum yield was about four times per year, or every 90 days. Brewbaker (1987) concluded that yields are maximized at 70 - 90 day intervals, depending on temperature.

Other tropical species

Galang <u>et al</u>. (1990) harvested stands of <u>Sesbania sesban</u> (L.) Merrill in subtropical Queensland at intervals of 28, 42, and 56 days. Total biomass increased significantly with interval length, but leaf dry weight remained about the same, giving a declining percentage of leaf in the biomass.

Seedlings of <u>Dalbergia sissoo</u> Roxb. were defoliated three times at monthly intervals, removing 0%, 25%, 50%, or 75% of leaves without cutting the stems. The 25% defoliation gave a large increase in nitrogenase activity, while greater defoliation percentages reduced it below the control level. Increased stem and root weights were recorded with 25% and 50% treatments, but treatments progressively reduced root collar diameter and leaf weight. Stem height was not affected (Pokhriyal et al. 1992).

Year-old seedlings of the leguminous tree <u>Paraserianthes falcataria</u> (L.) Nielsen produced significantly more biomass when coppiced at intervals of 84 days compared to 42 days. Yields of the 42-day group declined severely after the fifth of eight harvests, while the 84-day group maintained its yield level (Rogers and Rosecrance 1992).

Hardesty <u>et al</u>. (1988) cut coppice sprouts of five tree species (including some legumes) at different times during the year in northeast Brazil, where drought limits the growing season to the period from January to June. Cutting late in the growing season (May) gave the lowest stem, leaf, and total yields the next year in all cases. Yields were maximized by cutting in the early dry season (July) or mid dry season (November), depending on species. Leaf weight was affected less than stem weight by the time of coppicing.

Difficulty of applying tropical results in Michigan

Because tropical crops are usually limited by rainfall rather than temperature, and may be grown all year with irrigation, results from tropical leguminous trees can only give rough guidelines for temperate zone fodder trees. A harvest interval of 90 days is not practical when the growing season for black locust in Michigan is about 160 days. The season extends from bud break in late April until the first killing frost in late September or early October.

EXPERIMENTAL OBJECTIVES

To determine which harvest schedule would give the highest yields of green biomass over two years, an experiment was conducted with eight harvest dates. It was designed to determine the optimal time for harvesting black locust new growth, in order to maximize cumulative yields and long-term survival. The patterns of daily productivity, dry weight percentage increase, and canopy coverage were also investigated, to test the following hypotheses:

1. Biomass yield increases with height, and levels off when height growth ceases.

2. Daily productivity rates (g dry weight/m²/day) are directly related to solar radiation, and vary significantly between harvest dates due to changing weather conditions and day lengths.

3. Daily productivity rates for the same harvest date vary significantly between years due to weather differences.

4. Daily productivity rates per plant (g dry weight/plant/day) increase each year.

5. Dry weight percentage (dry weight/fresh weight) increases in direct proportion to time from bud break.

6. Survival varies significantly with harvest date.

7. Autumn and spring canopy coverage (area covered by leaves/total area) vary significantly with harvest date.

MATERIALS AND METHODS

General information for all trials

A bulk mixture of equal numbers of seeds from four Michigan sources was planted. The sources were selected on the basis of availability, and not for any judgement of quality. The seed accessions were 442 from Russ Forest in Cass County, 445 from the corner of Sandhill and Hagadorn roads, and 446 from the Dansville State Game Area, both in Ingham County, and 450 from Kellogg Forest in Kalamazoo County. Prior to sowing, the seeds were scarified in concentrated sulfuric acid for 50 minutes. They were directly sown in late June 1988 at the Michigan State University Tree Research Center in East Lansing (420 41' N, 840 28' W). The nursery beds were surrounded by evergreen windbreaks and had been fumigated with methyl bromide. The soil was mapped as a complex of soil series including Riddles, Hillsdale, Owosso, and Marlette, all of which were well drained with 2% to 6% slopes and sandy loam topsoil. Subsoils were sandy loam, loam, or clay loam (Soil Conservation Service 1979).

Prolonged heat and drought in 1988 impaired growth and sprinkler irrigation was necessary. After normal weather returned in mid August, growth was rapid until early September, with seedlings reaching heights of 60-120 cm. In 1989, 1990, and 1991 growing conditions were favorable.

Because the soil had been fumigated, there were few weed problems in 1988. In the spring of 1989 and 1990, the plots were sprayed with glyphosate (trade name Roundup) at 0.7 kg active ingredient/ha and DCPA (trade name Dacthal) at 8.4 kg active ingredient/ha. Potassium sulfate (0-0-50) fertilizer was added at the rate of 225 kg/ha (112 kg/ha K₂O) on May 7, 1990, to bring soil potassium levels up from around 90 kg/ha. No other fertilizer was applied.

In each plot, all new growth above the designated harvest height was cut with hand tools and bagged to determine the fresh weight. The paper bags of harvested material were dried in an oven at 60°C for at least three days before measuring the dry weight. Weights per plant were calculated from the number of plants harvested. Multiple sprouts from the same root were counted as one plant. Shoots from different roots were counted as separate plants. Due to the presence of suppressed seedlings, the total survival in 1989 was often higher than the number harvested, but few suppressed seedlings survived to 1990. Survival to 1991 was often higher than the number harvested that year because of rabbit damage on the smallest plants.

All trials were planted using a randomized complete block design. Analysis of variance, Duncan's multiple range tests, and other statistical operations were conducted on NCSS computer programs (Hintze 1987). The probability level reported for each factor below a table is the probability of the difference between treatments occurring by chance, according to F-test comparisons.

Row plots at eight harvest dates

Early in the 1989 season, 48 plots 1.00 m long by 2.00 m wide were selected within two parallel sown areas each 45 m long by 2.5 m wide. Utilizing a randomized complete block design, the 48 plots were divided into six replications, each containing eight plots within 15 m, which were
randomly assigned to the eight harvest dates. Sections with uneven plant distribution were avoided and plot borders adjusted so that each plot contained either 55 (\pm 4, with two plots under 50) or 70 (\pm 4, with two plots at 64) evenly distributed surviving plants. Three plots from the lowpopulation group and three from the high-population group were cut on each of the harvest dates. Plots were spaced 10 cm to 150 cm apart, and the plants between the plots were cut when the second adjacent plot was harvested. This caused many of the earliest harvested plots to be quickly overshadowed by taller neighbors, creating ideal conditions for rabbits to stay hidden and consume the new growth. Consequently, survival to 1990 was poor in the earliest plots and five had no survivors at all (four from June 29 and one from July 13).

In 1989 new growth from the 20 cm stumps was harvested at 25 cm the first time, and at 30 cm if harvested a second time. All harvests in 1990 and 1991 were made at 30 cm. In 1990 all plots had closed canopies before the first harvest and had very little leaf area remaining afterwards, while for the second harvest in early October, canopy coverage depended on the time since the first harvest and the vigor of the plants. In 1991 the plots were allowed to grow undisturbed until harvested in September.

Harvest dates in 1989 were usually at 14-day intervals: June 15, June 29, July 13, July 27, August 10, August 24, and September 7. The eighth and final harvest was delayed until September 28 to be nearer to the anticipated time of the first frost. Plots first cut in June were cut again in August, and plots cut before mid August were harvested in early October. Most plots were cut twice and some were cut three times, in an attempt to obtain higher yields. After the unexpectedly early first frost on September 24 some leaflets had already dropped, so total dry weight of the last harvest on September 28 would have been greater if it had been taken five days earlier.

The plots cut June 15 and June 29 were abandoned in 1990 because of poor survival, and the practice of harvesting some plots three times a year was discontinued. For each of the remaining plots, harvest dates in 1990 were one day earlier than in 1989 according to the calendar, but four days later when counted from the respective days of bud break in the spring. In 1990 the harvests were conducted on July 12, July 26, August 9, August 23, September 6, and September 27.

The 1991 bud break was 25 days earlier than in 1989, but growth was very slow until mid May. In 1991 the plots were harvested by replications between September 11 and 30, so that all harvest date treatments were treated alike.

The plots of the late September harvest were often adjacent to areas that were not cut in 1989. The uncut trees began growth at 1.5 to 2.5 m height, and grew laterally as well as upward in 1990. Four of the six plots harvested on September 27, 1990, were discovered to be shaded by these more vigorous neighbors when harvested (the degree of shading was not quantified), although they had not been shaded at the start of the 1990 growing season. The offending adjacent trees were cut back to 50 cm before the 1991 season, but they still shaded the late September plots on 20% to 70% of the plot area at harvest in 1991. Only the four plots shaded on 30% of their area or less were included in the 1991 average for comparison with previous years. For comparisons between treatments within the years 1990 and 1991, five replications were used.

Daily weight increments were calculated from both the number of days since growth began in spring (April 30, 1989, April 25, 1990, and April 5, 1991), and the number of days since the first harvest was taken, subtracting the yield and number of days of the earliest harvest from later measurements on other plots.

Because growth was very slow early in the season and more rapid at harvest time, daily productivity rates (g dry weight/m²/day) were also calculated from the "theoretical zero date". This date was found by regressing the yields at all first harvests on the number of days since bud break to locate the date where the regression line crossed the X-axis.

Plots harvested before September had produced new foliage on regrowth shoots, and these were harvested at the end of the season in early October in order to maximize annual yields. To obtain daily productivity rates up to this last harvest in 1989, the dry weights were divided by the

number of days between the previous harvest and the first frost on September 24, which halted growth. In 1990 days were counted from the previous harvest to the final harvest on October 4, which was before the first frost. Rabbit herbivory reduced the number of plots available for measuring, so statistical operations were .

Percentage canopy coverage was estimated visually, at 10% intervals, on September 28, 1989, May 30, 1990, October 3, 1990 and May 31, 1991. Although no measurements were made of the leaf area index (LAI), the percentage canopy coverage can be assumed to be much lower than the LAI, because the overlapping of leaves was not taken into account as it is when calculating the LAI. Average canopy height was measured May 31, 1991.

Dry weight/fresh weight comparisons

Fresh and dry weights were recorded from black locust plots harvested at 30 cm on July 9, 14, and 27, 1987. The seeds had been sown into fumigated soil in July, 1986, on the same site used for the later trials. The plots were 1.0 m², with an average of 86 surviving and 71 harvested seedlings in 1987, replicated five times in a randomized complete block design.

Fresh and dry weights were recorded from all row plots harvested in 1989, 1990, and 1991. Additional data, for purposes of illustrating seasonal trends, were obtained from a set of 107 seedlings within and between the row plots, selected before the 1989 growing season. All seedlings harvested on a particular date were used to calculate dry/fresh weight ratios. Five to 17 individuals were cut and weighed on each of the harvest dates in 1989, and three to 16 on each date in 1990. Harvest dates in 1989 were June 29, July 5, July 13, July 28, August 10, August 17, August 24, September 7, September 28, and October 5. Harvest dates in 1990 were June 22, July 19, July 26, August 10, August 24, September 7, September 27, and October 5. The first harvest in 1989 on each plot or individual was made at 25 cm, and all later harvests were made at 30 cm.

In 1991, fresh and dry weights were recorded for samples of new growth on 18 dates from June 14 to October 23. Harvests on five dates (September 11, 17, 23, 27, and 30) were made at 30 cm on sets of six plots in a single replication of the row plots. Harvests on the other 13 dates were made on three to eight scattered individual seedlings, and took all new growth regardless of the previous harvest height. All samples had fresh weights of over 1000 g, except for those taken July 19 (237 g) and October 17 (816 g).

RESULTS

<u>Height growth</u>

Growth in 1988 was slow until mid August when adequate rain and seasonable temperatures returned, then rapid until early September. Seedling heights in all replications averaged 5 - 10 cm in mid July, 20 - 30 cm in mid August, and 80 - 90 cm in mid September. Growing conditions were ideal in 1989, 1990, and 1991, with rainfall well distributed. Undisturbed coppice sprouts reached 250-300 cm each year.

After harvesting new growth from replicated plots on the same dates for two years, the average canopy height of new growth the following spring was lower with August harvests and significantly higher using latest harvest date (Table 2.1).

Dry weight yields

In 1989, dry weight yields at first harvests increased at a steady rate of 150-200 g each 14 days, with a slight slowing in the 21 days before the September 28 harvest (Table 2.2). In 1990 the average yields were much lower until September, when they reached about 90% of the 1989 levels. This was mainly due to poor survival, but weight per plant showed an additional loss of vigor in the survivors harvested before September. Averages for the two dates in September 1990 show the proportion of survivors from 1989 to 1990 was much lower than the ratio of dry weights, meaning that the average plant had more space in 1990 and had the vigor to grow and occupy it. Although the September 28 harvest date plots always had higher yields per plot and per plant than the September 7 plots, the differences were never statistically significant.

Harvest date	Height (cm)
July 13	66b
July 27	56bc
Aug. 10	44cd
Aug. 24	34d
Sep. 7	66b
Sep. 28	92a

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Table 2.1. Effect of harvest date 1989 - 1990 o	on May 31, 1991 canopy height.

Harvest	D	ry weight (g/m	²)	1	.990/1989 Rati	ios
date	1989 ¹	1989 ²	1990 ²	Yield	Survival	Wt./plant
June 14	203f					
June 28	341f					
July 13	554e	554d	243b	.44b	.48b	.87Ь
July 27	741d	722d	361b	.50Ъ	.63 ab	.83b
Aug. 10	905c	938c	326b	.35b	.51b	.71b
Aug. 24	1116b	1110bc	439b	.40b	.59ab	.69b
Sep. 7	1277a	1206ab	1095a	.91 a	.71a	1.33a
Sep. 28	1433a	1363a	1225a	.90a	.70a	1.28a

Table 2.2. Dry weight yields (g/m^2) for those plots harvested the same date in 1989 and 1990, and comparisons of yields, numbers of survivors, and weights per plant expressed as ratios.

¹ Means of all seven replications harvested in 1989.

² Means of all five replications harvested in 1990.

Including additional harvests did not change the pattern of higher yields with later first harvests (Table 2.3). Total dry weight accumulation was about 150 - 200 g each 14 days, with slower rates early and late in the season.

Dry weight productivity per day

When measured from the date of bud break, daily dry weight productivity in 1989 showed a plateau in June and a higher plateau from late July onward, although the means always increased from June to September (Table 2.4). Daily productivity data from those plots harvested on the same dates both years show the plateau starting in mid July 1989. In 1990, July and August plots gave a plateau of very low productivity. A second, higher plateau in the 1990 rates was observed in September, which was equivalent to the 1989 rates.

The correlation of 1989 dry weight from the eight first harvest dates with days from bud break to harvest was very high (r = .9492), and the Y-intercept was negative (-721). The slope of the regression line was 24.5 g/day. At this rate, average dry weight would have reached zero on May 29, the "theoretical zero date". The correlation of 1990 dry weight from the first harvest with days from bud break to harvest was not as high (r = .8501), and the Y-intercept was much more negative (-2002). The slope of the regression line was 27.9 g/day. At this rate, average dry weight would have reached zero on July 7.

With the first 29 days of the 1989 growing season removed, counting dry weight from May 29 instead of May 1, the results were much different (Table 2.5). The daily increments were not significantly different for any harvest dates. Growth was very linear, departing little from a rate of 12 g/m²/day. Growth in 1990 showed wide fluctuations which were not statistically significant, except for the overly high rate on July 14, which was only five days after the theoretical zero date.

Results from 1989 showed a pattern similar to the results of a harvest date trial in 1987. First harvests were made on July 9, 14, and 27, 1987. With bud break presumed to have been at May 1, first harvests were conducted 70, 75, and 88 days later. Regressions of the dry weight on

	Dry weight (g/m ²)				
First harvest date	August	October	All 1989		
June 15	121a	125a	432f		
June 29	38b	49b ¹	400f ²		
July 13		71ab	625e		
July 27		99ab	840d		
Aug. 10		62b	967cd		
Aug. 24			1116bc		
Sep. 7			1277ab		
Sep. 28			1433a		

Table 2.3. Effect of first harvest date in 1989 on yields (g/m^2) at later harvests in 1989, and cumulative yields.

¹ The average total for the June 29 plots was 49, but three of seven plots had lower yields because they did not survive to the end of the season. The average for the four surviving plots was 86.

² The average total for the June 29 plots was 400, but three of seven plots had lower yields because they did not survive to the end of the season. The average for the four surviviving plots was 894.

	Days from	Rate (g/	/m ² /day)
Harvest date	bud break ²	1989	1990
June 15	46	4.4c	
June 29	60	5.7c	
July 13	74	7.5b	3.1b
July 27	88	8.1ab	3.9b
Aug. 10	102	9.1ab	3.0b
Aug. 24	116	9.6 a	3.6b
Sep. 7	130	9.3ab	8.1a
Sep. 28	151	9.0ab	7.9a

Table 2.4. Daily dry weight productivity rates $(g/m^2/day)$ in 1989 and 1990 in relation to the number of days from bud break, for plots harvested on the same date both years.¹

¹ Means were averaged from five replications only.

² Elapsed days for 1989; add five days for 1990.

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Table 2.5. Daily dry weight productivity rates $(g/m^2/day)$ in 1989 and 1990 in relation to days from the theoretical zero date on May 29, 1989 or July 7, 1990.

	19	89	19	90
	Days from	Rate	Days from	Rate
Harvest date ¹	zero date	(g/m²/day)	zero date	(g/m²/day)
June 15	17	12a		
June 29	31	lla		
July 13	45	12a	5	49a
July 27	59	12a	19	18b
Aug. 10	73	12a	33	10b
Aug. 24	87	13a	47	9b
Sep. 7	101	13a	61	18b
Sep. 28	122	12a	82	15b

¹ Harvest dates in 1990 were one day earlier than in 1989.

the number of days gave the equation y = -409+12.4x, with r = .61. This gave a theoretical starting date 33 days past May 1, on June 3. There were significant differences between harvest dates for yield, but not for yield per day. Daily increments in 1987 ranged from 5.4 - 7.0 g/m² starting May 1, and from 10.2 - 12.6 g/m² starting June 3, which were close to those measured in 1989 (Table 2.5).

When the first harvest date was used as the baseline, the 1989 numbers fell within a narrow range, with no significant differences (Table 2.6). This method highlighted the extreme fluctuations in 1990, with the August dates depressed significantly below September dates, and below the same dates in 1989.

In 1989, dry weights of the last harvests taken in October generally increased with time since the first harvest, and daily productivity varied little (Table 2.7). In 1990, both parameters increased with time since the first harvest. Daily productivity of regrowth was very low compared to productivity before the plots were cut (Tables 2.4, 2.5, and 2.6).

Dry weight productivity per plant and per plant per day

While the average number of surviving plants was quite even for the first harvests of 1989, with 48 - 53 per plot, this was not the case in 1990, after severe winter mortality had produced a range of 22 - 36 per plot (11 - $18/m^2$). In order to fairly compare 1990 productivity rates with each other and 1989 rates, the numbers of survivors must be taken into account.

The daily productivity rates per plant did not vary significantly by harvest date in 1989, averaging 0.35 g. In 1990, plots harvested in July and August averaged 0.26 g, while those harvested in September averaged significantly higher at 0.45 g. In 1991, when all plots were harvested in September, daily rates averaged 0.53 g per plant, with no significant variation. Due to the extreme loss of vigor in 1990 for plots at earlier dates, only the September harvest dates are comparable between years. For September plots, daily productivity per plant rose 15 - 27% each vear from 1989 to 1991.

	19	89	19	90
Harvest date ¹	Days from first cut	Rate (g/m ² /day)	Days from first cut	Rate (g/m²/day)
June 29	14	9.9a		
July 13	28	12.5 a		
July 27	42	12.5 a	14	8.4bc
Aug. 10	56	12.5 a	28	3.0d
Aug. 24	70	13.0 a	42	4.7cd
Sep. 7	84	12.8a	56	15.2a
Sep. 28	105	11. 7a	77	12.8ab

Table 2.6. Daily dry weight productivity rates $(g/m^2/day)$ after the first harvest on June 15, 1989, and July 12, 1990.

¹ Harvest dates in 1990 were one day earlier than in 1989.

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Table 2.7. Effect of first harvest date on dry weight yields (g/m ²) and daily dry weight productivity
rates (g/m ² /day) for second harvests in 1989 and 1990.

		1989		1990	
Harvest date ¹	Days of growth ²	Yield (g/m ²)	Rate (g/m²/day)	Yield (g/m ²)	Rate (g/m ² /day)
June 28	86	116	1.3		
July 13	72	72	1.0	101	1.4
July 27	58	107	1.8	66	1.0
Aug. 3	51	66	1.3		
Aug. 10	44	60	1.4	12	0.2
Aug. 17	37	53	1.4		

¹ First harvest dates in 1990 were one day earlier than in 1989.

² Elapsed days since first harvest in 1989; add 10 days for 1990.

Because of variable numbers of plots, statistical analysis was not possible. Dates with only one surviving plot were not included.

Changes in dry weight percentage

The dry weight/fresh weight percentage (D/F) represents the dry matter proportion of the green biomass. D/F is low early in the season when all new growth is succulent, but increases as tissues become lignified.

The D/F rose in a step-wise manner (Table 2.8). In the 1989 season there were two major increases, after 60 days and again after 130 days. However, the D/F was well correlated with days from bud break (r = .9564) with an average rate of increase of 1% dry matter each five days. In the 1990 season there was one much more extreme increase after 121 days. The final D/F in 1989 and 1990 was about the same, but the longer growing season in 1991 gave a higher final D/F. Data from individual trees showed a similar pattern of rapid increases and plateaus (Table 2.9). While green leaves remained, D/F stayed below 50%, but increased to about 60% after leaves abscised.

When matched against days from bud break rather than calendar dates, the differences between years were reduced (Figure 2.1). Each year it took about 70 - 90 days to reach a dry weight proportion of 30%, 130 - 140 days for 40%, and 160 - 170 days for 50%.

When separated, the leafy upper stems had the same D/F as the leafless lower stems until late in the season, when the D/F of the more woody lower stems increased at a faster rate (Table 2.10). In 1989 the tops and lower stems had the same D/F on August 24, but after that the percentages varied. The rapid increase in the proportion of leafless stem was due to the shedding of shaded lower leaves. In 1990, leafy and lower stems were not separated at the September 6 harvest, but such data were taken at the last harvest on September 27 and from a separate sample on September 25. The D/F percentages resembled those in late September, 1989, and at September 11, 1991. In 1991 five replications were harvested on different dates, so the variation also includes the effects of location within the plantation. A smaller sample harvested October 17, with many rachi but few leaflets remaining, had the same D/F throughout. In 1991 the D/F of

	Days from	_	Percent d	ry weight	
Harvest date	bud break ¹	1987	1989	1990	1991 ²
June 15	46		21e		28
June 29	60		22e		29
July 9	70	27c			29
July 13	74	30b	29d	26c	30 ³
July 27	88	36a	31c	28Ь	33 ³
Aug. 10	102		35b	28Ь	38 ³
Aug. 24	116		35b	29b	41
Sep. 7	130		36b	43a	46
Sep. 28	151		45a	44a	49

Table 2.8. Dry weight/fresh weight percentages for entire plots in 1987, 1989 and 1990, and for small samples in 1991, according to date and days from bud break.

¹ Elapsed days for 1987 and 1989; add 5 days for 1990 and 25 days for 1991.

² Statistical analysis was impossible in 1991 due to a lack of replication.

³ Data were interpolated because the actual harvest date was not within one day of the date indicated.

	Days from	Percent d	lry weight
Date	bud break ¹	1989	1990
June 29	60	23	
July 5	66	29	
July 13	74	28	
July 19	80		24
July 27	88	32	30
Aug. 10	102	36	
Aug. 17	109	35	
Aug. 24	116	34	36
Sep. 7	130	36	40
Sep. 25	148		41
Sep. 28	151	44	39
Oct. 6	158	47	47

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Table 2.9. Dry weight / fresh weight percentages for sets of individual plants in 1989 and 1990, compared to days from bud break.

¹ Elapsed days for 1989; add 5 days for 1990.

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² Dormant with no foliage remaining.

Nov. 11



Figure 2.1. Dry weight percentage of fresh weight for samples harvested in four seasons, related to days from bud break.

Table 2.10. Dry weight / fresh weight percentages of leafy and woody portions of material harvested in September, and the percentage of the total sample represented by the dry weight of the woody portion.

	Percent dry weight			Woody
Harvest date	Total	Leafy	Woody	proportion
Sept. 7, 1989	36	35	40	06
Sept. 28, 1989 ¹	44	42	51	35
Sept. 25, 1990	41	38	51	31
Sept. 27, 1990	44	40	53	36
Sept. 11, 1991	44	41	54	31
Sept. 17, 1991	50	47	58	32
Sept. 23, 1991	51	46	59	46
Sept. 27, 1991	49	44	58	41
Sept. 30, 1991 ¹	57	53	60	51
Oct. 17, 1991 ¹	60	60	60	84

¹ Harvested after the first frost.

woody lower stems increased faster before frost, and the D/F of leafy upper stems increased faster after frost, until the ratios equalized again by mid October.

Survival after harvesting

Average plant numbers per m² declined from 30 at the time the plots were selected, to seven at the last harvest in September, 1991 (Table 2.11). Mortality in summer, between the first harvests on various dates and the last harvest in early October, was higher than over the winters. During the 1989 growing season mortality varied little by harvest date, but survival to 1990 was highest with September harvests, and survival to 1991 was significantly poorer for plots harvested in August.

<u>Canopy coverage</u>

Canopy coverage was assessed by visual inspection from a position directly above the plot, and quantified at 10% intervals. Canopy coverage at the end of the season was usually incomplete due to mortality after harvesting, or lack of time for regrowth to restore the canopy (Table 2.12). In September, 1989, the plots harvested earlier generally had more coverage, with a steep decline for harvest dates after mid August. Canopy coverage on May 30, 1990 reflected the number and the vigor of the survivors, which were highest with September harvests. Canopy coverage on October 3, 1990 varied directly with regrowth season length. Canopy coverage on May 31, 1991 varied significantly, with the highest values for harvests in September and the lowest for harvests in August.

Canopy coverage on May 30, 1990 was poorly correlated to survival over the previous winter (r = .3222). However, when only plots with over 33% coverage were considered, there was a better correlation (r = .8581). In 1991 the correlation of spring canopy percentage with survival was higher than in 1990 (r = .6201). When only the August and September plots were considered, the 1991 correlation improved (r = .8965). For both years, more complete spring coverage was closely related to better survival, while plots with poor coverage had quite variable survival.

Harvest	Original	1989		1990		1991
date	density	lst	2nd	lst	2nd	Sept.
July 13	29	24(83ab)	17(60a)	11(40b)	9(30 ¹)	8(27a)
July 27	31	24(77b)	19(62a)	15(48ab)	9(28 ¹)	8(25a)
Aug. 10	31	27(87a)	21(69a)	13(44ab)	5(18 ¹)	4(15b)
Aug. 24	32	26(80ab)		15(47ab)		2 (6b)
Sep. 7	32	26(83ab)		18(58a)		9(28a)
Sep. 28	32	25(78ab)		17(55a)		11(35a)
Mean	30 ²	25 ²	19	16	8	7

Table 2.11. Numbers of plants harvested per m^2 and percentage of original plants surviving for those plots harvested the same date 1989-1990, for first and second harvests.

¹ Statistical analysis was impossible because of differing numbers of plots per harvest date.

² Means include two additional harvest dates in June.

Means within the same column followed by the same letter are not significantly different at the P=0.05 level according to Duncan's Multiple Range Test.

First harvests were taken on the date indicated, while second harvests were taken in early October from plots with adequate regrowth. In 1991, all harvests were taken in September.

Table 2.12. Effect of harvest date on average canopy coverage percentages from visual estimates on September 28, 1989, May 30 and October 3, 1990, and May 31, 1991, related to number of days from first harvest to first frost in 1989 or to recording in 1990.

Harvest date	Days of regrowth ¹	1989 % Sep.	1990 % May	1990 % Oct.	1991 % May
July 13	72	66	18	66	78b
July 27	58	85	30	48	60c
Aug. 3	51	75	30		
Aug. 10	44	75	23	33	36d
Aug. 17	37	70	20		
Aug. 24	30	40	13	0	20d
Sept. 7	16	0	43	0	88ab
Sept. 28	-5 ²	0	63	0	100a

¹ Elapsed days for 1989; add 10 days for 1990.

² The last harvest date was five days after the first frost in 1989, and five days before the canopy coverage recording date in 1990.

Statistical analysis was impossible because of variable numbers of plots per harvest date in 1989 and 1990.

First harvest yield varied directly with May canopy coverage the same year, and was well correlated in 1990 (r = .8544) and 1991 (r = .7499). Canopy coverage in May, 1990 had some predictive value for 1990 yields within each of the harvest dates. July and August plots tended to have above average 1990 yields if coverage in May was above 15%, and yielded much above average if coverage was above 25%. Average May canopy coverage for each of the four July and August harvest dates ranged from 14 to 20%. September plots had greater average coverage in May, 1990, with all above 25%. Those with coverage above 65% or below 35% yielded above or below average, respectively, in 1990.

DISCUSSION

Growth, yield, and survival

Height growth ended in late August or early September, 120 - 130 days from bud break, followed by abscission of apical buds. Although no new apical growth was being produced, and shaded lower leaves were abscising, above-ground dry weight continued to increase. Isarasenee <u>et</u> <u>al</u>. (1983) observed that the increasing leaf weight on leucaena plants during autumn in subtropical Queensland was due to the increasing weight of existing leaves, not increasing numbers of leaves. In this study, where leaves and stems were not weighed separately, it is possible that either or both the leaves and stems gained dry weight.

Although no distinct yield plateau appeared in September as had been hypothesized, yields at the last two dates were never significantly different. These dates were three weeks apart, but yields were significantly different for five of six earlier pairs of dates in 1989 that were only two weeks apart.

Complications involving harvesting after frost in 1989, and shading from adjacent taller plots every year, must have reduced the harvested weights of the late September plots, but the amount is impossible to calculate. Without those reductions in potential yield, it is likely that yields would have increased significantly from early to late September, but the results remain inconclusive.

While June plots would have vielded more and survived better if not shaded by adjacent uncut trees, the strategy of harvesting black locust three times a season appears too deleterious (and tedious) to justify further investigation. Harvesting twice a season, in late June or early July and again in late August, was also unfavorable, yielding (in adjacent trials) at most about half the biomass of the plots harvested on September 28 (Barrett 1992). Cutting coppice sprouts back to the stump once or twice during the growing season significantly reduced total biomass yields, but not leaf yields, in three tree species in Brazil. The yield differences between one and two harvests were not significant (Hardesty and Box 1988). It is not likely that the untested method of harvesting in early July and again in late September would yield as much as a single harvest in late September. Almost any harvest during the growing season will remove enough leaves to reduce photosynthesis, and a severe defoliation can result in carbohydrates being consumed faster than they are produced, as will be explained below. Therefore, to maximize yields and minimize the labor required per unit of biomass produced, a single late harvest is recommended. But if the harvest is too late, problems with freezing are encountered. Mebrahtu (1992) found that photosynthesis rates in mature black locust leaves declined to almost zero the day after a freeze. but then recovered over the next week to about 75% of the normal rate, and that photosynthesis can continue to the end of October. Although undamaged leaves continue functioning, exposed leaves abscise when damaged by frost, so that the harvestable yield can be greatly reduced from one day to the next. Therefore, the optimal time to harvest is just before the first killing frost.

Survival varied with harvest date, as had been hypothesized, being significantly reduced by August harvests. Survival to 1991 was poor for all treatments, but improved greatly once densities fell below 10/m², which could be due to individual plants growing larger and stronger. Whether high mortality continues or not, it is clear that populations above 10/m² cannot be maintained with

annual harvesting. In black locust forage stands, it appears that harvesting more than once a year is too frequent for optimal survival.

The hypothesis that significant differences in daily productivity rates would be found was confirmed, but not for the reasons expected. Although changes in daily dry weight productivity in 1989 could be related to weather, a full comparison between years was impossible. Productivity rates during 1989 varied significantly when calculated from the date of bud break, and were inversely related to day length. However, when rates were calculated from the theoretical zero date or from the baseline established at the first harvest, they did not vary significantly from June to September as day length decreased.

Significant variation in daily dry weight increments was predicted between years, and it occurred, not from variable weather, but because most 1989 treatments greatly reduced 1990 survival and vigor. Comparisons between years were not valid except for harvests made in September, where results were consistent. Mebrahtu (1992) recorded the photosynthesis rate on 60 black locust seedlings at the M.S.U. Tree Research Center in a nursery bed adjacent to this trial, and found the average photosynthesis rate in 1990 to be higher than in 1989 during July, but lower in August and September. From mid July to mid September, 1989, the average rate rose about 40%. Three factors could reconcile Mebrahtu's observations with the results of this study. Mebrahtu's measurements were taken on plants from different seed sources, which were transplanted much farther apart, frequently irrigated, and shaded longer each morning by a windbreak to the east than were the plots in this study. The photosynthesis rate was measured on a leaf area basis, and it is possible that leaf area in the more crowded plots declined between July and September due to abscission of more shaded lower leaves than were replaced by new growth. It is also possible that net carbon assimilation did increase in the plots of this study, but was diverted to below-ground parts which were not harvested, as was found in <u>Populus</u> by Hinckley <u>et al.</u> (1989).

Leucaena yields per day were highly correlated with temperature in Australia and Hawaii (Brewbaker 1987), while the yield of <u>Paraserianthes falcataria</u> in Western Samoa varied directly

with rainfall (Rogers and Rosecrance 1992). In this study, black locust yields per day in 1989 were highly correlated with mean temperature (r = 0.75), but better correlated with pan evaporation (r = 0.85). On average, each additional 1 mm/day of pan evaporation was associated with about 2 g/m²/day additional dry weight. This finding may indicate that the effect of higher temperatures is not simply to allow more rapid carbon accumulation, but to promote more rapid transpiration which was associated with more rapid growth. It should be noted that the black locust plants were well established and did not appear to suffer from a shortage of moisture at any time after 1988. A possible mechanism for increased transpiration to accelerate growth is through the transport of cytokinins from the roots to the leaves (McNaughton 1983); mineral nutrition may also contribute. The high correlations with temperature and pan evaporation support the hypothesis that the daily growth rate varies directly with solar radiation. Linear relationships between dry matter production and absorbed solar radiation have been shown for <u>Eucalyptus globulus</u> Labill. (Linder 1985) and many agricultural crops (Monteith 1977). Unfortunately, in this study the available solar radiation data were unreliable due to inadequate equipment maintenance.

The hypothesis that daily productivity rates per plant increase each year was confirmed, although yields and productivity per area declined. With continued mortality of some of the surrounding plants each winter, it is likely that growth rates of survivors would continue to increase.

The hypothesis that the dry weight percentage (D/F) increases in direct proportion to time from bud break was supported by the multi-year average, but not in any particular year. In a climate with a longer growing season, the D/F would probably rise even higher before frost than the 51% recorded in 1991. After frost, the D/F rises due to the loss of frozen leaflets and the drying of those that are damaged. Kinch and Ripperton (1962) found the D/F of leucaena forage varied between 20.4% and 31.4%, with no clear pattern, as harvest interval varied between 63 and 117 days. Jeyaraman <u>et al.</u> (1989) obtained dry weight percentages of 22.6%, 26.1%, and 28.9% with harvest intervals of 40, 50, and 60 days, respectively, for irrigated leucaena. Black locust harvested 60 days after bud break in 1989 had only 23% dry weight. The greater water content would be expected from slower growth in spring for a plant in a temperate climate.

When harvested 16 times over five years, the dry weight of leucaena forage varied between 50% and 52% of fresh weight when averaged by year. The range was 55 - 58% for <u>Albizzia</u> <u>lebbeck</u> (L.) Benth. and 56 - 61% for <u>Delonix regia</u>, which were cut 17 times. There was no clear trend over the five years (Oakes and Skov 1962). Similarly, there was no clear trend over three years from 1989 to 1991 in the black locust data from this study. It appears unlikely that the D/F of the forage would vary with the age of the stumps.

Stem lignification proceeded through the entire season, but no difference in the dry weight percentages of leafy upper and woody lower stem portions appeared until after height growth had ceased. This finding could simply be due to the re-allocation of photosynthate to cambial growth and/or storage in the stems after new growth ceased. However, as the D/F increased more rapidly in leafless lower stems during September, the succulent stem tips became harder and less flexible, and presumably less watery as well. To account for the observed low rates of D/F increase in the leafy tops between the cessation of height growth and the first frost, the leaves must have maintained a high water content while the attached stems became less succulent.

In the annual cycle of most deciduous woody plants, proteins and nucleic acids are broken down into amino acids as the leaves senesce in autumn, translocated to the stem, re-assembled into storage proteins in the bark, and re-mobilized as a nitrogen source for rapid leaf growth the next spring (Bray 1983; Feller 1990). During autumn, the solute content in the phloem changes from primarily carbohydrates to primarily amino acids, which are mainly asparagine and glutamine (Bray 1983). The possibility that black locust does not follow this pattern is suggested by the fact that the leaves remain green in autumn, and abscise green when killed by freezing. If chloroplasts are maintained, then the leaves do not senesce as in other species. Mebrahtu (1992) recorded photosynthetic rates about 25% lower after frost than before, but noted that the difference may have been due more to low temperatures than to leaf damage. Photosynthesis was observed to continue through the month of October. A speculative explanation for this behavior would lie in the ability of black locust to fix nitrogen, which is obtained from the rhizobial nodules in exchange for carbohydrates. If obtaining new nitrogen from well-fed nodules is more efficient than recycling it from senescent leaves, then continuing photosynthesis as far into autumn as possible would be a valuable adaptation. An alternate explanation is that Michigan is so far north of the native range of black locust that the leaves are killed by freezing before the shorter days of autumn can induce a signal to senesce. This hypothesis is countered by the observation that black locust grown in a heated greenhouse without supplemental lighting will stay green all winter.

Defoliation and refoliation

Results confirmed the hypothesis that autumn and spring canopy coverage vary significantly with harvest date. Variation in autumn was related to the time available for regrowth, and in spring to the numbers of survivors. However, more variation in spring canopy coverage was observed than could be explained by the survival rate; survivors from some harvest dates were more vigorous than from others. A decline in vigor due to refoliation and regrowth after leaf removal has been demonstrated in other temperate zone species. Measurable factors related to low vigor include low levels of stored carbohydrates, increased winter dieback of new growth, reduced leaf areas, reduced growth rates, and increased death rates.

Refoliation in late summer is hazardous, for often the time remaining before frost is too brief to regain the carbohydrate reserves consumed to produce the new growth, much less the reserves needed to survive the winter and grow rapidly the next spring. Wargo (1981b) found higher mortality rates after defoliation in three tree species were associated with lower root starch contents. In xylem tissues of sugar maple, the autumn starch content, as a percentage of the control, in shoots and roots, respectively, was 98% and 97% after complete defoliation on June 6, 81% and 59% after defoliation July 15, and following defoliation July 29 only 27% and 1%. The concentration in the shoots was 38% of that in the roots of the undefoliated control group (Gregory

and Wargo 1986). Complete defoliation reduced starch reserves in roots of sugar maple saplings severely if done in mid June or mid July, but had little effect if done in late August (Parker 1981).

In deciduous trees in late summer and early autumn, older shoots that have ceased growth suffer no drain of resources to produce new foliage, so carbohydrate reserves might be accumulated at a more rapid rate than in actively growing plants. No matter whether the composition of phloem sap in autumn is dominated by remobilized nutrients from the senescent leaves, or by carbohydrates from continued photosynthesis, it is clear that the death of tender new growth at the first frost would terminate either process.

A major factor in variable survival in these trials was the indeterminate character of refoliating shoots. While black locust is considered to have indeterminate growth, compared to other tree species, all shoots that began growth before July generally ceased new growth in late August or early September. However, refoliating shoots that began growth after June stayed succulent right up to frost, which wilted them immediately. The same process is observed with black locust seedlings that germinate too late in the summer, indicating that a stem may require a certain number of days of growth (over 50) before its apical meristem will go dormant.

Normally, growth of black locust is affected by day length. Kramer (1936) reported that seedlings growing outdoors in North Carolina exposed to long days (duration not specified) continued growing rapidly until killed by freezing temperatures in November, while those with the normal day length ceased growth in September and were not injured. Wareing and Roberts (1956) found that the duration of cambial activity in seedlings, after height growth has ceased, depends upon day length. Their results indicated that photoperiod is sensed by mature leaves and not by the stem or buds. It is possible that younger leaves on refoliated stems lack the ability to distinguish short days, which would explain why they grow until frozen.

Gregory and Wargo (1986) found that the timing of defoliations of sugar maple (<u>Acer</u> <u>saccharum</u> Marsh.) between May 27 and August 5 affected the survival of buds over the next winter. With earlier defoliation, terminal shoots refoliated and their buds survived the winter, but

with progressively later defoliations, more buds on refoliated shoots died, and the next years growth depended more on axillary buds formed before defoliation. In sugar maple, however, defoliations after early August did not stimulate regrowth the same year, which reduced winter dieback of terminal shoots. This dieback was probably related to low food reserves and the inability of new buds to properly harden in the shorter growing season before winter (Wargo 1981a, b). In black locust, survival of buds appears less important than the extent of winter dieback of stems or their consumption by herbivores, but these processes were promoted by late harvests.

The effects of low carbohydrate reserves and/or a shortage of live buds are often expressed the next spring in a reduction of leaf area. In 12 to 15 year old (4 - 6 m tall) specimens of sugar maple, white oak (Quercus alba L.), and black oak (Quercus velutina Lamarck), refoliation was induced by 100% defoliation in May, June, and July. Leaf area measured the following June was most severely reduced by June and July defoliations in the oak species, and by June defoliations in sugar maple. Refoliation did not usually follow defoliation in mid-August, and if so, the few leaves produced were small (Wargo 1981a).

The average size of individual primary leaves in years following severe defoliations was reduced in red oak (Quercus rubra L.) and red maple (Acer rubrum L.). When defoliations were repeated for three successive years, the total leaf area per tree was reduced only after the second year with 50% and 75% defoliations, and after the third year with 100% defoliation (Heichel and Turner 1976). In this study, canopy coverage at the end of the season in plots of the later harvest dates was much lower in 1990 than in 1989, showing the effect of a second year of 100% defoliation in late summer. It appears likely that fewer and/or smaller leaves were produced by black locust stumps with lower vigor, although leaf numbers and areas were not measured.

Since spring canopy coverage is a measure of both survival and vigor, it is also an indicator of yields later in the same season. The correlation was best for 1990 yields because the September plots, which had significantly higher spring coverage, also had a longer period of

growth before harvest. If canopy coverage is measured at the optimal time, about 30 - 40 days after bud break, it could be an excellent indicator of biomass yields later in the season. It is possible that the proportion of canopy remaining after an early summer harvest could predict the yield at the second harvest two or three months later, but no data were taken to test this hypothesis.

Estimating canopy coverage visually, or measuring solar interception with a light meter, would be much easier than measuring the leaf area index of a plot directly and destructively, as had been originally planned but never done for lack of time. As shown by previous work with annual crops (Monteith 1977) and <u>Eucalyptus</u> trees (Linder 1985, Linder <u>et al</u>. 1985), the correlation of solar interception and yield should be a fruitful area for future research, as it would give a common reference point for the effects of harvest time, height, and plant spacing, and all their complex and confusing interactions.

The growth rate, and thus the harvestable yield, declines with any defoliation, but its timing strongly affects future conditions. Wargo (1981a,b) summarized results from artificial defoliation studies on deciduous trees, and concluded that defoliation is most injurious when the new leaves are just fully expanded and the tree is growing rapidly. At this time the demand for energy is greatest and food reserves are lowest, prior to being restored by photosynthate from the new leaves. The effect of the timing of defoliation depends on the species, its phenology, and the length of the growing season remaining, which influence whether the stems refoliate.

Defoliation followed by refoliation in deciduous trees reduces growth through several mechanisms. Productive leaves are absent for a time, and food reserves (primarily starch) are metabolized to maintain living tissues. About three to four weeks after defoliation the new leaves begin growth, but the total area of replacement leaves is significantly smaller. The refoliated tree is out of phase with the seasons: weather is usually hotter and drier, day length is declining, and fewer days remain before frost. Because buds intended for the next spring have opened, new buds must be formed before autumn. Newly formed tissues may be physically and chemically immature, and thus more likely to die during the winter. Food reserves may be too low to maintain

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0 74, living tissues during dormancy. The following spring, fewer and smaller leaves are produced, food reserves are lower, and mineral imbalances may also arise. The tree becomes more vulnerable to pests and diseases that it would normally resist. These factors combine to reduce the vigor of refoliated trees, and can be compounded by repeated defoliations in succeeding years (Wargo 1981a,b).

By Wargo's description, defoliation of black locust should be more harmful in June, when leaves are young, rather than in mid summer. Rapid growth was recorded during three to four months in this study, yet the results varied widely during this period. According to Parker (1981), after defoliation, the recovery or death of an individual tree depends on several crucial factors: health and vigor, how much foliage is removed, timing during the growing season, abundance of pathogens and insects, and the number of successive years of defoliation. In this study, the timing of the harvest determined the percentage of leaf area removed, which directly affected the health and vigor of the tree. Refoliation in mid summer further reduced vigor, for even had the regrowth not been harvested in October, rabbits and winter dieback would have claimed the immature stems. When repeated a second year, defoliation resulted in higher winter mortality. Variation between harvest dates can be explained by two major factors: whether defoliation was total (in June it was not), and whether refoliation occurred (in September it did not).

Black locust plants cut in June suffered only partial defoliation (25 - 75%), so had much less interruption of growth than plots cut later. Recovery was not delayed by removal of all active apices, as might be expected, because the lower branches were not damaged. A few vertical stems escaped harvest, and most horizontal branches assumed a vertical orientation to become new leaders. In addition to this process, several modifications of plant metabolism and of the external environment that can contribute to rapid recovery from partial defoliation were examined by McNaughton (1983). These included more rapid photosynthesis in remaining leaves, mobilization of stored carbohydrates and redirection of current photosynthate to produce new growth, and the greater availability of cytokinin hormones, nutrients, water, and sunlight per unit of remaining leaf area. Heichel and Turner (1983) documented increased CO₂ assimilation rates in residual primary (30 - 60% higher) and regrowth (50% higher) foliage of defoliated red oak and red maple. Partially defoliated plants of the legume <u>Vigna mungo</u> (L.) Hepper compensated for foliage losses by growing new leaves and increasing the areas and photosynthetic rates of remaining leaves (Pandey and Singh 1981). Increased photosynthetic rates and leaf areas have also been reported in remaining foliage of common bean (<u>Phaseolus vulgaris</u> L.) (Alderfer and Eagles 1976). It is possible that black locust displays similar improvements in photosynthetic efficiency after partial defoliation, in addition to the observed production of new leaves. Although the low growth rates of refoliated shoots argue against such compensation mechanisms having a major effect on yields, they may have been important for winter survival.

Another factor in the observed reduction of vigor following mid summer harvests, which was not addressed by previous researchers, could be the effect of temperature on carbohydrate consumption. Plots cut in June retained some foliage, but plots cut later in the summer lost all their leaves. Unshaded stumps and roots became much hotter, enhancing respiration in the remaining stems, roots, and rhizobial nodules. Pawlick (1989) warned against coppicing at the hottest time of the year, because plants already affected by drought will recover poorly from the added stress. Although drought was not a factor in these trials after 1988, average daily temperatures were lower in September than in July or August each year.

Applications for forage management

It can be concluded that in central Michigan, July and especially August harvests are more stressful to black locust plants than June or September harvests, resulting in lower survival and reduced yields the next year. Plants cut in July and August are less likely to have adequate carbohydrate reserves for winter survival or vigorous growth the next spring. They expend much of their reserves to refoliate, but do not have time to collect an adequate return on the investment. They miss out on sunshine with their canopy destroyed twice, first by harvesting and again by the first frost. They suffer greater losses from respiration in sunny weather, and can lose all their new

growth to herbivores or winter dieback. Though survival in plots harvested twice, in June and September, may equal that in plots cut only in September, the yield would be much lower. Therefore, to obtain the highest yields each year and maintain adequate survival, a green biomass crop of black locust coppice growth should be harvested as late in the growing season as possible, but before any leaves are killed by frost.

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EFFECTS OF HARVEST HEIGHT ON SURVIVAL AND FORAGE YIELD OF BLACK LOCUST

ABSTRACT

Black locust seedlings planted at five spacings in 1988 were harvested for forage in two trials. Plots were cut twice each year in late June (or early July), and in late August, from 1988 to 1990. Harvest height treatments were at 5 cm and 20 - 30 cm. In August, 1988, harvesting at 5 cm gave significantly higher forage yields per plot and per plant than at 20 cm. Winter mortality was significantly greater at 5 cm (73%) than at 20 cm (under 10%). This trial was discontinued in 1989. Harvesting during the year of establishment should not be practiced.

In the second trial, dormant intact stems were cut at 5 cm or 20 cm in March, 1989. Harvests at 5 cm gave equal or lower yields than at 25 - 30 cm, and cumulative yields for 1989 and 1990 were significantly reduced. Yields declined from 1989 to 1990, but more severely at 5 cm (74%) than at 25 - 30 cm (20%). Yields per plant were significantly greater when cut at 30 cm, and increased from 1989 to 1990.

The effect of harvest height on dry weight percent of fresh weight was slight but sometimes statistically significant. Mortality was low for the 20 - 30 cm plots before 1991, and for the 5 cm plots between harvests in the summer. Mortality was high over the winters for 5 cm plots, and from 1990 to 1991 at 5 cm (84%) and 30 cm (56%). Harvesting at 5 cm is not recommended, due to reduced future survival and yields.

INTRODUCTION

Literature review

Black locust (Robinia pseudoacacia L.) is a nitrogen-fixing leguminous tree, suitable for cultivation for biomass and high-protein forage. It grows rapidly from seed or coppice, and has often been recommended for short-rotation intesive culture. When tree species are grown at close spacings and cut at short intervals, the stumps tend to die quickly. Cultural procedures are a major factor in the health and productivity of coppice stands (Blake 1983). Because little previous research on black locust is applicable to forage production, this review includes much data from leguminous trees in the tropics, especially concerning the cultivation of leucaena (Leucaena leucocephala (Lam.) de Wit) for forage.

Meginnis (1940) observed that cutting dormant black locust seedlings at ground level significantly increased mortality compared to pruning at 20 cm. Survival of seedlings cut at 20 cm was not significantly different from uncut controls. Mebrahtu and Hanover (1991) compared regrowth of black locust seedlings cut at 1 cm or 25 cm. Height did not affect the timing of coppice sprouts from the stumps in spring. None of the 25 cm stumps had sucker sprouts from the roots, but all the 1 cm stumps did, averaging 7.9 suckers per stump. Most suckers survived to the end of the season. Above ground dry weight was 14.3 tons/ha/year for both heights.

Many researchers have reported on yields of leucaena leaves in relation to harvest height, and in six cases the highest yields were obtained at the highest height tested: 30 cm (Pathak <u>et al</u>. 1980), 50 cm (Petheram <u>et al</u>. 1982), 90 cm (Ezenwa and Cobbina 1991), 100 cm (Pathak and Patil 1983; Sampet 1992), and 120 cm (Isarasenee <u>et al</u>. 1984). The highest biomass yields (leaves and stems combined) occurred at the greatest cutting height tested in seven reports: 75 cm (Relwani <u>et al</u>. 1983), 90 cm (Ezenwa and Cobbina 1991), 100 cm (Field and OeMatan 1990), 120 cm (Mohatkar and Relwani 1985), and 150 cm (Krishnamurthy and Mune Gowda 1982, 1983). Mendoza <u>et al</u>. (1983) obtained fodder dry weight yields of 10.7 tons/ha/year at 15 cm,

15.8 at 150 cm, and 23.6 at 300 cm. This is the only available report of a harvest height above 150 cm.

Four leucaena researchers have reported maximum yields at less than the maximum harvest height. Osman (1981) found an optimal harvest height below 150 cm. Harvest between 45 and 90 cm was recommended since yields at those heights did not significantly differ. Tukel and Hatipoglu (1989) tested 20, 40, and 60 cm harvest heights, obtaining significantly higher leaf yields at 40 cm the first year and at 60 cm the second year. The average yields of leaves and total biomass did not vary significantly between 40 and 60 cm. Ezenwa and Cobbina (1991) found higher yields of cv. Cunningham at 90 cm than at 45 or 15 cm (not significant) during the first year of harvesting only. In the second year, the 45 cm height yielded most, and significantly more than at 15 cm. Horne and Blair (1991) found no significant differences in yields of leaves or biomass, or the leaf percentage, in cv. Cunningham planted at 20,000/ha in Indonesia when harvested at 30 or 100 cm at irregular intervals of 43 to 64 days. It was proposed that the long establishment phase (four years) before the first cut allowed the accumulation of large carbohydrate reserves in the roots, contributing to the rapid recovery from the initial cut at 30 cm.

Several authors have summarized previous research and made harvest height recommendations for leucaena as a forage crop. Blair <u>et al</u>. (1990) cited nine earlier reports and put the optimal range at 90 - 120 cm, affirming that promoting branching for a solid canopy and timely harvest before lower leaves are shaded out appear important for high yields. Hegde (1983) recommended 90 - 100 cm for hand harvest, but 30 - 50 cm for mechanized harvest. Brewbaker (1987) recommended hedges be maintained at above 60 cm to retain some foliage and vigorous side branches, shrubby Hawaiian types be cut as low as 10 cm, but arboreal types be cut above 25 cm. NFTA (1985) advised starting harvesting hedges at 25 cm to stimulate branching, and slowly raising the cutting level to the recommended 80 - 100 cm. Cutting the hedge lower again after two or three years was said to rejuvenate the plants.

In addition to leucaena, the effects of harvest heights have been investigated in other tropical leguminous trees. Leaf, stem, and total dry weights varied significantly among three species in Samoa, but not between harvest heights of 100 and 150 cm, except for the higher leaf weight at 150 cm in <u>Gliricidia sepium</u> (Jacq.) Walp. (Tekle-Haimanot <u>et al</u>. 1991). <u>Desmodium gyroides</u>, a shrub from South Asia, was tested in Belize at harvest heights of 5, 25, and 50 cm, spaced 100 cm apart, with three harvest intervals. Leaf, stem, and total dry weights did not differ between the 25 and 50 cm heights, which always yielded significantly more than the 5 cm height. Yields at 5 cm did not recover greatly after the dry season, and were reduced by weeds. Survival rate increased with harvest height from 25 to 50 cm, but not significantly (Lazier 1981).

Acacia mangium Willd. trees in China, averaging 9 m tall and 8 cm dbh, were cut at 0, 30, 60, and 100 cm above ground level. Harvesting at ground level gave significantly lower results for all features measured: percent of stumps sprouting, number of sprouts per stump, length and diameter of coppice shoots, and 12-month stump survival. Significant differences among the 30, 60, and 100 cm heights were found for number of sprouts per stump and 12-month stump survival, with the highest levels recorded at 100 cm (Huang 1989).

Eight species of <u>Acacia</u> native to Australia were coppiced after growing four years in Malawi. Survival six months later was 7% if cut at 10 cm, 29% at 30 cm, and 40% at 50 cm (Ngulube 1991). <u>Paraserianthes falcataria</u> (L.) Nielsen always produced more biomass when harvested at 100 cm than at 30 cm in a trial in Western Samoa (Rogers and Rosecrance 1992).

Objectives

If black locust is to be grown as a woody perennial intercrop or field crop for green biomass or forage, the optimal mechanized harvest height must be determined. Field trials must be repeated for more than one season, to determine how the harvest height affects survival and yields. The dry weight percentage, important for preservation as silage, may vary with height. The inverse relation of individual plant biomass to stand density has been well documented for some woody species at short rotations of one to seven years (Cannell and Smith 1980), but harvesting leaves

twice a year has rarely been investigated by foresters. The optimal density, defined as the lowest planting density to give the maximum yield, may vary with height and age. Experience with other species, primarily arboreal cultivars of leucaena, indicates that the ideal harvest height for black locust may be found in a similar range of 90 - 150 cm. This was not considered practical for mechanized harvest with conventional equipment designed for hay or silage, so this experiment was conducted with lower harvest heights (5 cm and 20 - 30 cm) that could be attained by hay harvesting equipment commonly used on Michigan farms.

An experiment was designed with two harvest heights, at five population densities, to address the following hypotheses.

For black locust plants of up to four years of age:

- 1. Optimal density decreases with harvest height.
- 2. Optimal density decreases with time, but the pattern differs according to harvest height.
- 3. Survival rate increases with harvest height.
- 4. Survival rate increases with time for all harvest heights.
- 5. Yield per plant increases with harvest height.
- 6. Yield per plant increases with time for all harvest heights.

The experiment was also used to test the response to different harvest heights in plants of different ages. It was thought that stems of seedling and coppice origin would differ in their yields, numbers harvested, and dry weight percentages, and would respond differently to the harvest height treatments. These responses were monitored in order to address the following hypotheses.

For intact first year seedlings:

- 7. Dry weight yields per plot decline with height.
- 8. Dry weight yields per plant decline with height.
- 9. Number of livivng plants harvested declines with height.
- 10. Dry weight percentage declines with height.

For regrowth from coppiced stumps:

- 11. Dry weight yields per plot increase with height.
- 12. Dry weight yields per plant increase with height.
- 13. Number of livivng plants harvested increases with height.
- 14. Dry weight percentage increases with height.

MATERIALS AND METHODS

General information for all trials

A bulk mixture of equal numbers of seeds from four Michigan sources was planted. The sources were selected on the basis of availability, and not for any judgement of quality. The seed accessions were 442 from Russ Forest in Cass County, 445 from the corner of Sandhill and Hagadorn roads, and 446 from the Dansville State Game Area, both in Ingham County, and 450 from Kellogg Forest in Kalamazoo County. Prior to sowing, the seeds were scarified in concentrated sulfuric acid for 50 minutes. They were directly sown in late June 1988 at the Michigan State University Tree Research Center in East Lansing (420 41' N, 840 28' W). The nursery beds were surrounded by evergreen windbreaks and had been fumigated with methyl bromide. The soil was mapped as a complex of soil series including Riddles, Hillsdale, Owosso, and Marlette, all of which were well drained with 2% to 6% slopes and sandy loam topsoil. Subsoils were sandy loam, loam, or clay loam (Soil Conservation Service 1979).

Prolonged heat and drought in 1988 impaired growth and sprinkler irrigation was necessary. After normal weather returned in mid August, growth was rapid until early September, with seedlings reaching heights of 60-120 cm. In 1989, 1990, and 1991 growing conditions were favorable.

Because the soil had been fumigated, there were few weed problems in 1988. In the spring of 1989 and 1990, the plots were sprayed with glyphosate (trade name Roundup) at 0.7 kg active ingredient/ha and DCPA (trade name Dacthal) at 8.4 kg active ingredient/ha. Potassium sulfate (00-50) fertilizer was added at the rate of 225 kg/ha (112 kg/ha K2O) on May 7, 1990, to bring soil potassium levels up from around 90 kg/ha. No other fertilizer was applied.

In each plot, all new growth above the designated harvest height was cut with hand tools and bagged to determine the fresh weight. The paper bags of harvested material were dried in an oven at 60°C for at least three days before measuring the dry weight. Weights per plant were calculated from the number of plants harvested. Multiple sprouts from the same root were counted as one plant. Shoots from different roots were counted as separate plants. Due to the presence of suppressed seedlings, the total survival in 1989 was often higher than the number harvested, but few suppressed seedlings survived to 1990. Survival to 1991 was often higher than the number harvested that year because of rabbit damage on the smallest plants.

All trials were planted using a randomized complete block design. Analysis of variance, Duncan's multiple range tests, and other statistical operations were conducted on NCSS computer programs (Hintze 1987). The probability level reported for each factor below a table is the probability of the difference between treatments occurring by chance, according to F-test comparisons.

Harvest height trials

Four replications were planted in a randomized complete block design. Ten plots were included in each replication, representing all combinations of the two harvest heights and the five spacings. In June, 1988, seeds were planted by hand in a grid pattern, 10, 12.5, 16.7, 25, or 50 cm apart, to give 1.0 m² plots of 100, 64, 36, 16, or 4 seedlings, respectively. With one or two border rows at the same spacings on all sides, the planted area was 1.5 m wide and covered 2.25 m² per plot. Multiple seedlings were common because two to four seeds were sown at each grid position. Empty grid positions were replanted with seeds in early July, and with seedlings in early August. The effect of spacing treatments was included in the analysis of variance, but it will not be reported here unless the interaction with harvest height was statistically significant.

In late August 1988, 65 days from sowing, the plots were harvested at either 5 cm or 20 cm above the ground. At this time the seedlings were mostly 20 - 30 cm tall. Regrowth was weak, and was consumed by rabbits during the winter. Most 5 cm stumps died and were frost-heaved out of the ground before spring. Survival to 1989 was recorded, and the trial was terminated.

A duplicate set of plots was established as described for 1988, but not harvested that year. In March, 1989, the dormant plants were cut back to 5 or 20 cm, and the stems left to decay on the ground. Coppice shoots from three of the four replications were harvested at 5 and 25 cm between June 28 and July 5, and again at 5 and 30 cm between August 23 and 31, 1989. The fourth replication was discarded because of variations in treatment.

In 1990 first harvests occurred between June 18 and 22, and second harvests between August 16 and 27, all at 5 and 30 cm. In 1991 the survivors were counted for both heights, and the trial was terminated.

RESULTS AND DISCUSSION

Relation of optimal density to harvest height

To investigate the relation of harvest height to optimal population density, five spacing treatments were combined with the two height treatments. The hypothesis that optimal population density declines with harvest height was not supported. Rather than decreasing, the optimal density increased with harvest height in 1988, from 64/m² at 5 cm to 100/m² at 20 cm (Table 3.1). In the other trial, the interaction between height and density was never statistically significant, so there was no variation in optimal density with height in 1989 and 1990. The pattern of change in optimal density did not vary with harvest height.

Dry weight yields

In 1988, harvesting at 5 cm about doubled the yields obtained at 20 cm (Table 3.1). Yields generally increased with density, but when cut at 20 cm, yields showed a plateau from 16 to

Planting density	Harvest he	eight	
per square meter	5 cm	20 cm	
4	22 a	16a	
16	125b	72b	
36	147b	67b	
64	261c	80b	
100	245c	144c	
Mean	160	76	
Factor	Probability		
Harvest height	.0000		
Planting density	.0000		
Interaction	.0002		

Table 3.1. Dry weight yields (g/m^2) for square grid plots at five planting densities harvested at 5 cm and 20 cm in late August 1988, 65 days from sowing.

Means in the same column followed by the same letter are not significantly different at the 0.05 level according to Duncan's Multiple Range test. Probability levels of the effects of factors and their interaction were determined by F test.

 $64/m^2$. The treatment factors and their interaction gave highly significant results. These plots could not be compared again because of poor survival at 5 cm.

In the other trial, the effects of harvest height and planting density treatments on yield were highly significant in 1989 and 1990, but the treatment interaction was not statistically significant. In 1989 the 5 cm harvests removed all regrowth, but the higher harvests did not. When cut at 25 cm in July and at 30 cm in August, 5 cm of new growth was retained above the stump each time. However, the 5 cm harvests did not result in higher yields (Table 3.2). For the plots cut at 25 cm in July, 1989, the greater number of retained leaves gave an advantage for regrowth before the August harvest, which was nullified by harvesting the new growth 5 cm higher than the July stumps. If all regrowth had been harvested in August, the higher cutting height probably would have yielded significantly more at every harvest. In 1990 and in total for two years, yields were significantly higher at 30 cm. Two year totals were 589 g/m² at 5 cm and 1112 g/m² at 30 cm. After the 1990 season the experiment was terminated because of poor survival at 5 cm.

The hypotheses that dry weight yields per plot decline with height in intact seedlings, and increase with height for coppice regrowth, were both confirmed. Yields declined from 1989 to 1990, although growing conditions were similar and fertilizer was added at the start of the 1990 season. Forage production was reduced more severely in the 5 cm (73%) than in the 30 cm plots (20%).

Possible factors giving an advantage to greater harvest heights are the vigor of regrowth due to greater carbohydrate reserves in remaining stems (Meginnis 1940; Hardesty and Box 1988), and more branching (Brewbaker 1987; Blair <u>et al</u>. 1990) to maintain at least a partial canopy after harvest which raises photosynthesis and suppresses weeds. Total defoliation, as usually occurred at the 5 cm height, has been shown to reduce future growth in temperate species, including English oak (Quercus robur L.) (Hilton <u>et al</u>. 1987), red oak (Quercus <u>rubra</u> L.), and red maple (<u>Acer</u> <u>rubrum</u> L.) (Heichel and Turner 1976, 1984). Defoliation by leaf miner insects can be fatal to mature black locust if the first flush of leaves and the regrowth are destroyed for two consecutive

Table 3.2. Dry weight yields (g/m^2) for square grid plots harvested at 5 cm and 25 cm in early July and at 5 cm and 30 cm in late August 1989, and at 5 cm and 30 cm in late June and late August 1990.

	June Harves	e-July st height	Au Harves	gust st height	Cum Harves	ulative st height
Year	5 cm	30 cm	5 cm	30 cm	5 cm	30 cm
1989	354	504	112	115	466	619
Probability level	.0	002	.7	955	.0	002
1990	43	172	80	321	123	493
Probability level	.0	000	.0	000	.0	000
2 year total	397	676	192	436	589	1112
Probability level	.0	000	.0	000	.0	000

The probability level for the effect of harvest height was determined by F test.

years (Hoffard 1992). The death of black locust seedlings, which have smaller reserves, was more rapid in this study.

The primary factor working to reduce yields at greater heights is leaf abscission below the canopy before harvest (Blair <u>et al</u>. 1990). This occurs when the harvest interval is too long for the combination of height and spacing, and lower leaves become heavily shaded and senesce. In black locust, senescent leaves turn bright yellow before dropping.

Because plot yields are influenced by the number of survivors, comparison of yields per plant is necessary to determine whether a harvest height treatment had an effect on the vigor of the survivors. Because each remaining plant has more space after some die, a slight increase in yield per plant would be expected each year.

Dry weight yields per plant of intact seedlings declined with height, as predicted. In 1988, the average dry weight yield per plant at 5 cm was 4.1 g, significantly higher than the average of 2.6 g harvested at 20 cm. Yields were greater at 5 cm because all plots were the same height before treatment. The interaction with density treatments was not significant because the seedlings had little time to crowd each other.

The hypothesis that regrowth yield per plant increases with harvest height was clearly supported (Tables 3.3 and 3.4), but yield per plant did not increase with time regardless of height. At 5 cm the average yield per plant declined from 1989 to 1990, and was too low to justify harvesting at all in 1991. The average July 1989 yield for the 5 cm group was 12.8 g per plant, significantly lower than the average of 20.3 g per plant harvested at 25 cm. At the second harvest in August 1989, the effect of height was not significant, but the interaction of height and density treatments was (Table 3.3). This was because yields per plant were nearly equal for all but the widest spacing (50 cm apart), which gave half the yield per plant at 5 cm as at 30 cm. The significant interaction continued in 1990. Yields per plant at the June 1990 harvest for the 5 cm group were about half those for the 30 cm group, and continued lower at the second harvest.

Planting density Au		ugust 1989		June 1990		August 1990	
per square meter	5 cm	30 cm	5 cm	30 cm	5 cm	30 cm	
4	10.2 a	21.0a	4.1ab	33.4a	7.6ab	75.7a	
16	7.4b	7.8b	5.0a	10.3b	11.9a	18.4b	
36	3.5c	3.9b	3.5ab	6.8b	8.8ab	10.5b	
64	2.1c	2.0b	1.9b	4.5b	3.7b	7.2b	
100	2.3c	1.9b	1.8b	3.3b	2.9b	6.6b	
Mean	5.1	7.3	3.2	11.7	7.0	23.7	
Factor	Prob	ability	Proba	ability	Proba	ability	
Harvest height	.0801		.00	000	.0	152	
Planting density	.0000		.00	000	.00	081	
Interaction	.0375		.00	000	.01	133	

Table 3.3. Dry weight yields (g/plant) from square grid plots at five planting densities harvested at 5 cm and 30 cm in late August 1989, late June 1990, and late August 1990.

Means in the same column followed by the same letter are not significantly different at the 0.05 level according to Duncan's Multiple Range test. Probability levels of the effects of factors and their interaction were determined by F test.

Table 3.4. Annual total dry weight yields (g/plant) from square grid plots at five planting densities harvested at 5 cm and 30 cm in 1989 and 1990.

Planting density 1989		89	1990		
per square meter	5 cm	30 cm	5 cm	30 cm	
4	18.0a	30.0a	11.5ab	109.9a	
16	12.0b	15.1b	16.8a	28.8b	
36	8.4bc	11.9b	12.4ab	17.9b	
64	4.5c	6.4c	5.8b	12.1b	
100	3.8c	6.0c	4.8b	10.1b	
Mean	9.3	13.9	10.1	35.8	
Factor	Probability		Probability		
Harvest height	.0001		.0021		
Planting density	.0000		.0009		
Interaction	.0125		.0018		

Means in the same column followed by the same letter are not significantly different at the 0.05 level according to Duncan's Multiple Range test. Probability levels of the effects of factors and their interaction were determined by F test.

For the cumulative yields per plant in 1989 and 1990, both height and spacing treatments produced highly significant differences, and the interaction was also significant (Table 3.4). At most spacings, total yields per plant in 1990 increased slightly over 1989 in the 5 cm plots, but about doubled for the 30 cm plots from 1989 to 1990. The widest spaced plants at $4/m^2$ departed from these patterns. In June, 1990, the 5 cm group averaged one eighth of the yield per plant in the 30 cm group (Table 3.3). In August, 1990, yields of the 30 cm plots increased to 10 times the average of the 5 cm plots. When compared with the 1989 totals, or with the other spacings at the same harvest height, it is clear that growth of the $4/m^2$ plants was retarded by harvesting at 5 cm and promoted by harvesting at 30 cm.

Dry weight percentage

The dry weight/fresh weight percentage (D/F) represents the dry matter proportion of the green biomass. The D/F was low early in the season when new growth was succulent, but increased as plant tissues became lignified. Differences between height treatments were statistically significant at both harvests in 1989, but not in 1988 or 1990 (Table 3.5), so the hypothesis that the D/F of intact seedlings declines with height was rejected. The results from coppice regrowth were inconclusive, since the D/F increased significantly with height in 1989, but not in 1990. This is similar to the experience of Holden <u>et al.</u> (1989), who reported the dry matter percentage in <u>Sesbania macrantha</u> was 7% at 25 cm and 12% at 50 cm at one harvest, but equal at two other harvests.

The slight difference in the D/F appears to depend on the volume harvested, since the drier group always had the greater dry weight as well (Tables 3.1 and 3.2). Greater dry weight from an equal area requires larger stems with a higher proportion of wood, and thus a higher D/F. Although the D/F was sometimes significantly different between treatments, this represented at most an extra 2% moisture by weight. Under field conditions, such a difference could be erased by a short exposure to the sun after cutting, and would be of no concern.

	Harves	t height	Probability
Date	5 cm	30 cm	level
August 1988	23.8	23.2	.1838
July 1989	23.4	25.5	.0025
August 1989	23.5	24.7	.0035
August 1990	25.9	26.3	.5030

Table 3.5. Dry weight percentage of fresh weight for square grid plots harvested at 5 cm and 20-30 cm in 1988-1990.

Data not suitable for comparison in June 1990 because of rain which biased fresh weight measurements.

Survival after harvesting

The number of plants surviving was always equal to the number harvested at 5 cm, but this was not true for the 20 - 30 cm plots. Uncut live plants in the 20 - 30 cm plots were not counted because they made no contribution to yield, did not shade their taller neighbors, and probably used a negligible fraction of the water and nutrients consumed by the entire plot. Although the number harvested sometimes increased from one harvest to the next, it was a close estimate of survival in the 20 - 30 cm plots from 1989 onward.

At the first harvest in August, 1988, all seedlings exceeded 5 cm but about one quarter had not yet reached 20 cm (Table 3.6). Those not cut at 20 cm continued to grow for the rest of the season and survived well over the winter, giving an increase of 18% over the 1988 level when harvested in July 1989. Winter mortality was 73% for seedlings cut at 5 cm, and under 10% for those in the 20 cm plots.

The estimate of under 10% mortality was calculated as follows. The 5 cm plots averaged 51 seedlings in August, 1988. The plots harvested at 20 cm in 1988 averaged $46/m^2$ harvested in July, 1989, representing 90% of the $51/m^2$ presumed to have been present in 1988. An unknown number of additional plants survived but were not tall enough to harvest.

In the other trial, mortality was low for the 30 cm plots before 1991, and for the 5 cm plots between harvests in the summers, but high over the winters for 5 cm plots (Table 3.7). The non-significant increase between June and August in 1990 resulted when the new growth of some weak seedlings did not reach 30 cm by the first harvest, but passed 30 cm before the second. After four harvests, survival was still adequate to maintain a closed canopy in the 30 cm plots, but was so low in the 5 cm plots that the comparison trial was ended.

Survival rates increased with harvest height, as predicted, but not with plant age. Two more hypotheses, that the number of intact seedlings harvested declines with height, and that the number of coppiced plants cut at any single harvest increases with height, were confirmed.

Table 3.6. Average number of plants harvested from square grid plots at five planting densities harvested at 5 cm and 20 cm in late August 1988, 65 days from sowing, and at 5 cm and 25 cm in early July 1989.

Planting density	August 1988		July	1989
per square meter	5 cm	20 cm	5 cm	25 cm
4	4.0	3.3	1.3a	4.0a
16	21.0	21.5	6.3ab	27.3ъ
36	40.3	32.3	13.5bc	42.3bc
64	75.0	47.0	21.0cd	58.0c
100	112.5	88.3	26.0d	96.5d
Mean	50.6	38.5	13.6	45.6
Factor	Probability		Probability	
Harvest height	.0002		.0000	
Planting density	.0000		.0000	
Interaction	.0070		.0000	

Means in the same column followed by the same letter are not significantly different at the 0.05 level according to Duncan's Multiple Range test. Probability levels of the effects of factors and their interaction were determined by F test.

Table 3.7. Average number of plants harvested from square grid plots at 5 cm and 25 or 30 cm starting a year after sowing (three replications).

Date	5 cm	25-30 cm	Probability
July 1989	40.9	38.0	.0592
Aug. 1989	32.8	32.6	.8501
June 1990	14.7	27.3	.0458
Aug. 1990	13.8	30.3	.0406
July 1991 ¹	2.2	13.5	

¹ Counted but not harvested.

At both heights, mortality up to July 1989 was three to four times higher if the first cut was made in August 1988 compared with March 1989. It is likely that delaying the first cut even longer would result in larger stronger plants and improved survival (Pawlick 1989). The same outcome would probably result from harvesting at heights above 30 cm. Holden <u>et al.</u> (1989) reported 100% survival in <u>Sesbania macrantha</u> coppiced at 50 cm, but not at 25 cm or 10 cm. Large <u>Acacia mangium</u> trees cut at 30 cm survived significantly better than those cut at ground level, but not as well as those cut at 60 or 100 cm (Huang 1989). Survival of eight species of <u>Acacia</u> after six months was 7% if cut at 10 cm, 29% at 30 cm, and 40% at 50 cm (Ngulube 1991). Although survival of black locust seedlings cut at 20 cm by Meginnis (1940) was not significantly different from uncut controls, those seedlings were widely spaced and were cut only once. Under the strain of crowding and repeated harvesting, it is likely that black locust survival would be improved by harvest heights above 30 cm.

CONCLUSIONS

Because of severe mortality the first winter, a harvest height of 5 cm or below is recommended only if the plantation of black locust is treated as an annual crop. For every aspect of growth, yield, and survival that was measured, the harvest height of 30 cm is superior to 5 cm in the long term. It is reasonable to project improved performance with heights above 30 cm.

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EFFECTS OF SPACING ON SURVIVAL AND FORAGE YIELD OF BLACK LOCUST

ABSTRACT

Black locust seeds were planted in 1988 to give plots of 4, 16, 36, 64, and 100/m² (40,000 - 1,000,000/ha) in a square grid pattern. Plots were cut back to 20 cm while dormant before the 1989 growing season, and were harvested in early and late summer at 30 cm the next two years. Plots of 4 and 16/m² were harvested at 50 cm in 1991. Effects of spacing on plot yields were highly significant at the early summer harvest in 1989, and significant at the late summer harvest in 1989, but were not significant in 1990 and 1991. Effects of spacing on the proportion of dry matter in fresh material were minimal, although sometimes statistically significant. Numbers of plants harvested changed little from early to late summer, but the decline was greater over winter. Survival rates were significantly higher at 4/m². The different spacings became less distinct with time, and in 1991 the numbers harvested per plot at all spacings narrower than 4/m² were not significantly different. To establish black locust as a perennial forage crop, a wide spacing of transplanted seedlings or a narrow spacing of seeds would be advised.

INTRODUCTION

The black locust tree (<u>Robinia pseudoacacia</u> L.) is noted for its rapid juvenile growth, adaptability to difficult sites, and high protein content in new growth. Efforts to cultivate the species as a perennial crop for fuel, fiber, or forage require more information on optimal agronomic practices. These trials were conducted in order to determine the proper spacing between *Plants* in the field. Trials were monitored for four seasons, to determine how the treatments affected survival and yields.

Literature review

Many researchers have noted how the size of black locust seedlings depends on the spacing betveren them (Wilson and Bailey 1957; Geyer <u>et al</u>. 1987; Genys and Harman 1990) or the volumeme of the pot in which single plants are grown (Mebrahtu and Hanover 1991), but the species has mot previously been tested as a forage crop.

The multi-purpose nitrogen-fixing leucaena tree (Leucaena leucocephala (Lam) de Wit) has been extensively researched in the tropics and behaves much like black locust under cultivation. Much attention has been given to the optimal plant spacing for leucaena forage. Over a range of planting populations, yields have typically been highest at the greatest density. Such results at maximum populations of 20,000/ha have been reported by Visuttipitakul <u>et al</u>. (1983), Mohatkar and Relwani (1985), and Yantasath <u>et al</u>. (1985); at 40,000/ha by Pathak <u>et al</u>. (1980), Van Den Beldt (1982), Relwani <u>et al</u>. (1983b), Ella <u>et al</u>. (1989), and Tukel and Hatipoglu (1989); at 62,500/ha by Cooksley and Goward (1988); at about 66,000/ha by Ferraris (1979); at 73,000/ha by Lahiri (1983); and at 100,000/ha by Relwani <u>et al</u>. (1982).

Trials with leucaena planted at over 100,000/ha often gave the highest green biomass yields at populations other than the highest tested. Jayaraman <u>et al</u>. (1988) obtained significantly higher yields at 66,666/ha, while yields at 33,333 and 133,333/ha were not significantly different from each other. Desai <u>et al</u>. (1988) grew three strains of leucaena at five densities from 33,333 to 200,000/ha. The Cunningham cultivar yielded best at 100,000/ha, but K8 and Peru yielded best at 50,000/ha. Yields from rows 50 cm apart were 43 - 57% of rows 100 cm apart, confounding the population effects. Shih and Hu (1981) found green biomass yields of four strains at four densities from 50,000 - 200,000/ha rose with population in the first two years. Yields averaged 24% higher at 200,000/ha than at 50,000/ha, although the differences were not significant. In the third through fifth years there were no significant yield differences between spacing treatments (Shih <u>et al</u>. 1989).

Jiang and Liu (1991) obtained significantly higher yields at 83,000/ha than at 42,000/ha or 167,000/ha using cv. Salvador.

At higher populations of over 200,000/ha, yields usually increased with plant numbers. Guevarra <u>et al</u>. (1978) found forage and stem yields increased significantly with population in the range from about 110,000 - 330,000/ha when averaged over all harvest intervals and cultivars. Relvani <u>et al</u>. (1983a) compared two cultivars at two sites, at 111,111, 166,666, and 333,333/ha, obtaining the highest forage yields at the highest density. Ghatnekar <u>et al</u>. (1983) attempted growing leucaena at 16,000,000/ha (2.5 by 2.5 cm), but survival was about 134,000/ha.

Savory <u>et al.</u> (1980) concluded from experimental results in Malawi that the optimal forage population varied by region. In the Shire Highlands about 200,000/ha served best, but in the hotter and drier Lower Shire Valley about 100,000/ha was optimal. Hegde (1983) considered a leucaena population of 100,000 - 150,000/ha ideal for forage production, with only marginal yield increases at higher densities. The National Research Council (1984) judged forage production best at planting densities of 75,000 - 140,000 plants/ha. Horne <u>et al.</u> (1985) concluded that most researchers reported better yields from leucaena planted at higher densities, but gave no upper limit. In populations above 100,000/ha the stems are probably crowded enough that new growth after each harvest closes the canopy so quickly that additional plants would not improve the speed of recovery.

Spacing trials have been reported with tropical leguminous trees other than leucaena. Highest yields were obtained at the highest density tested (40,000/ha) for the tropical legume fodder trees <u>Calliandra calothyrsus</u> Meissn., <u>Gliricidia sepium</u> (Jacq.) Walp., and leucaena, but not for <u>Sesbania grandiflora</u> (L.) Poir. <u>Sesbania</u> yields were low and did not increase much at higher densities because of poor survival after cutting, although the yield at the first harvest had been much greater at 40,000/ha (Ella <u>et al</u>. 1989). <u>Gliricidia sepium</u> yielded the most biomass and crude protein at the maximum density (20,000) (Karim and Savill 1991). Although individual tree growth rates were inversely related to population density, the highest yields of leaves, stems, roots,

and total biomass were obtained at the highest density tested (40,000/ha) for <u>Albizia lebbeck</u> (L.) Bernth. at 6, 12, 18, and 24 months of growth (Parrotta 1988).

<u>Ob jectives</u>

The optimal density, defined as the lowest population per square meter to give the highest yie **I** < I, was expected to be affected by the age of the plantation, due to rates of canopy closure and differences in mortality. An experiment was designed to test the following hypotheses:

1. Optimal density is higher at earlier ages, when more plants are needed to form a closed

canopy.

2. Mortality over time increases with density, due to competition stress.

3. Survival is greater with older plants.

4. There is some final optimal density, which will be reached when mortality of surplus plants ceases.

5. Dry weight percentage decreases with density.

6. Stem percentage decreases with density.

MATERIALS AND METHODS

General information for all trials

A bulk mixture of equal numbers of seeds from four Michigan sources was planted. The sources were selected on the basis of availability, and not for any judgement of quality. The seed accessions were 442 from Russ Forest in Cass County, 445 from the corner of Sandhill and Hagadorn roads, and 446 from the Dansville State Game Area, both in Ingham County, and 450 from Kellogg Forest in Kalamazoo County. Prior to sowing, the seeds were scarified in concentrated sulfuric acid for 50 minutes. They were directly sown in late June 1988 at the Michigan State University Tree Research Center in East Lansing (420 41' N, 840 28' W). The nursery beds were surrounded by evergreen windbreaks and had been fumigated with methyl

bromide. The soil was mapped as a complex of soil series including Riddles, Hillsdale, Owosso, and Marlette, all of which were well drained with 2% to 6% slopes and sandy loam topsoil. Subsoils were sandy loam, loam, or clay loam (Soil Conservation Service 1979).

Prolonged heat and drought in 1988 impaired growth and sprinkler irrigation was necessary. After normal weather returned in mid August, growth was rapid until early September, with seedlings reaching heights of 60-120 cm. In 1989, 1990, and 1991 growing conditions were favorable.

Because the soil had been fumigated, there were few weed problems in 1988. In the spring of 1989 and 1990, the plots were sprayed with glyphosate (trade name Roundup) at 0.7 kg active ingredient/ha and DCPA (trade name Dacthal) at 8.4 kg active ingredient/ha. Potassium sulfate (0-0-50) fertilizer was added at the rate of 225 kg/ha (112 kg/ha K2O) on May 7, 1990, to bring soil potassium levels up from around 90 kg/ha. No other fertilizer was applied.

In each plot, all new growth above the designated harvest height was cut with hand tools and bagged to determine the fresh weight. The paper bags of harvested material were dried in an oven at 60°C for at least three days before measuring the dry weight. Weights per plant were calculated from the number of plants harvested. Multiple sprouts from the same root were counted as one plant. Shoots from different roots were counted as separate plants. Due to the presence of suppressed seedlings, the total survival in 1989 was often higher than the number harvested, but few suppressed seedlings survived to 1990. Survival to 1991 was often higher than the number harvested that year because of rabbit damage on the smallest plants.

All trials were planted using a randomized complete block design. Analysis of variance, Duncan's multiple range tests, and other statistical operations were conducted on NCSS computer programs (Hintze 1987). The probability level reported for each factor below a table is the probability of the difference between treatments occurring by chance, according to F-test comparisons.

<u>Directly sown trial</u>

Three replications with five treatments were planted in a randomized complete block design. In June 1988 seeds were planted by hand in a grid pattern, 10, 12.5, 16.7, 25, or 50 cm apa_rt, to give 100, 64, 36, 16, or 4 seedling positions per 1.0 m² plot, respectively, with one or two bor cler rows on each side.. The size of the planted area was about 4.0 m² for each plot. Multiple seecellings were frequent because two to four seeds were sown at each grid position. Gaps were replanted with seeds in early July, and with seedlings (transplanted out of designated pathways) in early August.

In March 1989, the previously uncut plots were cut back to 5 or 20 cm, and the stems left to decay on the ground. Plots were harvested at 25 cm between June 28 and July 5, and again at 30 cm between August 23 and 31, 1989. In 1990, first harvests were taken between June 18 and 22, and second harvests between August 16 and 27, all at 30 cm. In 1991 first harvests were taken from plots of 4 and 16/m² only, between July 10 and 17, at a height of 50 cm. Because of shading from nearby uncut plots and feeding by rabbits, no second harvest was possible, and the experiment was terminated.

Transplanted trial

Seedlings sown in 1987 were transplanted in June and July, 1988 into 1.0 m² plots with either four plants 50 cm apart or 25 plants 20 cm apart. With one border row at the 50 cm spacing, or two at the 20 cm spacing, the total space required for each plot was 4.0 m². There were two plots of each of six seed sources in each of three replications, giving 36 plots. Data from three more plots planted at 64/m² were included in cases where a statistically balanced design was not required. Seed source differences were tested in the analysis of variance, but are not reported as they had no statistical significance.

No fertilizer was applied. Chemical weed control was attempted but was ineffective, and the 4/m² plots had vigorous grass growing between and often above the seedlings. These seedlings were harvested at 30 cm in July and September 1988, 1989, and 1990. They were counted but not

cut in 1991. No more data could be obtained because the research plots were destroyed without notice in June 1992.

Although the yield differences between spacings were usually statistically significant, it was judged that weed competition varied between treatments and caused much of the difference. The refore, only data concerning survival rates and the composition of harvested material are presented from this trial. Mortality soon after planting was attributed to severe damage by her bivores, so survival was calculated from the number living in September, 1988.

RESULTS AND DISCUSSION

Dry weight yields per plot

Effects of spacing treatments were highly significant in July and non-significant in August, 1989 (Table 4.1). In July, yields were very low at 4/m², significantly higher at 16/m², again significantly higher at 36/m², and plateaued at higher densities. In 1990, the yields did not vary significantly with spacing at either harvest.

Harvesting in July 1989, long after the canopy closed, resulted in a poor second harvest. Most lower leaves had already abscised, and a closed canopy was restored slowly. In 1990, harvesting in late June retained more lower leaves, restoring a complete canopy sooner and giving a much larger second harvest. In leucaena, a strong interaction between time of harvest and planting density has been shown. To maximize leaf yields, the crop must be harvested when the leafy biomass is greatest, just before shading causes lower leaves to abscise. Leaf yields will be lower if harvest is delayed, but more frequent harvesting will increase the proportion of time spent growing with less than a complete canopy, and also reduce cumulative yields. At higher densities where the canopy closes earlier, earlier harvests would yield more (Horne <u>et al</u>. 1985; Blair <u>et al</u>. 1990). Castillo <u>et al</u>. (1979) reported higher leucaena herbage yields at higher populations, especially with shorter harvest intervals.

Planting density	1989		19	990
per square meter	July	August	June	August
4	233a	117ab	163a	330a
16	412b	125ab	178a	305a
36	695c	134b	181a	293a
64	558c	85a	174a	314a
100	623c	114ab	164a	363a
Mean	504	115	172	321
Probability	.0004	.2221	.9960	.9305

Table 4.1. Dry weight yields (g/m^2) for square grid plots at five planting densities harvested at 25 cm in early July and at 30 cm in late August 1989, late June and late August 1990.

Means within the same column followed by the same letter are not significantly different at the P=0.05 level according to Duncan's Multiple Range Test.

Sumberg (1986) found that forage yield differences between six spacing treatments 4 - 50 cm apart ($4 - 625/m^2$) in Nigeria with <u>Gliricidia sepium</u> (Jacq.) Walp. were significant at the first three harvests but not at the fourth. Regrowth after each harvest was during the rainy season, so drought was not involved. It is likely that the canopy had closed at all spacings by the fourth harvest, as occurred in these trials by the third harvest.

Cooksley and Goward (1988) found leucaena yield increased three-fold when density increased 20-fold from 3100 to 62,500 plants/ha. With a 25-fold increase in density in this study, the yield of black locust forage doubled in 1989, and remained level in 1990 (Table 4.2), when the differences in canopy coverage between treatments were slighter. Although growing conditions were excellent both years, and fertilizer was added at the start of the 1990 season, yields declined from 1989 to 1990 for all spacings but 4/m², with an average reduction of 20%.

For the plots of 4 and 16/m² harvested in 1991, yield differences due to spacing were only significant in July, 1989 (Table 4.3). Although cumulative yields of these plots did not vary significantly by density after 1989, the much higher yields at 4/m² in 1991 indicated that this spacing would likely yield significantly higher over a longer period.

Savory <u>et al</u>. (1980) reported that leucaena forage yields tend to rise over the first four years, presumably due to greater root penetration. Yields have risen over the first three years in some black locust trials, but in this study average yields declined the third year (1990). In the fourth year, only the two widest spacings were harvested, and only once, in July. Still, it is clear that the plots of $4/m^2$ gave higher yields each year, and the $16/m^2$ plots did not.

It is unclear whether the lower yields in 1990 were due to changed harvest dates, the age of the plants, fewer plants surviving, or weather conditions. The pattern of declining yields in measured plots may also have been due to shading by the more vigorous plants in the outside border rows, so that the forage yield of the entire plantation may have continued rising. Border rows also tended to have better survival than the measured plots. Future research should

Planting density	1090	1000	Two-year Total	1001	Three-year
per square meter	1909	1990	10181	1991	10181
4	350a	493a	843	579a	1422a
16	536b	482a	1019	316a	1335a
36	829d	474a	1303		
64	643bc	489a	1132		
100	737cd	527a	1264		
Mean	619	493	1112		
Probability	.0006	.9882	.0265	.4937	.8616

Table 4.2. Annual and cumulative dry weight yields (g/m^2) for square grid plots at five planting densities harvested in 1989, 1990, and 1991.

Means within the same column followed by the same letter are not significantly different at the P=0.05 level according to Duncan's Multiple Range Test.

Harvest	4/m ²	16/m ²	Probability
7/1989	233	412	.0002
8/1989	117	125	.4305
6/1990	163	168	.1957
8/1990	330	305	.9761
7/1991	579	316	.2445
Total	1422	1336	.4780

Table 4.3. Single harvest and cumulative dry weight yields (g/m^2) from grid plots of 4 and $16/m^2$.
investigate patterns of plant growth and competition, both above and below the ground, in relation to yield levels and survival.

Dry weight yields per plant

Yields of plots were influenced by the number and vigor of survivors. Comparison dry weight of yields per plant was used to determine at what population the plants start to compete. Because each remaining plant has more space after some die, a slight increase in yield per plant would be expected over the years.

At both harvests in 1989, the effect of spacing treatments was highly significant (Table 4.4). August 1989 yields were 20 - 35% of July yields, except at 4/m² where it was over 50%. Yields at the early summer harvest in 1990 were about half those at the second harvest that year. Population density effects were highly significant in June and significant in August. Only the yield per plant at the 4/m² spacing was significantly different from an adjacent spacing at either 1990 harvest. Total yields per plant in 1990 averaged higher than in 1989, but the average was biased by the 4/m² plots, while plots at higher densities yielded about the same both years. Spacing treatments produced highly significant differences in 1989 and 1990 totals. Again, only the yield per plant at the 4/m² spacing was significantly different from an adjacent spacing. While yield per plant at the 4/m² spacing was significantly different from an adjacent spacing. While yield per plant at the 4/m² spacing was significantly different from an adjacent spacing. While yield per plant at the 4/m² spacing was significantly different from an adjacent spacing. While yield per plant at all other spacings had level or declining trends from 1989 to 1990, the 4/m² plots increased sharply. The 4/m² plants were still growing to fill the available space between them above ground, and presumably below ground also. This growth continued into 1991.

August 1989 yields were 20 - 40% of July yields, except at the lowest population, where more leaves were retained below the harvest height. At the higher populations, almost all lower leaves had already dropped from shading, and recovery was slower. While yields at the June harvest in 1990 were about half those in July 1989, which were cut two weeks later, the yields of plants at 4/m² were almost as high in 1990. At the second harvest of 1990, yields per plant were about double those at the first harvest or at the second harvest of 1989, reflecting fewer plants at the three highest densities in 1990 than in 1989, plus a longer period of regrowth.

Table 4.4. Single harvest and annual dry weight yields per plant (g) from grid plots at five planting densities harvested at 25 cm in early July and at 30 cm in late August, 1989, late June, and late August, 1990.

Planting density		1989			1990	
per square meter	July	August	Mean	June	August	Mean
4	40.6a	21.0a	60.0a	33.4a	75.7a	109.9a
16	22.0b	7.8b	30.2b	10. 3 b	18.4b	28.8b
36	19.3b	3.9b	23.7b	6.8b	10. 5 b	17.9b
64	9.8c	2.0b	12.8c	4.5b	7.2b	12.1b
100	9.5c	1.9b	11.9c	3.3b	6.6b	10.1b
Mean	20.2	7.3	27.7	11.7	23.7	35.7
Probability	.0001	.0022	.0000	.0009	.0341	.0106

Means within the same column followed by the same letter are not significantly different at the P=0.05 level according to Duncan's Multiple Range Test.

Composition of harvested biomass

The dry weight/fresh weight ratio (D/F) represents the dry matter proportion of the green biomass. Spacing treatments had no significant effect on D/F in grid plots. In the transplanted plots, a significant difference due to spacing was found in the dry weight percentage at the late summer (September) harvest in 1990. The D/F averaged 36.6% at 4/m² and 34.4% at 25/m². Differences were not significant at three earlier harvests. The D/F was predicted to decrease with density, but the difference was rarely statistically significant. The slight differences observed appeared to depend on the size of harvested stems. Spacing at 4/m² produced larger stems with a higher proportion of wood, and usually a higher D/F percentage.

In the grid plots, the proportion of woody stem in the harvested material in 1989, did not vary significantly by spacing. Woody stems comprised 20 - 30% of harvested material in early July, 5 - 15% of the regrowth harvested in late August, and 15 - 25% of the total biomass harvested in 1989. In the transplanted trial, the proportion of woody stems in mid July 1990 averaged 27% at 4/m² and 23% at 25/m², a statistically significant difference.

The proportions of dry weight and of stems in the harvested black locust forage had been predicted to decline as populations increased, but this did not always occur. It is possible that abscission of shaded lower leaves in the denser plots, shortly before harvest in June 1989, changed the stem proportions of the samples. A similar result with leucaena was reported by Guevarra <u>et al.</u> (1978). Under conditions of a closed canopy and a long harvest interval, leafy forage and stem yields both increased significantly with population, but forage yield rose more slowly. Two other leucaena reports, though not mentioning increased leaf loss before harvest at higher populations, show results consistent with such a process. Jayaraman <u>et al.</u> (1988), using leucaena cv. K8, found no variation in the protein content of dry matter from densities of 33,000 to 133,000/ha. This would indicate that the proportion of woody stems changed little with density. Jiang and Liu (1991) found the stem proportion of leucaena cv. Salvador was significantly lower (under 40%) in the range of 21,000 - 83,000/ha than at 167,000/ha (41%) or 17,000/ha (45%).

Severe defoliations have been observed to reduce the regrowth of stems more than leaves in red oak (<u>Quercus rubra</u> L.) and red maple (<u>Acer rubrum</u> L.) (Heichel and Turner 1984), and the Brazilian species <u>Mimosa caesalpinia</u>, <u>Caesalpinia pyramidalis</u>, and <u>Auxemma oncocalyx</u> (Hardesty and Box 1988), although the opposite was found in English oak (<u>Quercus robur</u> L.) (Hilton 1987). In this study, plots with narrow spacings tended to suffer greater defoliation at each harvest than plots with wide spacings.

Survival after harvesting

In the grid plots, the number harvested was not exactly equal to survival, as numbers increased slightly in August 1990 (Table 4.5). The greatest reductions occurred over the winters. While mortality was low (6 - 21%) between harvests in the summer of 1989 at the narrower spacings, plots at 4/m2 had a 13% increase in numbers harvested. The weakest seedlings, which tended to die under competition at narrower spacings, lived to be harvested in the plots of 4/m2. The increase between June and August in 1990 resulted when the new growth of some weak seedlings did not reach 30 cm by the first harvest, but passed 30 cm before the second. This increase was not significantly affected by spacing treatments.

Survival to 1991 was generally poor, but significantly higher for plots at $4/m^2$. The narrower spacing treatments lost about half of their remaining plants between August 1990 and July 1991, and the different spacings became less distinct (Table 4.6). In 1989 and in 1990 the numbers per plot typically were not significantly different from consecutive spacing treatments, but differed significantly from a second higher or lower spacing. In 1991 the original spacings had less influence, as the narrowest spacing (100/m²) differed significantly only from the widest (4/m²).

Therefore, plots were grouped by the number of survivors in August 1990, and mortality over the following winter was calculated (Table 4.7). Winter mortality after the 1990 season was less severe in the plots where individual plants were the largest and strongest from being spaced farthest apart. Plots with over 15 plants in 1990 all suffered 54 - 59% mortality. Correlation of numbers present in August 1990 and July 1991 gave a survival rate of 38% (r = .7749).

Date		Num					
	4	16	36	64	100	Mean	Probability
July 1989	1.00	1.00	1.00	1.00	1.00	1.00	
Aug. 1989	1.13a	.91b	.94b	.79	.91b	.90	.3766
June 1990	.91a	.91a	.68	.71	.75	.70	.5575
Aug. 1990	1.06a	.89	.81	.84	.81	.75	.5348
July 1991	.77a	.43b	.39b	.38b	.37b	.47	.0850
Aug./June 1990 ¹	1.17a	.99a	1.20a	1.20a	1.05a	1.12	.3462

Table 4.5. Number harvested (plants/m2) from grid plots at five planting densities in subsequent harvests relative to the number harvested in July, 1989.

1990¹
¹ The number harvested in August, 1990, relative to the number harvested in June, 1990.

Means within the same row followed by the same letter are not significantly different at the P=0.05 level according to Duncan's Multiple Range Test.

Date		Numb					
and group	4	16	36	64	100	Mean	Probability ¹
July 1989	ба	19ab	36bc	57cd	72d	38	.0037
Aug. 1989	7a	17ab	34bc	43c	62d	33	.0006
Jaane 1990	5a	17ab	25b	40c	50c	27	.0007
<u>Aug. 1990</u>	ба	17ab	29bc	46cd	54d	30	.0016
Juane 1991	4a	8ab	14ab	20b	21b	13	.0877

Table 4.6. Number harvested (plants/m²) each time 1988 - 1991 from grid plots at five planting \mathbf{C} ensities.

► Teans within the same row followed by the same letter are not significantly different at the = 0.05 level according to Duncan's Multiple Range Test.

Table 4.7. Effect of 1990 plot population (plants/m²) on 1991 plot population, and ratio of survival from 1990 to 1991, for square grid plots originally planted at five spacings, and transplanted plots originally planted at three spacings.

Number of plots	1990 Mean	Range	1991 Mean	Range	Survival ratio
3	5.66	4-7	4.0	4-4	.71
3	17.5	16-20	7.25	5-11	.41
3	34.5	32-38	16.0	6-24	.46
3	57.75	50-73	24.25	17-40	.42
19 ¹	3.4	1-8	3.3	0-8	.97
15 ¹	15.0	11-19	13.4	9-17	.89
51	26.4	20-36	21.0	12-27	.80

Statistical analysis was impossible because of differing numbers of plots.

Transplanted plots.

Regression of the survival rate on the number present in August 1990 gave a decline of 6% for each 10 additional plants (r = -.4534).

In the other trial, the seedlings transplanted at $4/m^2$ had a significantly higher survival rate wer three years (78%) than those at $25/m^2$ (61%) (Table 4.8). Compared to two year survival in the trial with sown plots, three year survival in this trial was nearly the same at $4/m^2$, but at $25/m^2$ as about double the rate for any of the spacings narrower than $4/m^2$. Survival rates from 1990 to 1 991 generally declined with density, but were much higher than in the directly sown trial (Table - 7). Correlation of numbers of transplanted seedlings present in August 1990 and July 1991 gave survival rate of 79% (r = .9753). Regression of the survival rate on the number present in ugust 1990 gave a decline of 5% for each 10 additional plants (r = -.2425).

Secause crown closure and competition for water and nutrients occur more rapidly at narrow
Spacing, the added strain of cutting in coppice stands typically increases mortality, as shown in
Several studies with Eucalyptus and Populus species (Blake 1983). The mortality rate increased
with density in these black locust trials also, as had been predicted. This was true whether
considering planting density (Tables 4.5, 4.6, and 4.8) or the number actually present (Table 4.7).
Im Gliricidia sepium, survival through four forage harvests in the first 15 months was near total
with under 12 seedlings per meter of row. At the highest density (62,500/ha) with 25 per meter of
row, only 60% survived (Sumberg 1986). Survival of leucaena below 62,500/ha (6.25/m²) was
not affected by density nor by planting arrangement (Cooksley and Goward 1988). At such low

The hypothesis that survival is greater with older plants was not supported. The lowest survival rates were found in the last interval for the sown plots (Table 4.5) and in the first, fourth, and last of five intervals for the transplanted plots (Table 4.8). Lower mortality in some plots after 1990 can be attributed to wider spacing of the survivors, but not directly to plant age.

	Mean s	urvivors	Surviv	al ratio	
Date	4/m ²	25/m ²	4/m ²	25/m ²	Probability
Sept. 1988	3.89	22.44			
J uly 1989	3.44	21.28	.88	.95	.1915
Sept . 1989	3.39	19.33	.99	.92	.0580
J why 1990	3.39	18.11	1.00	.94	.1028
Sept. 1990	3.17	15.17	.94	.85	.0408
Sept. 1991	3.06	13.22	.94	.88	.3744
Three year			.78	.61	.0247

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Table 4.8. Numbers of survivors (plants/ m^2) and ratio of survival from the previous date for **Transplanted seedlings at two population densities.**

Optimal density

The hypothesis that optimal density is higher at earlier ages was confirmed, as it declined from 36/m² in 1989 to 4/m² in 1990. No significant yield differences between spacings remained in 1990, the third growing season. This experiment was designed to find the final optimal density, where the yield per area is equivalent to that in more crowded plots and mortality of weak plants ceases, but the search was inconclusive. In these trials, survival at the widest spacing was ignificantly higher, but still below 80% over three or four growing seasons. Though it is possible that mortality would cease at some time after four years, the experiment gave no evidence that a final optimal density actually exists. If it does exist at a harvest height of 30 cm, mortality would be expected to cease somewhere below five plants per square meter.

Defoliation severity and solar interception

The distance between plants not only influenced competition between them, but affected **t**he percentage of foliage removed by harvesting. Even when black locust was cut before the **shaded** lower leaves abscised in late June, the denser spacings (16/m² and above) lost more of their **leaves** than the 4/m² plots did. The 4/m² plots had enough space between the plants so that lower **leaves** could be illuminated adequately, and they remained green until harvest. The denser plots **lost** their lowest leaves before the first harvest in 1989, and had very few remaining after harvest, **generally** 0 - 10%, compared to 25 - 75% for the 4/m² plots. Later harvests were taken at an **earlier** stage of growth so as to retain a partial canopy (about 10 - 25% of leaf area) in the denser **plots**.

The canopy in 4/m² plots did not close until shortly before harvest in 1990 and 1991, but little sunlight was observed reaching the ground, due to the greater height of the stems and the oblique angle of the sun at 42° north latitude. The absence of a closed canopy may account for continued vigorous growth and better survival in 1991, since leaves around the sides of the plants did not abscise from shading, providing more photosynthate per plant and possibly per plot. Mebrahtu (1989) reported that the light saturation level of black locust was above the highest level

tested (1900 umol/m²/second of photosyntheticallly active radiation), and that similar levels had been observed only for lodgepole pine (<u>Pinus contorta</u> Dougl.) among woody plants, which usually reach saturation at 400 to 1100 umol/m²/second. To expose more leaves to the sun and increase photosynthesis, Mebrahtu recommended wider spacing in plantations. Since the plants at the widest spacing showed no evidence of exhaustion or crowding in this study, it remains unknown how many years they would remain productive. Plants at all narrower spacings were clearly exhausted by the fourth growing season, after two years of harvesting.

Spacing recommendations for stand establishment

A perennial forage crop requires enough plants per area to maintain a closed canopy at the harvest height. With the 30 cm height used in this experiment, the widest spacing tested (50 cm apart) was adequate the third growing season, when yield differences were not significant. Survival was also best at this spacing. With higher cutting, even wider spacings could be used, so transplanting seedlings may become an economical means of establishing a crop. But considering the low cost of the seed and the loss of potential yields before canopy closure, narrow spacing of seeds is to be recommended over wide spacing. A thick sowing would probably also be more profitable than transplanting, because of the much higher expenses for seedlings and the labor to plant them. A more thorough comparison of sowing or transplanting black locust has been published (Barrett 1992). The grower should plant enough seed to give a density of over $35/m^2$ when ready to begin harvesting at 30 cm in the second growing season, or should transplant seedlings at $1 - 4/m^2$ depending on the intended harvest height.

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EFFECTS OF YEAR OF FIRST HARVEST ON SURVIVAL AND FORAGE YIELD OF BLACK LOCUST

ABSTRACT

Black locust seeds were sown at five spacings (40,000 - 1,000,000/ha) in a square grid pattern. Plots were harvested at 20 cm height two months after sowing (group 1), or were cut back to 20 cm while dormant before the second growing season (group 2). All were harvested in early and late summer at 30 cm the next two years, and plots of 4 and 16/m² were harvested at 50 cm the fourth year. Black locust seeds from five sources were sown in rows 20 cm apart to give 25/m². Plots were harvested as above, two months after sowing (group 3) or while dormant (group 4).

Harvesting the first year gave slight yields and damaged future productivity. At the July harvest the second year, the average yield of group 1 was 75% of group 2, and only 90% when combined with the first year's total, while the average yield of group 3 was 70% of group 4, and 93% when combined with the first year's total. Two-year totals were significantly higher for group 2, but not significantly different for groups 3 and 4. Yields declined the third year, by 43% for group 1 and 19% for group 2, but increased by 35% for group 3 and 52% for group 4. Third-year yields were significantly higher in groups 2 and 4.

Effects of year treatments on the proportion of dry matter in fresh material were minimal, although sometimes significant. Effects on the branching pattern were significant, but changed over time. The number of plants harvested per plot increased 26% from the first to the second year. Numbers harvested changed little from early to late summer. Survival from the second to third year declined highly significantly with harvesting in the seedling year.

INTRODUCTION

The black locust tree (Robinia pseudoacacia L.) is noted for its rapid juvenile growth, adaptability to difficult sites, and high protein content in new growth. Efforts to cultivate the species as a perennial crop for fuel, fiber, or forage require more information on optimal agronomic practices. These trials were conducted to determine the amount of growth required before initiating harvesting, and the interactions of year-of-first-harvest treatments with seed sources, spacings, and harvest heights. Trials were monitored for three or four seasons, to determine how the treatments affected survival and yields.

Literature review

Although older and larger diameter (greater than 20 - 40 cm) trees of many species typically show reduced coppicing ability, regrowth is usually optimal from sapling-sized trees (Blake 1983). However, Pawlick (1989) warned not to coppice tropical trees until they are well established, and suggested an acceptable height of 300 - 400 cm, nine months to two years after planting.

In black locust, reported maximum heights of 2.5 m for first year seedlings and 4.5 m for the new growth from one year old stumps indicate that harvestable biomass increases with the age of the plant. However, the same report documents wide variation among seed sources in branching patterns, which affect the relation of weight to height, and root to shoot ratios averaging 0.41, with a range of 0.27 to 0.55, which affect the vigor of coppice growth (Mebrahtu 1992). In a study of 25 black locust seed sources, first year heights averaged 84 cm and ranged from 64 to 98 cm. The heights of second year and third year coppice sprouts (above the 30 cm stumps) ranged from 84 to 200 cm, and 120 to 270 cm, averaging 140 cm and 220 cm, respectively (Genys and Harman 1990).

After one year in the field in Uttar Pradesh, India, at a spacing of 50 cm by 50 cm, black locust seedlings were found to consist of 31% stem, 24% branches, and 45% roots (collected down

to 45 cm). Black locust had the highest proportion of branches of six species tested (Bhatt and Todaria, 1991).

Annual forage yields of <u>Leucaena leucocephala</u> (Lam.) de Wit. and <u>Gliricidia sepium</u> (Jacq.) Walp. increased with age of first harvest up to 21 months, the longest period tested. The yield of regrowth varied directly with stump size (Blair <u>et al</u>. 1990). Increasing stump diameters and biomass production with age at first harvest have also been reported in <u>Sesbania macrantha</u> (Holden <u>et al</u>. 1989). A comparison of newly sown and one year old stands of <u>Sesbania sesban</u> (L.) Merr. var. <u>nubica</u> revealed no significant yield differences at three harvest heights and three interval lengths (Galang <u>et al</u>. 1990).

In summary, variations among black locust seed sources in growth rate, and the proportion of first year growth allocated to roots, stems, and branches will cause variations in the proportion of biomass removed by a harvest treatment at a constant height. This could lead to significant interactions between seed sources and years of first harvest treatments. Spacing treatments, which affect the allocation of growth to stems and branches (and possibly to roots as well) could interact with the year treatments. Experience with other species indicates that the size of the first harvest varies directly with the size and age of the plants, but the pattern of cumulative yields has not been reported and requires more investigation.

Objectives

It was expected that delaying the year of first harvest would improve yields in the second year, but the pattern of cumulative yields from all harvests was not known. It was also desired to determine whether the age of the plants at first harvest leads to differences in mortality, the percentage of dry matter, and the branching pattern. An experiment was designed to test the following hypotheses:

1. Yields the second year are higher for plots not harvested the first year.

2. Cumulative yields for first and second years are similar to second year yields for plots not harvested the first year.

3. Cumulative yields for first, second, and third years are lower than cumulative second and third year yields for plots not harvested the first year.

4. Dry weight percentage the second year is lower for plots not harvested the first year.

- 5. Number of leaders harvested the second year is higher for plots harvested the first year.
- 6. Survival is not affected by harvesting the first year.
- 7. Survival rate increases with plant age.

8. Interactions of year-of-first-harvest treatments and other treatments are not statistically significant for any measured parameters.

MATERIALS AND METHODS

General information for all trials

A bulk mixture of equal numbers of seeds from four Michigan sources was planted. The sources were selected on the basis of availability, and not for any judgement of quality. The seed accessions were 442 from Russ Forest in Cass County, 445 from the corner of Sandhill and Hagadorn roads, and 446 from the Dansville State Game Area, both in Ingham County, and 450 from Kellogg Forest in Kalamazoo County. Prior to sowing, the seeds were scarified in concentrated sulfuric acid for 50 minutes. They were directly sown in late June 1988 at the Michigan State University Tree Research Center in East Lansing (420 41' N, 840 28' W). The nursery beds were surrounded by evergreen windbreaks and had been fumigated with methyl bromide. The soil was mapped as a complex of soil series including Riddles, Hillsdale, Owosso, and Marlette, all of which were well drained with 2% to 6% slopes and sandy loam topsoil. Subsoils were sandy loam, loam, or clay loam (Soil Conservation Service 1979).

Prolonged heat and drought in 1988 impaired growth and sprinkler irrigation was necessary. After normal weather returned in mid August, growth was rapid until early September, with seedlings reaching heights of 60-120 cm. In 1989, 1990, and 1991 growing conditions were favorable. Because the soil had been fumigated, there were few weed problems in 1988. In the spring of 1989 and 1990, the plots were sprayed with glyphosate (trade name Roundup) at 0.7 kg active ingredient/ha and DCPA (trade name Dacthal) at 8.4 kg active ingredient/ha. Potassium sulfate (0-0-50) fertilizer was added at the rate of 225 kg/ha (112 kg/ha K₂O) on May 7, 1990, to bring soil potassium levels up from around 90 kg/ha. No other fertilizer was applied.

In each plot, all new growth above the designated harvest height was cut with hand tools and bagged to determine the fresh weight. The paper bags of harvested material were dried in an oven at 60°C for at least three days before measuring the dry weight. Weights per plant were calculated from the number of plants harvested. Multiple sprouts from the same root were counted as one plant. Shoots from different roots were counted as separate plants. Due to the presence of suppressed seedlings, the total survival in 1989 was often higher than the number harvested, but few suppressed seedlings survived to 1990. Survival to 1991 was often higher than the number harvested that year because of rabbit damage on the smallest plants.

All trials were planted using a randomized complete block design. Analysis of variance, Duncan's multiple range tests, and other statistical operations were conducted on NCSS computer programs (Hintze 1987). The probability level reported for each factor below a table is the probability of the difference between treatments occurring by chance, according to F-test comparisons.

Identity of groups referrred to in the text:

Trial	Cut 1988	Cut 1989
30 cm	Group 1	Group 2
5 cm	died	Data omitted
Spacings	Group 1	Group 2
Seed sources	Group 3	Group 4

Grid plots at two harvest heights

The field was divided equally for the two year-of-first-harvest treatments. Each treatment was on one side of the field, so the effect of soil variation was uncontrolled. Within each side, a randomized complete block design was used with 10 plots in each of four replications. Each replication contained all combinations of two height treatments and five spacing treatments. Spacing treatments were included in the analysis of variance, but will not be reported here.

In late August 1988, 65 days from sowing when most seedlings were 20 - 30 cm tall, plots in one half of the field were harvested at either 5 cm or 20 cm above the ground. The weak regrowth was consumed by rabbits during the winter. Most 5 cm stumps died and were frostheaved out of the ground before spring, so those plots were discontinued. Survivors at 5 cm were counted in July, 1989, but not harvested. Survivors at 20 cm were harvested in July, 1989 and at later dates; results are given in the report of the spacing trial (Chapter 4).

In March 1989, the previously uncut plots in the other half of the field were cut back to 5 or 20 cm (but not harvested and measured) while dormant. These plots were harvested at 5 and 25 cm between June 28 and July 5, and the numbers harvested were counted for comparison with the plots first cut in 1988.

Grid plots at five spacings

This trial used a subset of the plots planted for the harvest height trial described above. The field was divided for the two year treatments, with each side containing four replications in a randomized complete block design. Each replication consisted of five plots representing all spacing treatments. At the July harvest in 1989, yield data were recorded from three replications only, but plant numbers were recorded from all replications. Cumulative yields which included July 1989 data are also reported for three replications, resulting in inconsistent tables.

Seeds were planted by hand in June, 1988, in a grid pattern, 10, 12.5, 16.7, 25, or 50 cm apart, to give 100, 64, 36, 16, or 4 seedling positions per 1.0 m² plot, respectively, with one or two border rows on each side. The size of the planted area was about 4.0 m² for each plot. Multiple

seedlings were frequent because two to four seeds were sown at each grid position. Gaps were replanted with seeds in early July, and with seedlings (transplanted out of designated pathways) in early August.

In late August 1988, 65 days from sowing when most seedlings were 20 - 30 cm tall, plots in one half of the field were harvested at 20 cm above the ground. This set of plots harvested at 20 cm in 1988 was designated Group 1. In March 1989, plots on the uncut side of the field were cut back to 20 cm while dormant, and the stems left to decay on the ground. This set of plots first cut at 20 cm in 1989 was designated Group 2.

Plots in both groups were harvested at 25 cm between June 28 and July 5, and again at 30 cm between August 23 and 31, 1989. In 1990, first harvests were taken between June 18 and 22, and second harvests between August 16 and 27, all at 30 cm. In 1991, because of the reduced availability of labor, first harvests were taken from plots of 4 and 16/m² only, between July 10 and 17, at a height of 50 cm. Because of shading from nearby uncut plots and feeding by rabbits, no second harvest was possible in 1991, and after counting survivors at all spacings, the trial was terminated.

Row plots with five seed sources

The trial included as treatments five seed sources (four accessions and a mixture for the control) and two years of first harvest. The field was divided in half for the year treatments, so the effect of soil variation was uncontrolled. Each half contained four replications of five plots in a randomized complete block design. In July 1989 yields were recorded from three replications only.

Plots consisted of five rows 20 cm apart, with an area of 1.00 m². Two outside border rows on the east and west sides were planted with the bulk mixture, giving nine rows with a total width of 1.8 m. Interior border plants on the north and south sides were from the same seed source as the plot. Plots were sown by hand with 50 seeds to give stands of 25/m², and small seedlings were transplanted where necessary. Spacing of survivors within the five rows was random.

Half the field was harvested at 20 cm in August 1988. The other half was cut back to 20 cm while dormant in March, 1989. All plots were hand harvested at 25 cm in July 1989 and at 30 cm in August 1989, June 1990, and August 1990. The trial was ended at the August 1990 harvest. During the August 1988 harvest, plots were thinned to at most 30 seedlings/m². The unharvested plots were not thinned, but mortality over the winter resulted in nearly equal populations on both halves of the field.

RESULTS AND DISCUSSION

Dry weight yields per plot

In the grid plots, effects of year treatments in 1989 were highly significant in July and nonsignificant in August, while the interaction with spacing treatments was not significant at either time (Table 5.1). The July average yield of 380 g/m^2 for group 1 was 75% of the yield for group 2, and even combined with the 1988 average of 76 g/m², it reached only 90% of the yield of group 2. In August there was no significant variation in regrowth yields; group 1 averaged 95% of group 2. The yields at both harvests in 1990 varied highly significantly with year of first harvest. The group 1 plots averaged 57% and 55% of the yields of group 2 in June and August, respectively.

Although growing conditions were excellent both years, and fertilizer was added at the start of the 1990 season, yields declined from 1989 to 1990; the total 1990 yield was 43% below 1989 for group 1, compared with 19% below for group 2, so that group 1 yields declined from 79% to 55% of the yields of group 2.

Cumulative yields from 1988 to 1990 of group 1 compared with group 2 ranged from 56% at 4/m² to 99% at 16/m² (Table 5.2), averaging 77% (Table 5.1). The interaction of spacing and year treatments was not statistically significant for any single harvest, but was significant for the 1989 total yield. For the subset of plots of harvested in 1991 (4 and 16/m² only), yield differences

	Year treatment group		Probability of F-value			
Harvest	1	2	Year	Spacing	Interaction ¹	
8/1988	76	-	-	.0000	-	
7/1989 ²	380	504	.0015	.0004	.0641	
8/1989	109	115	.6202	.2221	.5867	
All 1989 ²	489	619	.0005	.0000	.0196	
6/1990	99	174	.0003	.8015	.5965	
8/1990	179	327	.0002	.7083	.7739	
All 1990	278	501	.0000	.7902	.6106	
Total ²	857	1112	.0000	.0000	.1596	

Table 5.1. Dry weight yields per plot (g/m^2) from grid plots with first harvests in the seedling year (group 1) or a year after sowing (group 2).

Interaction of first harvest year and spacing factors.
 Three of four replications used.

	4/m ²		16/	^{m2}	Pro	Probability of F-value		
Harvest	1	2	1	2	Year	Spacing	Interactio n ¹	
8/1988	8		60			.0216		
7/1989	103	233	490	412	.5084	.0002	.0284	
8/1989	112	117	131	125	.9760	.4305	.7275	
6/1990	98	163	147	168	.0713	.1957	.4623	
8/1990	153	330	175	305	.0186	.9761	.6326	
7/1991	252	579	126	316	.1366	.2445	.6640	
Total	726	1422	1129	1336	.0754	.4780	.2853	
I Ir	teraction of f	irst harvest y	ear and spacing	ng factors.				

Table 5.2. Single harvest and cumulative dry weight yields (g/m^2) from grid plots of 4 and $16/m^2$ first harvested the seedling year (group 1, 1988 - 1991) or a year after sowing (group 2, 1989 - 1991).

due to year of first harvest became significant only in August, 1990 (Table 5.2). Although cumulative four-year yields of group 1 were 51% and 85% of the three-year yields of group 2 at 4/m² and 16/m², respectively, the year effect was not significant. The year by spacing interaction was significant in July, 1989 only.

In the row plots, effects of year treatments were highly significant in July and nonsignificant in August of 1989, while the interaction with seed sources was not significant at either time (Table 5.3). For both harvests combined, year treatments were not statistically significant, but the year by seed source interaction was. Group 3 yielded 70% as much as group 4 in July, 114% in August, 87% for the entire year, and 102% for 1988 and 1989 together. In 1990, effects of the year treatment were significant at both harvests, and highly significant for both harvests combined, while the interaction was not significant. Group 3 yielded 80% as much as group 4 in June, 76% in August, and 78% for the entire year. Average annual yield levels rose 35% for group 3 and 52% for group 4 in 1990 compared to 1989. The three-year total for group 3 was 89% of the two-year total for group 4, and not significantly different.

Savory <u>et al.</u> (1980) reported that leucaena forage yields tended to rise over the first four years, presumably due to greater root penetration. Yields have risen over the first three years in some of these black locust trials, including transplanted seedling plots which were not fertilized (Barrett 1992; Chapter 4). In the directly sown plots at five densities, yields declined the third year (Table 5.1), even with applied fertilizer. In the fourth year, 1991, only the two widest spacings were harvested, in July only. Still, it is clear that the plots of 4/m² gave higher yields each year, as the canopy became more complete, and would have produced much more the fourth year if there had been a second harvest (Table 5.2). The yields of the 16/m² plots did not continue rising, and may have given their peak yields in the second year when the canopy first closed. Declining yields *in measured* plots may have been due to shading by the more vigorous plants in the outside border *rows*, so that the forage yield of the entire plantation may have continued rising.

	Year treatr	nent group	Probabili	ty of F-value
Harvest	3	4	Year	Interaction ¹
8/1988	75	-	-	-
7/1989 ²	226	322	.0089	.0760
8/1989	249	218	.1317	.6677
All 1989 ²	438	501	.0968	.0422
6/1990	235	294	.0180	.6837
8/1990	357	469	.0150	.8465
All 1990	592	763	.0045	.8595
Total ²	1105	1240	.1032	.3676

Table 5.3. Dry weight yields per plot (g/m^2) from row plots with first harvests in the seedling year (group 3) or a year after sowing (group 4).

Genys and Harman (1990) recorded dry weights of third-year black locust coppice sprouts of 1.3 to 7.0 kg/m², averaging 3.6 kg/m² for 25 seed sources. Stump density averaged 17/m², and the weights included wood and bark but not foliage. Third-year coppice sprouts in the present experiment were harvested in June and August, 1990. Cumulative 1990 yields, including foliage, ranged from .278 kg/m² in group 1 to .763 kg/m² in group 4. Factors that would account for the much higher yields reported by Genys and Harman (1990) include the use of different seed sources, a longer growing season and different soils at their experimental site in Maryland, and harvesting of coppice shoots only once a year, while dormant, rather than twice a year during the growing season. Yield reductions of over 45% have been reported for harvesting twice compared to once during the growing season (Barrett 1992).

Two hypotheses, that not harvesting the first year gives higher yields the second year, and that cumulative yields over three years would be lower in groups 1 and 3, were confirmed. Another hypothesis, that cumulative yields for first and second years are not affected by year treatment, was refuted by results from groups 1 and 2, but supported by results from groups 3 and 4. Yields were usually significantly higher for groups 2 and 4, and when all harvests from 1988 through 1990 were added together, group 2 yielded highly significantly more than group 1, but there was no significant difference between groups 3 and 4. But with the advantage of groups 2 and 4 increasing with time, it is likely that both groups would have yielded significantly more than the other treatment over a longer period than the duration of these experiments.

Dry weight yields per plant

Yields of plots were influenced by the number and vigor of survivors. Comparisons of dry weight yields per plant were used to determine whether harvesting the first year had an effect on vigor separate from the effect on survival.

In grid plots, year treatment effects were highly significant at the first harvest of 1989 (Table 5.4), but at the second harvest, the effect was not significant. Group 1 yields were 64% and 105% of Group 2 in July and August, respectively. In 1990, year treatment effects were

	Year treatment	nt group	Probability of F-value	
Harvest	1	2	Year	Interaction ¹
8/1988	2.6	-	-	-
7/1989 ²	12.9	20.2	.0000	.0641
8/1989	7.7	7.3	.7095	.4851
6/1990	8.4	12.7	.0159	.0857
8/1990	14.6	22.9	.1097	.6239

Table 5.4. Dry weight yields per plant (g) from grid plots with first harvests in the seedling year (group 1) or a year after sowing (group 2).

Interaction of first harvest year and spacing factors.
 Three of four replications used.

significant at the first harvest only. Group 1 yields were 66% and 64% of Group 2 in June and August, respectively. The interaction with spacing was not significant at any time. In the subset of plots of 4/m² and 16/m² harvested in 1991, the effects of the year treatment and the year by spacing interaction were never statistically significant.

In row plots in July 1989, the effect of harvest year on weight per plant was highly significant, with group 3 yielding only 59% of group 4 (Table 5.5). The effect was not significant in August, 1989, when yields per plant were identical. The year effect was significant in both July and August, 1990, when group 3 yielded 80% and 77% of group 4, respectively. The interaction with seed sources was never significant.

Yields per plant increased with each harvest in groups 1 and 3 from 1988 through 1990, but the levels declined in groups 2 and 4 from July to August 1989, before increasing at the next two harvests. Because each remaining plant has more space after some die, a slight increase in yield per plant was expected over the years.

Genys and Harman (1990) stressed the importance of considering both weight per plot and per plant when judging productivity of black locust. Their tallest seed source was the most productive per plant at 256% of the mean, but because there were only eight such trees/m² compared to an average of 17/m², the productivity per plot was only 118% of the mean. Pecson and Brewbaker (1991) noted that larger stumps in a leucaena spacing trial had more coppice shoots, and that the correlation of number of shoots and stump basal area was highly significant. When the first harvest of <u>Sesbania macrantha</u> was delayed three or four months (date of first harvest not reported) during the growing season, average stump diameter increased from 24 to 42 mm (Holden et al. 1989).

Mebrahtu and Hanover (1989) found that black locust root cuttings of larger diameter sprouted sooner and maintained a height growth advantage over cuttings of lesser diameter. Since the results of this study indicated no sprouting time difference for coppiced stumps related to diameter in 1989 or 1990, it is uncertain whether root biomass size, which is related to age at first harvest, would have had an effect on growth in the field trials.

	Year treatment group		Probability of F-value		
Harvest	3	4	Year	Interaction ¹	
8/1988	3.2	-	-	-	
7/1989 ²	8.9	15.1	.0000.	.0713	
8/1989	10.1	10.1	.9893	.4382	
6/1990	10.2	12.8	.0126	.3337	
8/1990	16.1	20.9	.0262	.9067	

Table 5.5. Dry weight yields per plant (g) from row plots with first harvests in the seedling year (group 3) or a year after sowing (group 4).

Interaction of first harvest year and seed source factors.
 Three of four replications used.

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In this study, the difference in weights per plant between year treatments, when significant, always favored groups 2 and 4 which were not cut until the second year. Except for the interval between July and August, 1989, the weight per plant increased with time, as expected.

Changes in dry weight / fresh weight ratio

The dry weight/fresh weight ratio (D/F) represents the dry matter percentage of the green biomass. Significant differences in the D/F were found between the grid plot groups in 1989 only. The D/F ratios for groups 1 and 2, respectively, were 23.4% and 25.5% in July, and 23.9% and 24.7% in August, 1989. For the row plot groups, the year effect was significant in July 1989, and highly significant at the three following harvests, while the interaction with seed sources was never significant. The D/F ratios for groups 3 and 4, respectively, were 24.6% and 28.3% in July, 1989, 24.6% and 25.0% in August, 1989, 24.5% and 25.1% in July, 1990, and 25.2% and 27.1% in August, 1990.

The greatest difference between year treatments found in four seasons was 3.7% moisture by weight, and it was usually under 2.0%. This slight difference in D/F appeared to depend on the size of harvested stems. In every case of statistical significance, the group first cut in 1988 had less dry matter content than the group cut in 1989. Delaying harvesting until the second season produced larger stems with a higher proportion of wood, and a thus a higher D/F percentage. The hypothesis that D/F the second year is lower for plots not harvested the first year was refuted.

Number of branches harvested in row plots

In 1989 and 1990 when the row plots were harvested at 30 cm, the number of upright branches cut was recorded (Table 5.6), and the average number of branches per plant harvested was calculated.

The number of branches per plot was significantly higher in group 3 than in group 4 in July (17% higher) and August 1989 (31% higher) (Table 5.6). In June, 1990, the number per plot was slightly higher for group 4, and in August group 3 had only 80% as many cut branches as group 4, a highly significant difference. Numbers harvested increased from the first harvest to

	Year treat	tment group	Probabili	robability of F-value	
Harvest	3	4	Year	Interaction ¹	
8/1988					
Plant	1.1	-	-	-	
Plot	27	-	-	-	
7/1989 ²					
Plant	2.2	2.3	.5492	.0230	
Plot	55	47	.0500	.0071	
8/1989					
Plant	3.4	3.1	.0487	.0324	
Plot	84	68	.0025	.0097	
6/1990					
Plant	4.4	4.8	.0665	.8843	
Plot	98	110	.1233	.9129	
8/1990					
Plant	2.8	3.6	.0003	.7901	
Plot	66	83	.0016	.9921	

Table 5.6. Numbers of upright branches cut per plant and per plot from row plots with first harvests in the seedling year (group 3) or a year after sowing (group 4).

¹ Interaction of first harvest year and seed source factors.

June, 1990, but declined at the last harvest. The interaction with seed sources was highly significant at both harvests in 1989, but not significant at either harvest in 1990.

The average number of branches harvested per plant varied significantly due to year treatments at the August harvests both years, but not in the early summer harvests (Table 5.6). Group 3 averaged fewer branches than group 4, except in August, 1989. The widest variation was in August, 1990, when group 3 averaged 78% of group 4. Average numbers increased from August, 1988 to June, 1990, but declined in August, 1990. The interaction with seed sources was significant at both harvests in 1989, but not significant at either harvest in 1990.

Average stem numbers per plant and diameters declined as density increased in leucaena plots (Cooksley and Goward 1988). The same effect on branch numbers was observed in black locust plots (Barrett, unpublished data). The effect of delaying the first harvest was to produce significantly fewer branches per plant and per plot in 1989 and significantly more in 1990. The hypothesis was supported that the number of leaders harvested the second year is higher for plots harvested the first year, but the pattern reversed in the third year, making any conclusions uncertain. The important factor related to yields is not the number of branches, but how rapidly the plants can form a closed canopy, and it was clear that this could have been accomplished with fewer than 10 plants/m². When there were over 20 plants/m², it mattered little how many branches each plant had.

Survival after harvesting

If all grid spaces had been filled with one seedling, the mean of all spacings would be 44 plants per plot. All grid plots were sown alike with extra seeds, giving an average of 51 for the 5 cm plots in 1988. It should be assumed that all treatments had similar surplus germination, but that some seedlings died over the first winter. The group 1 plots harvested at 20 cm in 1988 averaged 46 plants/m² harvested in July, 1989, representing 90% of the 51/m² presumed to have been present in 1988. Therefore, winter mortality was about 10% for those cut at 20 cm (group 1), while it was 73% for seedlings cut at 5 cm in 1988.

Table 5.7 gives a false impression of survival, because at the first harvest in August, 1988, not all seedlings exceeded the 20 cm harvest height. Plants of group 1 that escaped cutting continued to grow for the rest of the season and survived well over the winter, giving an increase of 21% over the 1988 level when harvested in July 1989.

Year effects on the numbers harvested in grid plots were significant in July but not in August, 1989, when group 1 outnumbered group 2. In 1990, group 2 had significantly more plants harvested at both dates. Group 2 had higher yields per plot and per plant both years (Tables 5.1 and 5.4). The survival difference was not significant in 1991, and the interaction with spacing was never significant. The most deaths occurred over the winters and in group 1.

In row plots, the average numbers harvested in group 3 rose from 1988 to July 1989, and then declined at the next two harvests before rising again at the last harvest (Table 5.8). In group 4, numbers harvested increased at each harvest. These increases were caused by the height growth of plants which were below the harvest height at one harvest and above it at the next, and not by delayed germination of surplus seeds. By harvesting in early and late summer, the amount of sunlight reaching the weak seedlings was increased, and the relative advantage of stronger seedlings was reduced. Although numbers harvested were significantly lower for group 4 compared to group 3 at both 1989 harvests, there were no significant differences in 1990. The interaction with seed sources was significant in August 1989.

The two hypotheses, that survival is not affected by harvesting the first year, and that survival is higher with older plants, were refuted by data from grid plots, while the pattern in row plots was inconclusive, except that numbers harvested could not continue increasing indefinitely.

	Year treatment group		Probability of F-value	
Harvest	1	2	Year	Interaction ¹
8/1988	38	-	-	-
7/1989	46	36	.0142	.1438
8/1989	35	31	.1045	.1953
6/1990	20	26	.0193	.1443
8/1990	23	29	.0373	.2083
7/1991	11	13	.4431	.2133

Table 5.7. Number of plants harvested from grid plots with first harvests in the seedling year (group 1) or a year after sowing (group 2).

¹ Interaction of first harvest year and spacing factors.

	Year treatment group		Probability of F-value	
Harvest	3	4	Year	Interaction ¹
8/1988	23.5	-	-	-
7/1989	25.1	19.8	.0006	.2368
8/1989	24.9	22.5	.0416	.0359
6/1990	22.6	23.0	.7179	.4366
8/1990	23.5	23.3	.8322	.3148

Table 5.8. Number harvested from row plots with first harvests in the seedling year (group 3) or a year after sowing (group 4).

¹ Interaction of first harvest year and seed source factors.
Interactions of year treatments with other factors

Many responses to year treatments varied according to seed source or spacing, so that the last hypothesis, that no statistically significant interactions would be found, was refuted. Examination of the eight tables in this chapter shows that out of 22 and 23 possible interactions with spacing and seed sources, respectively, zero and two were significant at the 1% level, with two and four more interactions significant at the 5% level. The interactions with spacing were significant at the 5% level twice out of 22 times, which can easily be attributed to chance, while only 17 of 23 interactions with seed sources were non-significant. Genotype by treatment interactions were important, especially concerning branching behavior, and future researchers should be alert for them.

Delaying the initial harvest beyond the second growing season

Pawlick (1989) warned not to coppice trees until they are well established, and suggested an acceptable height of 300 - 400 cm, nine months to two years after planting. The time of first harvest treatments on black locust were on plants two months old and about 30 cm tall, compared to plants about 100 cm tall with four months of growth. Under cultivation, black locust trees would usually reach a height of 300 - 400 cm in the second growing season, 15 - 18 months after sowing. Waiting to harvest black locust seedlings until the third growing season would certainly increase the annual yield, but it is uncertain when or if cumulative yields would surpass those of plantings harvested the second year, and whether such a delay could be economically justified in practice. Commercial production of leucaena for leaf meal in Malawi starts when the plants are about 100 cm tall, one year after sowing; yields of leafy material are usually less than 0.3 tons dry weight per ha (Savory <u>et al</u>. 1980). This would be under 30 g/m², compared to 75 g/m² of leafy material harvested two months after sowing in this study, and far lower than the yields one year after sowing. Thus, yields of black locust would appear to be adequate for commercial production.

Considering the high costs of either removing the large stumps from a depleted coppice stand and replanting mechanically, or transplanting large numbers of replacement seedlings by

hand, delaying the first harvest until the third year appears advisable if it substantially reduces mortality. Another reason to consider a further delay is when direct sowing is not practical and the trees must be established by transplanting. To reduce planting costs, fewer seedlings would be planted at a wider spacing, necessitating a longer establishment period to close the canopy. Future research should address how long to delay the first harvest, in combination with wider spacing treatments than those tested here, and harvest heights above 30 cm.

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AN IDEOTYPE FOR TREE SPECIES GROWN AS PERENNIAL FORAGE CROPS, WITH SPECIAL REFERENCE TO BLACK LOCUST

INTRODUCTION

The black locust tree (Robinia pseudoacacia L.) has rapid growth, nitrogen fixation capability, high protein content, a deep taproot, and many other features that would make it a good forage crop plant. By growing black locust seedlings at close spacings with annual coppicing at 30 cm, annual dry weight yields of up to 14 tons/ha were obtained (Barrett 1992). Yield improvements are possible from refinements in cultivation practices, and also from selective breeding.

Selecting for high yielding ability from a diverse wild population can take two approaches, conventional breeding or ideotype breeding. Under the conventional approach, large numbers of genotypes grown under standard conditions are rated for productivity, and the best retained for the breeding population. By selective pollination, a large number of progeny are produced, and the cycle is repeated. Testing the progeny to select the parents is a variation on the conventional approach. The ideotype approach is to define characteristics known or expected to improve productivity, and then select individuals for the breeding population according to how closely they conform to the list of desired features, rather than at random. By not measuring yield in the first generation, a great deal of time and effort can be saved, and a larger population can be screened. This is especially important when breeding trees, which can take many years to reach reproductive age. Selecting without measuring yield is also an advantage for forage crops, because the seed-bearing portion of the plant is generally removed by harvesting. When breeding black locust or

any other woody species for use as a forage crop, the ideotype approach should be seriously considered.

DEFINITION OF IDEOTYPE

Ideotype refers to a biological model expected to perform well in a given environment. It is an idea, and an ideal, which plant breeders strive for in cultivar development. Attaining this goal is expected to result in higher yields of useful products, or at least higher profits to the grower. The word ideotype should not be confused with idiotype, properly used to describe all the hereditary influences on an organism, and more inclusive than the word genotype. Phonetically, ideotype is accented on the second syllable, and idiotype on the first (Zevin 1975). In practice, an ideotype must involve heredity, but it describes an unreached ideal, while an idiotype already exists.

As Rasmusson (1987) wrote, "An ideotype is a hypothetical plant described in terms of traits that are thought to enhance genetic yield potential. Ideotype breeding is defined as a method of breeding to enhance genetic yield potential based on modifying individual traits where the breeding goal (phenotype) for each trait is specified."

THE IDEOTYPES OF CULTIVATED PLANTS

Donald and Hamblin (1976) defined three types of ecosystems for cultivating plants, as widely spaced plants without competition, as a mixed community in competition, and as a dense monoculture. The criteria for high yields are different in each situation, requiring "isolation", "competition", and "crop" ideotypes, respectively. The isolation ideotype may be useful for orchard or landscape trees, but it is not pertinent to this discussion. The competition ideotype must be able to gain a larger share of nutrients, water, and sunlight at the expense of its neighbors, so it is rapid growing, tall, spreading, and leafy. In contrast, the crop ideotype is erect and narrow, with small erect leaves, which do not shade its neighbors. Leaves, roots, and branches of individuals are at the minimum level required to fully exploit the resource by the entire community rather than by single plants, which must be weak competitors. Plant parts not included in the harvest are a small portion of the total biomass. In a dense monoculture, yield per area becomes more important than yield per individual plant. Donald and Hamblin (1976), writing about cereal grains, emphasized that a successful cultivar will have a greater biological yield at high density or fertility, and will maintain a high harvest index (the harvested part being a high percentage of total biomass). These principles also apply to tree plantations and forage crops.

GENERAL OBSTACLES TO IDEOTYPE BREEDING

Usually, ideotype breeding proceeds in three steps. First, the important traits are selected and a phenotypic goal is set for each. Next, adequate genetic diversity for a breeding program must be verified. Finally, each trait must be tested, in different genetic backgrounds and under a variety of conditions (Rasmusson 1987). Then the traits that are known to improve yield can be combined into cultivars. However, they do not always behave as expected.

Four types of trait interrelationships that often slow breeding programs are symmetry or harmony in size of plant parts, compensation among plant parts, pleiotropy, and genetic background. These were noted as obstacles to ideotype breeding of cereal grains (Rasmusson 1987), but apply as well to any type of breeding program for any plant. Symmetry requires a plant to maintain a balance among its components, so that it is impossible to enlarge the harvested portion at the expense of the other parts. Compensation occurs in the yield of a product that depends on more than one yield component. For example, an effort to raise the yield of seeds by increasing the number per fruit may fail because fewer fruits or smaller seeds are produced. With pleiotropy, a gene that was presumed to raise yield actually has negative effects that reduce it. When desired genes are available only in low-yielding parents, many breeding cycles are required to incorporate the positive genes and remove the negative ones. It is possible that some genes will be rejected as negative, when they would have raised yield if placed in a different genetic background.

A general obstacle to tree breeding is the length of time required, both to select for quality of the harvested portion, and to obtain the next generation. Because of this, and the fact that effective selection is limited to two or at most three traits at a time, most ideotype criteria must be met by choosing a suitable multi-purpose tree at the species level.

IDEOTYPES OF CULTIVATED TREES

The two factors with the most influence on an ideotype are the agroecosystem where it is to be grown, and the commodity or service to be produced. Many trees, especially legumes, can be managed for multiple products, often simultaneously. Black locust has been grown for honey, forage, fuel, poles, posts, pulpwood, and lumber.

The first tree crop ideotype published was for producing wood fiber under short rotation intensive culture. Dickmann (1975) described an ideotype with eight features:

- 1. rapid juvenile growth
- 2. indeterminate shoot growth
- 3. upright single stem habit
- 4. narrow crown with steep branch angle
- 5. high shoot/root ratio (aided by good nutrition)
- 6. ease of establishment and regeneration
- 7. acceptable product quality
- 8. freedom from major insect and microbial pests.

Later, Dickmann (1985) expanded the ideotype by adding other qualities:

9. low competition between neighbors, resulting in:

- A. stands with a narrow range of stem diameters
- B. low mortality before harvest
- C. high productivity per unit of area
- 10. high response to inputs, such as:

A. weed control before crown closure

B. adequate nutrient levels

11. nitrogen fixation or ability to dominate n-fixing intercrop

- 12. phenotypic plasticity allowing rapid crown closure but little competition later with neighbors, OR
- 13. tolerance to common herbicides
- 14. optimal phenology for rapid growth in environment:
 - A. rapid growth early in season
 - B. leaves retained until late autumn
 - C. cambium active until late in season
- 15. delayed reproduction and/or minimal fruiting
- 16. short internodes to maximize leaf number
- 17. strong taproot.

With the exception of conifer breeders in Finland, the ideotype concept has not been popular among forest geneticists, and few tree ideotypes have been published (D. I. Dickmann, personal communication). Whether the word ideotype was used or not, a number of authors have provided lists of desirable features for cultivated trees. While the designated agroecosystems ranged from short rotation intensive culture systems for the temperate zone to subsistence farms in the tropics, all the following publications were useful in preparing an ideotype for a tree grown as a perennial forage crop.

Felker and Bandurski (1979) proposed a tree crop ideotype to minimize expenditures of capital, fossil fuels, and machinery. Anderson and Zsuffa (1984) proposed 11 ideotype features for biomass plantations of <u>Populus</u> and <u>Salix</u>. Kang <u>et al</u>. (1984) gave nine desirable criteria for woody species suitable for alley cropping. Ranney <u>et al</u>. (1985) stressed several parameters to evaluate in selecting species and cultivars for short rotation energy and fiber use, and Koski and Vihera-Aarnio (1986) mentioned 11 items. Von Maydell (1989) discussed eight features required by food producing trees and shrubs in semi-arid regions, but the qualifications apply to multipurpose trees generally. Chuntanaparb and Ranganathan (1990) reported on the ideotypes of multi-purpose trees preferred by farmers in six countries of south and southeast Asia. Ponce <u>et al</u>. (1991) investigated the multi-purpose tree species ideotypes preferred by farmers in two villages on the island of Leyte, in the Philippines. Anderson <u>et al</u>. (1991) considered eight desirable attributes for tree genera suitable for short rotation forestry in southern Ontario, and selected <u>Populus</u>, <u>Salix</u>, Robinia, and Alnus. The six items that appeared most frequently in the above lists and ideotypes

were easy establishment, rapid growth, deep roots, nitrogen fixation, rapid regeneration after pruning or coppicing, and resistance to insects and disease.

PERENNIAL FORAGE CROP TREE IDEOTYPE

This list is a summary compilation of a number of previous lists. It must be kept in mind that not all features are necessary for improving forage yields, that no single species or cultivar can be expected to posess all of them, and that some of the features may be mutually exclusive. Two debatable points from Table 6.3 require clarification. If optimal phenology for rapid growth is taken to mean early bud break to maximize the length of the growing season, then the relatively late bud break of black locust is not optimal. If it is defined as late bud break to avoid spring frost damage, then black locust fails again, for in central Michigan in 1989 and 1992 the flower buds were killed by frosts in May. Although the phenology of black locust may indeed be judged inferior to most other tree species, its growth rate is more rapid despite these failings. On another point, most authors emphasize the vulnerability of black locust to borer insects. While insect damage typically renders the wood unfit for commercial lumber, it would not impair the production of forage from small or coppiced trees.

Plant Part	Feature
Roots	1. nitrogen fixation by symbiotic microbes ¹
	2. deep, extensive root system to survive drought ¹
	3. adaptable surface root system to nourish plant ¹
Stems and	1. rapid growth early in season ⁴
branches	2. rapid regeneration after pruning stem tips ²
	3. indeterminate shoot growth ¹
	4. short internodes to maximize leaf number4
	5. leaves spirally arranged on stem ²
	6. no thorns or spines ⁴
	7. cambium active until late in season ³
	8. coarse bark to protect from wildlife damage4
	9. good forage quality of new growth ⁵
	10. phenotypic plasticity, allowing rapid crown closure but little competition
	later with neighbors ²
	11. rapid healing of wounds ⁴
Foliage	1. rapid leaf area growth early in season ⁴
	2. rapid regeneration after pruning ²
	3. narrow or compound leaves to minimize self-shading ¹
	4. high light saturation level ¹
	5. high net photosynthesis rate ¹
	6. low light transmission through heavy foliage ²
	7. long leaf retention time (until late autumn)4
	8. rapid leaf position adjustment ¹
	9. good fodder qualities:
	A. no hazardous toxins or allergins of livestock
	B. low tannin content ⁵
	C. low lignin content
	D. high caloric value ⁵
	E. high protein content ¹
	F. good protein quality
	G. high digestibility ⁵

Table 6.1. Root, stem, and foliage features of a perennial forage crop tree ideotype.

¹Typical of black locust according to Hanover (1990).

²Typical of black locust based on observations by the author.

³Typical of black locust according to other published references.

4Not typical of black locust based on observations by the author.

⁵Not typical of black locust according to other published references.

Table 6.2. Propagation, reproduction, and stand establishment features of a perennial forage crop
tree ideotype.

Operations	Features
Propagation and	1. early fruiting to allow rapid selective breeding ¹
reproduction	2. abundant seed crops with minimal effect on growth ¹
	3. seeds easy to remove from fruit ¹
	4. inexpensive seed ¹
	5. readily available seed ¹
	6. easily stored seed (not perishable, long viability) ¹
	7. easily sown seed ¹
	8. rapid germination ¹
	9. seedlings resistant to soil fungi
	10. ease of vegetative propagation ¹
	11. vigorous sprouting of root cuttings ¹
	12. vigorous rooting of stem cuttings ⁴
	13. ease of surface-sterilization and micropropagation ¹
	14. vigorous cells in culture ³
	15. vigorous regenerated plantlets from tissue culture ²
	16. strong inheritance of desired qualities (dominant genes) ¹
	17. much genetic variation within species ¹
	18. much genetic variation in hybridizable species ³
Establishment	1. ease of establishment and regeneration ²
	2. high response to inputs such as weed control, fertilizer ²
	3. efficiency of nutrient utilization
	4. low danger of escape from cultivation ⁴
	5. ability to prevent soil erosion ²
	6. suitability for monoculture plantations ²
	7. ease of eradication when no longer useful ²
¹ Typical of black	c locust according to Hanover (1990)

in the second second

²Typical of black locust based on observations by the author.

³Typical of black locust according to other published references.

4Not typical of black locust based on observations by the author.

5Not typical of black locust according to other published references.

Adaptations	Features
Growth rate	1. optimal phenology for rapid growth in environment ^{3,4} (debatable)
	2. rapid juvenile growth ¹
	3. rapid crown closure ³
	4. ability to outcompete weeds ¹
Tolerances	1. saline groundwater
	2. saline soils
	3. low fertility soil ¹
	4. drought stress ¹
	5. saturated soil6
	6. extreme low and high temperatures ¹
	7. frost ²
	8. air pollutants ¹
	9. coppicing ²
	10. common herbicides used for weed control ⁴
	11. herbivore browsing ²
	12. intentional human damage or mis-management ³
	13. insect pests2.5(debatable)
	14. diseases ²
	15. does not harbor agricultural pests or diseases ²
ITypical of bla	ack locust according to Hanover (1990)

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Table 6.3. Environmental adaptation features of a perennial forage crop tree ideotype.

¹Typical of black locust according to Hanover (1990).

²Typical of black locust based on observations by the author.

³Typical of black locust according to other published references.

4Not typical of black locust based on observations by the author.

5Not typical of black locust according to other published references.

6Not typical of black locust according to Hanover(1990).

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CONCLUSIONS

CONCLUSIONS FOR EACH TREATMENT AND ASPECT

Ideotype breeding goals

The black locust has many of the qualities that are most useful for cultivated multipurpose trees. Improvement of certain traits by selective breeding would produce cultivars or clones more suitable for specific agricultural purposes, including alley cropping, short rotation biomass production, and forage.

ALLEY CROPPING

The most important traits to be added are:

- 1. Reduced propagation from cut roots.
- 2. Reduced extent of surface roots.
- 3. Spineless stems.
- 4. Increased nitrogen fixation.

SHORT ROTATION BIOMASS

The most important traits to be added are:

- 1. Earlier bud break and/or later leaf drop.
- 2. Easier reproduction from stem cuttings.
- 3. Tolerance of saturated soil.
- 4. Resistance to insect pests.

FORAGE

The most important traits to be added are:

1. Higher digestibility of protein.

- 2. Higher digestibility of calories.
- 3. Spineless stems.
- 4. Longer retention of shaded lower leaves.
- 5. Improved horizontal branching for canopy closure.

Harvest date

Harvesting two times a year was found unsatisfactory. Harvest dates early in the season were unfavorable because of low regrowth productivity, while those in July or August were rejected because of low survival. Since yields continued rising during September, a harvest date as late as possible was indicated. Harvesting was necessary before frost caused the leaves to drop.

Harvest height

Harvesting at 5 cm damaged future survival and yields, except when done at the very end of the growing season. For every aspect of growth, yield, and survival, the harvest height of 30 cm was superior compared to 5 cm. Continued improvement with heights above 30 cm was projected.

Spacing

With the 20 - 30 cm cutting height used in these trials, the narrowest spacing tested (10 cm) gave superior yields the first season only. The widest spacing tested (50 cm) gave yields which were lower the first and second seasons, equal the third, and superior the fourth. Four year total yields did not vary with density. The optimal spacing for survival was always the widest.

Year of first harvest

In all trials, harvesting the first season reduced future productivity and survival, often severely. The small amount of forage available the first year was judged not worth the penalty paid for harvesting it.

Long term trends

Survival rates did not increase over the years, although it is possible that beyond four years they would improve as more space per plant becomes available. At a 30 cm harvest height, yield per plant increased with time as survivors expanded into the spaces left by dying adjacent plants, but this was not observed at a 5 cm harvest height. Yields per plot increased each year in some trials and declined in others, but the pattern was not related to fertilizer application.

ITEMS FOR FURTHER STUDY

Harvest date

Several reasons have been proposed to explain why July and August harvests are more stressful to black locust plants than June or September harvests, resulting in lower survival and reduced yields the next year. Are these results due more to reduced carbohydrate storage or to winter dieback? Which factors affecting net photosynthesis and carbohydrate storage are most important, and which can be addressed by agricultural practices or breeding? Does disease play a role in winter mortality?

Shoots that begin growth before July generally respond to autumn signals and cease new growth in late August or early September, but those that begin growth after June stay succulent right up to frost, which wilts them immediately. In central Michigan, what is the latest date that regrowth can begin and still enter dormancy normally? Does this date depend on day length (and thus latitude if grown elsewhere), temperature, other weather factors, days from bud break, genetics, harvest height, or other factors? It is possible that only the day length and leaf age factors are involved; if the leaves are too young (under about 50 days of age) they may be unable to detect the decline in day length and then signal the apex to cease growth.

Black locust leaves do not change color in autumn, indicating that they continue functioning instead of senescing as in most other deciduous trees. Is this odd habit related to nitrogen fixation? Can nodulated black locust plants obtain more nitrogen from the nodules by continuing photosynthesis than from their own leaves by gradual senescence? How would the leaves behave in autumn in a specimen that was not nodulated? Is the lower photosynthetic rate recorded after frost due to injury to the leaves, partial senescence, lower temperatures, or a combination of these and other factors?

Complications involving harvesting after frost in 1989, and shading from adjacent taller plots every year, must have reduced the harvested weights of the late September plots, but the amount is impossible to calculate. Without those reductions in potential yield, would yields have increased significantly from early to late September?

Harvest height

At what higher harvest height will yields begin to decline? Is this decline attributable to competition for water, soil nutrients, light? Were diseases involved in the high death rate observed at the 5 cm cutting height, and did the proximity of wounds to the soil surface favor their spread? Is stem growth from coppiced stumps rapid only until a certain root:shoot ratio is restored, and then much slower as a normal share of photosynthate is devoted to root growth? In a tall crowded stand with limited foliage on each plant, does maintenance respiration in the extra length of stems reduce the amount of photosynthate available for growth? Is the stem a major site for storage of carbohydrates and/or nutrients over the winter? Is slower growth in taller plants related to the passing of the juvenile stage? Questions of pathology and physiology arise, which can not be answered by any of the data that were collected.

Spacing

Plants at spacings of 16 to 100/m² were clearly exhausted by the fourth year, but how many more years would plants at 4/m² remain productive? Is it primarily competition for water, soil nutrients, or light that makes the mortality rate increase with density in black locust?

Year of first harvest

The annual yield should increase when delaying the first harvest until the third growing season, rather than the second. Would the cumulative yields ever exceed those of plantings harvested the second year? Which treatment would be more profitable for the farmer? Future research should address how long to delay the first harvest, in combination with wider spacing treatments than those tested here and harvest heights above 30 cm, in order to minimize the costs of stand establishment.

2 W 2

Spacing by harvest height interaction

Because populations declined under the stress of frequent harvesting, especially over winters, and never stabilized, it is uncertain whether an optimal density actually exists. Would optimal density vary with harvest height as hypothesized? Would larger plants grown at wider spacings and harvested at greater heights than tested in these trials survive longer and/or yield more? Is the photosynthetic rate per unit of ground area maximized by allowing space between plants, so as to illuminate a greater number of leaves, or by maintaining a closed canopy?

Concerning yields, the main reason for significant interactions of spacing by harvest height was that the plots of 4/m2 grew well at 30 cm and very poorly at 5 cm. Why did this occur? Weeds and rabbits may have played a part, but the main reason for the extremely low yields of the plants at 4/m2 cut at 5 cm was probably soil compaction from people stepping in the plots. The 1.5 m width of the plots was too far to step over, and the designated transverse pathways were spaced 15 m apart. When measuring or harvesting the harvest height trial or the adjacent harvest date trial, workers desired to switch pathways as quickly as possible to avoid being scratched by spines of the tall growth on one side. Because the 4/m2 plots cut at 30 cm developed side branches which impeded passage, the 5 cm plots were uniquely suited for use as shortcuts. Whether or not this bias is severe enough to warrant discarding the data is academic; the conclusion that a 30 cm harvest height is superior would not change. This problem could be avoided in the future by

providing more transverse pathways, or by making the paths between trials 2.5 - 3.0 m wide instead of 0.75 m.

Spacing by harvest date interaction

How do planting density and time of harvest interact? Is the optimal time for forage harvest early in the season when shaded lower leaves are about to abscise, or is it at the end of the season when the stems are woody and the leaves are about to abscise from frost damage? The answer is clear if the goal is to produce the most biomass, but if the goal is to produce the most digestible nutrients for animal feed, the answer is not clear, and it may vary for different livestock species.

Harvest date by harvest height interaction

In an unreplicated comparison, in September the plots cut at 5 cm yielded more than those cut at 25 cm. Was this a fluke or a typical result? How would yields and survival compare in the long term?

Year of first harvest by seed source interaction

Seed sources often produced significant interactions with the year of first harvest treatments, especially for branching behavior. Is genetic diversity adequate for breeding cultivars that will tolerate harvesting the first season? Can heavily branching cultivars be planted at wider spacings, allowing lower expenditures for plantation establishment?

Long term trends

Did random fluctuations give the illusion of rising or falling yields in different trials? How many years can yields continue to rise before the limit is reached? Is mineral nutrient depletion a concern in the long term? Would disease problems or insect pest populations increase over the years and eventually reduce yields? Can a closed canopy be maintained in the long term, or will competition between plants result in gaps due to mortality of weaker specimens? Would competition be reduced by planting a single clone, rather than a diverse mixture of seedlings?

Height growth

The hypothesis that the height of new growth is greater at lower cutting heights, but the total height is less, was generally supported by the data, but no clear conclusion can be made because the sample size was too small. Does this always occur?

The most rapid growth (averaged from ten plants) was in 1991, with a gain of 40 cm between 47 and 56 days from bud break, averaging 4.4 cm/day. The most rapid height growth in 1989 and 1990 was recorded after 47 days from bud break. Is the peak growth rate at this time due to hormonal factors, the leaf area, the root:shoot ratio, or environmental conditions? Is it because early growth requires less woody stems than later in the season, when more support is needed to keep a taller and heavier stem upright? The speed record was 8.9 cm/day. How much could agricultural treatments or breeding improve the growth rate?

The slopes of the average height growth curves were very similar in 1989 and 1990, but growth was more rapid in 1991. Was this due to weather, plant age and size, or more space for survivors following the severe mortality after the 1990 season?

What signals growth to stop in early September? Is it day length, the number of days since bud break, soil moisture depletion, temperature, or a combination of factors?

Yields

After apical growth ceased, dry weight yields continued increasing. Did stems, leaves, or both account for this increase? Were roots also gaining weight at this time? Although no distinct plateau appeared as had been hypothesized, yields at the last two harvest dates were never significantly different. Without the observed reductions in potential yield from frost and shading, would normal yields increase significantly from early to late September?

Harvesting in late June or early July, and again in late August, yielded about half the biomass of the September 28 plots. How would yields compare for leafy material only?

Declining yields in measured plots may have been due to shading by the more vigorous plants in the outside border rows, so the forage yield of the entire plantation may have continued

rising. Future research should investigate patterns of plant growth and competition, both above and below the ground, in relation to yield levels. It is unclear whether the lower yields and survival in 1990 compared to 1989 were due to harvest date effects, the age of the plants, or weather conditions. What is the long term trend in yield levels? Can declining yields be raised by fertilization? What are the optimal soil pH and fertility levels? Drought slowed growth of the new seedlings in 1988, but would a similar drought affect established plants as severely? How much farther do the roots extend each year, vertically and laterally, and how is the pattern influenced by the soil texture and drainage class?

Yields per plant

Yields per plant generally increased with time. Was this due primarily to the greater surface area occupied, or the presumed greater rooting depth? More space was available as weaker neighboring plants died, but which was the limiting factor, light, nutrients, or water?

<u>Yields per day</u>

In 1989 the daily dry weight increment showed a plateau from late July onward. Measurements of height growth in 1989 were too infrequent to tell when it was fastest, but the most rapid height growth was recorded in June in 1990 and May in 1991. Was this apparent inverse relation of height and dry weight growth rates due to weather, leaf area, or late season secondary branching and stem lignification?

Dry / fresh weight proportion

What caused the dry weight percentage (D/F) to increase unsteadily each year in step-wise fashion? In climates with a longer growing season, would D/F continue increasing beyond 50%? Do larger stems with a higher proportion of wood always have a higher D/F?

Stem lignification proceeded through the entire season, but no difference in the D/F ratios of leafy upper and woody lower stem portions appeared until after height growth had ceased.

During September, the succulent stem tips became less flexible and probably less succulent. Did the leaves then became more succulent, and what physiological process would cause that?

Survival

Was it primarily competition for water, soil nutrients, or light that caused the mortality rate to increase with density? Was the death rate inversely related to the content of stored carbohydrates, as has been shown in other species? What is the normal seasonal pattern of carbohydrate storage and depletion in black locust?

The second se

Was the severe mortality at 5 cm influenced by inadequate rooting depth or volume, possibly aggravated by evaporation from bare soil, fungal attack, herbivore attack, weed competition, inadequate carbohydrate storage, hormonal imbalance from total defoliation, frost heaving, or a combination of these factors? By severely reducing the top in relation to the roots, was root growth restricted to the extent that malnutrition or drought susceptibility resulted?

The planting density experiment was designed to find the optimal final density, where yields were equivalent to those at higher densities and mortality of crowded plants ceased. In the field, mortality at the widest spacing was lower but still substantial. Would a planting of identical clones survive better than the genetically diverse seedlings that were used? It is clear that populations above 10/m² cannot be maintained with annual harvesting at 30 cm, and the optimal final density is probably below five plants/m², if such a plateau even exists. What population density can be maintained, and how many years are required to reach a stable level? How would initial spacing, fertilization, climate, genetics, and different harvest times or heights affect the pattern?

<u>Canopy coverage</u>

The canopy at 4/m² only closed shortly before harvest in 1990 and 1991, but the taller plants probably intercepted almost as much sunlight as those in more crowded plots. Did the absence of a closed canopy account for the continued vigorous growth and better survival in 1991 observed at the 4/m² plots? If leaves around the sides of the plants do not abscise from shading,

will they provide more photosynthate per plant and per plot than in a closed canopy? At what point would such an advantage disappear at wider spacings, lower harvest heights, or lower latitudes, as more sunlight strikes the ground instead of the foliage? Plants at all narrower spacings were clearly exhausted by the fourth year, but how many more years would plants at 4/m² remain productive?

What density of planting would produce a canopy thick enough that chemical weed control could be discontinued? The required density should decrease as the time span is extended or the harvest height is raised, but how do these factors interact?

How does defoliation or shoot decapitation increase the rate of net photosynthesis in the remaining leaves, and how can this phenomenon be utilized to best advantage? What proportion of leaf area or canopy coverage is best to retain, and how is the optimal amount influenced by harvest height, timing, or spacing? Is retaining some leaves at the last harvest beneficial or harmful in the long term, and how does this relate to harvest date or day length?

If measured at the optimal time, about 30 - 40 days after bud break, canopy coverage could be an excellent indicator of biomass yields later in the season. This should be investigated further. It is possible that the proportion of canopy remaining after an early summer harvest could predict the yield at the second harvest two or three months later, but no data were taken to test this hypothesis. The correlation of solar interception and yield should be a fruitful area for future research, as it would give a common reference point for the effects of harvest time, harvest height, plant spacing, and all their complex and confusing interactions.

Juvenile stage

Can black locust plants be kept in the juvenile stage indefinitely by annual coppicing? If the harvest height is high enough to retain some branches, will these branches ever flower? Are the rapid growth and profuse spines of the juvenile stage inseparable? Observations of trees growing older, and of spineless mutants, indicate that they are. Could coppice growth possibly be rendered spineless? Is slower growth in taller plants related to the passing of the juvenile stage? Can growth rates in mature trees be improved by preventing flowering?

RECOMMENDATIONS

Crop establishment

Recommended agronomic practices depend on whether black locust is grown as an annual or a perennial crop, but the goal in both cases is to maintain a closed canopy for as much of the growing season as possible. An annual crop should be sown thickly (125 - 250 seeds/m2) to give 50 - 100 seedlings/m2, and harvested as near to the ground as possible to maximize yield. Herbicides should be used before cultivating and planting the field the next year, so that the few survivors do not become established. A perennial crop requires enough plants to maintain a closed canopy at the harvest height. With the 30 cm height used in this trial, the widest spacing tested (50 cm) was adequate the third growing season and superior the fourth. With more time or higher cutting, even wider spacings could be used, and transplanting may become economical. But considering the low cost of the seed compared to the loss of potential yields the first and second seasons before the canopy closes, a thicker sowing would be preferred if weed control permits it.

Experimental logistics

Future field trials with black locust should be designed so the plots can be planted, sprayed, and harvested mechanically, or they should be conducted in a temperate region outside of North America where labor costs are lower. The use of square plots with border rows made the planted areas too wide to drive tractors or self-propelled harvesters over them, forcing us to use hand tools to simulate mechanical harvest. This caused much aggravation for the field workers, who suffered from the heat if they wore thick clothing, and from frequent wounds if they did not. A gasoline fueled hedge trimmer was tried once; it cut succulent stems with ease, but had difficulty getting through woody stems and the wire flags that marked plot boundaries. Many stems and leaves were cut repeatedly, so that the small fragments were difficult to collect. All who used the motorized trimmer found its weight, noise, and fumes so unpleasant that it was not tried again. An electric model would be more suitable, if enough extension cords could be obtained.

If randomized plots are to be cut mechanically at different times, care must be taken to allow room for the tractor to turn, so as not to damage the uncut plots. Also, uncut plots must be kept from shading the plots cut earlier. If a small number of plots are cut early, rabbits and rodents may destroy the regrowth, so fencing is advisable.

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Finally, a major complication in most trials was that plants in border rows next to paths grew larger and shaded the measured portions between them. This could be avoided by trimming them frequently, as we did, or by using wider plots with narrow paths for the tractor tires.

