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Black Walnut for the Future

North Central Forest Experiment Station
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PREFACE

Interest in planting and managing black walnut trees continues at a high level. The premium prices paid for walnut logs, the value of the nut crop, and the satisfaction derived from tending trees all contribute to this interest and to the resultant need for information on how to grow walnut trees. A workshop on walnut culture held in 1966 focused on the then existing information and identified some of the research needed to obtain additional knowledge. A second symposium in 1973 continued this process, and in 1981 a third symposium was held to summarize current information on walnut and to establish the direction of research for the next several years. These proceedings are the product of the 1981 symposium.

The symposium resulted from the same cooperative effort that proved so effective for its predecessors. Primary among these cooperators were Purdue University, the Walnut Council, North Central Forest Experiment Station, and the Northern Nut Growers Association. Numerous other institutions, industry representatives, and private individuals contributed significant amounts of time and effort. This cooperation produced not only a sucessful symposium but, of equal importance, these proceedings.

The proceedings bring together in one publication much of the currently available information needed to successfully grow black walnut; much of this information is new or has been refined since the previous symposium. The 1973 proceedings served as a guide for several thousand people. We expect that these proceedings will likewise serve as the basis for management recommendations during the next decade.

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THE WALNUT COUNCIL IN PERSPECTIVE[1]

Gary G. Naughton[2]

This twelfth annual meeting of the Walnut Council is truly an auspicious occasion. We have already survived almost 4 times as long as the average new business enterprise in America, our numbers are still growing, and we have a right to be truly proud of our accomplishments.

Those of us who have had the good fortune to have been part of this Council since its beginning at Indianapolis in 1970 have had the opportunity to see, first hand, the finest groves of walnut trees on the face of this earth. Not only seeing walnut trees in all their glory, but getting to know them and the people who own, plant, manage, harvest, and use walnut trees are the things which make the walnut Council go.

The Walnut Council is unique among organizations. Founded on the principle of sharing knowledge and experiences for the benefit of society, our membership is open to anyone with an interest in walnut. We are neither solely scientific nor technical nor educational nor recreational nor financial in our interests. Yet, we are all of these things in good measure. Landowners, scientists, educators, manufacturers, and speculators all form important parts of our Council. And all contribute to the benefit of the group.

Our significant strength is that we challenge each other. We have the audacity to ask the hard questions, the charity to share our ideas with others, and the grace to accept criticism--all of which are part of every meeting we have ever held.

From the beginning, the members of this Council have expressed an attitude of friendly competition. Remarks such as "It's too bad you folks can't grow as good walnut in your part of the country as we do in my area" are accompanied with the unspoken belief that even poor walnut trees are good property.

And, the competition will always be friendly because we know that--even in the face of our past 12 years of organized effort--walnut trees are becoming increasingly scarce. The strength of consumer demand for walnut products continues to assure us that our only true competition in this business is with time and nature. We are truly fortunate that we need not hold back, selfishly, from helping each other. Our combined effort to overcome common problems is the source of our strength.

This is the Third Walnut Symposium. Each in its turn has served to focus on the current "State of the Art" in walnut culture and management. And, as you shall see, each has become progressively more fruitful in bringing us toward our goal of improving the production of walnut and its many products. The proceedings from the 1966[3] and 1973[4] symposia, along with those from this year are an invaluable collection of the best information available for persons interested in walnut.

We still have a serious task ahead of us. Many of the problems we experience in our personal endeavors with walnut are still unsolved and pose a challenge to us for the future.

PROBLEMS

We are still looking for the magic formula to solve the two biggest questions that foresters the world over must constantly address. They are: 1) "How many trees should we plant?", and 2) "When should we harvest?"

I can assure you, today, that the best answers to these questions will never be the

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[1]Paper presented at the Black Walnut Symposium, West Lafayette, Indiana, August 10-14, 1981.

[2]Gary G. Naughton, Chairman Assistant State Forester, Kansas.

[3]"Black Walnut Culture", proceedings of a walnut workshop, Carbondale, Illinois, August 2-3, 1966. USDA Forest Service North Central Forest Experiment Station. (This workshop held before start of the Walnut Council.)

[4]"Black Walnut as a Crop", proceedings of the black walnut symposium, Carbondale, Illinois. August 14-15, 1973, USDA For. Serv. North Central For. Exp. Stn., Gen. Tech. Rep. NC-4, p. 97-100.

same for all of us. We still find that it all depends on "the situation and the terrain."

It is quite possible to start with 1,000 or more seedlings per acre and plan the final harvest for the age of 200 years, producing as a result exceptionally high quality veneer log which would be in demand throughout the world. But we also know that there is good profit in stands which start at 200 to 300 trees per acre and are at final harvest stage in 60 to 80 years.

It is my opinion that we need both styles of management systems to complement each other. The longer rotations fit nicely into forest management systems on public lands, while the shorter rotations are a matter of economic practicality and reality on private lands. In any case, walnut management requires a profound and unwavering sense of optimism for the future.

One of the first external problems addressed by this Council was the need for a realistic and consistent National policy on the export of raw walnut logs into the International market. This has proved to be a two-edged sword--an enigma of gigantic proportions. As in most situations of this sort, idealism gets totally entangled and confused with reality. From the beginning there was general recognition that a problem existed in this area, but no agreement on how to solve it.

Ideally, the valuable natural resources of a nation (walnut in this case) serve that nation best when they are exported as components of finished products rather than as raw materials. But market forces are fickle. For example, in International markets there are frequently substantial import duties levied on consumer goods--because all nations recognize the differences in capital flow and employment opportunities represented by the contrast between a log and a piece of furniture.

Human nature also dictates that the landowner offering timber for sale is interested in getting the best cash price, sometimes in spite of the nationality of the buyer.

I believe that this problem has been more or less solved by default. The major walnut log processing companies--many of whom have had active membership in this Council since the beginning--have developed their own international markets and have substantially increased world demand for walnut products by introducing them to new customers in foreign countries.

The result is that more partially processed material is being exported than before and this provides more jobs at home. The situation has evolved to the point now that the current slump in walnut prices is more a function of the strength of the U.S. dollar against other currencies than it is a function of consumer demand.

ACCOMPLISHMENTS

At the risk of overlooking something of significance in terms of this Council's accomplishments, I will address only two. Naturally, it is my conclusion that these two accomplishments are the most significant.

One is the fact that, under the crusading leadership of Don Gott, Council member and former Executive Director of the Fine Hardwoods--American Walnut Association, we obtained consumer protection labelling restrictions for walnut products on the retail market.

These attractive tags and labels have since become a hallmark of quality and reliability for the American consumer. It is my understanding that the FH-AWA office at Indianapolis dispenses over 1/2 million of these labels annually. (See Article in 1973 Symposium Proceedings, page 23).

The net effect of this accomplishment is to protect and stabilize the market of walnut products, and consequently the producers from farm to mill to factory. To paraphrase a well-known commerical advertisement--"When you are number one you are prouder."

The second and most significant accomplishment I want to recognize is the communication forum that this Council has established. Although imperfectly developed this is our greatest asset. Because of the unique structure of the Walnut Council--a fact already discussed--the development and transfer of knowledge and information is rapid and continuous.

Landowners have the opportunity to meet and question research and industry interests face-to-face on a person-to-person basis. When the links of the chain from production, research, industry, technology, and finance know each other as individuals <u>true</u> communication exists.

But, I want to offer a word of caution here. Members of the Executive Committee--past, present, and future--have been and will continue to receive mail and telephone inquiries relating to walnut from people outside their normal sphere of operation and influence. We must not forget our obligation to refer such requests to appropriate people closer to the situation. These might be consultants, service foresters, extension specialists, researchers, or industry people. The proper function of the Council in this respect is to put the request into the best hands available not to directly respond to requests. Except for general inquiries which can be handled by sending the appropriate printed information, it is folly for someone in Kansas to try to offer advice to a walnut grower in Indiana.

THE FUTURE

I have spent most of this period talking about the past and I don't apologize for that. Perspective depends upon looking back to see where you have been so that you can decide where you ought to go in the future. So, having been there, where do we go next?

I believe that, first of all, the Walnut Council is a viable organization with a long future ahead of it. This assumption leads to the following suggestions as goals:

1. We should plan now for another symposium, to be held sometime between 1988 and 1990 . . .

2. We should make a strong effort to triple our membership by 1985 (approximately 2,000 members), and work hard to reach 5,000 by 1990.

3. We should seriously consider establishing some type of endowment fund within the Council for the purposes of financing research and/or educational efforts on the broad spectrum of interest relating to walnut.

4. We should begin, at the first opportunity, to aid in the establishment of state walnut associations, patterned after the Council, but affiliated only to the extent they wish to formalize.

5. We should plan now to hire a part-time Executive Director in about 1990 and to have this position become full-time by about 1995.

There is our challenge. Nothing remains constant very long. We must forge ahead or fade into obscurity.

WALNUT IN PERSPECTIVE: THE CHALLENGE CONTINUES[1]

R. Max Peterson[2]

I congratulate you on your joint meeting, and on the extensive program which you have underway. The wealth of information exchanged at this meeting is impressive, and something you can all be proud of.

This forum continues to serve as the catalyst for excellence in cooperation among public agencies, colleges and universities, industry, and landowners. That type of cooperation existed before this Council was formed. But it's better because of it.

When he invited me here, Gary Naughton made it a point to tell me that former Chief Ed Cliff keynoted the first of these walnut conferences in 1966--before the Walnut Council was even formed . . . and that John McGuire--who was Chief just before me--gave the keynote speech at the second of these conferences.

So I'm pleased to be at Purdue, and to keynote this third walnut conference . . . and the second joint meeting of your two groups.

But before I left the office to come out here, I was discouraged to look at some of the walnut data assembled by our forest survey staff.

Despite two of these conferences in the last 15 years . . . which focused on what needed to be done about the problem of declining walnut quality and quantity . . . the problem doesn't seem to be getting any better. At least, not very fast.

As a generality, we have a lot of hardwood timber. Anyone driving through the East can attest to that. In some parts of the Eastern United States it's difficult to find markets for a number of hardwoods. Supply significantly exceeds demand. Growth is much greater than removals. We have an underutilized resource in hardwoods in general.

But, as you know, the situation is quite the opposite for black walnut and other fine hardwoods. We have an overutilized resource. Demand has been greater than supply for several years. And that gap is projected to widen over the next 50 years.

Yet, to meet that demand, we're seeing only a slight increase in walnut growing stock, nationwide . . . and a significant decrease in inventories for trees larger than 15 inches in diameter.

In some states, this decrease in walnut inventories is quite significant. In Iowa, for example, walnut growing stock inventories have shrunk by more than a third in twenty years . . . and sawtimber inventories have been reduced by more than half.

In Missouri, where I grew up, black walnut was a well-known and respected tree that was valued, not only for the wood it produced, but also for the nut itself. The inventory of walnut growing stock in Missouri has shrunk by 3 percent between 1959 and 1972 . . . sawtimber inventories have diminished by 9 percent.

Now let's admit it . . . that's discouraging. But all of that bad news doesn't reflect the work you've been doing.

Jack Spencer of our forest survey staff at North Central Station tells me that there's a lot of walnut planting going on . . . but that the trees aren't yet big enough to show up in the inventory figures.

And judging by the program here, it's quite likely that those walnut trees will grow faster, be better protected, produce more nuts, be better utilized, and be worth a lot more than the generation of walnut trees we've been working with in the past.

I say that because we've learned a lot about growing walnut over the past 20 years.

We've learned a lot about defining suitable walnut sites. Enough to establish a reliable system for site evaluation.

We've come to realize the beneficial effects of weed control on walnut growth.

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[1]Paper presented at the Black Walnut Symposium, West Lafayette, Indiana, August 10-14, 1981.

[2]R. Max Peterson, Chief of the Forest Service, United States Department of Agriculture, to the joint meeting of the Walnut Council and Northern Nut Growers Association, Purdue University, Lafayette, Indiana, August 11, 1981.

We've learned a great deal about the possibilities of interplanting walnut with nitrogen-fixing trees and shrubs.

Through Bry Clark's early research, we've learned that thinning to favor walnut in natural stands holds good potential for accelerating the growth of the remaining trees.

And through the work of Walt Beinecke, Dave Funk, Calvin Bey, and others we've come a long way in walnut tree improvement. We've defined preliminary seed collection zones and established improved seed sources. Three states have initiated walnut tree improvement programs.

Each of these advances--and many others I haven't mentioned--can lead to greater walnut production. There's ample opportunity for even further advances in most of these important areas, too.

The record of research accomplishment and research cooperation in walnut culture and utilization is one which we can all be proud of.

But developing all of that knowledge will not, by itself, solve the black walnut shortage problem . . . the problem of declining quality and increasing cost.

That problem can be moderated in the short run, but not solved, through improved utilization. That aspect of your work will become even more important as walnut prices increase.

A longer-term solution will come, however, only to the extent that we put that knowledge to work on a wide basis . . . that landowners and forest managers recognize the opportunities in walnut, and actively manage for it.

That's how we are challenged in the next two decades . . . in motivating and informing landowners. It's a challenge which Ed Cliff laid out at the first walnut workshop in 1966 . . . and which John McGuire reiterated and emphasized in 1973.

That challenge continues today . . . because we need to devote much more energy and skill to getting walnut management started on a significant scale. We need to motivate landowners to manage for walnut. And we need to give them the information they need to do it right . . . information such as that presented at this conference.

We want to do our share on the National Forests, by managing appropriate sites for high-quality hardwoods. Growing walnut in natural stands over long rotations is particularly well-suited to multiple use management. So it fits well into what we are trying to do on the Eastern National Forests.

Many of these National Forests have active black walnut programs, particularly in tree improvement and plantation establishment.

For example, we are cooperating with the Tennessee Valley Authority, and with the states of Indiana, Kentucky, and Tennessee, in provenance and progeny testing. These tests involve several hundred selections over much of the range for Black Walnut. If successful, several of these experimental outplantings on the National Forests will be converted to first-generation seed orchards.

We have been disappointed with the results from introducing walnut into cutover stands and with establishing black walnut on abandoned fields. Therefore, we will no longer make special efforts to introduce walnut as a component in mixed stands until we have better prescriptions for doing it.

However, we have established nearly 3,000 acres of black walnut plantation on the National Forests over the past 10 years. Some of the earlier plantations were put on poor sites. Some of the others apparently didn't receive proper site preparation or follow-up treatments.

Anyway, the results of these plantations can't all be considered successful, though we're generally pleased with the plantation effort.

We will continue to establish black walnut plantations on suitable sites. Most of these will be on the Daniel Boone, Wayne-Hoosier, Shawnee, Mark Twain, and Monongahela National Forests.

And where it occurs in natural stands, we will continue to manage and favor black walnut as a component of mixed stands.

We don't have a lot of sites on the National Forests which are suitable for intensive walnut management. However, we will use those that are there. Because, just as you're interested in increasing black walnut production, we're interested in having the National Forests do their share.

However, to change the focus of our attention, let me quote John McGuire from his keynote to the 1973 walnut conference:

He said that "the success or failure of our program to increase production of walnut and other fine hardwoods will depend on the degree of participation by nonindustry private landowners who own 70 percent of the hardwood sawtimber. Their land includes most of the productive walnut sites and nearly all the growing stock. We need to stimulate greater interest among the small private landowners in developing maximum productivity of their forest lands."

How well are we doing with these landowners?

Not as well as we should be.

Yet, it seems to me that there are several factors--such as the current combination of market, incentives, and national mood--which should give landowners unprecedented motivation to grow walnut on appropriate sites.

First, the nature of the tree is such that it can be managed in harmony with nearly any sort of landowner objective short of wilderness.

Second, there appears to be an emerging interest in trees which produce nuts which people can eat.

Third, the outlook for walnut shows future demand exceeding supply, and continued high prices.

Fourth, it seems to me that the increased use of wood for energy has a lot of landowners coming to realize the value of their woodlots . . . first for firewood, then for other products as well.

But there's a danger there, too. The same axe that's used to thin a woodlot . . . can be used to wreck it as well. We must educate landowners to recognize high-value hardwoods and leave them to grow to maturity.

Fifth, as the Forest Service and cooperating universities get further along with their Eastern Hardwood Initiative, it may well open up some additional opportunities to manage for fine hardwoods . . . walnut included. This Initiative is a broad-scale effort to find some better uses and better markets for all eastern hardwoods, particularly where they can take over some of the uses which are placing such demand on softwoods. It will probably have some good effects upon the supply of fine hardwoods as well.

And sixth, let me briefly note--since you have a broader discussion scheduled for your program tomorrow--that in recent years, Congress has legislated a comprehensive package of tax incentives and other forms of encouragement to help landowners quickly recover many of their costs.

The combination of all of the factors I've just cited indicate an especially auspicious time for walnut management on private forest lands.

But we've got to point out those opportunities.

We have to speak from the economic point of view--to let the landowner know that walnut management can pay if it's done right, and on the right sites.

And after spending these several days at Purdue . . . talking with each other . . . we've got to go out and talk with the landowner.

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AMBROSIA BEETLES IN YOUR BLACK WALNUT PLANTATION--

HOW SERIOUS ARE THEY?

Barbara C. Weber

Abstract.--The life history of Xylosandrus germanus and its effects on black walnut trees were studied from 1976 to 1980 in two plantations, one in North Carolina and one in Illinois. X. germanus has two generations per year with the heaviest attack period occurring in May and June. Signs and symptoms of attack include pinholes, basal sprouts, wilted leaves, and top dieback. Although tree survival is little affected by X. germanus attacks on black walnut, growth losses are potentially serious depending on the age of the trees when attacked and the management goals of the plantation. Some management and silvicultural control recommendations are included.

At the last Black Walnut Symposium in 1973, one of the insect problems discussed was an imported ambrosia beetle, Xylosandrus germanus (Blandford), that was associated with an unexplained dieback of young black walnut trees (Juglans nigra Linnaeus) in Illinois and Indiana. At that time, little was known about the beetle, but since then we have learned much about its life history and about the damage it does to black walnut trees. The purpose of this paper is to briefly summarize what we have learned about the biology of X. germanus, to describe the effects of attack on black walnut trees, and to recommend some ways to reduce the damage by this insect.

Much of the information presented in this paper comes from the study of X. germanus from 1976 to 1980 in two black walnut plantations. One plantation is located in McDowell County, North Carolina; the approximately 12 acres (4.9 hectares) were planted in 1973 and were attacked by X. germanus in spring 1976 and probably also in 1974 and 1975. Study of X. germanus was concentrated in a 5-acre (2.0 hectares) area located in the center of the plantation. The second plantation is located in Alexander County, Illinois; the approximately 7 acres (2.8 hectares) were also planted in 1973 but were not attacked by X. germanus until spring 1978.

[1]Research Entomologist, North Central Forest Experiment Station, Forestry Sciences Laboratory, Carbondale, Illinois.

SEASONAL LIFE HISTORY

Adult female X. germanus are black and approximately 0.1 inch (2.5 millimeters) long (fig. 1). Males are brown and about 0.06 inch (1.5 millimeters) long but are rarely seen because they do not fly and usually do not leave the gallery in which they live. The immatures are white, legless, and wormlike. They live in galleries made by the parent female in trees or other woody plants (fig. 2)

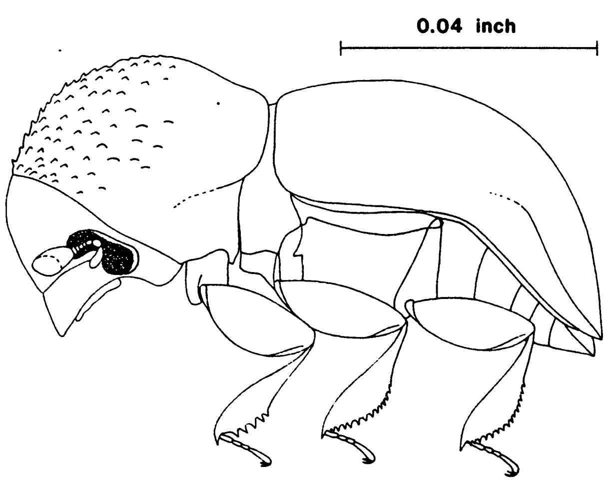

Figure 1.--Side view drawing of adult female X. germanus. (Drawing by S. W. Wilson.)

Figure 2.--Cross section of black walnut showing X. germanus gallery.

Adult females leave their overwintering sites in galleries at the bases of trees in March and April to search for new hosts. They fly primarily in the late afternoon and early evening. The beetles are slow, weak flyers and are, therefore, easily carried by the wind. In North Carolina, beetles in flight are present from late March until late August. In Illinois, beetles in flight are present from early April until early September. The average flying height is 4.9 feet (1.5 meters).

Once the beetles have located their new hosts, they bore into the tree and excavate the galleries in which they will lay their eggs and produce new adults. X. germanus apparently has two generations per year. In North Carolina, egg-laying occurs from early May to probably late June and from early June to early September. Adults of the first (summer) generation are present from mid-May to mid-July and those of the second (overwintering) generation from early July to the end of the season. In Illinois, egg-laying occurs from mid-May to early June and from late June to late July. Adults of the summer generation are present from early to late June and those of the overwintering generation from mid-July to the end of the season (fig. 3). The number of offspring per female ranges from 2 to 53.

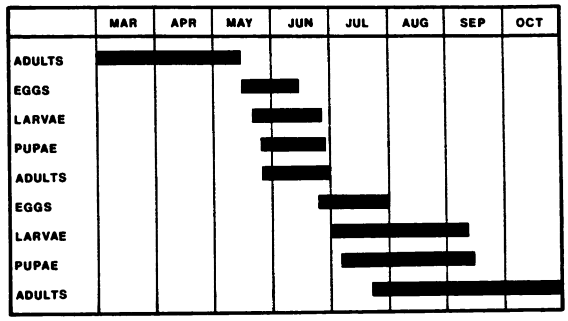

Figure 3.--Combined life history diagram of field-collected X. germanus in North Carolina and Illinois.

DISTRIBUTION AND HOSTS

The ambrosia beetle X. germanus was first reported in the United States in 1932 on Long Island, New York (Felt 1932). The beetle now occurs from New York to Missouri and from Louisiana to South Carolina. It attacks several kinds of woody shrubs and trees. In its native country of Japan, X. germanus attacks about 160 different species of plants (Nobuchi 1981). In the United States, Deyrup (1981) reported that in Indiana alone it attacks 20 different species of plants, including black walnut.

Miller (1973) and Kessler (1974) first reported attacks by X. germanus on black walnut in Illinois. Since then, many more damaged plantations have been found (table 1).

SYMPTOMS OF ATTACK

Signs and symptoms of X. germanus attack on black walnut trees include pinholes, basal sprouts, wilting leaves, and dieback. Pinholes are approximately 1/32 inch (1 millimeter) in diameter and are usually found in the lower trunk of attacked trees. Pinholes may also be found in branches that are within about 6.5 feet (2 meters) from the ground. Basal sprouts originate from the tree trunk at or below the groundline or they may occur above the groundline on the lower trunk. Wilting leaves and dieback may occur over the entire aboveground portion of the tree or on only one branch (fig. 4). Wilted and dead tops are the most easily detected symptoms of attack and can be found most frequently during May and June, the period of heaviest attack by X. germanus. Occasionally, cankers are also associated with beetle attacks.

Table 1.--Location, age, and height of plantation black walnut trees attacked by X. germanus

Location	Age when attacked[1]	Avg. ht. (ft.)[1]
ILLINOIS		
Alexander County	5	6.0
Jackson County	4	5.3
INDIANA		
Daviess County	-	-
Du Bois County	8	4.9
Fountain County	1	seedlings
Green County	-	-
Hamilton County	1	seedlings
Washington County	5	-
NORTH CAROLINA		
McDowell County	3	5.6
OHIO		
Scioto County	1-7	-
TENNESSEE		
Davidson County	2	3.9

[1]Dashed line means that the age and/or height of the trees at the time of attack were not known.

Figure 4.--Wilting leaves and top dieback of black walnut tree attacked by X. germanus.

Sometimes the only symptom of attack is the pinholes, but they are small and difficult to find. In the Illinois plantation, I found that the percentage of trees attacked by X. germanus could be estimated from the percentage of trees that had wilted leaves or dead tops. Work is continuing to determine if this method of estimating the number of trees attacked by X. germanus can be applied to all walnut plantations.

EFFECTS OF ATTACK

The effect of attack by X. germanus on tree survival is less serious than first appearances show, although initial tree losses may appear high. Although the tops of attacked trees may die, the roots are usually still alive and send out sprouts that can replace the original tree. Approximately 350 of the 1,400 trees in the North Carolina plantation were attacked by early June 1976 and approximately 30 trees died. About 330 of the 2,220 trees in the Illinois plantation were attacked in spring 1978. Nearly 75 percent of the attacked trees suffered top dieback. All but four of the trees with top dieback eventually sent up basal sprouts from the still-living roots. If sprouts are pruned to one per root system, the original attacked trees can be replaced by fast-growing sprouts and thus reduce the effects of X. germanus on tree losses in a plantation. However, the time required to cut and remove beetle-infested trees and to remove excess sprouts can be significant and costly.

The effect of beetle attack on tree growth is potentially more serious than on tree survival. In the Illinois plantation, the average height of trees attacked by X. germanus in spring 1978 was 5.7 feet (1.7 meters) compared to 6.1 feet (1.9 meters) for trees not attacked. The average diameter at breast height (dbh) of trees attacked was 0.5 inch (1.3 centimeters) compared to 0.6 inch (1.4 centimeters) for trees not attacked. After three growing seasons, the average height of those trees attacked in spring 1978 was 8.5 feet (2.6 meters) compared to 9.8 feet (3.0 meters) for trees not attacked. Average dbh of attacked trees was 1.0 inch (2.6 centimeters) compared to 1.3 inches (3.3 centimeters) for trees not attacked. These comparisons show that X. germanus apparently selected smaller trees and suggest that smaller trees may be more susceptible to attack than larger ones. Younger trees may also be preferred because all of the plantations in which we found X. germanus were less than 8 years old when attacked. Black walnut trees older than 10 years or more than about 2.5 inches (6 centimeters) in dbh probably will not be attacked by X. germanus. It is not known whether the smaller trees in the Illinois plantation were attacked because they were less healthy than the larger ones or whether they were simply slow growers and were preferred by X. germanus because of their smaller size.

The comparisons of sizes of attacked and not attacked trees also show that the attacked trees, or their replacement sprouts, were not able to catch up in height and diameter growth, three growing seasons after attack, to those trees not attacked. The attacked trees may be compared to the coppiced trees studied by Schlesinger (1981). He found that 5 years after treatment (that is, removing the entire aboveground portion of coppiced trees and allowing one sprout to replace the original tree), coppiced trees were about 20 percent shorter in height and about 26 percent smaller in dbh than noncoppiced trees. Schlesinger (1981) also found that the older the tree at the time of coppicing, the less likely it would be able to catch up in size to noncoppiced trees. Trees coppiced when they were 2 years old were only about half a year "younger" in size at age 11 than same-age noncoppiced trees, but trees coppiced when they were 5 years old were 3 years "younger" in size at age 11 than same age noncoppiced trees. That is, trees coppiced at age 5 would have to grow for 3 more years after the harvesting of noncoppiced trees to equal the size of the noncoppiced trees. These findings suggest that trees attacked by X. germanus when they are younger (for example, 2 years old) will be closer in size at harvest time to trees not attacked, and, thus, more likely to be selected as harvest trees, than trees attacked by X. germanus when they are older (for example, 5 years or more).

The seriousness of growth losses due to X. germanus attack depends on the total number of trees attacked and the management goals for the plantation. If a large percentage of the trees has been attacked, the average tree size may be significantly reduced, as indicated in the Illinois plantation, and result in a longer time to final harvest of commercial-sized trees.

If management goals require that all plantation trees become final crop trees, every tree is important. No tree loss and little growth loss can be tolerated. Such situations may develop when few trees are planted originally. On the other hand, if more trees are planted initially than are needed for final crop trees, individual tree selections can be made periodically to keep the faster-growing, straighter trees and eliminate the slower-growing, less desirable ones. Under these more flexible management goals, most trees attacked by X. germanus that are not comparable in size to trees not attacked will probably be removed by harvest time.

Another factor in assessing the seriousness of X. germanus attack is the genetic background of the trees. The Illinois plantation was designed to compare growth characteristics of trees from different sources in six States--Arkansas, Illinois, Kansas, Kentucky, Missouri, and Tennessee. Kansas trees were attacked least frequently (2 percent) and Kentucky trees were attacked significantly more often than trees from any of the other sources (13 percent) (table 2). These results suggest that genetic variation in susceptibility to attack may be important. Further study in this area is needed.

Table 2.--Trees from each State attacked by X. germanus in spring 1978 in the Alexander County, Illinois, black walnut plantation

State	Total no. trees	% attacked
Arkansas	233	9
Illinois	261	7
Kansas	59	2
Kentucky	354	13
Missouri	159	5
Tennessee	928	7

An aspect of concern, however, is the planting of large numbers of trees from a few seed sources (a seed source refers to the parent tree) or grafted seedlings taken from only one or two trees if one or more of these seed sources or clones are susceptible to beetle attack. If the grafted portion is attacked and sprouts are produced by the root stock, the selected, superior growth characteristics or nut potential of the grafted portion are lost and the tree's value is reduced to that of a normal, nursery-run tree.

CONTROL RECOMMENDATIONS

Good management and silvicultural control practices may provide the best options for minimizing damage by X. germanus. Direct chemical control of the insects on walnut trees is not practical because the beetles spend most of their life cycle within trees where chemical sprays cannot penetrate. Treatment with systemic insecticides may be effective during the initial stages of attack, but no research has been done to test their effectiveness. Therefore, I recommend the following practices to reduce the effects of X. germanus on black walnut plantations.

1. Select planting sites that have deep, well-drained soils; if possible, have your local forester examine the site.

2. Plant trees at close spacing (e.g., 10 feet x 10 feet [3m x 3m]) to allow later thinning and selecting for the best trees.

3. Plant trees from several locations or seed sources to reduce the chances of severe losses if one or two seed sources are highly susceptible to X. germanus attack.

4. Manage the trees, especially during the first 10 years, with techniques known to promote rapid growth. Examples of such techniques would be weed control and interplanting with nitrogen-fixing plant species such as autumn olive.

5. Treat fresh hardwood stumps within a 1/4 mile (about 500 meters) radius of the plantation with diesel fuel or other stump treatment because X. germanus often live in stumps in cutover forested areas.

6. Remove affected trees from the plantation as soon as possible after attack by X. germanus, evidenced by wilting or dead tops. Destroy them to prevent population buildup within the plantation.

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VARIATION IN INHERENT DECAY RESISTANCE OF BLACK WALNUT[1]

John H. Hart[2]

Abstract.--Sapwood and heartwood from fast-growing black walnut decayed at the same rate as sapwood and heartwood collected from slow-growing trees. Based on results from 15 trees (three trees from each of five states) the sapwood was more decay susceptible than the heartwood. There were no significant gradients in decay resistance of the heartwood associated with radial or longitudinal position in the trunk. The heartwood of individual trees from the same site varied significantly in decay resistance. This variation is attributed mainly to genetic variability. Similarities in heartwood decay resistance between trees collected in different states suggest that site is not a major factor in determining decay resistance.

Considering that black walnut is one of our most desirable and valuable timber species, there is little information on the chemistry and durability of its heartwood. Almost all available material on walnut describes the heartwood as decay resistant (Scheffer and Cowling, 1966), but published data to substantiate this claim could not be located.

Individual trees of the same species may vary considerably in their decay resistance (Scheffer and Cowling, 1966). This variation mainly is controlled genetically rather than by differences among sites on which the trees developed. Decay resistance also varies among different parts of the same tree (Scheffer and Cowling, 1966). Research with other tree species has shown that decay resistance decreases progressively from the outer heartwood to the pith. Decay resistance of the outer heartwood decreases progressively from the base of the tree upward, whereas the opposite is true for inner heartwood. Variation in decay resistance between individual black walnut trees or within individual trees has not been investigated.

As walnut wood is used in products that are expected to last for years or even decades, the resistance of this wood to microbial deterioration of importance even though the wood is seldom used under conditions conducive to decay. How durable is black walnut heartwood and does this durability vary in the different geographical areas that it inhabits? Is the heartwood in one part of the tree more durable than in another part of the tree? Will heartwood from fast-growing, intensively managed trees be as durable as that from naturally-occurring trees? The purpose of this research was to collect data which would answer these questions.

MATERIALS AND METHODS

To determine the effect of growth rate of walnut on decay resistance, four trees with different rates of growth were sampled. Blocks 2 cm^3 were cut 5 m above ground from logs harvested in Lansing, Michigan. The

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number of annual rings per cm was determined for each block. Blocks were dried at 45°C for one week, weighed, steamed for 15 minutes, placed aseptically into decay chambers containing Coriolus vesicolor or Poria placenta for eight weeks (McNabb, 1958), removed, dried at 80°C for one week, and reweighed. Ten blocks were used from each tree, each wood type and for each decay fungus.

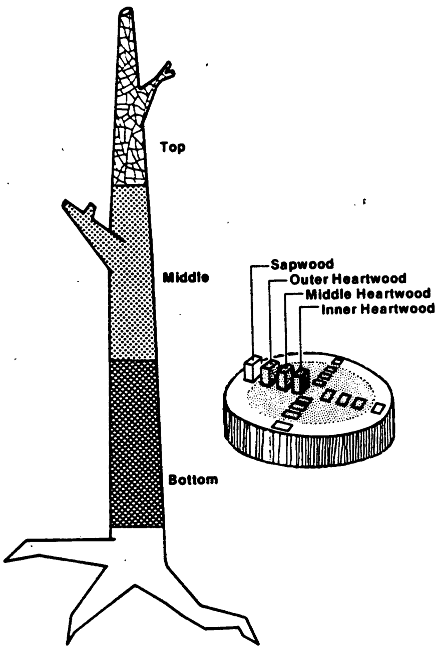

Figure 1.--Diagram of sampling procedure used in collecting blocks for decay studies. Samples were collected from the top, middle and bottom of the tree and, at each of these positions, from the sapwood and heartwood as illustrated.

To determine the variability in decay resistance throughout the range of black walnut and from different locations within a tree, three mature walnut trees were collected from five states: Kansas, Kentucky, Michigan, Pennsylvania and Wisconsin. All trees were dissected within one week of cutting except for the trees from Pennsylvania which were stored for 5 weeks at 0°C before sampling. Blocks 1.9 cm^3 were cut from three vertical positions from each tree: 0.5-1.0, 5-6 and 9-10 m above ground line. All samples had to be free from decay and defect; therefore, precise sample heights were impossible. At each vertical position cylinders 1.9 cm in thickness were cut. Blocks were cut from four radii so that there would be 4 sapwood, 4 outer heartwood, 4 middle heartwood and 4 inner heartwood blocks (fig. 1). Blocks from a given cylinder were used for one of the test fungi (P. placenta, C. versicolor or Schizophyllum commune) or as control blocks. The agar-block method (McNabb, 1958) with an exposure period of 10 weeks was used to determine rates of decay. Data were obtained from approximately 3,000 blocks which were analyzed statistically.

RESULTS

Growth and decay rates of black walnut are shown in Table 1. Tree 1 was a consistently fast growing tree, tree 4 a consistently slow growing tree and trees 2 and 3 were growing relatively fast when the heartwood tissue was formed but recent growth was only one-half that of earlier growth. Analysis of variance revealed significant differences in decay resistance between trees for a given fungus but these differences were not correlated with growth rate (Table 1).

Table 1.--Growth and decay rate of slow- and fast-growing black walnut collected in Michigan

Wood type and tree number		Average no. of annual rings/cm	Weight lost - % dry weight: Poria placenta	Weight lost - % dry weight: Coriolus versicolor
Heartwood	1	1.8	21.4	3.9
	2	3.0	11.6	5.8
	3	3.7	17.4	7.5
	4	6.5	16.1	3.7
Sapwood	1	2.0	29.3	10.5
	2	6.5	34.4	6.7
	3	7.0	31.1	12.7
	4	7.0	33.4	14.1

To answer the question 'Does the durability of the outer heartwood differ from that of inner heartwood?' an analysis of variance was run on the data for each state for each of the three fungi. Data for all three trees and for all three locations within the tree (top, middle, and bottom) were lumped for analysis. As expected, the sapwood was consistently more decay susceptible than the heartwood. However, outer, middle and inner heartwood did not differ significantly from one another in their rates of decay (fig. 2).

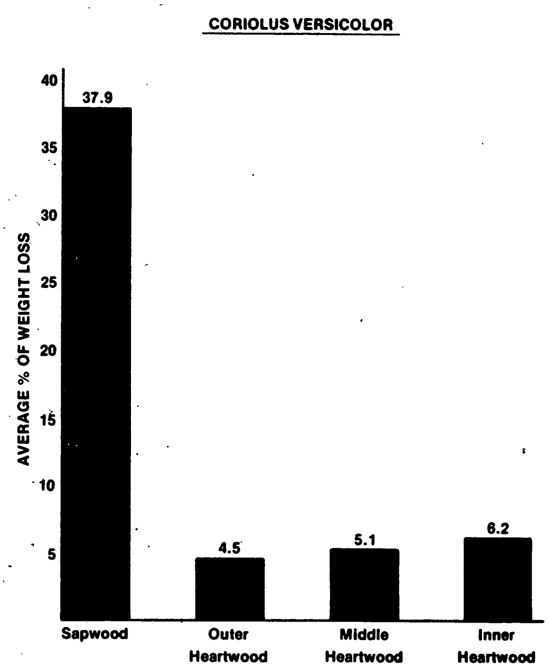

Figure 2.--Decay rates of black walnut sapwood and heartwood when exposed to Coriolus versicolor for 10 weeks. Decay rates for Poria placenta and Schizophyllum commune showed a similar pattern.

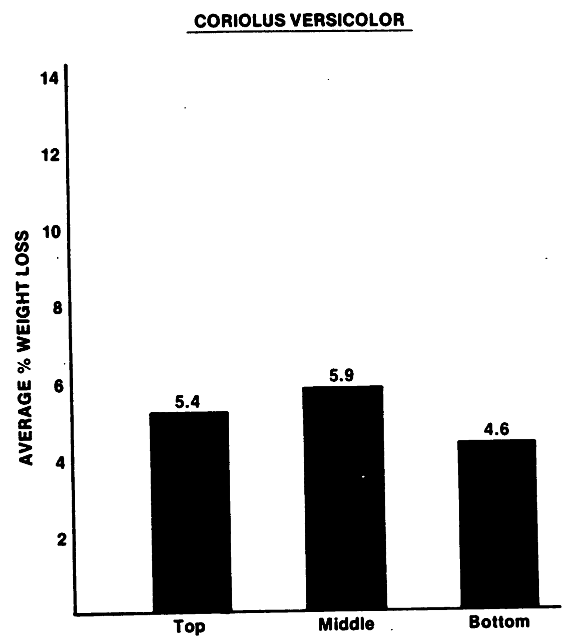

Figure 3.--Decay rates of black walnut heartwood collected from the top, middle and bottom of the trees when exposed to Coriolus versicolor for 10 weeks.

A similar procedure was used to determine if the sapwood or heartwood from the top, middle and bottom of the trees differed in their resistance to decay. Rates of decay for the sapwood did not differ significantly with position in the tree. Generally, the same pattern was true for the heartwood (fig. 3). However, P. placenta was capable of causing a faster rate of decay of bottom heartwood compared to heartwood from the top for trees collected from Pennsylvania and Kentucky (fig. 4).

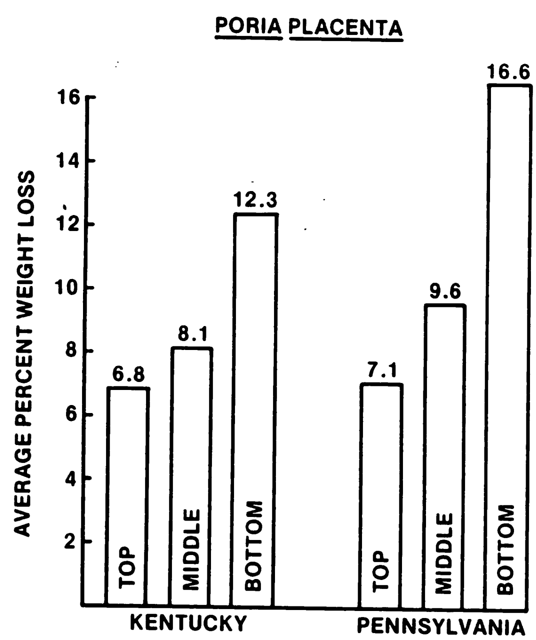

Figure 4.--Decay rates of black walnut heartwood collected from Kentucky and Pennsylvania when exposed to Poria placenta for 10 weeks.

The decay rates of the heartwood for each tree were compared for trees collected in each state to determine if durability varied between trees on the same site. Decay rates were not significantly different between trees for either C. versicolor or P. placenta for trees collected in Michigan, Kentucky or Pennsylvania. However, there were differences between trees collected in Kansas and Wisconsin. The heartwood from tree no. 2 from Kansas was significantly more decay resistant when exposed to either C. versicolor or P. placenta than either trees no. 1 or 3 (figs. 5-6).

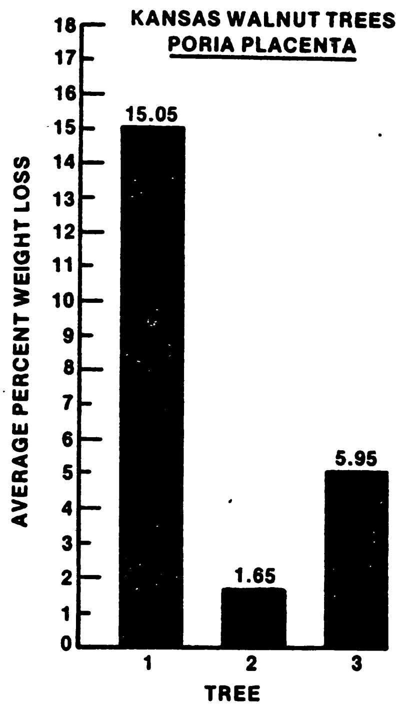

Figure 5.--Decay rates of black walnut heartwood collected from three trees in Kansas and exposed to Coriolus versicolor for 10 weeks.

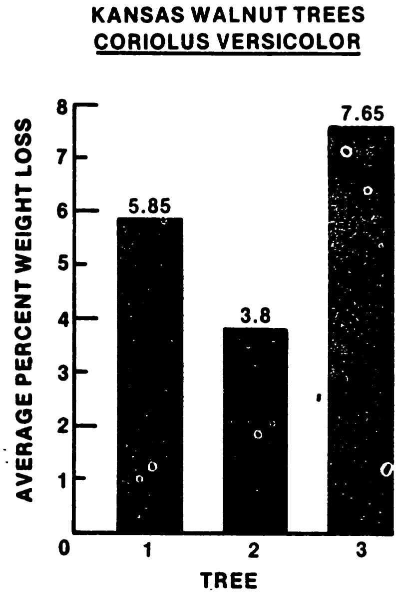

Figure 6.--Decay rates of black walnut heartwood collected from three trees in Kansas and exposed to Coriolus versicolor for 10 weeks.

The last comparison was between states, i.e. does the durability vary from one state to another. Rates of decay for heartwood from all radii, positions and trees were lumped for each state. An analysis of variance was then conducted to determine differences between states. Heartwood from trees collected in Kentucky and Pennsylvania decayed at a significantly faster rate than heartwood collected in Kansas, Wisconsin and Michigan when exposed to C. versicolor (fig. 7). However, there were no significant differences in decay rates between states when the heartwood was exposed to P. placenta (fig. 8).

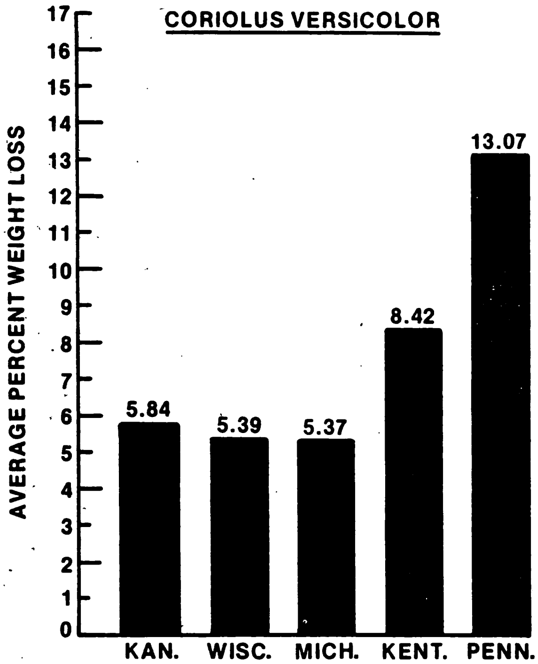

Figure 7.--Decay rates of black walnut heartwood collected from five states and exposed to <u>Coriolus versicolor</u> for 10 weeks.

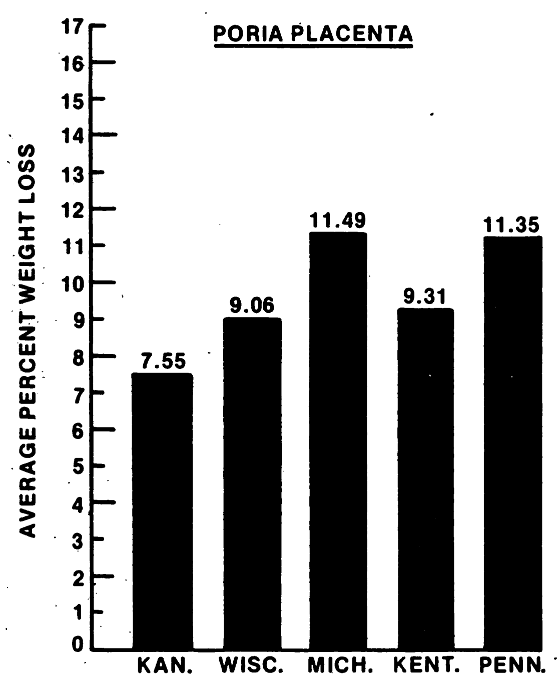

Figure 8.--Decay rates of black walnut heartwood collected from five states and exposed to <u>Poria placenta</u> for 10 weeks.

DISCUSSION

The heartwood from fast-growing plantation trees should be just as decay resistant as the heartwood from slower-growing trees in natural stands, according to evidence presented above. Since wood durability is directly correlated with the amount and type of heartwood extractives formed when sapwood is transferred into heartwood, it appears heartwood formation is basically the same in fast and slow-growing trees. This has additional significance because heartwood extractives give walnut its distinctive color and influence its workability.

The fact that the heartwood did not vary in decay resistance radially differs from previous reports (Scheffer and Cowling, 1966). Radial gradients in decay resistance are the result of chemical alteration (polymerizations) of the toxic components as the heartwood ages. This explains, at least in part, why we find hollow trees in nature.

My results with black walnut would suggest that the compounds responsible for decay resistance do not polymerize as the heartwood ages. However, not enough is known about the chemistry of decay resistance in walnut to provide a conclusive explanation of why there seems to be little chemical alteration as the heartwood ages. The explanation of this phenomenon of consistent decay resistance will have to await further investigation.

While variation in decay resistance of the heartwood within individual trees differed from previous studies, variation in decay resistance between individual trees and between trees from different sites was similar to previous reports (Scheffer and Cowling, 1966). It is known that individual trees of the same species may vary considerably in their decay resistance and that this variation is primarily genetically controlled. The data presented support these previous conclusions. If significant variations in decay resistance occur between trees from a given state (e.g. tree 2 from Kansas, figs. 5-6), the variation is most likely due to genetic differences and it should not be attributed to site differences. All trees from one state were collected from the same site. On the other hand, there were major site differences between states, yet decay resistance as measured by <u>P. placenta</u> did not differ significantly between states. Even though there were some differences in decay rates caused by <u>C. versicolor</u>, trees from Kansas, Wisconsin and Michigan were remarkably similar even though the sites of collection were not similar.

Additional collection of trees will be made during the coming year in Indiana, Illinois, Mississippi and North Carolina. Hopefully, this additional sampling will help clarify variations in decay resistance of black walnut throughout its range.

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EPIDEMIOLOGY OF BUTTERNUT CANKER[1]

N. A. Tisserat and J. E. Kuntz[2]

Spores of Sirococcus clavigignenti-juglandacearum, the causal fungus of butternut canker, were liberated only during rainfall by the action of rain splash impaction on the spore matrix of fruiting pycnidia. During rainfall, conidia were trapped on rotorod samplers up to 30 m from cankered trees, although observation of natural spread indicated some spores probably travel greater distances. A high concentration of spores were washed down the tree trunk from branch cankers in stem-flow water. Infection and canker development following artificial inoculation occurred throughout the summer on butternuts in the field. Natural infection of potted seedlings placed under diseased trees occurred from late July to October. The fungus continued to sporulate heavily on recently killed, cankered trees that remained standing or that were felled. These trees served as potential inoculum reservoirs.

INTRODUCTION

Butternut canker, first reported in Wisconsin in 1967 (Renlund, 1971), is the most serious disease of butternut (Juglans cinerea L.). Since the first report, the disease has been found throughout the natural range of butternut in eastern United States (Anderson and LaMadeline, 1977) and threatens to eliminate this beautiful and valuable hardwood in many areas of the country (Nicholls, 1979). The disease is especially severe in southern Wisconsin where some survey plots had a disease incidence of 80% (Prey and Kuntz, 1981). Symptoms of the disease include branch mortality and multiple cankering of both the main stem and the buttress roots. The causal organism has been identified as the imperfect fungus, Sirococcus clavigignenti-juglandacearum (Nair et al., 1979).

A better understanding of the epidemiology of butternut canker, especially with regards to environmental conditions favorable for sporulation, spore dispersal, and infection, is needed before silvicultural control measures can be recommended. The objectives of our research were 1) to identify environmental conditions favorable for sporulation and dispersal of the pathogen; 2) to examine the rate at which branch and stem cankers develop; and 3) to evaluate the potential of dead or dying butternuts to serve as inoculum sources.

Spore Liberation and Dispersal

Seasonal spore release was studied in pockets of diseased butternuts in the University of Wisconsin Arboretum, Madison, during 1979 and 1980. Vaseline-coated microscope slides were placed beneath cankered trees and removed at daily or weekly intervals. The number of spores per interval was determined by counting all S. clavigignenti-juglandacearum spores in 20

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random light microscopic fields at X430. Spores of the fungus were liberated from cankered trees from mid-April through October in both years, but only during those days in which there was measurable rainfall. Table 1 indicates results for the 7-day period of June 15-21, 1979. Slides placed beneath trees directly after rainfall or during periods of relative humidity greater than 90% did not have spores deposited on them. Spore collection on rotorod and Hirst spore traps also showed that liberation of conidia only occurred during rainfall.

Table 1 Number of spores trapped daily on vaseline-coated microscope slides placed beneath a cankered butternut tree.

	June 1979						
	15	16	17	18	19	20	21
Rainfall (inches)	0	0	.13	0	.60	.10	0
Number of spores 1/	0	0	186	0	275	134	0

1/ Total spores on 20 fields at X430.

The spores of S. clavigignenti-juglandacearum are tightly bound in a gelatinous matrix as they are extruded from pycnidia embedded in stromatic tissue beneath loosening outer bark, and are not easily removed, even under windy conditions. Preliminary experiments with blowing air, mist, and water droplets proved that rain splash impaction on the matrix is needed for liberation of the spores (Tisserat et al., 1981).

Many of the spores liberated from branch and stem cankers during rainfall are washed down the tree trunk in stem flow water. The quantity of conidia in stem runoff was determined by placing water-tight funnel traps around the main trunk of two cankered trees (dbh 20 cm) at a height of 1 meter. After periods of rainfall, stem runoff collected in the funnels was siphoned into 1 liter plastic bottles. The runoff water then was centrifuged at 8,000 g for 20 minutes to sediment the S. clavigignenti-juglandacearum conidia and other particulates. The sediment was resuspended in a mixture (5:1 v:v) of distilled water and trypan blue in lacto-phenol (for easier identification of the spores). The concentration of S. clavigignenti-juglandacearum spores in the suspension was determined with a light-field haemacytometer, and the number of spores/ml water was adjusted to the original amount of stem runoff water in each sample. Concentrations greater than 100 spores/ml of runoff water were common and occasionally concentrations higher than 10,000 spores/ml were recorded (Table 2). Spores in rainwater flowing down the stem can become lodged in lenticels, bark cracks, and wounds where they may germinate and start new infections. This may explain the multiple cankering typical of diseased butternuts especially on the lower trunk and buttress roots. Cankers of various ages and sizes commonly occur on the same tree.

Table 2 Mean number of S. clavigignenti-juglandacearum spores/ml in stem-runoff water from two heavily cankered butternut trees for 3 rainfall dates in 1980.

	Number of spores/ml stem-runoff 1/		
	6/27/80	7/4/80	7/16/80
Tree 1	5.2×10^2	2.3×10^2	2.5×10^2
Tree 2	1.3×10^4	2.2×10^4	1.5×10^3

1/ Mean of two samples, five counts per sample.

One of the unique symptoms of this disease is the formation of basal stem and buttress root cankers. Basal cankers may extend below the soil line to a depth of 30 cm, but appear to progress laterally for only a few cm on the roots before marginal callus forms. The girdling of the cambial regional at the base of the tree by multiple cankers is often the cause of tree death, rather than girdling occurring higher on the trunk.

Buttress roots also may become heavily cankered. Roots exposed at the soil line have been found to be cankered up to 2 m from the trunk, but cankers on roots below the soil line have not been detected. The possibility of tree-to-tree spread of the fungus through root grafts is being studied.

The spores of S. clavigignenti-juglandacearum also can be carried from tree to tree in rainsplash droplets resulting in new infections. Spore dispersal gradients from an isolated pocket of diseased butternuts were determined by placing rotorod spore traps at 7.5 m intervals to 30 m downwind from the trees. The number of spores impacted on the traps during rainfall was plotted against the distance the traps were placed from the inoculum source (Fig. 1). Spore numbers decreased rapidly as the distance increased from the inoculum source, but some conidia were trapped at 30 m. The curve is hollow shaped, similar to curves of many airborne fungal spore and pollen dispersal gradients.

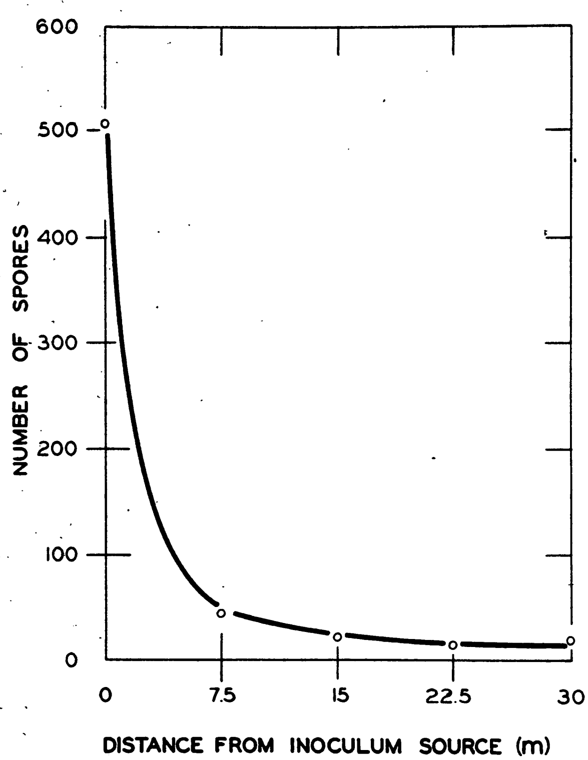

Figure 1. Average number of S. clavigignenti-juglandacearum spores caught during five rainfall periods (1980) on rotorod traps positioned up to 30 m from a diseased pocket of butternuts.

Spore dispersal curves may be useful in determining eradication distances needed to prevent the influx of inoculum into healthy butternut stands. Similar curves have been used to define the zone for Ribes eradication in white pine blister rust control programs (Van Arsdel, 1961). Based on our present results, we recommend that all diseased butternuts should be cut, removed, and destroyed for at least a 60 m radius from a healthy butternut stand or black walnut plantation. Butternuts and black walnuts should not be planted under or near diseased butternuts. While these control measures should reduce the amount of inoculum reaching healthy butternuts and black walnuts, they may not eliminate infection since it is not known whether insects or other vectors also aid in spore dissemination.

To determine environmental conditions favorable for infection, groups of 30 potted butternut seedlings were placed among cankered trees in the woods at two-week intervals (May through October, 1980). After each two-week period, the respective seedlings were brought back to the greenhouse and observed for symptoms of butternut canker. Most naturally invected seedlings showed initial symptoms witnin 2 weeks. Nevertheless, all seedlings were held in the greenhouse to observe canker development.

None of the seedlings placed in the woods prior to August 1 became diseased. Some seedlings placed out from August 1 through October became infected and subsequently were killed by the fungus. Leaf scars appeared to be the major infection court, but lesions also developed at lenticels and at the root collar on several trees. Initial symptoms appeared as small black necrotic flecks which rapidly expanded to dark brown ellipitical lesions. Bark cracking was commonly observed at the lesions, followed by an inky exudate from the opening. The root collar or basal stem lesions progressed into the root itself causing black irregular lesions on the main tap root of young seedlings.

Early in the summer, rainfall was sparse and the weather was hot and dry. In contrast, frequent heavy rainfalls occurred from mid-July through September. Natural infection of the potted seedlings occurred only during the late-summer rainy period. Rainfall and high relative humidity are optimal for spore dispersal and infection by S. clavigignenti-juglandacearum (Kuntz et al., 1979). The results also support the hypothesis that a major infection period is in the late summer and early fall. Fresh leaf scars during this time create a suitable infection court for the fungus (Kuntz et al., 1979).

Canker development

Canker development was studied in a plantation of butternuts at the University of Wisconsin Arlington Experimental Farm. Ten trees were inoculated bi-weekly from May 1 through October 10, 1980, by puncturing three leaf scars on a healthy branch with a dissecting needle and placing approximately .05 ml of a spore suspension (10^6 Sirococcus spores/ml water) on the wound. Cankers formed on branches after all inoculation dates. Two types of canker development were noted. In the first type, lesions appeared discrete, sunken, and were bounded by a callus layer. Cankers of this type progressed slowly and the branches were still alive after six months. In the second type, fungus invasion and colonization of the branch after inoculation occurred rapidly. Some branches were killed and hyphal pegs were produced in as little as one month after inoculation. No distinct canker margin was noted on these branches. The reason for the difference in reaction types is not known, but it was noted that those inoculated branches that died rapidly were partially shaded or were located on the lower portion of the tree. The shaded branches may have been physiologically stressed and were more susceptible to colonization by the fungus. In other cases, no cankers developed until the spring following inoculation in late summer.

Inoculum source

To determine whether felled trees could serve as important inoculum sources, five heavily cankered trees, 8-11 cm in diameter and 8-11 m tall, were cut and placed on the forest floor (February , 1980). By June 1, 1980, all cut trees showed evidence of extensive colonization and sporulation by _S. clavigignenti-juglandacearum_, even beyond the originial canker margins. Large quantities of spores were produced. Therefore, infected trees should be removed from the site to prevent inoculum buildup. Present studies seek to determine if basal stem girdling or poisoning of diseased trees will hasten bark shedding and tree drying and thereby reduce sporulation by the fungus.

CONCLUSION

Spores of the fungus _Sirococcus clavigignenti-juglandacearum_ are liberated during rainfall by rain splash impaction. A high concentration of spores from cankered branches are washed down the tree trunk via stemflow water, leading to multiple infections of the same tree. The multiple cankers eventually girdle the cambium resulting in the death of the tree. The girdling often occurs at the base of the tree (at the soil line) rather than higher on the trunk.

Short distance dispersal of inoculum occurs when splash droplets containing spores are windblown from tree to tree. Spores have been trapped 30 m from a diseased pocket of butternuts during rainfall, although observations of natural spread among butternut plantings indicate spores travel even greater distances. Mechanisms of long distance dispersal of the fungus are not known but it has been postulated that vectors, spores traveling in aerosols, or both may be involved.

Infection and canker development after artificial inoculation can occur at any time during the summer. Twigs and small branches can be killed in as little as one month. In 1980, a major infection of noninoculated, potted seedlings placed under diseased trees occurred during rainy, humid conditions from August 1 through October. These dates corresponded with senescence and leaf drop. Fresh leaf scars are known to be infection courts of the fungus. From such late summer and fall infections, cankers appear and develop rapidly the following spring.

The fungus sporulates heavily on recently killed or cankered trees, either standing or felled, which serve as a potential inoculum reservior. In order to prevent inoculum buildup, dead or dying trees should be removed from the site. Walnuts and butternuts should not be planted under or near cankered trees.

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THE DISTRIBUTION AND IMPACT OF BUTTERNUT CANKER IN WISCONSIN[1]

A. J. Prey and J. E. Kuntz[2]

Widespread dying of butternut (Juglans cinerea L.) was reported in 1967 in southwestern Wisconsin. Since then, this canker-dieback disease, incited by the fungus Sirococcus clavigignenti-juglandacearum Nair et al, has been found throughout eastern U.S.A. Diagnostic symptoms have been described, the disease cycle clarified, and the host range expanded. Current studies concern disease epidemiology and possible disease resistance in butternut and other Juglans species.

INTRODUCTION

Widespread dying of butternut (Juglans cinerea L.) first was reported in southwestern Wisconsin in 1967 (Camp, 1967; Renlund, 1971). The number and extent of the diseased areas and the deterioration of the dead trees indicated that the disease had been active for several years (Kuntz et al., 1977). Canker-dieback since has been found throughout the range of butternut in eastern United States (Anderson, 1978; USDA, 1976; USDA, 1977a; USDA, 1977b) and the fungus pathogen has been isolated from diseased specimens collected in Indiana, Illinois, Iowa, Michigan, Missouri, Minnesota, Ohio, and Wisconsin.

An initial examination of diseased trees indicated that Melanconium oblongum Beck was associated with branch dieback and fruited abundantly on dead branches. However, distinct cankers also were present on both living branches and trunks. In contrast, Graves description in 1923 (Graves, 1923) of the Melanconis disease in Connecticut specifically stated that no well marked lesions or cankers were found with the Melanconis dieback. Moreover, recent inoculations of young butternut seedlings and saplings with M. oblongum failed to incite either branch or stem cankers. The fungus is considered a weak parasite that needs a stressed host to permit its development (Hepting, 1971). Melanconis dieback also was reported on black walnut, J. nigra L., and other Juglans species (Graves, 1923).

Diagnostic symptoms of butternut canker include discrete, elliptical cankers of both bark and wood of twigs, branches, stems, and even exposed buttress roots (Kuntz et al., 1977; Kuntz et al., 1979; Nicholls et al., 1979). Young cankers commonly originate at leaf scars, other natural openings such as lenticels, buds, bark wounds including insect wounds, natural bark cracks, and occasionally at points apparently free of any injury. Older cankers on trunks are large, open or partly covered by shredded

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bark, vertically oriented, and perennial. Cankers of different ages and sizes commonly occur on the same tree. Some stem cankers have persisted for several years as evidenced by the repeated layers of annual callus and by differential growth-ring counts. In many cases, their origin is unknown. However, adventitious buds, dead branches, and branch stubs are present in the centers of some cankers.

Peeling the bark from branches and trunks may disclose dark brown to black inner bark and wood of undetected cankers. Older cankers often bear shredded bark underlain with blackened wood, may be bordered by repeated callus layers, and frequently coalesce to girdle branches and stems. Branch suckers and trunk sprouts often develop below the girdled portion, are readily infected, and die shortly thereafter. Sprouts are infected commonly in the fall through leaf scars and small, irregular lesions or large dark areas develop rapidly early the following spring. Infection of lenticels result in tiny, round, chocolate brown lesions of the bark. Initially only the outer bark is infected, but soon the wood is invaded (Jutte et al., 1978). On older trees, in the spring and early summer, an inky black exudate issues from canker fissures; later in summer, sooty black patches remain. Often the exudate also indicates initial infections and incipient cankers. Eventually, infected trees die.

It is now known (Jutte et al., 1978; Nair et al., 1978; Nair et al., 1979) that under the outer bark, the causal fungus forms a thin, black mycelial stroma from which arise hyphal pegs and pycnidia. Spores are extruded either in sticky masses or as fine, hairlike cirri. Spores are dispersed by rain or mist and disseminated by wind (Nicholls, 1979; Tisserat et al., 1981). The role of insects and other possible vectors remains unknown.

In 1969, studies were initiated on the etiology and epidemiology of butternut canker (Kuntz et al., 1979). The causal fungus, coded BN-5 and identified as a new *Sirococcus* species (Nair et al, 1978; Nair et al., 1979), was readily isolated in pure culture on common nutrient media from both bark and wood. The pathogen grew best at 24-28 C in light or dark; formed characteristic mycelial colonies, hyphal pegs, and pycnidia in culture; and sporulated profusely, especially when growing on thin malt agar. Inoculations of fresh wounds with mycelium, the spore matrix, or a spore suspension in water incited lesions on midribs and petioles of leaves and cankers on branches, stems, and roots of butternut and black walnut seedlings and saplings (Kuntz and Prey, 1978). Both hyphal pegs and sporulating pycnidia frequently formed on the thin fungus stroma beneath loosening outer bark of inoculated seedlings and saplings.

MATERIAL AND METHODS

Wisconsin's 1968 Timber Resource Survey (Spencer and Thorne, 1972) was used to locate forest inventory plots containing butternut. A maximum of five one-fifth-acre plots per county was selected and examined by U. S. Forest Service and WDNR field crews in 1976. Where possible, up to 50 butternut trees were examined on or adjacent to each plot. Data were recorded as to general tree health, canker incidence, limb or top dieback, and death from cankering or other causes. Trees also were grouped into poletimber (< 10 inches or 25 cm dbh) and sawtimber (> 10 inches or 25 cm dbh) classes. Dying or cankered branches were collected from diseased trees in each plot. Isolations for possible pathogens (Kuntz et al., 1977; Nicholls et al., 1979) were made in the laboratory on acidified potato dextrose agar (PDA) medium.

RESULTS

A total of 2,882 butternut trees were examined on or adjacent to 83 study plots in 33 counties. Of all trees examined, 44% appeared healthy, 30.9% were stem-cankered, 42.1% exhibited some degree of branch cankering and dieback, and 8.7% already were dead. Of all trees examined, 61.8% were classed as poles and 38.2% were sawtimber. Of the poles, 34.5% were cankered; of the sawtimber, 25.1% were cankered.

In several counties in northeastern Wisconsin, no cankered trees were discovered. In contrast, in southwestern Wisconsin counties, as many as 80% of the butternuts were cankered and 32% were dead. The fungus pathogen was isolated from most cankers collected in western and southwestern Wisconsin but not from trees in eastern Wisconsin. In addition, the fungus was isolated from cankered butternuts in Iowa, Michigan, Minnesota, and Wisconsin. Meanwhile, *M. oblongum* was found on many dead branches throughout the range of butternuts in Wisconsin.

Cankers were found on all woody parts of diseased butternuts. Cankers developed on trees growing on many different soils and sites, including dry, infertile ridgetops with shallow soils as well as in moist, fertile bottom lands with deep soil. Trees of all ages and sizes growing in mixed and relatively pure stands were diseased. Infected trees occurred either in local pockets or over fairly extensive areas. In these disease areas, occasional butternuts appeared canker-free and healthy. So far, small branch and stem cankers have been detected on a few black walnuts growing in mixed stands with severely infected butternuts. The fungus pathogen was isolated from cankered walnuts. Walnut isolates, wound-inoculated into butternut and walnut seedlings and saplings, incited typical perennial branch and stem cankers. Especially with black walnuts, many inoculated branches died without forming distinct cankers. The fungus has been reisolated repeatedly during a 6-year period from perennial cankers on walnut stems.

DISCUSSION

Butternut occurs throughout the northern two-thirds of eastern United States under a wide range of soils and climatic conditions (Schroeder, 1972). Although it grows best on rich, deep moist soil, butternuts grow faster than do walnuts on dry, rocky soil.

Although, butternut is a minor species in Wisconsin (18.3 million cu. ft. net volume of growing stock) (Spencer and Thorne, 1972), select butternut lumber is second only to walnut in economic value (Peterson, 1977). In 1967, 343,000 cu. ft. of butternut were harvested, compared to 292,000 cu. ft. of black walnut (Spencer and Thorne, 1972). In fact, Wisconsin ranks second in the amount of butternut found in the United States and is a major producer of butternut lumber, used primarily for furniture, cabinets, and other fine woodwork (Schroeder, 1972; Spencer and Thorne, 1972).

In the past, butternut has suffered from few diseases (Hepting, 1971; USDA, 1960) or insect pests (Schroeder, 1972). Now, however, it appears that the canker is potential threat to butternut throughout its natural range (Anderson, 1978). Meanwhile, little or no regeneration of butternut has occurred in disease areas. Both sprouts and seedling trees are infected and rapidly killed. Fortunately, an occasional butternut remains healthy even though growing in the midst of severely cankered trees (Orchard, 1981). Whether such trees are "disease escapes" or are resistant to attack by the fungus pathogen is unknown. Branch and stem cankers are detected infrequently on black walnuts in woodlands even though artificial inoculations have incited cankers on walnut seedlings and saplings. Most cankers develop slowly, forming marginal callus. However, infected branches frequently die without forming distinct cankers. Hopefully, most black walnuts will remain canker-free. Otherwise, the increasing number of walnut plantings in the Midwest would be in grave danger.

The formulation of effective control measures must await further information, but certain silvicultural controls already are indicated. Meanwhile, do not plant walnuts or butternuts under or near infected butternuts. Canker distribution and impact in Wisconsin has been determined, the causal fungus has been identified, and its means of spread have been clarified. Present research seeks to clarify conditions favoring infection and disease development (Kuntz *et al.*, 1979).

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REACTIONS OF *JUGLANS* SPECIES TO BUTTERNUT CANKER AND IMPLICATIONS FOR DISEASE RESISTANCE[1]

L. P. Orchard, J. E. Kuntz, and K. J. Kessler, Jr.[2]

Butternut canker, caused by the fungus *Sirococcus clavigignenti-juglandacearum* Nair *et al*, is the most important disease of butternut (*Juglans cinerea* L.). Infected butternuts often have many cankers and severely cankered trees die. Several economically important species belong to the genus *Juglans*. In order to determine their relative resistance or susceptibility, saplings of several *Juglans* species and hybrids were wound-inoculated under field conditions at the U.S.F.S. Tree Improvement Center, Carbondale, Illinois. Cankers developed on all inoculated species and hybrids including trees of *J. nigra*, *J. regia*, *J. sieboldiana*, *J. regia* x *nigra*, and *J. sieboldiana* x *cinerea*. Nine months after inoculation the largest cankers had developed on *J. regia* which appeared to be highly susceptible to the canker fungus pathogen.

INTRODUCTION

Butternut canker, caused by the fungus *Sirococcus clavigignenti-juglandacearum* Nair *et al*. (1979), is the most important disease of butternut (*Juglans cinerea* L.). The disease was noticed first in Wisconsin in 1967 (Renlund, 1971). In 1978, Anderson and LaMadeleine (1978) reported its occurrence throughout the range of *J. cinerea* in the eastern United States.

On butternut, the fungus incites perennial cankers, of various sizes and ages, which can occur at all heights on the twigs, branches, and stems. In the spring, a thin black fluid exudes from cracks in the bark; it stains the bark brown. This is often the easiest way to detect young cankers. The wood beneath the exudate is stained dark brown to black in a vertically oriented, elliptical pattern. Young cankers on branches appear as dark, irregularly elongate, sunken areas frequently associated with a leaf scar, lenticel, or various wounds. Older cankers are perennial, fusiform, vertically oriented, and may be wholly or partially covered with shredded bark. The fungus produces a thin stroma in the bark from which hyphal pegs and spore-bearing pycnidia form under the loosening outer bark (Kuntz *et al*., 1979). Infected trees usually bear numerous cankers and often die as a result.

In some stands all the infected butternut trees have died, but in other stands one or several apparently healthy trees remain. These canker-free trees are found in infection pockets where inoculum is abundant, which suggests that they may be resistant to the pathogen.

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In addition to butternut, several economically important species belong to the genus Juglans. These include black walnut (J nigra L.), Persian walnut (J. regia L.), and Japanese walnut (J. ailantifolia Carr.) (Smith, 1953).

In order to determine their relative resistance or susceptibility to butternut canker, trees of these species and some of their hybrids were wound-inoculated with S. clavigignenti-juglandacearum under field conditions at the U.S.D.A. U.S. Forest Service Tree Improvement Center, Carbondale, Illinois.

MATERIALS AND METHODS

In October, 1979, certain Juglans species and hybrids, 10-20 years old, (Table 1) were branch-inoculated with mycelium and spores of S. clavigignenti-juglandacearum. Inoculated branches were generally 1-3 cm in diameter.

Six tangential slanting knife wounds, approximately 1-2 cm long, were made through the bark and into the sapwood on each tree tested. Four wounds were used for inoculations, and two served as noninoculated controls. Usually, the inoculated wounds were made on one branch and the control wounds were made on another branch, but sometimes the control wounds were made distal to the inoculated wounds on the same branch. Immediately after wounding, a piece of mycelial colony of the pathogen growing on agar was inserted into each of the four wounds used for inoculation. For controls, a piece of sterile agar alone was inserted into each of the two control wounds. The wounds were wrapped with wet cotton and covered loosely with aluminum foil.

In the spring of 1980, the inoculations were observed for canker development, and on July 31, 1980, all the inoculations were examined, cankers were measured, and symptoms were described.

RESULTS

Cankers began to appear and the fungus pathogen was reisolated in the early spring. Both confirm our observation of similar fall infections and rapid canker development in the spring on trunk sprouts. By July 31, 1980, cankers had developed on all species and hybrids which had been inoculated in October 1979 (Table 1). The cankers were distinctive for each species of Juglans. No cankers developed at any of the noninoculated control wounds. J. ailantifolia is now the accepted name for Japanese walnut and is synonymous with J. sieboldiana and J. sieboldiana var. cordiformis (Brinkman, 1974; McDaniel, 1979). In order to preserve information, however, the taxonomic designations below follow those used at the Tree Improvement Center.

Characteristic symptoms and signs of butternut canker for each species were as follows:

Table 1. Canker development following branch inoculations of Juglans species and hybrids.

Species	Trees Inoculated	Cankers measured[1]	Mean canker length (cm)
J. nigra	15	46	16.5
J. regia	15	51	19.5
J. regia x nigra	15	58	18.0
J. sieboldiana	8	28	14.0
J. sieboldiana var. cordiformis	9	34	10.5
J. sieboldiana x cinerea	3	8	14.0
J. cordiformis x cinerea	5	18	15.5
J. cinerea x cordiformis	6	12	19.0

[1] Cankers were not measured on branches that had been killed.

J. nigra

Cankers were usually externally indistinct, but were detected as a discoloration of the inner bark. Cankers were elliptical; chocolate brown exudate and/or a dry black "soot" appeared on some canker faces; branches 1 cm in diameter or smaller were killed; and hyphal pegs were produced beneath loosening bark on these dead branches.

J. regia

Cankers were slightly sunken to flat, but with distinct margins, often appearing blue-gray in color, elliptical in shape, and extending for roughly equal distances up and down the branch from the inoculation point. The bark often was cracked in the tissue alongside the canker. A chocolate brown exudate and/or a patch of sootiness appeared on some canker faces. Branches 1 cm in diameter died, and characteristic hyphal pegs developed under loosening bark on these dead branches. Branches 3 cm in diameter were approximately 3/4 girdled.

J. regia x *nigra*

Cankers resembled those on *J. regia*. Cankers were sunken, distinct, blue-gray in color, with longitudinal bark cracking both adjacent to and within the canker. Hyphal pegs were present occasionally on living branches.

J. sieboldiana and *J. sieboldiana* var. *cordiformis*

Cankers varied from indistinct, slightly sunken cankers to distinct, discrete, sunken to flat cankers. The branches often were swollen in the canker region with bark cracking alongside the canker. Occasionally there was a trace of sootiness on the canker face. On one tree of *J. sieboldiana* var. *cordiformis*, the inoculated wounds completely sealed and were indistinguishable from the check wounds except that the inner bark of the inoculated wounds was discolored (as with all inoculations), whereas the inner bark of the noninoculated checks was not discolored. Branches up to 2 cm in diameter were killed, and hyphal pegs formed on the dead branches.

J. sieboldiana x *cinerea* and *J. cordiformis* x *cinerea*

Cankers were distinct, sunken, and slightly discolored. Small branches (2 cm) were killed and dead branches bore hyphal pegs. Cankers resembled those formed on *J. sieboldiana*.

J. cinerea x *cordiformis*

Cankers resembled those formed on *J. cinerea*. Cankers were smooth, slightly sunken, light blue to gray often with a sooty patch, with abundant hyphal pegs, and little callus production along the canker margin.

DISCUSSION

The collection of *Juglans* species at the Tree Improvement Center at Carbondale, Illinois provided trees to inoculate under field conditions within the known range of the pathogen. The potential threat of *S. clavigignenti-juglandacearum* to *Juglans* species is great. With the exception of one tree (*J. sieboldiana* var. *cordiformis*), cankers developed at every wound inoculation on every tree, or the branch was killed by girdling before a discrete canker formed. We realize that our technique, i.e. direct inoculation of a wound with mycelium and spores of the pathogen, may mask some mechanisms of disease resistance. Such factors as low sporulation, inability of the inoculum to spread, adverse environment, or barriers to penetration could dramatically affect the course of the disease in the field. Nevertheless, given the high value of the trees, a severe technique established their resistance or susceptibility to cankering once infected. Factors which can influence disease incidence and severity for these species must be the subject of future investigations.

THE IMPORTANCE OF *S. CLAVIGIGNENTI-JUGLANDACEARUM* TO THE MAJOR *JUGLANS* SPECIES

Black Walnut

Kuntz et al. (1979) reported that black walnut is infected only infrequently in natural woodlands, but that artificial inoculations in experimental nurseries produce progressive, killing stem cankers on black walnut seedlings and branch cankers on saplings. Following our inoculations, cankers developed on black walnut; also inoculated branches of black walnut were killed more often than were those of other species tested. Current studies seek to determine whether infected black walnut branches die more often and more quickly than do infected branches of other *Juglans* species. If infected walnut branches do die rapidly, a hypersensitive reaction may exist. Such quick killing of infected host tissue might restrict further development of the pathogen and account for the low frequency of cankered walnuts in natural forest stands. Meanwhile, new plantings of black walnuts should not be made under or near cankered butternuts.

Persian Walnut

J. regia appears to be highly susceptible to *S.clavigignenti-juglandacearum*. At the Tree Improvement Center the longest cankers developed on this species. Because of this, butternut canker may become a serious disease through much of the world where this commercially important species is grown.

Further study will continue examination of these and other inoculations. Meanwhile detection surveys of midwestern plantings are needed to assess the disease potential of butternut canker on *J. regia*.

Hopefully the disease may not prove serious in some regions, e.g. California, for climatic reasons. Nevertheless, infected material must not be transported to regions where the disease has not been reported. Infected butternuts in the vicinity of Persian walnut plantations in the eastern United States should be removed and destroyed. Named varieties of Persian walnut must be tested for disease reaction and possible resistance.

Japanese Walnut

Japanese walnut is not as important a species as Persian walnut or black walnut. The species appears to be susceptible to the canker fungus. Nevertheless, the cankers that developed on this species were generally smaller, and on one tree the wound sealed and canker development was restricted. Possibly this species may provide a type of resistance in breeding programs, not only for improved Japanese walnut but also for butternuts, black walnuts, and Persian walnuts.

Butternut

Butternut is highly susceptible to *S. clavigignenti-juglandacearum* in all stages of growth; it may become an endangered species (Anderson and LaMadeleine, 1978). Canker-free butternuts do occur in infection pockets and may be resistant. Orchard *et al.* (1981) and Orchard (1981) reported a possible form of resistance in young butternut seedlings in which cankers do not develop in certain infected seedlings.Reasons for survival of asymptomatic seedlings, though infected, are sought. Whether this reaction can be a significant source of resistance in breeding programs is not yet known. Butternut is an attractive and useful nut tree that is hardy in the northern United States and southern Canada, but butternut canker must be controlled if this species is to be exploited. The role of environmental conditions, especially stress factors that may favor or inhibit infection and disease development, and possible resistance of selected species and hybrids also must be clarified.

SUMMARY

J. nigra, *J. regia*, *J. ailantifolia*, *J. cinerea*, and several of their hybrids are susceptible to *S. clavigignenti-juglandacearum*. The fact that *J. regia* proved highly susceptible to canker development following direct inoculation warns that butternut canker may well have international significance. Further testing must determine the long-term course of the disease on these species, especially *J. regia*, the nature of the "hypersensitive" reaction in *J. nigra*, the possibililty for resistance in *J. ailantifolia* and *J. cinerea*, and the environment and site factors that influence disease spread, especially for regions where the susceptible *Juglans* species are economically important.

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DIEBACK, DECLINE, AND STEM CANKER OF BLACK WALNUT IN WISCONSIN[1]

J. E. Kuntz and A. J. Prey[2]

Abstract.--The survival, growth, and productivity of walnuts are limited by several deleterious agents including diseases, insects pests, and weeds. Although many walnut diseases cause little economic loss, several can be destructive under conditions favoring infection and disease development. Recently in Wisconsin (SW), Iowa (NE), and Minnesota (SE), a vertical, elongate, and sometimes girdling stem canker has severely damaged and even killed young walnuts in plantations. Two species of Fusarium have been isolated consistently from representative cankers. One Fusarium sp. has induced cankers on stem-inoculated walnut seedlings in greenhouse studies. Meanwhile, this stem canker has been complicated by branch cankers associated with a Phomopsis species and twig dieback associated with a Phyllosticta species. Current research seeks to clarify the significance and relative roles of these fungus pathogens.

INTRODUCTION

Black walnut (Juglans nigra L.) is an extremely valuable hardwood in eastern and central United States, prized for the flavor of its nuts (Zarger, 1969), for the beauty of its wood (Blyth, 1973; Clark, 1969), and for its aesthetic appearance as a shade tree (MacDaniels, 1979). In recent years, its culture and management have been studied extensively (Clark, 1973), facilitating the establishment of numerous plantations in Central States (Burke and Williams, 1969; Schlesinger and Funk, 1977). To meet the increasing demand for planting stock, forest nurseries have greatly expanded their seedling production (Brinkman, 1974).

Unfortunately, the survival, growth, and productivity of walnuts are limited by several deleterious agents and including diseases, insect pests, and weeds (Berry, 1973; Bey and Williams, 1976; Johnson, 1969; Miller, 1973; USDA, 1979; Weber, Anderson, and Hoffard, 1980). Numerous plant pathogens, mainly fungal, attack walnuts of all ages and incite different types of disease (USDA, 1960). Although most walnut diseases cause little economic loss, several can be destructive under conditions favoring infection and disease development.

STEM DISEASES

Stem diseases of walnut are of special concern since they lower the quality and quantity of lumber and veneer logs, reduce nut yields, and may even kill infected trees. According to Hepting (1971), perennial target canker, caused by the fungus Nectria galligena Bres., seriously damages walnuts in the southern Appalachian region. In Wisconsin, this canker has been of little consequence.

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[1]Paper presented at the 1981 Joint Meeting of Walnut Council/Northern Nut Growers Association. Purdue University, West Lafayette, Indiana, Aug. 9-14, 1981.

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In contrast, recently in Wisconsin, Iowa, and Minnesota, a vertical, elongate, and sometimes girdling stem canker has severely damaged and even killed young walnuts in plantations. (Kuntz, Orchard, and Tisserat, 1980). The sunken, elongate cankers are of various sizes from small bark cracks to long, vertical strips, sometimes extending from the root collar into the crown. Both bark and wood are affected. In old cankers, bark loosens and sloughs off. Infected bark is dark brown with distinct margins adjacent to healthy tissue. Underlying wood is brown to black. Trunk or basal sprouts frequently develop below girdling cankers.

Two species of Fusarium have been isolated repeatedly from representative cankers. Pathogenicity of one Fusarium isolate has been demonstrated by wound-inoculation of walnut seedlings in greenhouse studies. Young walnut seedlings that became infected developed dark, sunken, elongate, stem lesions. In cases where stems were girdled, the inoculated seedlings died.

In two Minnesota plantings, more than 50% of the trees are cankered. (MN DNR, 1980). Most cankers range in age from 2 to 6 years old. Cankers may encompass either lateral branch pruning scars or dead branch stubs. Fortunately, in the field, most perennial stem cankers have progressed slowly and some cankers are closing by the formation of marginal callus.

A Fusarium canker of walnuts has been reported in North Carolina, Indiana, Tennessee, and Missouri (Minnesota DNR, 1980). Whether this stem canker is the same as that reported by Kessler (1974) to occur on walnut plantations in Illinois, Indiana, Missouri, and Iowa remains to be clarified. Kessler found an apparent symbiosis between Fusaria and ambrosia beetles, Xylosandrus germanus, which provided wounds and infection courts. Berry (1973) also reported a basal canker disease in plantation walnuts where bark and cambium tissues were killed at the ground line. The resulting canker girdles the stem and the crown dies. The cause is unknown. Recently, several species of Fusarium are reported to cause cankers on black walnut in the Midwest (Weber, Anderson, and Hoffard, 1980).

A major canker of butternut, incited by the fungus pathogen, Sirococcus clavigignenti-juglandacearum (Nair, Kostichka, and Kuntz, 1979), has been detected infrequently on black walnuts growing in mixed stands with severely infected butternuts (Kuntz et al, 1979). Nevertheless, artificial inoculations of young walnut seedlings, older saplings, and branches of mature walnuts have incited typical elliptical to fusiform, dark, sunken cankers or a rapid dying of inoculated branches. Girdling stem cankers frequently killed inoculated walnut seedlings. Trunk inoculations of walnut saplings incited slowly progressing perennial cankers from which the fungus has been isolated repeatedly (presently up to 6 years).

Meanwhile, these stem and branch cankers, together with the crown dieback and tree decline, have been complicated by small, dark, sunken branch cankers associated with a Phomopsis species and a rapid wilt and dieback of succulent shoots associated with a Phyllosticta species (U.S.D.A., 1960). Moreover, Melanconium oblongum Beck frequently invaded dead and dying branches where it fruited abundantly.

Detection and appraisal surveys will continue to monitor canker-diebacks of walnuts and butternuts. Meanwhile, current research seeks to clarify the role, impact, and activities of pathogens associated with these diseases.

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DEVELOPMENTS IN DISEASE CONTROL OF WALNUT ANTHRACNOSE

Steven Cline[1]

Abstract.--Walnut anthracnose, caused by Gnomonia leptostyla, is the most serious foliar disease of black walnut. Fungicide treatments, nitrogen fertilization, and mechanisms of disease resistance have and are currently being examined for use in anthracnose control. Benomyl sprays can reduce anthracnose severity but are restricted for use only on nonnutbearing trees. Chemical analysis of nut meat tissue detected benomyl but at levels below the federal tolerane level required for registration. Bioassays of benomyl residues on leaves and nut hulls showed that only two timed applications per year are necessary, provided normal rainfall conditions exist. Disease severity may be reduced by nitrogen fertilization. Trees treated with N alone had less anthracnose than those receiving other combinations of macronutrients. Resistance to anthracnose has been observed in juvenile leaves and is currently being investigated.

The fungal disease, walnut anthracnose, is caused by Gnomonia leptostyla (imperfect stage, Marssonina juglandis) and has become the primary important leaf pathogen of the host in the central and eastern United States. Berry, in the 1960's, suggested that this disease reduced tree growth through premature defoliation and that it affected nut quality and quantity. Exactly how damaging this disease is to growth and nut production is yet to be quantitatively determined.

Studies concerning mycology (Matteoni and Neely), pathogenesis, and epidemiology (Black and Neely) were done in the 1970's. The information that was generated has paved the way to better understand the host-pathogen relationships and the avenues for disease control strategy.

Disease control at the present time is limited to preventive cultural practices and the use of protectant fungicides applied to the foliage. Epidemiological studies indicate that tree moisture is essential for infection. Pruning trees to increase the sun's penetration and air circulation will hasten evaporation and reduce disease incidence. The removal of infected leaf material (overwintering site) is also suggested to reduce the inoculum potential. Under forest conditions this practice is not practical but certainly pruning could be employed by the homeowner for shade trees. At the present time, anthracnose control in walnut plantations is achieved with the use of protectant fungicides. Alternatives to fungicide applications are currently being investigated. Nitrogen fertilization seems to reduce disease severity. While disease-resistant cultivars are not currently available to growers, studies are being conducted to understand the nature of resistance observed in juvenile leaves and the applicability to breeding for resistance.

FUNGICIDES

Of six commercial fungicides applied as foliar sprays, by researchers at the Illinois Natural History Survey, benomyl (Benlate 50 WP, DuPont) at the rate of 1 lb/100 gal was the most effective for anthracnose control. Sprays were applied twice, one on June 2 and then on July 1. This fungicide was statistically superior to Topsin M 70 W, Manzate 200 80 W, Polyram 80 W. Bravo 6 F, and Triflorine 6.5 EC, giving 97% control over defoliation.

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The timing of fungicide applications is important to good control. Epidemiological studies in Illinois showed that infection from ascospores occurred in late May while conidial infections were produced in early July. To determine how the timing of benomyl sprays is important to control, a study was conducted to examine the persistence of this compound on black walnut leaves and nut hulls in 1978 and 1979. Four testing sites were chosen in Illinois. Foliar sprays were applied at the rates of 1 lb (1X), 2 lbs (2X), and 4 lbs (4X)/100 gal between late May and early July to established trees. Fungicide bioassays were conducted on samples of leaf and nut hulls collected at various periods following treatment. A benomyl-sensitive fungus was used to detect persisting residues on these plant parts. Rainfall was monitored over the testing periods.

Our results determined benomyl to be fairly persistent as the compound inhibited germ tube development for approximately 6 weeks on the foliar surface, provided that precipitation did not exceed 10 cm/week. Higher rates of application (2X, 4X) did not persist significantly longer than the 1X rate, implying that these higher rates would not increase anthracnose control. When benomyl persistence was studied under conditions following simulated rainfall applications, benomyl residues were inhibitory to germ tube development of the test fungus in excess of 24 cm of rainfall. Our conclusions suggest that other factors besides rainfall cause its removal or degradation under field conditions.

On nut hulls, benomyl was persistent for 5-7 weeks at the 1X rate while 2X and 4X rates remained effective in excess of 7 weeks. The effect of rainfall on nut hull persistence could not be determined.

Based on our studies in Illinois, we recommend spray applications of benomyl fungicide to begin in mid- to late-May when ascospores are released. A rate of 1 lb/100 gal was demonstrated to be effective for control of walnut anthracnose. With moderate (normal) rainfall, a second spray is not generally required until early July when conidia are released. When rainfall does exceed 10 cm/week, an earlier second application may be necessary.

The systemic action of benomyl and the uncertainty of movement into floral parts and developing nut meats limits its registration for use on non-nutbearing trees. To establish the potential for registration, we conducted a study to determine the level of residue accumulation of benomyl in nut meats following its application for disease control. In 1979, trees at Carbondale, Illinois were soil-injected or foliar-sprayed with benomyl or trunk-infused with Lignasan BLP. Nuts collected in August and September were analyzed for the breakdown product MBC (carbendazim) by gas chromatography. Results indicate that very low levels of MBC were present in several samples tested, however, in all samples examined, the quantities detected were well below the federal tolerance level of 0.13 ppm. We, therefore, have recommended the registration of benomyl for use on nut-bearing trees.

FERTILIZATION

Preliminary field testing of nitrogen fertilizers on anthracnose severity (Neely, 1981) from 1973-1977 showed that a reduction in diseased leaflets from 46 to 61% occurred as evaluated in August and September, respectively. This was studied more intensely in 1978 and 1979 in order to verify these trends. Tests were designed to establish the effect of nutrient source, rate and timing of fertilizer application. Nitrogen (N) alone and other combinations of nitrogen, phosphorus (P), and potassium (K) were compared at a uniform soil surface application rate of 29 g N/m^2 (1X) (6 lbs/1000 sq ft) applied in April, June or October. Additional applications of ammonium nitrate were made at 1/2X and 2X rates. A foliar treatment of urea was also tested spraying trees to run-off with three applications in mid-May, early June, and late June at the 10 g/l rate.

Black walnut is observed to be more resistant to anthracnose and there is a delay in premature defoliation when nitrogen fertilizers are applied. The rates of application are correlated directly with foliage color and growth, and inversely correlated with disease severity (table 1). Disease control increased by 20, 31, and 52% with 1/2X, 1X, and 2X nitrogen treatments as compared to the untreated controls. Soil-applied ammonium sulfate, ammonium nitrate, and urea were equally good nitrogen sources. Early spring as well as mid-summer applications are both effective. The combination of potassium and/or phosphorus with nitrogen reduced the effectiveness of nitrogen applied alone. Foliar treatments with urea were not significantly more effective than no treatment.

At present, we recommend fertilizing trees with N-containing compounds (ammonium sulfate, ammonium nitrate or urea) applied at the rate of 250 lbs/acre to reduce disease severity and stimulate tree growth. Fertilizers may be applied any time during the year, however, best response can be expected when applications are made prior to bud break in the spring.

Table 1.--Effects of nutrients applied to black walnut trees in 1978 and 1979.

Treatment	Rate (g/m^2)	Disease severity[2/]	Color rating[3/]	Diameter growth (mm)
None		44.0	3.1	4.3
Urea (foliar)[1/]		44.7	3.3	4.8
PK	29	41.5	3.3	4.5
NPK	29	36.8	3.6	6.1
NH_4NO_3	14.5	35.2	3.5	5.0
NK	29	34.3	3.9	6.7
NH_4NO_3	29	34.2	3.7	6.5
NP	29	33.7	3.8	5.4
NH_4NO_3	29	31.1	3.9	6.0
$(NH_4)_2SO_4$	29	30.8	3.7	5.8
Urea	29	28.8	3.7	6.3
NH_4NO_3	58	21.3	4.1	7.7

[1/] Three foliar applications sprayed to runoff at 10 g/l.
[2/] Percentage leaflets with one or more lesions.
[3/] 1=yellow green; 3=average green; 5=dark green.

RESISTANCE

Currently, cultivars resistant to walnut anthracnose are not available to foresters. Early attempts by Berry (1964) to rate infected field-grown trees across 40 cultivars failed to show conclusive evidence for disease resistance. When optimum conditions for infection were present, trees that were previously thought to be less susceptible became as severely infected as other cultivars. Attempts by Black (1977) to select for resistance among species of Juglans showed that a large variation in resistance exists. In field studies by Neely (1981) correlations between height, diameter, and anthracnose ratings were not significant, however, faster growing trees tended to be more resistant.

Observations of artificially infected and naturally infected leaves suggest that juvenile leaves are more resistant to infection than older, more mature leaves. Pathogenesis testing by Matteoni (1977) determined that leaves of all ages exhibited some lesions but lesions on younger leaves are smaller and either have fewer or no acervuli. Research efforts investigating the effects of nitrogen fertilization, leaf age and growth as related to anthracnose susceptibility, are currently underway to determine the potential applicability of this type of resistance for controlling anthracnose.

Walnut anthracnose is not well known in terms of the economic loss in annual growth and nut production. Successive years of premature defoliation can weaken trees and reduce the energy reserves from efforts to refoliate. Stressed trees are more subject to damage due to insects, root-rotting and other pathogens. While we recommend sound cultural practices (good site selection, scheduled pruning and a balanced fertilization program) to reduce favorable conditions for anthracnose development, fungicides are sometimes the only alternative. From our studies, benomyl is the most effective chemical means for control when applied to the foliage at the rate of 1 lb/100 gal. Current IPM strategies require that we move from pesticides to other means of disease control. Additional research efforts into alternatives are needed before they become valid, environmentally and economically sound.

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WALNUT ROOT ROT IN SEEDBEDS, HEELING-IN BEDS, AND STORAGE[1]

N. A. Tisserat, J. E. Kuntz, R. P. Guries, and R. F. Camp[2]

Root rot can be a limiting factor in the production of one-year-old (1-0) black walnut seedlings at the Wilson State Nursery, Boscobel, Wisconsin. So far, root rot in seedbeds, though present, has not caused serious damage; however, fall-lifted seedlings held over winter in heeling-in beds are subject to heavy losses resulting from root rot. Soil-borne fungi commonly associated with walnut root rot in Wisconsin included Phytophthora citricola, Cylindrocladium sp., and Fusarium spp. In most years, root rot of stored seedlings was avoided by spring lifting. Fall-lifted seedlings stored at 4 C in heavy paper bags had a much lower incidence of root rot and higher field survival rates than did fall-lifted, heeled-in seedlings. Survival rates of trees stored over winter in bags were similar to survival rates of trees that were spring-lifted.

INTRODUCTION

In recent years, the demand for quality black walnut (Juglans nigra L.) has increased walnut plantings throughout southern Wisconsin and adjacent areas of central United States. Intensive management is practiced to provide optimal growth and quality of the trees (Schlesinger and Funk, 1977). To insure proper density and uniformity, new plantations are established with one-year-old nursery transplants rather than by direct seeding. In Wisconsin alone, the state forest nurseries distribute annually over 300,000 black walnut seedlings. Spring planting of young seedlings is recommended since fall-planted stock is subject to winter injury and frost heaving (Schlesinger and Funk, 1977).

In Wisconsin until 1978, seedlings were machine-lifted in November, hand-graded, bundled, and placed in "heel-in" beds for overwinter storage in preparation for spring shipment. Frequently, in the heel-in beds, many of the injured roots deteriorated or rotted, resulting in extensive spring culling (Tisserat et al., 1980). Although the exact cause of root rot in Wisconsin is not known, soil-borne root-rotting fungi have been associated with some of the decayed roots. Studies in other areas of the country indicate that both environmental (Young, 1943) and biotic agents (Green and Ploetz, 1979) may be involved. Species of Cylindrocladium and Phytophthora have incited root rot of black walnut seedlings growing in nursery beds (Cordell and Matuszewski, 1974; Green and Pratt, 1970; Tisserat et al., 1980) and incipient infections by these fungi may contribute to subsequent root rot in the heel-in beds (Green and Ploetz, 1979). Root-infected walnut transplants seldom survive outplanting to the field.

Heavy losses of young walnuts due to root deterioration in the heel-in beds have led managers to consider other methods of

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storing seedlings. The purpose of our study was to evaluate several methods of overwinter storage and to identify some of the factors (both biotic and environmental) contributing to this problem.

MATERIALS AND METHODS

Studies have been conducted from 1978 through May, 1981, and are continuing. One-year-old black walnut seedlings raised at the Wilson State Forest Nursery, Boscobel, Wisconsin were used in all studies. Seedlings were undercut approximately 20 cm below the soil surface the first week in November of each year. Undercut seedlings were hand-lifted, graded, and bundled into groups of 20 or 25 trees. Those trees which had a tap root of less than 20 cm in length or a root system showing discoloration were culled prior to bundling. Spring-lifted (April) seedlings were handled similarly.

Fall-lifted trees were stored overwinter either in heel-in beds or in heavy paper shipping bags. The heel-in method consisted of placing the bundled seedlings in trenches 30-45 cm deep dug in the seedbed. The roots then were covered with soil. Trees were overwintered in this manner until they were lifted in the spring. Other fall-lifted, bundled trees were placed in large shipping bags which were sewn or stapled shut. The bags were stored overwinter in large walk-in coolers maintained at a constant 4 C. No packing was added to the bagged seedlings, except in one treatment where damp straw mulch was distributed among the bundles of seedlings.

Fall-lifted seedlings were dipped in fungicides prior to overwinter storage. Bundled seedlings were immersed in one of several experimental fungicides for approximately one minute in the 1978-79 experiments (Tisserat et al., 1980). Two chemicals were tested further, in the 1979-80 and 1980-81 trials. The two fungicides were benomyl (Benlate 50% WP) at 5 lb active ingredient (a.i.)/100 gal water (6 g/l) and captafol (Difolatan 4F) at 4 lb a.i./100 gal water (5 g/l). Seedlings not treated, seedlings dipped in water only, and spring-lifted seedlings served as controls. A randomized complete block design was used.

In all experiments, data were recorded on the incidence of root rot before outplanting and seedling survival after outplanting. Any seedling showing root lesions and/or discoloration greater than one inch from the tip of the main tap root was considered rotted. Healthy seedlings showed little or no discoloration at the tip of the cut root, and were very firm in texture. The cortex of healthy roots was pearl-white in color. Discolored roots appeared spongy and water-soaked. The color of the rotted roots ranged from light brown to black. In other cases, rotted roots showed sunken, irregular, black lesions on the tap root. Tissue samples were taken from selected discolored roots, surface-sterilized in a 10% sodium hypochlorite solution for 2 minutes, and plated on potato dextrose agar. Typical discolored samples also were placed directly on VYS-PBNC, a selective medium for Phytophthora species (Schmitthenner, 1973). Pathogenicity tests of the isolates were made on one-year-old walnut seedlings planted in 12-cm diameter clay pots in a 2:1:1 (soil:sand:peat) mixture. Before planting the seedlings, a small agar block containing mycelia of the selected fungal isolate was placed in a knife wound made on the tap root. The seedlings were grown in the greenhouse for one month, then examined for root rot symptoms. Attempts were made to reisolate the causal organism from the rotted roots.

In 1979, all seedlings were outplanted by hand at the Knap Creek Wildlife Area near Boscobel, WI. In 1980, seedlings were outplanted at the Wilson State Forest Nursery. Transplant survival was recorded in September of the planting year. Since initial root rot and field survival were calculated as percentages of original seedlings, the data were transformed by the arc sin method (Snedecor and Cochran, 1967) prior to analysis.

RESULTS

Spring-lifting

In earlier studies the incidence and severity of root rot were compared between fall-lifted seedlings overwintered in heel-in beds and undisturbed seedlings left overwinter in the seedbeds. In some years, up to 100 percent loss occurred in the heel-in beds whereas little, if any, root rot was found in spring-lifted seedlings. Therefore, since 1978, overwintering root rot largely has been avoided by waiting until spring to lift the seedlings just before shipment.

Unfortunately, seedlings left in the seedbed during the winter 1980-81, and spring-lifted in April, also suffered extensive root deterioration. Surveys of the seedbed showed that 60% of the seedlings had complete root mortality and many of the remaining trees had varying degrees of root discoloration. Because the loss was so high and identifying healthy trees was so uncertain, the entire stock of black walnut seedlings was condemned.

Nevertheless, it appears that in most years, seedlings may remain overwinter in the seedbed, and may be spring-lifted without heavy losses from root rot. However this method may be disastrous in some years, as evidenced by the 1980-81 losses.

STORAGE METHODS

At the time the experiments were conducted, there was some question as to whether walnut seedlings would survive winter storage in the shipping bags. Results for all years show that fall-lifted seedlings survived overwinter storage at 4 C in sealed bags in excellent condition. In the 1979 plantings, little difference in root rot incidence and survival was found between the fall-lifted and bagged seedlings or seedlings overwintered in heel-in beds (Table 1). Seedling survival for all heel-in treatments averaged 93% compared to 95% for the bagged storage methods for that particular year. In contrast, data from the 1980 plantings indicated that the bagged seedlings had a lower percentage of root rot and a higher survival rate than did seedlings from the heel-in treatments.

Results from the 1980-81 experiments showed much larger differences between storage methods (Table 2). Fall-lifted seedlings placed in heel-in beds to overwinter without mulch had the highest percentage (75%) of root rot. Addition of straw mulch (marsh hay to 60 cm depth) to the heel-in beds resulted in reduced root rot. Seedlings stored in bags at 4 C had little or no root rot.

Table 1. Incidence of root rot in walnut seedlings following winter storage and survival after outplanting (1979-1980)

	Storage method			
	Bagged		Heel-in	
	1979	1980	1979	1980
Root rot[1/]	4.8	1.0	5.8	23.8
Survival	95.0	87.7	93.0	70.0

1/ Values are percent averages of 15 replicates, 25 seedlings per replicate, 1979, and 30 replicates, 20 seedlings per replicate, 1980.

Root rot incidence and subsequent survival of bagged seedlings were unaffected by fungicide treatments (Tables 2 and 3). Seedlings with and without a water dip survived as well as did seedlings with a fungicide dip. However, a sparse, but unsightly, covering of fungus mycelia occasionally developed on bagged seedlings. Nevertheless roots were sound and the superficial mycelia did not affect seedling survival after outplanting. Both the benomyl and captafol fungicide dips reduced this molding of seedlings stored in the bags, and may be desirable as a prestorage treatment.

Table 2 Incidence of root rot (%) of black walnut seedlings following various overwinter storage methods and treatments, 1980-81.

Bagged					Heel-in (fall)	
No dip	H_2O dip	Benomyl dip	Captafol dip	Straw packing	Straw mulch	No mulch
2.0a[1/]	0.0a	0.0a	1.0a	2.0a	7.0a	75.0b

1/ Mean percent root rot for 5 replicates, 20 seedlings per replicate. Values not followed by the same letter differ significantly (p less than .05) according to FLSD test.

Table 3. Effect of chemical and cultural treatments on storage root rot (winter 1979-80)and outplanting survival of walnut seedlings.

	No dip		H_2O dip		Straw		Benomyl		Captafol	
	Bag	Hi[1]/	Bag	Hi	Bag	Hi	Bag	Hi	Bag	Hi
Root rot(%)	1a[2]/	24d	0a	29e	0a	9b	0a	38f	1a	19c
Survival(%)	84b	68cd	85b	77c	94a	75c	92a	65d	83b	67d

1/ Fall-lifted heel-in treatments.
2/ Values represent an average of six replicates. Values in each row not followed by the same letter differ significantly (p is less than .05) according to FLSD test.

Associated Fungi

The role of fungi in the "overwinter root rot" problem is unclear. Several fungi were isolated from rotted roots stored in heel-in beds during the winters of 1978-79 and 1979-80. The most common fungi found were species of *Fusarium*, *Trichoderma*, and *Aspergillus*. Most of these fungi are not considered to be primary pathogens but can cause damage to weakened or injured root systems. Primary pathogens such as *Cylindrocladium* sp. and *Phytophthora citricola* were isolated less frequently from decayed roots. In both these years, very little root rot developed overwinter.

Root rot during the 1980-81 winter was severe, resulting in the loss of the entire crop. Attempts to isolate pathogens from discolored roots during April, 1981, showed that such roots were essentially sterile. Only rarely were fungi or bacteria found in rotted tissue. Because no biotic agent was isolated consistently, and the fact that fall-lifted seedlings in heavily mulched heel-in beds or stored in bags had very little root rot (Table 2) make it doubtful that fungi were the primary causal agents of root rot for that year.

Our results suggest that freezing temperatures or extreme fluctuations in temperatures in the heel-in beds or even in seedbeds may be important factors in the incidence of root rot. Initial studies indicated that bare-rooted seedlings exposed to freezing temperatures (-12 C for 30 minutes) prior to storage were heavily colonized by *Fusarium* spp. and did not survive outplanting the following year (Tisserat *et al*., 1980). The incidence of root rot in the heel-in beds for the 1979-80 study (Table 1) was higher than that for the 1978-79 experiments. Seedbeds during 1978-79 had two to three feet of snow cover most of the winter while in 1979-80, the seedbeds had little or no snowcover the entire winter. Temperature extremes in the soil during 1979-80 and fluctuating soil temperatures during the winter of 1980-81 may have injured roots and predisposed them to attack by soil-borne microorganisms. In contrast, bagged seedlings stored at 4 C (Table 1) in both years had very little root rot.

CONCLUSIONS

In past years, overwinter storage of black walnut seedlings in heel-in beds resulted in extensive root rot. Our results suggest alternative methods for storage of black walnut seedlings during the winter months. Spring-lifting and immediate distribution of seedlings are preferable to the fall-lifting and heel-in method of storage in avoiding overwinter root rot. However, there is still occasional risk involved in spring-lifting, depending on winter conditions. Spring-lifting should be used only where cold storage facilities are not available. Moreover, fall-lifting and cold storage may be more convenient for nursery managers, enabling them to avoid the spring rush in lifting other tree species.

Therefore, we believe that the best method of storage in Wisconsin is fall-lifting, placement of seedlings in sealed shipping bags, and overwinter storage at 4 C. Care must be taken to keep the temperature at a constant 4 C, because freezing temperatures result in direct damage to roots, a high incidence of root rot, and poor field survival.

Fungicide dip treatments of seedlings prior to storage in bags at 4 C had little effect on root rot or field survival. No dip or water dip controls also were essentially free of root rot. However, the benomyl and captafol dips did reduce superficial molding of walnut seedlings stored in shipping bags. While the molding did not affect survival of outplanted seedlings, it was unsightly and could reduce the marketability of bagged seedlings.

While methods for avoiding the root rot problem during winter storage are now available, the exact nature of the root deterioration is still unclear. It does appear that cold temperatures or extreme temperature fluctuations contribute to the incidence and development of storage root rot either directly or indirectly. Whether other factors such as incipient infections by pathogenic fungi are involved is not known. Future research will attempt to clarify the relative roles of abiotic (environmental) and biotic agents.

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BLACK WALNUT CURCULIO:

A FACTOR IN WALNUT NUT PRODUCTION[1]

Larry M. Blair[2]

Abstract.--The black walnut curculio is discussed as an important factor in premature nut loss of black walnut. In Missouri trapping studies, nut drop resulting from curculio activity reduced potential harvestable yields by 19% to 78% in three geographic areas of the state. Average loss was 51%. A brief biology of the insect is presented.

Since World War II, new uses for nut shells and kernels of black walnut (Juglans nigra L.) have created a growing demand for black walnut nuts. Potential nut returns are an important addition to the value of the species. Management practices are being designed to improve growth conditions for nut production as well as lumber. Revenues from nut sales can be used to ease long-term carrying costs associated with lengthy stand rotations.

A major factor influencing demand for nuts in recent years has been the shortage of black walnut planting stock. Landowner awareness of walnut values has caused a significant increase in the number of plantations established. Most states have been unable to produce enough seedlings to meet these demands because of nut scarcity (Grey, 1971). The problem is complicated by competition from the nut industry. Aside from the importance of black walnut kernels as a food item, research has shown important uses for the crushed shells. Uses include filtering agents in smoke-stack scrubbers, additives to drilling mud in oil-well drilling, and polishing agents for chrome and automotive parts, among others (Cavender, 1973). In addition, Hammons Products Company in Stockton, Missouri, has recently been successful in boosting nutritive values of cattle feed by adding low grade walnut kernels to a corn feed mixture. Continued research promises additional uses for black walnut nuts in the future.

[1]Paper presented at the Black Walnut Symposium, West LaFayette, Indiana, August 10-14, 1981.

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The black walnut curculio, Conotrachelus retentus (Say), is an important insect pest of walnut nut crops (fig. 1). The adult feeds on new walnut shoots and leaves, and the larva destroys developing nuts.

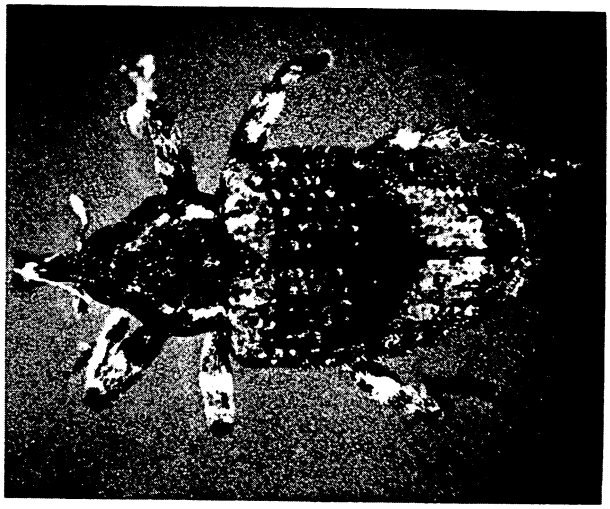

Figure 1.--Adult walnut curculio.

Previous research on this insect was limited, and revealed little about its habits and life history. Therefore, a research project was undertaken to study the curculio's biology and impact on walnut nut production in Missouri (Blair, 1978).

LIFE HISTORY

Adult curculios spend the winter in soil or heavy leaf litter near the base of walnut trees. Spring emergence is closely timed with bud break, and occurs from mid to late April. Newly emerged adults enter trees by crawling or flying. They feed on succulent foliage and male flowers with feeding damage appearing as a darkened spot on the base of the leaf stalk. It seldom causes leaf death, and is difficult to detect. Other feeding damage may occasionally appear as holes chewed in leaflets. However, this damage is similar to that of other leaf-feeding beetles, and is not diagnostic.

Eggs are laid on developing nuts shortly after the female flowers are fertilized. When nuts are small, single eggs are placed in crescent-shaped punctures chewed from the nut wall (fig. 2).

Figure 2.--Oviposition mark on nut.

Several eggs may hatch on a small nut, but the most active larva consumes the others to defend its food supply. On larger, more mature nuts, single eggs are placed in punctures resembling pin holes. These punctures are usually placed on the nut in clusters of 3 to 10. Large nuts may support the development of several larvae.

Hatching usually occurs five days after eggs are laid. Larvae bore into the watery centers of developing nuts and feed extensively. "June nut drop" occurs when infested nuts drop from trees in late May, June and early July. From the time the eggs are laid, it takes about three weeks for nut drop to occur. Most infested nuts abort when approximately ½" in diameter. For this reason, the premature nut drop is easily overlooked.

Larvae remain inside hollowed-out nuts for an additional two weeks before entering the soil to pupate. Nut exit holes are ¼" in diameter, and serve as evidence of curculio activity. The pupal stage requires three weeks and occurs at an average soil depth of two inches. After this, adult curculios emerge and feed on black walnut foliage until leaf drop occurs. Only one generation is produced per year.

SHOOT PROBLEMS

Infrequently, eggs may be laid on developing shoots of black walnut. Stem mining and loss of terminal buds are potential growth-form problems on young trees. However, surveys of Missouri walnut plantations under ten years of age revealed no curculio activity. Adult curculios probably do not associate with trees too young to bear nut crops.

IMPACT ON NUT CROPS

Missouri nut productivity studies were conducted in one area in 1976, and three areas in 1977. The initial study involved testing and comparison of three trapping designs at the Dupont black walnut plantation near Ashburn, Missouri. Trees in the plantation were 27 years old at the time of the study. Thirty-six trees were selected and sampled with 216 cone-shaped plastic traps. Traps were three feet in diameter, and each was suspended between two 5-foot stakes. Trap placement was statistically designed to accurately estimate damage for the entire plantation from sample tree collections.

Traps were checked weekly from early June until August, and biweekly for the remainder of the season. The collected nuts were dissected to determine the reason for early drop. Records were kept for each nut. Four factors were determined to influence premature abortion and loss to nut crops. These included curculio damage, infertility, squirrel activity, and natural abortion in response to moisture stress. Curculio damage had the greatest impact of the four factors. It accounted for 88% of the premature drop recorded during the two years of productivity studies.

Seasonal nut drop at the Dupont plantation in 1976 occurred in two distinct periods (fig.3). The "June nut drop" included all nuts which dropped before August 17 as a result of the four previously mentioned factors. These nuts were lost to production. The mature nut drop occurred from September 15 to November 5. Nuts which dropped during this period were harvestable. The black walnut curculio reduced the nut crop by 43% at Dupont in 1976.

The 1977 black walnut productivity study was expanded to include trapping sites in three geographic areas of the state. The Dupont plantation was again used to represent the northeastern part of Missouri. An unmanaged tract of black walnut near Fayette, Missouri, was used as a central Missouri site. The third site was an intensively managed black walnut fertilization plot in southwestern Missouri, near Stockton. Sample trees were of nut-bearing age, and ranged from 10" to 12" DBH. Thirty trees were randomly selected in each area. Each tree was sampled with four traps.

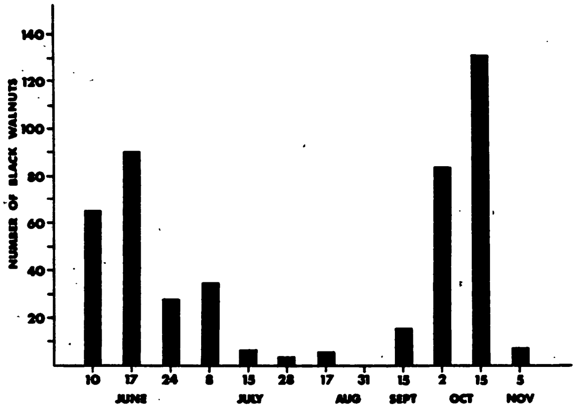

Figure 3.--Seasonal distribution of black walnut nut drop at the Dupont plantation, Ashburn, Missouri, in 1976.

Seasonal nut drop at the Dupont plantation differed greatly in 1977 from that of the previous season (fig. 4). Only a small percentage of the nuts reached maturity. Curculio damage was responsible for a 78% reduction of the potential harvestable yield.

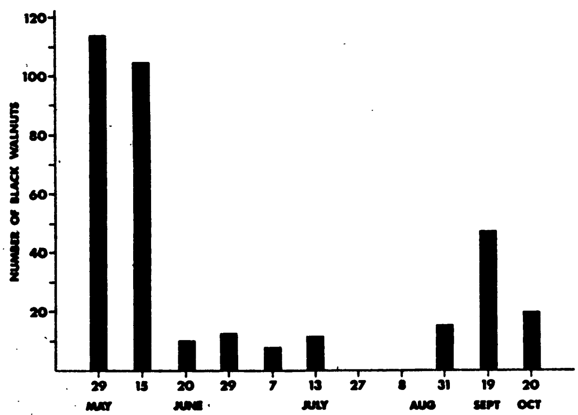

Figure 4.--Seasonal distribution of black walnut nut drop at the Dupont plantation, Ashburn, Missouri, in 1977.

A similar level of damage was recorded at the Fayette trapping site (fig. 5). Again, more nuts were collected during the June nut drop than during the mature drop. Sixty-six percent of the crop was destroyed by curculio activity.

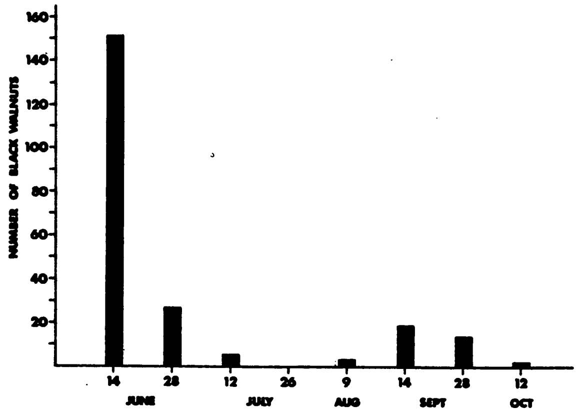

Figure 5.--Seasonal distribution of black walnut nut drop in natural forest, near Fayette, Missouri, in 1977.

The Stockton area was least affected by premature nut drop (fig. 6). Most of the crop reached maturity at this site. Curculio activity destroyed only 19% of the developing nuts.

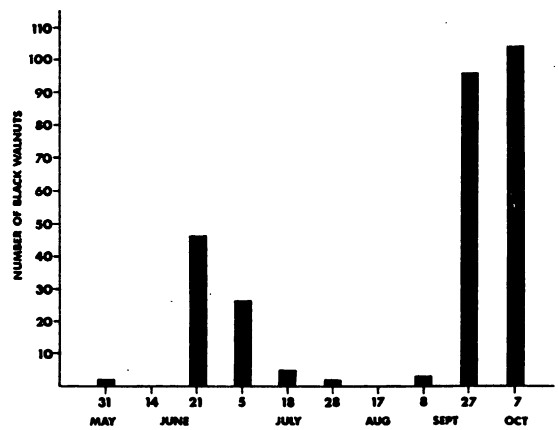

Figure 6.--Seasonal distribution of black walnut nut drop at the Fox plantation, Stockton, Missouri, in 1977.

This level of damage was not consistent with other Missouri areas. The comparatively low impact was possibly linked with site disturbance effected by former practices in the stand. Activities which affected the site included annual applications of simazine and paraquat to remove grass under trees, bulldozer work to release single trees, and the use of heavy equipment in an intensive spray schedule involving foliar fertilization. It is believed that the combination of compacted soil and lack of normal ground cover may have adversely influenced curculio populations on the site. This might explain the reduced level of curculio damage.

CONCLUSIONS

Seasonal nut collections in 1976 and 1977 showed that the black walnut curculio had an important impact on black walnut nut production in Missouri. Statewide, an average of 51% of the nuts collected in productivity studies dropped prematurely as a result of curculio activity. This indicates that control measures may be warranted in seed production areas, or where annual incomes from nut crops are desired. Continued research is needed in developing a sound control program to reduce the impact of this pest.

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PHYSIOLOGY AND SILVICULTURE OF BLACK WALNUT FOR COMBINED TIMBER AND NUT PRODUCTION

J. W. Van Sambeek and George Rink[1]

Abstract.--Research literature was reviewed for evidence supporting the management of black walnut plantations for combined timber and nut production. The silviculture of the species is discussed in relation to dual cropping. Stimulation and phenology of flowering and fruiting are reviewed.

Walnut growers face the same economic vagaries as other businessmen. The recent surges in the cost of capital have made standard economic forecasts obsolete. Current inflated interest rates may make plantation establishment costs prohibitive when projected over the length of walnut rotations. Nut crops could provide one source of early income to offset such costs (Kincaid and Kurtz 1981).

Industries marketing nut meats and shells would like a more regular yearly volume of nuts, although walnut is considered a fairly consistent bearer (Wylie 1966). Managers of seed orchards also need methods for enhancing nut production if they are to annually supply nurseries with genetically improved seed.

Evidence is presented showing that walnut can be managed for timber and improved nut yields.

MANAGEMENT STRATEGIES FOR TIMBER AND NUTS

Maximizing timber yield conflicts with maximizing nut yields. Maximizing production of quality timber requires greater stem pruning and closer spacing of trees to favor a longer branch-free bole, while increasing nut yield involves growing trees at a wider spacing to favor larger tree crowns. Optimizing both nut and timber production involves compromises in spacing as well as in timing and extent of pruning (Schlesinger and Funk 1977).

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Initial tree spacing in plantations intended for combined nut and timber production is recommended to be 15 to 20 feet square compared to 10 to 12 feet square for timber alone. Planting trees at a close spacing provides more opportunity for selection of superior crop trees. It also necessitates an earlier thinning (Schlesinger and Funk 1977, Funk _et al_. 1978).

A criterion for determining the necessity and timing of thinning is crown competition factor (CCF). For nut production, the CCF should not exceed 90. A CCF of 90 means that the plantation will have to be thinned when the total crown area covers 90 percent of the plantation's land surface (Schlesinger and Funk 1977). The plantation may have to be thinned three or more times during a rotation. For example, in simulating an 80-year rotation, Foster and Kung (1980) proposed thinning a plantation six times. With a 20-foot-square spacing, the first thinning (around age 20) would be after the trees have begun flowering and fruiting. Crop trees could be selected on the basis of seed production, seed quality and stem form.

Lateral pruning should begin when the trees are 10 to 15 feet tall (approximately age 5) and should be continued in stages until more than 9 feet of clear stemwood is obtained on every crop tree. The length of clear stem should not exceed 50 to 60 percent of total tree height. Only crop trees need to be pruned. Corrective pruning will probably not be necessary because trees with poor form will be removed during thinnings (Schlesinger, in press).

No research data are available on combined nut and timber production from walnut plantations. Using simulation techniques, Foster and Kung (1980) compared the economic efficiency of managing for combined nut and timber production versus managing for timber alone. They found that managing for combined nut and timber production was more profitable than managing for timber alone, as long as the annual compound interest rate exceeded 6 3/4 percent and rotations were longer than 40 years. Similar conclusions have been made by Wylie (1966), Callahan and Smith (1974), Garrett and Kurtz (1980), and Kincaid and Kurtz (1981) using different economic and tree growth assumptions.

Most projections for diameter growth assume it is a linear function of age with an average annual increment of 0.33 in/yr (Naughton 1970), 0.33 to 0.5 in/yr (Garrett and Kurtz 1980), or up to 0.56 in/yr (Wylie 1966). Projections for nut yields as a linear function of diameter at breast height for open-grown trees are illustrated in figure 1 (Foster and Kung 1980, Garrett and Kurtz 1980).

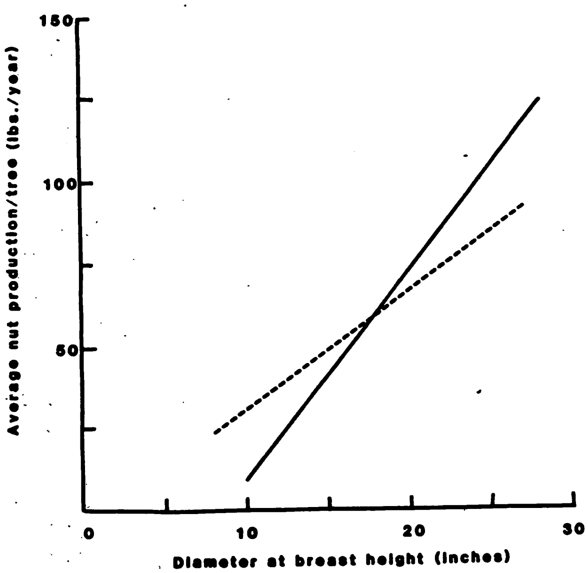

Figure 1.--Projections of average nut production by different diameter walnut trees. Solid line is for air-dried weight after Foster and Kung (1980); dashed line for freshly hulled weight after Garrett and Kurtz (1980).

One concern sometimes raised about combined timber and nut production is that potential tree growth may be diverted into a nut crop, possibly resulting in smaller trees. For apple trees (8 to 9 inches dbh) the stem cross sectional area lost due to fruit production is approximately 0.005 square inch per pound of fruit (Webster and Brown 1980). Because no such walnut data are available, it will be assumed that the reduction in walnut growth due to fruiting is similar to that of apples. According to Foster and Kung's projection (fig. 1), an 80-year-old walnut with an average annual diameter growth rate of 0.33 in/yr should produce about 3,100 pounds of air-dried, hulled nuts during its lifetime. This equals about 11,600 pounds of unhulled nuts (Funk and Polak 1979). Lifetime nut production will reduce potential stem diameter from 27.4 to 26 inches. This reduction equals 4 or 5 years of growth or about 18 board feet in the 8-foot veneer log. The value of the nut crop at current prices substantially exceeds the value of lost diameter growth for average grade walnut veneer logs. Shortening the rotation length can reduce both nut production and its potential effect on diameter growth.

Management guidelines are now available for improving diameter growth of black walnut on marginal sites (Schlesinger and Funk 1977). But what little information is available about improving nut yields has not been tested. Before we can reasonably expect to manipulate stands to improve nut yields, we must understand the physiology of flowering and fruiting for walnut. Most research on flowering and fruiting in Juglandaceae has been with English walnut and pecan, but it is assumed that much of this information also applies to black walnut.

FLOWERING BIOLOGY

Black walnut normally begins flowering about mid-April in the southern part of the range and mid-June in the northern part of the range, although within individual stands trees may vary by as much as a month in flowering dates (Masters 1974, McDaniel 1956). Flower development and leafing out occur at approximately the same time, early enough for possible damage by late spring frosts (fig. 2). Pollination and fertilization normally occur a few weeks after the mean frost-free date and are less likely to be affected by late spring frosts.

Walnuts bear separate male and female flowers on the same tree. Self-pollination is unlikely, however, because flowers of different sexes normally mature at different times; female flowers most often precede the males. However, spring floral development is definitely temperature dependent and warm temperatures at the time of flowering tend to increase the overlap between male and female flower maturation (Masters 1974).

Male flowers are found on wood grown in the previous season; they are initiated in vegetative buds during the period of rapid shoot elongation early in the growing season of the previous year. Female flowers are found at the tip of the current growing shoot, developing in dormant buds set after completion of the

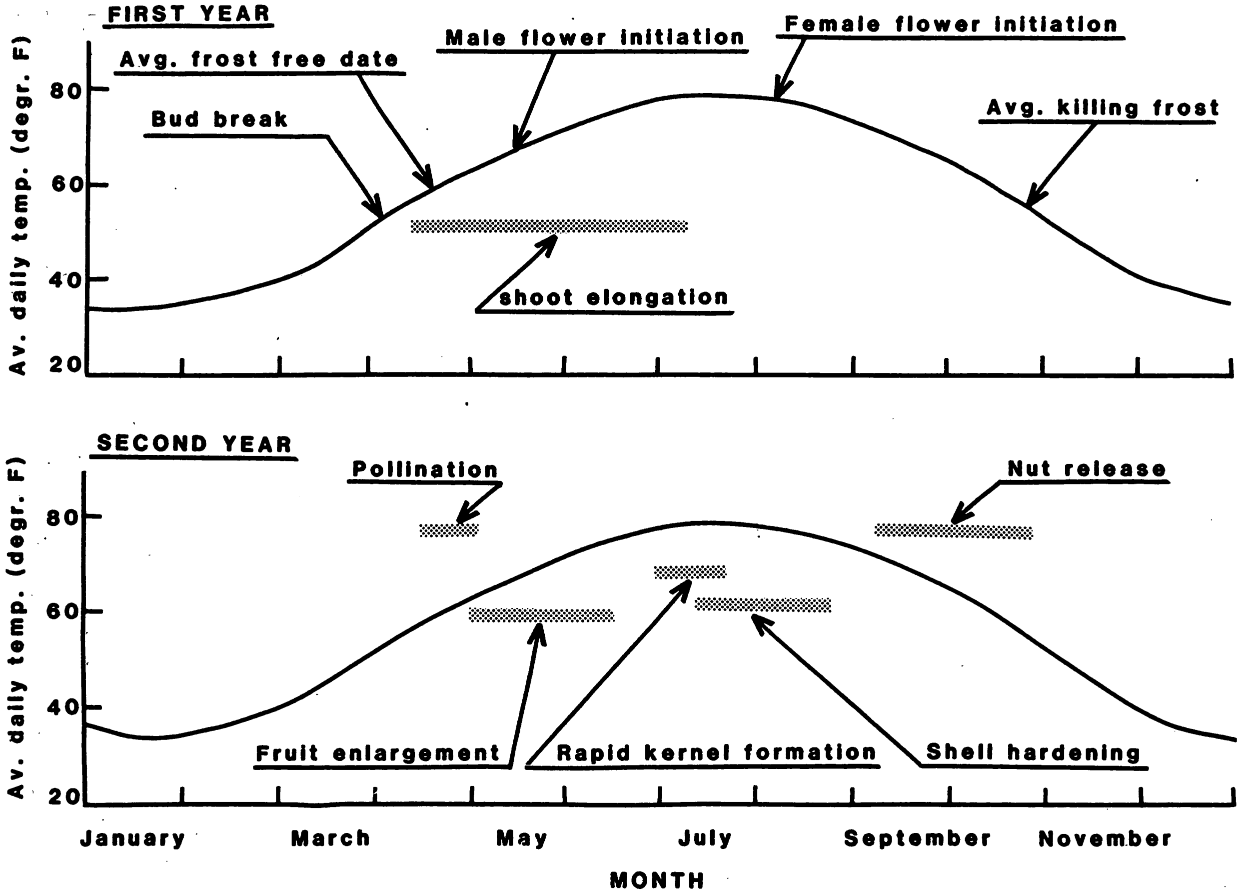

Figure 2.--Sequence of flower development, pollination, and nut maturation for black walnut in southern Illinois

previous year's growth (fig. 2) (Ramina 1969, Masters 1974, Funk 1978).

Several factors influence flowering abundance. All flowers are essentially borne on the crown surface. Any cultural practices increasing the crown surface area, or number of new branches, will increase the number of potential flowering sites. In English walnut the number of female flowers increases as growth is increased (Link 1961). Likewise, increased nut yields in black walnut in response to fertilization (Ponder 1979) and weed control (Holt and Voeller 1973) may be related to improved vigor resulting in more branches and branch growth and consequently more flower production.

Late spring frosts often reduce the number of flowers reaching maturity. Compared with clean cultivation, maintenance of leguminous or grass covers in walnut plantations may delay bud break by as much as 6 to 12 days, thereby decreasing the probability of damage to new growth and flowers (Wolstenholme 1970). Overtree irrigation in the spring will also delay bud break and flowering from 5 to 6 days (Beineke and Hunley 1979).

Little research has been done on the use of chemical sprays to alter new shoot growth and subsequent flower production. Marth and Mitchell (1961) found that gibberellin treatments promoted walnut shoot elongation. Foliar spray application may also increase flower production through improved branch growth. Langrova and Sladky (1971) found that auxin-containing sprays applied to English walnut when male flowers were forming decreased the number of catkins formed the following years; anti-auxin sprays applied after male flowers formed increased the number of catkins, many of which contained female flowers. The formation of male and female flowers is apparently controlled by the interaction of gibberellins, auxins, and growth inhibitors within the developing shoots (Sladky 1974). Further research is needed on cultural and chemical methods to stimulate flower formation and nut development.

FRUITING BIOLOGY

Fertilization occurs within 2 to 5 days of pollination, followed by a period of rapid expansion of the fruit during the next 5 to 6 weeks (fig. 2). Fruits increase in weight substantially before entering the shell-hardening stage in early July, although increases in size are not noticeable at this time. During the latter part of the shell-hardening stage (late July), the embryo and cotyledons begin to enlarge rapidly, incorporating most of the previously deposited endosperm. The kernel, composed of the embryo and cotyledons, usually does not develop until 4 to 5 weeks before the nuts are mature. By late August, some nuts can germinate after stratification. Most nuts, however, continue to increase in dry weight and do not drop from the tree until shortly after leaf fall in late September or early October.

Once the nutlets are formed, nutlet loss is usually due to disease or insect infestations. Blair and Kearby (1979) found that more than 50 percent of the potential nut crop in Missouri walnut plantations was destroyed by the walnut curculio. Epidemics of walnut anthracnose early in the growing season can cause significant nutlet losses; later or less severe disease outbreaks lead to poor nut filling and darkened kernels called ambers (Funk 1979).

Summer droughts can also lead to poor filling of the kernels and may also delay seed maturity (Batchelor et al. 1945, Crane 1949). Jones (1975) found that June, July, and August rainfall is an important variable in predicting annual nut crops in southwest Missouri. Irrigation during August and September may be important for high nut yields, because these months often include long dry spells.

Early fall frosts can injure new growth before it is completely lignified, preventing complete nut development and causing undesirable shrivel (Funk 1979). This frost danger is especially pertinent because recommendations for collecting seed 200 miles south of the planting site for greater timber production may result in immature nut crops (Sparks 1981). This problem may possibly be overcome by chemical treatment. In English walnuts, fall spraying with ethephon produces a mature nut crop 1 to 3 weeks sooner, and the sprayed trees produce higher quality nuts than the unsprayed trees (Martin 1971, Sibbett et al. 1974). Another alternative may be underplanting with leguminous winter annuals to accelerate tree dormancy (Auchter and Knapp 1937).

The minimum seed-bearing age for commercial quantities of nuts is about 12 years, although open-grown trees produce some seeds as early as 4 years after outplanting (Schlesinger and Funk 1977). The biggest challenge in managing walnut for timber and nut production is to maintain regular annual yields. On open-grown trees, nut crops are produced most commonly in an alternate-year cycle; some trees bear annually, others bear in 1 or 2 years out of 3, and many bear with no regular pattern at all (Zarger et al. 1969). Alternate bearing is characteristic of most fruit trees with late-season fruit maturation and is related to the carbohydrate concentration in the plant (Sparks 1979). Late-season kernel development makes a high demand on available carbohydrates and stored reserves when the new female flowers are forming. Increasing the leaf area per unit of fruit may decrease the alternate bearing tendency (Sparks 1979). Before thinning plantations, the manager may be able to identify those trees with good form that are persistent bearers or trees that produce crops during "off" years. Wylie (1966) suggested annually spot painting trees that have above-average nut yields for a period of 5 to 10 years before thinning to facilitate crop tree selection.

Nut quality should also be considered when selecting trees for yields. Kernel percentage, the dry weight of kernel as a percent of the dry weight of the entire nut, is the key factor in nut quality and should be more than 20 percent (Funk 1979). Such nuts can be expected to command a higher price (Garrett and Kurtz 1980).

CONCLUSIONS

Managing for nuts and timber requires a lower level of stocking than for timber alone to ensure rapid growth of large-crowned trees. The landowner must also prune trees to a minimum clear height of 9 feet and select for higher nut yielding trees before the last pre-commercial thinning.

Managers of seed orchards must select trees for rapid growth and nut production to provide landowners with the desired types. Also, they may have to select for late bud break and use techniques like overtree irrigation and herbaceous cover crops to delay bud break and flowering. Late-summer irrigation may be needed to ensure proper kernel development, and chemical ripeners may be used to ensure a harvest of mature nuts.

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NUT PRODUCTION--A VALUABLE ASSET IN BLACK WALNUT MANAGEMENT[1]

Harold E. Garrett and William B. Kurtz[2]

Abstract.--Black walnut nut production is a viable source of income for landowners involved in black walnut management. An evaluation of the impact of nut production on economic yields of two management options, timber vs. timber and nuts (timber option) and timber and wheat vs. timber, wheat and nuts (multicropping option) revealed greater economic returns from management regimes including nut production. Increases in internal rate of return (IRR) and present net worth (PNW) ranged from 0.5 to 2.2 percent and $438 to $2844, respectively, depending on management option and nut prices.

Eastern black walnut is regarded as one of the most valued of American native woods. Its wide use in the production of furniture, wall paneling, and gunstocks has resulted in substantial literature detailing the economic virtues of producing high quality veneer and sawlogs (Schlesinger and Funk 1977). However, little has been written on the economics of black walnut nut production. This is somewhat of an anomaly in view of the fact that one of the economic advantages of planting black walnut over other hardwood species is that it produces a marketable nut crop of considerable value. Although Mattoon and Reed (1924) suggested that "for the present the nut crop of the black walnut should be regarded only as incidental to the general farm operation--a by-product of the farm and not a staple crop," this does not hold in 1981. An available market for the sale of nuts exists in most states where black walnut is grown with the demand for nuts exceeding the supply.

With intensive management, black walnut will produce commercial nut crops on all sites by age 20 and will produce commercial crops on many by age 15. In recent years nut values have ranged from $3-$5.00 per hundred pound weight (cwt) for nuts collected from native groves. However, as high as $24.00 per cwt. has been paid for plantation-grown nuts. Differences in prices arise from differences in percentage crackability. Nuts from natural stands, under commercial processing, yield an average of only eight pounds of kernels per cwt. of hulled nuts. With plantation conditions, a yield of 20 or more pounds of kernels per cwt. is projected at a significantly higher value.

To evaluate the economic importance of nut production in walnut management, potential gains with and without nuts from two basic management options (timber and multicropping) are compared.

MANAGEMENT ALTERNATIVES AND ASSUMPTIONS

There are countless walnut management options which can be designed to accomodate the objectives of the landowner within limitations of the site. For the purpose of evaluating the impact of nut production on economic yields a comparison was made within two basic options: timber vs. timber and nuts (timber option) and timber and wheat vs. timber, wheat and nuts (multicropping option). These alternatives were developed using conditions relating to black walnut production in Missouri but are applicable throughout the natural range of the species. Factors considered are site quality, diameter growth rate, number of trees planted per acre, pruning height and thinning regimes. The reader is referred to Kincaid et al. (1981) for specific details on these factors.

[1]Paper presented at the Walnut Council/ NNGA Symposium, West Lafayette, Indiana, August 9-14, 1981.

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For this comparison site quality and rotation length are held constant. A site index of 80 is assumed with a projected average diameter growth rate of 1/2-inch per year. A rotation length of 60 years was selected for all management alternatives. Thinning recommendations are based on projected diameter classes and crown competition factors (CCF-Schlesinger and Funk 1977) resulting in precommercial and commercial thinnings.

Timber

Black walnut is a species of great genetic variation. Because of its variability, it is important in timber production to utilize a close spacing, securing selection gain through thinning. While the spacing may vary with site and specific management objective, a spacing of 12 x 12 feet (300 stems/acre) has been selected for this analysis. Forty trees are selected for a first pruning to a height of nine feet at age eight. A second pruning of 27 crop trees (to be selected from the original 40) is conducted at age 16 to a height of 17 feet. Through selective thinning, the number of trees are reduced to 27 (approximately 40 x 40 feet) by rotation end. A maximization of log quality is achieved through artificial pruning.

Timber and Nuts

Growing walnut for timber and nuts requires the use of a wider spacing than growing trees for timber alone. This is important to develop a large, relatively uninhibited crown. Therefore, a 40 x 10-foot spacing providing 108 trees per acre was selected. As in timber production, selection gain is achieved through precommercial and commercial thinnings applied to reduce the number of trees to 27 by age 33. Clear-length pruning within this regime differs from the pure timber regime in that the management objective is a shorter log with greater emphasis placed on crown size for nut production. At age ten, 40 trees are pruned to a height of 9 feet. As in the timber management regime, 27 crop trees are selected for a second pruning. Pruning occurs at age 20 and extends the clear length of the stem to 15 feet.

Nut prices are projected at $5,00, $9.00, $15.00 and $20.00 per hundred pound weight of hulled nuts. The prices are conservative in view of the fact that $24.00 per cwt has been paid in recent years for plantation grown nuts (personal communication, Gus Rutledge, Hammons Products Co., Stockton, Missouri). However, it provides a reasonable range of prices to cover a fluctuating market. Nut yields (Table 1) are also intentionally conservative in an attempt to offset the unknown cost of harvesting.

Table 1.--Projected nut yields from black walnut under plantation management.

Avg dbh (inches)	Estimated yield[1] (pounds of hulled nuts/acre)
11.0	2128
13.5	2286
15.5	2238
18.5	2937
22.5	2937
27.5	2916
32.5	2916

[1]After Kincaid, W. H., 1981. Economic-silviculture aspects of black walnut management, M.S. Thesis, School of Forestry, Fisheries and Wildlife, University of Missouri-Columbia. (Yield estimates derived by linear regression from Zarger (1946) and increased by fifty percent to account for increased yield from plantation management.)

Timber and Wheat

A timber and wheat management regime assumes plantation establishment and management practices similar to those of the timber and nuts alternative--i.e., number of trees per acre, thinning schedules, pruning heights, growth and nut yields are unchanged. However, an intercrop of winter wheat is grown between walnut rows for the first ten years. Although wheat could be produced over a longer period without significant yield reductions resulting from walnut competition, in our analysis it is projected for only ten years due to practical considerations relative to management. In growing wheat, a minimum of three feet is left between the crop and trees. This land is removed from production to minimize competition in the early spring and to reduce damage to the walnut root system that might occur during site preparation.

Timber, Nuts and Wheat

Timber and wheat establishment and management practices, and costs and revenues are the same for both the timber, nuts and wheat and timber and wheat regimes. However, the timber, nuts and wheat regime does have the additional benefit of nut yields which are assumed to be the same as from timber and nuts.

ECONOMIC EVALUATION

The economic contribution of nut production to a black walnut management scheme was assessed by comparing the internal rates of return (IRR) and present net worth (PNW) generated by cash flows from the two basic management options with and without nut production. As indicated previously, nut prices of $5.00, $9.00, $15.00 and $20.00 per cwt. were used in evaluating the two options that included nut production. All other prices are the same as those shown in Kincaid et al. (1981). Walnut stumpage prices for commercial thinning and final harvest material were inflated at an annual rate of 1.5 percent (Hoover 1978).

Greater economic returns were realized from those management regimes including nut production (Table 2). For both the timber and the multicropping options nut production accounted for an addition to IRR of from 0.5 to 2.2 percent depending on nut prices. In a similar fashion, increases in PNW ranged from $523 to $2844 per acre for the timber option and from $438 to $2598 per acre for the multicropping option. The slightly higher levels of difference in PNW for the timber option over the multicropping option are due to the additional costs incurred in establishing and precommercially thinning the extra 192 trees required in the timber regime--costs that are not offset by the greater stumpage yields for commercial thinning and final harvest in the timber regime.

With increased nut prices, the respective IRRs for the two regimes including nut production would increase by 1 to 6 percent over the $5.00 to $20.00 per cwt. price range (Table 2). For the timber and nuts regime an increase in PNW of $2321 per acre and for the timber, nuts and wheat regime an increase in PNW of $2159 per acre would result from the increase in nut prices. Obviously, the resultant increases in the financial return measures are linked directly to the expected nut yields of the respective regimes.

The sensitivity of IRR relative to changes in nut yields was examined to determine the effects of such variations on the stability of IRR for the two regimes incorporating nut production (Table 3). Since IRR is conditioned by product price, it becomes more sensitive to nut yield changes as nut price is increased. For example, at the lower nut price of $5.00 per cwt. annual nut yield would have to be increased by well over one-and-one-half times for either regime to increase IRR by one percent. In contrast, at a nut price of $20.00 per cwt. annual nut yields would only have to increase by just over one-half to increase IRR by one percent.

Conclusions

Management of black walnut stands for nut production in conjunction with timber production or a multicropping alternative is clearly to one's financial advantage. Higher returns are yielded by those management regimes incorporating nut production in comparison to those which do not. Depending on assumed nut price, increases in PNW of from $400 to $2900 per

Table 2.--Internal rate of return[1] (IRR) and present net worth[2] (PNW) of four alternative black walnut management regimes at nut prices of $5, $9, $15, and $20 per cwt.

Management regime	$5		$9		$15		$20	
	IRR	PNW	IRR	PNW	IRR	PNW	IRR	PNW
	(Pct)	($ per ac.)	(Pct)	($ per ac.)	(Pct)	($ per ac.)	(Pct)	($ per ac.)
Timber	6.68	2471.94	6.68	2471.94	6.68	2471.94	6.68	2471.94
Timber and nuts	7.27	2994.74	7.71	3613.65	8.33	4542.03	8.81	5315.67
Timber and wheat	8.20	3344.89	8.20	3344.89	8.20	3344.89	8.20	3344.89
Timber, nuts and wheat	8.74	3782.68	9.23	4358.62	9.91	5222.52	10.42	5942.44

[1]Internal rate of return is the average interest rate earned on all costs up until the time of investment maturity.
[2]Present net worth is the net value of the stream of costs and revenues discounted back to the present at a 5.0 percent interest rate.

Table 3.--Sensitivity[1] of internal rate of return to changes in nut yields for two black walnut management regimes at nut prices of $5, $9, $15 and $20 per cwt.

Management regime	$5	$9	$15	$20
	Percent			
Timber and nuts	189.33	110.57	72.08	58.15
Timber, nuts and wheat	168.35	101.14	68.52	56.79

[1]Sensitivity is expressed as the percent increase in annual nut yield required to increase internal rate of return by 1.0 percent.

acre may be attributable to the value of nuts produced over the 60-year rotation.

Nut production in a multicropping regime --timber, nuts and wheat, in this instance-- offers the greatest financial returns of those alternatives considered due to the earlier returns from crop yields, later supplemented by nut yields. In comparison to the timber and nuts management regime, the multicropping regime including nuts generates additional PNW of $600 to $800 per acre depending on assumed nut prices.

The financial success of managing for nut production is directly linked to the price of nuts. Obviously, the higher the price received the more profitable will be management for nut production. Although not completely supportable, given the present and the anticipated supply-demand situation for black walnut nut meats, it is quite likely that the price paid for quality hulled nuts will experience a continued rise.

Our view is based on the many potential uses for hulls, and nut meats as well as current market requirements which are not being met. In good crop years, Hammons Products Company, Stockton, Missouri, the Gravett Shelling Company, a Division of Hammons Products, Gravett, Arkansas, and Funsten Nut Division of Pet, Inc., Bolivar, Missouri, the major purchasers of eastern black walnut nuts attempt to buy a total of approximately 60 million pounds of hulled nuts. Only rarely is this achieved. In 1980, only four million pounds were available for purchase. Since eastern black walnut nut meat is presently sold only as a flavoring agent and little or no consideration has been made for its nutritional value, the extractable fat from the nut meat or the export market, the potential market for eastern black walnut kernels has hardly been tapped. In light of this, a market demand of 200 million pounds per year is not considered to be unrealistic.

These are encouraging results for black walnut growers. By emphasizing nut production, an additional reliable source of income is available for the majority of the rotation period.

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THE STATUS OF BLACK WALNUT TREE IMPROVEMENT PROGRAMS IN THE NORTH CENTRAL REGION

George Rink and Henry E. Stelzer[1]

Abstract.--Black walnut was found to be a high priority species for improvement in Central and North Central United States. Most State improvement programs have as their goal the ability to meet seedling requirements with improved seed. States included in this report may have orchard acreage sufficient to meet this goal. Anticipated year of production of improved seed from seed orchards and seedling demand projections are presented by States.

INTRODUCTION

Genetic improvement of black walnut has been advocated for at least 20 years. Although Wright (1966) outlined several approaches to such improvement, he felt that a basic improvement program to include selection, provenance, and progeny testing would be the most efficient and productive approach in the long run.

Although the feasibility of genetic improvement of walnut is fairly well documented by research, the application of research results has apparently lagged behind (Bey 1973, Funk 1973). However, walnut action tree improvement programs now exist and it seems that large-scale production of improved walnut seedlings will be a reality soon.

Most tree improvement programs have as their primary goal the production of faster growing, pest resistant trees with better form for increased timber yield. Such improvement is accomplished by identifying and selecting the best trees and propagating them in seed orchards. Seed from such orchards are used to produce improved nursery stock for future reforestation. From this standpoint the ability of these improved trees to produce nuts is critical. The essential concept of an orchard involves using trees of known high genetic potential for seed production as opposed to buying or collecting seed from perhaps unseen and certainly untested trees.

[1]Research Geneticist, North Central Forest Experiment Station, Forestry Sciences Laboratory, Carbondale, Illinois, and Forest Geneticist, Division of Forestry, Missouri Department of Conservation, Licking, Missouri.

INFORMATION SURVEY

Questionnaires were mailed to 11 State agencies or universities in the commercial range of black walnut requesting information on current status and future plans for the species. States included in this informal survey were Illinois, Iowa, Indiana, Kansas, Kentucky, Michigan, Minnesota, Missouri, Ohio, Tennessee, and Wisconsin. Although other states in the East and Northeast produce walnut seedlings, most of their activities are centered around growing walnut in an urban setting or for nut production. These States have small areas that would qualify as classical walnut sites and their seedling production is usually lower than in the Central and North Central States. Consequently, walnut tree improvement efforts have a lower priority in the East and Northeast and they were not included in this survey. Additional information was provided by USDA Forest Service, State and Private Forestry.[2]

RESULTS

All 11 States were involved with walnut improvement, although the level of involvement varied from State to State. The least intensive level of involvement was represented by cooperation in provenance/progeny testing, while the highest level involved actual orchard design and progeny testing with plans for creating second generation orchards. Most programs may be described as basic improvement programs (Wright 1966).

[2]Verbal communication, Mr. Clyde M. Hunt, Broomall, PA, June 1981.

Most responses to the questionnaire indicated high priority for walnut improvement and five States ranked walnut as the number one priority species (table 1). Many respondents also indicated that their long-term goal was to have all State nursery production of walnut from improved seed.

Responses reflect two basically different approaches to seed orchards--clonal vs. seedling. In a clonal walnut orchard, selected trees are propagated by grafting while seedling seed orchards are created by planting seed of select trees and subsequently thinning the resulting stand to retain only the best phenotypes for seed production.

In many cases, there is a fundamental philosophical difference between the two approaches. The clonal approach usually relies upon the belief that a certain amount of gain can be achieved by selecting superior trees in the wild and vegetatively propagating such trees. For example, Indiana, Kansas, and Kentucky rely upon selecting trees on the basis of growth rate, straightness, branch angle, bole quality, and apical dominance; trees are selected and cloned if they are above average to superior in all or most of these traits. This approach is most common with tree species growing in even-aged stands. Selection is on the basis of comparison of these traits with neighboring trees. However, due to the scattered distribution of walnut and its habit of growing in uneven-aged stands, such comparison tree selection schemes may not be reliable or efficient. As a result, selection of walnut in the wild is usually empirical, with no formal grading system.

By contrast, the seedling seed orchard approach is one selected by Iowa, Wisconsin, Minnesota, and USDA Forest Service. By this approach, single tree nut collections are used to create progeny tests. Mother trees from which nuts are collected for progeny tests are not rigorously selected; usually they are stipulated to be only of average or better quality. Rigorous selection at this stage is avoided because it is felt that there is no way to evaluate single trees for important traits without even-aged neighbor trees growing on a similar site under similar conditions. In this approach rigorous selection is carried out at the progeny test stage.

Actually, the differences between the two approaches are not clearcut because selected trees are usually progeny tested in the clonal approach, too. Final selection for seed orchard inclusion is usually withheld until progeny test results.

The two States with the most advanced walnut improvement programs are Indiana and Missouri. Both States expect to be producing improved seed from their first generation orchards by 1985 and both list black walnut as their first priority species.

The Indiana program is the oldest State-operated walnut improvement program. It is a coordinated effort between the Indiana Department of Natural Resources and Purdue University. This program has placed more emphasis on selection of wild trees than in any other State. Selections have been propagated in a clone bank and approximately 100 of 250 original selections are being progeny tested. Based on performance

Table 1.--Summary of responses from informal survey mailed to 11 States

State	Seedling seed orchard[1]	No. families	Clonal orchard[1]	No. clones	Progeny test	Anticipated date of orch. prod.	Current seedling prod. target	Priority
	(Acres)		(Acres)		(Acres)			
Illinois			30	60+		1990	500,000	1
Iowa	10	130			10	1995	700,000	1
Indiana			40	35	11	1985	300,000	1
Kansas			37	85	2	1987	125,000	1
Kentucky			10	9		2000	300,000	#1 hardwood
Michigan					18		100,000	high
Minnesota	7	150			7	1990	300,000	2
Missouri	73	144	10		73	1985	500,000	1
Ohio	0		0		15		250,000	low
Tennessee							0	high
Wisconsin	7	150	0		7	1988	300,000	#1 hardwood #5 overall

[1]Actual acres presently in orchard or in the midst of establishment.

in the clone bank and progeny test, 35 of these have been propagated in seed orchards. Second generation orchards are being planned from selections to be made from progeny test results.

The Missouri Department of Conservation program consists of 73 acres of Statewide progeny tests to be converted to seedling seed orchards by roguing the poorest individual trees and families. When the progeny testing is complete, superior genotypes will be combined into a clonal orchard.

Both Indiana and Missouri plan to maintain original selections in clone banks.

In Kansas, responsibility for walnut improvement rests with the Department of Forestry, Kansas State University. Although their seedling requirements are modest, the program is well underway with two established clonal orchards. The Illinois Department of Conservation and Natural Heritage is also in the midst of establishing two clonal orchards. These orchards will consist of selections from existing USDA Forest Service and Indiana Department of Natural Resources progeny tests.

The Iowa program is administered by the Iowa Conservation Commission. The program consists of two 5-acre progeny tests of 130 plus-trees selected throughout the State. The progeny tests were established in 1976 and are intended to serve as seedling seed orchards after roguing. These areas may have to be expanded by grafting to meet seedling production needs.

Both Kentucky and Tennessee walnut improvement programs are in the early stages of establishment. The Kentucky Division of Forestry has established 17 acres of regional and Statewide provenance tests that will serve as an interim seed source until a clonal orchard is established. Selection of superior phenotypes for the clonal orchard has already been initiated. The Tennessee Division of Forestry expects to begin walnut seedling production in 1982 and within 5 to 10 years anticipates production in excess of a half million seedlings per year. An orchard is being planned from expansion of a clone bank containing 50 plus-tree selections as well as incorporation of 66 selections in a Tennessee Valley Authority clone bank. Progeny testing will accompany seed orchard construction.

The walnut improvement programs of the Minnesota and Wisconsin Departments of Natural Resources are similar. Both call for 7-acre progeny tests to be converted to seedling seed orchards. Walnut is a second priority species in both States.

Both Michigan and Ohio are involved in cooperative USDA Forest Service provenance/progeny tests. Michigan has no plans for walnut seed orchards, while Ohio already has 15 acres of progeny tests in various parts of the State to be converted to seed orchards. Some of these Ohio tests were established in 1969 and should be producing seed soon if they are properly managed. Unfortunately, the State has no overall tree improvement program so these progeny tests may be neglected.

The USDA Forest Service has identified black walnut as a first priority species for tree improvement in the Central States. Walnut improvement in the USDA Forest Service is primarily the responsibility of the North Central Forest Experiment Station and the National Forests in the Central States. Progeny tests have been established on the Shawnee, Wayne, Hoosier, and Monongahela National Forests in the 1973-1976 period with the objective of conversion to seed orchards for National Forest walnut regeneration. Trees being progeny tested are of average or better quality from seed zones delineated for each National Forest; a minimum of 50 trees are included in each progeny test. In addition, the North Central Forest Experiment Station has established two progeny tests for conversion to seed orchards for the State of Illinois. These tests include 87 families. These progeny tests will probably be producing improved seed by 1990.

THE OUTLOOK FOR THE FUTURE

In 1966 Funk described an idealized hypothetical black walnut seed orchard. According to Funk's (1966) calculations, an orchard with 20-foot square spacing should be able to produce 30,000 seeds per acre in the "on" year and assuming an 80 percent seedling percent this would translate to 24,000 seedlings per orchard acre in good years. This means that a 10-acre orchard should average approximately 250,000 seedlings at least every other year. Using these figures as a crude, conservative guideline, it is clear that most States that list walnut as their first priority species already have orchard acreage that may meet their seedling needs upon maturity (assuming a 20-foot square spacing, which is probably too close). The one exception to this is Iowa, which has the highest seedling requirement but only 10 acres of orchard. Iowa's orchard acreage should be at least 3 to 4 times greater if all seedling production is to be from improved seed.

One source of concern is the fact that apparently many selections are not being adequately progeny tested. Acreage listed in table 1 for progeny tests seems rather low considering how many selections have been made and the number of orchards being established. Without good progeny tests, it will be difficult to demonstrate potential gains by using improved growing stock.

Nevertheless, improved walnut stock will be a reality in the near future. Once it is shown that improved walnut seedlings are pest resistant and have better form as well as providing higher survival and growth, demand for seedlings will likely increase dramatically. Conservative projections indicate possible growth gains of from 15 to 30 percent over current nursery stock by using first generation selections. An added improvement of that magnitude should be possible in subsequent generations.

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INDIANA DIVISION OF FORESTRY BLACK WALNUT

TREE IMPROVEMENT PROGRAM [1]

Mark V. Coggeshall and Stephen G. Pennington [2]

Abstract - The State of Indiana black walnut tree improvement program is a cooperative effort between the Department of Forestry, Purdue University and the Indiana Department of Natural Resources, Division of Forestry. The program steps include phenotypic selection, clone bank evaluation of selections, half-sib progeny testing, and clonal seed orchard establishment.

The Indiana Division of Forestry initiated a black walnut (Juglans nigra L.) tree improvement program in 1971. The program can be characterized as a half-sib progeny test, clonal seed orchard approach. A clone bank is included. The goal of the program is to insure that black walnut seedlings distributed by the two state nurseries will provide the best performance possible when outplanted by Indiana landowners. Specifically, there are four program objectives: 1) to preserve the highest quality specimens of black walnut trees in Indiana by grafting their genotypes into the clone bank and state seed orchards; 2) to counteract the effects of dysgenic selection by re-introducing the offspring of these superior genotypes into Indiana woodlands through seedling distribution from the state nurseries; 3) to develop tree varieties that exhibit a high genetic potential for such characteristics as growth rate, form, and disease resistance; and 4) to provide a continuous supply of seed from this improved stock for the state nurseries.

The following steps are included in the Indiana black walnut tree improvement program: selection of superior phenotypes, establishment of all selections in the clone bank, half-sib progeny testing of the selections, and cloning the best selections into state seed orchards. This paper summarizes our efforts to date for each of these activities.

[1]Paper presented at the 1981 Joint Meeting of the Walnut Council/Northern Nut Growers Association, West Lafayette, Indiana, August 9-14, 1981.

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CURRENT STATUS

Annual seed requirements for the two state nurseries is approximately 750,000 walnuts. An average germination rate of 50 percent and a cull rate of 20 percent yields 300,000 seedlings annually. Seed is presently collected by nursery personnel and other Division of Forestry properties with little regard for parent tree quality, especially in poor seed years.

The Indiana black walnut tree improvement program will supply high quality seed to the state nurseries by insuring that superior genotypes are the seed sources for the nurseries in the future. The rationale for using the half-sib, clonal seed orchard approach with a clone bank is addressed by Masters and Beineke (1972). Each of the steps in the black walnut tree improvement program are addressed below.

SELECTION OF SUPERIOR PHENOTYPES

Approximately 250 superior phenotypes have been selected from the natural black walnut population in Indiana. Most of these trees were graded on a point system for such characteristics as growth rate, apical dominance, straightness, and habitat (W.F. Beineke, personal communication). However, environment can influence these traits and some superior phenotypes have been found to be genetically inferior when progeny tested. As a result, comparison tree selection in plantations has lately received more emphasis. The majority of the newer selections now included in the program are from plantations or open-grown locations. New selections have also been made in older half-sib progeny tests established by Purdue University and the Indiana Division of Forestry. To date 13 recurrent selections are included in the program.

PURDUE CLONE BANK

Selections that have been accepted into the program are grafted and placed in the clone bank at the Purdue University Martell Forest. The purpose of this clone bank is fourfold: 1) to gain an insight into a selection's performance in future seed orchard situations (ie growth rate, flower production); 2) to evaluate the ease by which a selection can be grafted; 3) to provide a source of easily obtained scion wood for use in the production of grafted trees for the state seed orchards; and 4) to preserve the genotypes of the best quality specimens of black in Indiana. The clone bank is maintained by Purdue University.

Purdue University has been conducting black walnut genetics research, especially in the areas of selection, flowering, and progeny testing, since 1968. The results of this research has led to the incorporation of tested clonal material into state seed orchards. The Indiana Division of Forestry is fortunate to have this cooperative arrangement with Purdue University whereby intensive research efforts will result in direct benefits to the Indiana landowner.

HALF-SIB PROGENY TESTING

The purpose of a half-sib progeny test (male parent unknown) is to evaluate the selections based on the performance of their seedling offspring. Progeny testing provides information on the genetic value of the selections. In addition, recurrent selections can be made in older progeny test plantations.

Seed collected from the selections (both original parent trees and older clone bank individuals) are sown at the Vallonia Nursery and outplanted as 1-0 stock at various locations throughout Indiana (fig. 1). A total of 19 progeny test plantations representing 67 selections have been established at 12 sites since 1969 by Purdue University and the Indiana Division of Forestry.

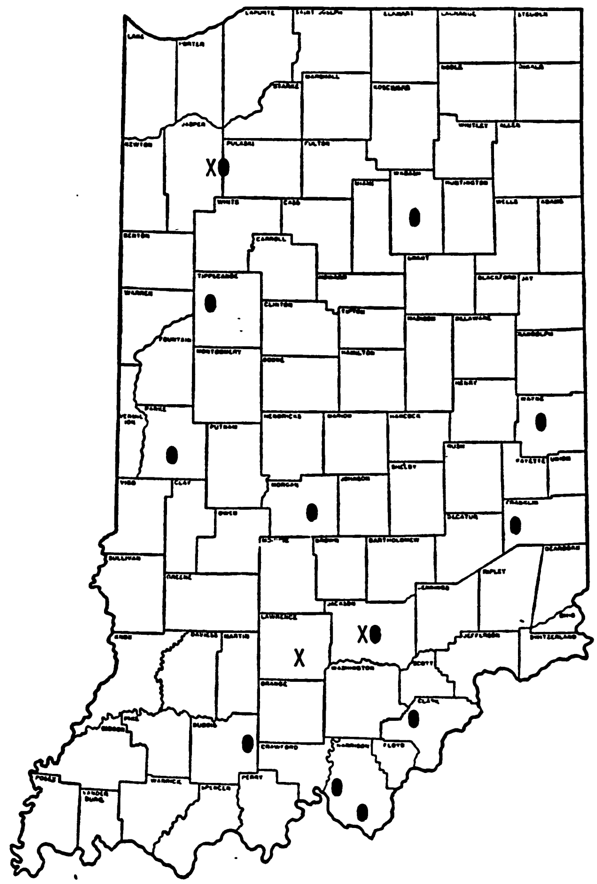

Figure 1.-- ●= Locations of half-sib progeny test plantations in Indiana established by Purdue University and the Indiana Division of Forestry. X= Locations of state seed orchards.

Since 1979 progeny tests have been planted at a spacing of 4 X 4 feet (Coggeshall and Beineke, 1979). These close-spaced, short term progeny tests were established to evaluate juvenile height growth. Kung (1973) used stem analysis from 30 year old black walnut trees to produce juvenile-mature correlations. He found that the correlation between juvenile height and cubic foot volume at 30 years reached a plateau at age 3. In addition, McKeand (1978) reported that family rankings for height growth in previous Indiana progeny tests stabilized by age 4. The tallest families at age 4 were also the tallest at age 9. Therefore, short term progeny testing is valid for black walnut. Rapid screening of families is essential because black walnut produces highly variable seed crops and new selections are constantly being added to the program making annual progeny test establishment necessary. Good black walnut sites at both state nurseries and at the Purdue University Martell Forest have been designated as progeny test areas.

There are several advantages to short term progeny testing. Less site variation will be encountered by planting at such close spacing and weed control problems common to standard progeny testing will be reduced. Also landowner interest will be intensified when planting fast growing planting stock is made available from the state nurseries.

CLONAL SEED ORCHARDS

A seed orchard is a collection of selected trees established and grown together under intensive management for mass production of genetically improved seed. Cloning achieves the result of bringing intensively selected, but widely scattered trees to a common location in their original genotypes. Higher genetic gains can be realized by using this approach (Masters and Beineke, 1972). Each selection is replicated several times in the seed orchard and arranged so as to maximize outcrossing. Selections are grafted into the seed orchards based on progeny test results and the performance of grafts in the clone bank- form, foliation dates, and fecundity. Many excellent clones are not included in the orchards because of poor nut production.

Thirty-four acres of clonal seed orchards have been established in 3 locations throughout the state (fig. 1). Seed orchard establishment began in 1970. Approximately 30 to 40 clones have been selected from the 250 original selections to be included in the seed orchards and 20 to 25 clones are being propagated annually at Vallonia.

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NEW DIRECTIONS IN GENETIC IMPROVEMENT:

GRAFTED BLACK WALNUT PLANTATIONS[1]

Walter F. Beineke[2]

Abstract.--Black walnut produces fewer seed per tree than most tree species which leads to problems of providing sufficient seed from traditional seed orchard production of genetically superior planting stock. Seedlings seldom capture the full complement of genetic improvement possible from parent trees particularly when the male parent is unknown or inferior.

Vegetatively propagated plantations provide a method to take advantage of the complete potential improvement of an improved selection. Patenting and licensing provide protection for researchers who have invested time and money in developing and proving superiority.

Gains in height, diameter, and form are discussed as well as risks from monoculture and containerized planting.

INTRODUCTION

Authors of past Walnut Symposium articles on tree improvement have predicted promising results from the genetic manipulation of black walnut (Bey 1973, Brunk 1973, Funk 1966, Funk 1973, and Wright 1966). Geneticists have cut years from the projected time needed to produce improved stock, but we are still 10 to 15 years from producing significant volumes of improved black walnut seed.

Improving trees through genetics is long-term and black walnut poses some particularly vexing problems (Beineke 1979). Walnut, unlike pines, cottonwood, sycamore, sweet gum, and many other species, is not a prolific seed producer. While a pine tree can produce many thousands of seed each year, most walnut trees produce, at best, only several hundred seed, and pests can claim a large share of those. From the remaining seed, nurserymen routinely obtain only 50 to 60 percent germination.

The number of nuts produced per tree can be increased by selecting good nut producers, wide spacing, fertilization, and weed control, but walnut still requires many years to produce quantities of seed and never approaches the prolific seed production of the light-seeded species. Thus, seed orchard programs for black walnut must provide for this lack of seed production with increased seed orchard acreage and improved management.

SEEDLING VS. CLONAL PROPAGATION

Seedlings are the product of pollination and fertilization, a sexual process, and are genetically different, just as brothers and sisters differ, even though they have the same parents. Of course, siblings usually do have some resemblance to their parents and to each other, but they are variable. That portion of variation is one source of inherited improvement--the additive portion. That is the only portion that can be depended on to provide improvement when sexual reproduction is used.

On the other hand when grafting or other means of vegetative reproduction is used, all of the genetic potential (non-additive plus the additive portion) of the superior tree can be passed on to the next generation (Libby 1977). That is, a graft is an exact

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genetic duplicate (clone) of the selected tree containing all of the improvement possible from the aboveground portion of the parent. For some traits such as volume growth, having low additive inheritance, Zobel (1981), states that, "it appears possible to more than double short-term genetic gain by using vegetative propagules rather than seed regeneration."

Once a superior tree is identified and tested for a sufficient time, it can be multiplied by vegetative propagation at a fairly young age without waiting for seed production to occur. In the first 12 years it is estimated that nearly 10 times more plants can be reproduced from a young walnut by grafting than from seed (table 1).

Table 1.--Estimates of average numbers of propagules available from walnut clones at various ages.

Tree age/ year	Numbers of seed produced	Numbers of grafting buds produced
1	0	0
2	0	5
3	0	15
4	3	50
5	7	100
6	10	200
7	15	350
8	30	500
9	60	650
10	110	800
11	130	1000
12	150	1300
Total	515	4970
Average	43	414

Also, nut production in black walnut tends to be cyclic with most trees producing large crops only once in 2 to 4 years, and the crop may be subject to frost and insect damage every year. That is why average yearly nut production does not rise sharply after the first few years (table 1). In contrast, new branches having graftable buds grow every year. Even following years of slow growth, large amounts of grafting wood are available; especially from trees pruned vigorously and annually.

Genetic uniformity in tree size, form, nut production and wood properties is a positive factor in favor of clonal propagation. Economic advantages accrue in the marketing and harvesting of uniform stands (Zobel 1981).

At the present time, the only operational, practical vegetative propagation technique for black walnut is by grafting (Beineke and Todhunter, 1980). However, two other methods may show promise in the future - rooted cuttings and tissue culture.

Rooting of cuttings is a commonly used method to propagate many plant species. Major advantages of rooted cuttings are that the plant is supported by its own genetically compatible root system and is cheaper than grafting. With few exceptions, (Carpenter 1975, Farmer 1971, Shreve and Miles 1972), rooting of black walnut cuttings has proven to be extremely difficult. Cuttings require a length of stem, usually with a terminal meristem intact, thus greatly reducing the number of propagules obtained from a tree compared with grafting. In black walnut the same length of stem used for one cutting could produce three or four grafts.

Tissue culture, a fairly new tool, is emerging as a revolutionary vegetative propagation technique for many species (Murashige 1974, Durzan and Campbell 1974). Briefly, tissue culture in black walnut would probably involve removal of a vegetative bud from a superior tree and placement on a sterile growing media in a petri dish. Subsequent bud growth and shoot elongation would produce lateral bud formation along the shoot. Each of these lateral buds would then be excised and placed on media to grow and multiply proliferating a single bud into hundreds or thousands of plantlets. Shoots for operational planting would have to be placed on special rooting media to induce root formation and growth. Plantlets would then be transferred to containers and moved to the greenhouse and hence to the field.

Each step in this process has an incredible array of problems to be solved and, at present, is strictly theoretical. However, it has been accomplished for roses, apples, loblolly pine, and a few other woody species (Hasegawa 1979, Huth 1978, Mott and Amerson 1981). The advantages of this technique are, of course, the unlimited number and rapid propagation of an improved cultivar from a few buds. Once techniques became operational, tissue culture would probably be cheaper than grafting (McKeand 1981).

PATENTING

The use of vegetative propagation provides an opportunity to patent improved clones. Plant patents grant protection from indiscriminant propagation of improved material. The rationale behind patenting is that the developer who took the risks and funded the work should have the opportunity to profit without competition from those who did not have the foresight to provide funding for the development of the new material. To obtain a plant patent, the "unique" attributes of the plant must be proven. Note that "genetic improvement" is not necessarily a criteria for patenting. Proving a tree unique is a time-consuming, difficult and expensive process which involves comparisons of traits with known or previously patented material of the same species.

Patenting black walnut for timber purposes had never been previously attempted until the patents on Purdue 1, 2, and 3 were issued. After the patent is granted, the patented tree can be licensed for propagation and sale to the public. Purdue 1, 2, and 3 were patented by and licensed for propagation through the Purdue Research Foundation. This arrangement allows the University to collect royalties on the sale of each tree, thus obtaining some return on its investment in research.

The grafted clone approach differs greatly from the seed orchard approach outlined in previous papers at this symposium. The use of buds rather than seed is the basis of propagation and involves several additional items - i.e., budwood collection, storage, and care. Seedling production requires only the standard nursery installation. Grafted black walnut requires much more investment in production facilities such as greenhouse, propagation areas, potting equipment, grafting materials, budwood storage, holding areas for completed grafts, and skilled technicians to do the grafting in addition to the standard nursery to produce rootstocks for grafting.

GENETIC GAINS

How much gain can be expected using vegetative propagation rather than seedling reproduction? Unfortunately, large, well-designed, older tests are not available to study this crucial aspect. However, from our older tests containing seedlings from patented Purdue 1 vs. a nursery-run check and grafted patented Purdue 1 vs. a nursery check, some rough estimates can be made (table 2). The seedling test is located in southern Indiana, while the clonal test is at Martell Forest near West Lafayette, in central Indiana. Therefore, differing soils and climatic factors apply. The southern Indiana seedling test is on a marginal walnut soil while the Martell soil is a fair to good walnut soil. Both sites have had fair to good weed control, annual pruning, and occasional fertilizer applications of Urea or 12-12-12.

Table 2.--Growth and form characteristics of patented Purdue 1 grafts vs. checks compared with Purdue 1 seedlings vs. checks.

	Height (ft.)	DBH (in.)	Volume (cu.ft.)	Stem Form[1/]
9 years old -				
Purdue 1 grafts	26.6	4.9	1.77	1.3
Seedling checks	20.3	3.8	.92	3.3
Percent gain	31	29	92	61
11 years old -				
Purdue 1 seedlings	23.9	4.4	1.36	2.7
Seedling checks	21.5	3.7	.92	3.3
Percent gain	11	19	48	18

[1/]Rating Scale: 1 = excellent form to 5 = very poor form.

Seedlings vs. the check do not show the percent gain of grafts vs. the check (table 2). This is an expression of several factors, including the graft's ability to exploit the full complement of inherited superiority as was discussed earlier. Another factor of great importance is that the seed collected from the superior tree in the natural setting includes an unknown male pollinator or several unknown pollinator components. They may have passed on superior genes or inferior genes for growth, etc. Therefore, the seedling mix contains a genetic component that is unknown and in all liklihood detrimental.

Form improvement is perhaps most indicative of the value of using clones. Stem form was obtained by subjectively rating the straightness of the main stem on a scale of 1 to 5 with 1 representing a perfectly straight stem, 2 - slight crook or deviation of the central stem, 3 - about average straightness, 4 - several severe crooks or a single fork, and 5 - a very crooked, forked and/or leaning central stem. In table 2, form improvement from seedling progeny is good, but improvement from clonal material is truly outstanding. It is significant to note that the check trees in both plantings had identical poorer than average stem forms, even though the two plantings are located 150 miles apart.

RISKS

The alleged problems associated with the planting of the same genotypes over large acreages, is often mentioned as a reason for not using clones (Zobel 1981). Monoculture invokes the specter of catastrophic losses to some unknown disease, insect or climatic happening. Dutch elm disease and chestnut blight are often used as examples. If a disease of this magnitude invades walnut, it will destroy them all whether they are of seedling or clonal origin. Monoculture was not the reason Dutch elm disease or chestnut blight spread so rapidly. Walnut is a native species well-adapted to the climate, diseases, and insects of the eastern U.S. Care must be taken to select only those clones that show some resistance or are not overly susceptible to the pests that affect black walnut. Of course, there is risk involved in using only a few clones but this must be balanced against potential gains in time, tree form, and nut production.

Black walnut growers are not the first long-term-tree crop orchardists to contemplate growing a few varieties over rather large acreage. For instance, fruit orchards usually contain a very limited number of clones (cultivars) that are usually not native to the area. The crop is long-term and there are few reports of catastrophic tree loss due to monoculture. A possible exception may be climatic losses due to varieties being planted outside of their hardiness zones. Fifty-year-old grafted pecan orchards are a closer comparison with black walnut and I'm sure that many NNGA members could point to similar examples of a few nut tree varieties planted in rather large blocks. In fact thousands of grafted Thomas black walnut trees have been planted in large blocks during the past 50 years with no reports of catastrophic disease or insect losses.

Even so, single clone monocultures are not recommended and mixtures of several clones and/or seedlings should be planted. Such mixes are probably more diverse genetically than most natural walnut stands when you consider that the various genetically improved clones and seedlings are from scattered geographic areas, while natural stands develop from local, often isolated, and related individuals (Beineke 1972).

Unique, often unexpected problems accompany any new endeavor and plantations of grafts rather than seedlings have their share. Most plantings of grafts have been made with containerized milk carton stock. The graft is usually only a few months old. The cartons are bulky and difficult to transport and plant. Also, root systems are reluctant to grow from the optimum rooting media of the container into the soil of the real world. Death or dieback of the graft often results during the winter months after outplanting. Unlike seedling dieback, which seldom results in any significant losses, graft dieback and resprouting of the root system means that the expensive and pampered graft has become a common seedling. This also occurs if the graft is damaged by animal predation, weed control tools, or wind. Winter dieback can be reduced by holding grafts over winter, and outplanting them as dormant bare-root grafts the following spring. This technique allows grafts to be handled and planted in the same manner as seedlings. Weed control, pruning, fertilization and other cultural treatments are the same for grafted plantations or seedling plantations.

CONCLUSIONS

Black walnut tree improvement has shown that rapid increases in growth and form can be made and in a few years grafts and seedlings from improved trees will be available in sufficient quantities to begin to meet the demand.

Seed orchards for genetically improved seedling production will still provide most of the black walnut seed required for regeneration purposes far into the future. As outlined in previous papers at this symposium, demand for walnut seedling stock is staggering. Due to the investment required and the unpredictability of propagation success, numbers of grafted trees will always be limited. Therefore, clonal propagation will probably remain a rather small percentage of total production. Grafted stock will be available for those growers who desire the maximum genetic improvement possible now and are willing to pay the high cost.

Despite cutbacks in research dollars and scientists involved in the genetic improvement of black walnut, prospects for future improvement appear optimistic. We have just begun to tap the tremendous genetic variation in growth, form, and nut-bearing capabilities in black walnut. New selections are presently under test that may prove to be far superior to anything now available. Studies have indicated methods that may allow us to select for superior growth rate at very early ages, perhaps one year, making it possible to avoid some of the long-term testing presently necessary. Selection, breeding and testing walnut for superiority must be a continuing process. Grafted plantations will prove to be a tool that will allow the landowner to take full advantage of rapid improvement.

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SOME GUIDELINES FOR SELECTING BLACK WALNUT PLANTING SITES

Felix Ponder, Jr.[1]

Abstract.--Black walnut grows best on fertile, deep, well-drained soils. Sites most often considered for growing walnut are abandoned farms that have never supported walnut. Therefore, soil information taken from other walnut sites must be used to evaluate the suitability of new areas for walnut.

Growing a crop of high-value walnut (Juglans nigra L.) trees is a long-term project that requires investments of land, time, and money. One of the black walnut grower's most important decisions is where to grow this valuable timber- and nut-producing hardwood. Successful walnut plantations are rare, mainly because many were established on unsuitable soils. But from successful plantations on suitable soils and from a few naturally established stands, we have learned much about where to plant black walnut. Frankly, a lot of what we know came from failures, also.

Broadly speaking, soil variables such as origin, physical condition, available water during the growing season, aeration, and nutrient availability determine how productive a site will be for black walnut or for any other vegetation. Losche and others (1972) developed a guide for selecting black walnut sites using these variables. As a result of their work, soils in Illinois were classified as suited, questionable, and unsuited for black walnut. However, the guide has been only partially successful, mainly because our knowledge is still too meager to measure accurately what determines the success of a walnut plantation. But the few variables we do know that contribute to good walnut growth have consistently shown to be reliable in determining plantation success.

Most soil site studies indicate that no single factor alone makes a site good, but that a combination of factors are involved. On the other hand, one single factor might make a site unsatisfactory for black walnut. Auten (1945) found that soil drainage, depth to mottling, and texture were the major factors determining site quality. A mottled zone is a layer that has spots or blotches of different colors or shades of colors; it is usually associated with water saturation. Losche (1973) concluded that an easily recognized soil characteristic "depth to gravel layer" can be used to rate the suitability of some flood-plain soils for black walnut. More recently, Geyer and others (1980) showed that site quality for black walnut was closely related to soil and topographic characteristics. They found, in addition to those factors described by Auten and Losche, that soil origin, surface soil thickness, aspect, and water holding capacity were also important. These factors will be discussed here in detail.

LANDFORM

Site position and slope aspect are very important in site selection. Walnut grows best on deep, loose, alluvial soils, free of mottling. Carmean (1966) reported that on Sharon silt loam, a 25-year-old plantation had dominant trees 84 feet tall. Such exceptional growth exceeds all previously known growth records for black walnut.

Such bottomland sites are usually flat except for depressions of a few inches or, at most, a foot or two. Little depressions often indicate a tight, shallow soil that restricts water absorption. But this condition may be corrected by deep tillage and/or subsoiling.

Slope position and steepness as well as total soil depth often relate closely to surface soil thickness (Geyer and others 1980). Smooth and gently rolling landscapes generally present no critical problem. More important on these sites are soil characteristics such as texture and internal drainage. Shallow, heavy-textured, imperfectly drained upland soils are not suitable for walnut.

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The better planting areas on rolling and mountainous landscapes are usually located on the lower north- and east-facing slopes, stream terraces, and flood plains. These areas usually have the soil moisture and soil thickness required for satisfactory walnut growth. Steep, south-facing slopes and narrow ridge tops would generally be poor walnut sites. Such sites are often dry and because of their susceptibility to erosion are generally shallow. Depending on the geographic location, water deficiencies on south and southwest aspects may be intensified by high daytime temperatures and strong winds throughout the growing season. On soils having good soil moisture and more nutrients, organic matter tends to accumulate because of the more favorable conditions. But on dry and excessively drained soils, especially on hot sites, organic matter is quickly oxidized.

SOIL DEPTH

Black walnut tends to develop a large taproot which will penetrate 4 feet in 1 year and more than 9 feet in 3 years in well-drained, medium-textured soils. Because of walnut's deep rooting habit, Auten (1945) proposed that the surface soil in planting sites should be at least 16 inches thick and that soils having thinner surface soil should not be considered for walnut planting sites. However, I recommend that the minimum soil depth in a prospective site should not be less than 3 feet. Shallower soils will not hold enough water to support satisfactory growth. Also, the grower must realize that even the 3-foot depth could limit growth and the final product to be harvested. An effective soil depth of 5 feet (without restrictive layer) would better ensure good walnut growth.

TEXTURE

Soil texture influences the water holding capacity, available water, and the ease at which roots are able to penetrate. Black walnut generally prefers deep, well-drained silt loam soils. Suitable topsoil textures also include sandy loam and loam. The subsoil should have the same texture as the topsoil or a sandy clay loam or clay loam. Even though no consistent relationship has been found between pH and growth, soils with acid, clayey subsoils should be avoided. Good planting sites also include limestone soils with silt loam over clayey subsoils and deep rocky soils unsuitable for cultivation because of their rockiness. Usually walnut grows poorly on coarse-textured soils.

DRAINAGE

Walnut usually does not grow satisfactorily on poorly drained soils but it can tolerate occasional flooding of short duration. The site should be examined for evidence of restricted internal drainage which may affect surface drainage. Restrictive internal drainage causes poor aeration, leading to inhibited root growth and reduced tree height and diameter growth. Good internal drainage provides favorable conditions for the development of extensive root systems and more complete use of moisture and nutrients.

To estimate internal drainage, the grower must consider soil factors including texture, compaction, and structure. Color seems to be a good correlator of internal soil drainage and is the easiest to recognize. The color (mottling) of the subsoil is usually an indication of how much air (aeration) occupies the spaces between soil particles (table 1). Poor drainage due to heavy subsoil or a high water table is likely to produce a blue or drab color because the oxides of iron remain in the ferrous condition. If the soil has good internal drainage, the iron compounds are oxidized to red ferric oxides and the soil becomes red, brown, or yellowish-brown. Soils with evidence of mottling within 2 feet of the surface should be avoided.

Table 1.--Estimation of internal drainage based on soil color[1]

Drainage class	Color (mottling)	Possible topography
Very slow	Drab and blue below 8"	Swampy, high water table
Slow	Dull yellowish-brown below 14"	Low areas
Fair	Yellow 14-24"	Level upland
Moderate	Brownish-yellow below 35"	Rolling upland
Good-fast	Yellowish-brown	Terraces
Good-very fast	Red-brown	Moraines or loose sand

[1]Auten (1945) and USDA Soil Survey Manual (1962).

Both the gravel layer and mottling zone indicate soil conditions that inhibit deeper root growth. Therefore, soils with coarse sand or gravel layers and bedrock within 3 feet of the surface should be avoided.

OTHER FACTORS

Black walnut growing on bottomland sediments benefits from the greater water availability. Comparatively, upland soils, though well drained, usually lack the depth and organic matter which increase the amount of water a soil can hold.

Wind affects the establishment of black walnut. Seedlings planted in level, windswept, open fields are less vigorous, have smaller leaf areas, and suffer more foliage damage than those planted in similar soils in either forest openings or protected fields (Schneider and others 1970).

Vegetation on the site may indicate the fertility and/or moisture condition of the soil. A sparse cover of weeds and grasses generally indicates low fertility, erosion, or droughty soil conditions; such sites should not be planted to walnut. In contrast, a vigorous ground cover suggests the site may be suitable for planting walnut. Composition of the cover is also important. For example, sedges indicate a wet soil that probably is unsuitable for adequate walnut growth.

The soils of some old fields may contain toxic substances produced by other plants which could inhibit the nutrient uptake and growth of black walnut seedlings (see Rietveld paper presented at this symposium). Such toxic substances may also affect beneficial root-infecting fungi and microorganisms.

SITE IMPROVEMENT

Now comes the ultimate question: How can walnut be grown successfully on a parcel of land that lacks the proper drainage, depth, or other characteristics of an ideal walnut site? Several practices have been tried in an effort to increase the productivity of marginal sites. Most attempts such as fertilizing sites believed depleted of nutrients and refilling deep trenches and tile drainage in poorly drained soil have resulted in limited success. An alternative to fertilization may be interplanting with nitrogen-fixing plants such as autumn-olive or European alder. These plants can biologically fix atmospheric nitrogen which can later be released and used by other plants. Several studies have shown that planting autumn-olive with walnut increased site index by an average of 14 feet, changing what was originally considered a marginal site into a medium quality site for walnut. The effect of autumn-olive on growth was most dramatic on poor sites. However, care must be taken to prevent the spread of autumn-olive onto unwanted areas. Also encouraging are the early results from a forage legume study being done by researchers at Carbondale. Hairy vetch, which required 2 years for establishment, significantly increased seedling growth more than Korean lespedeza, crimson clover, and Sericea lespedeza did after 2 years of growth. Both hairy vetch and Sericea lespedeza controlled weeds better than the other legumes did (Van Sambeek and Rietveld 1981). Thus, planting companion trees and forage legumes on walnut sites may provide an alternative to chemical weed control and fertilization.

Cultural practices designed to increase available soil moisture might promote walnut growth. These practices include irrigation, terracing, mulching, and control of undesirable moisture using vegetation. Practices designed to improve subsoil drainage and aeration might include surface and tile drainage and, in addition, deep tillage may promote better rooting in the subsoil.

SUMMARY

To summarize, these are the major soil conditions to avoid in locating black walnut planting sites:

Problem	Indicators
Poorly drained	Compact subsoil; mottled 8-14"; sedges
Excessively dry site	Bedrock, coarse sand, and/or gravel layer <36" below the surface; compact subsoil; inadequate infiltration
Clay and silty clay	Compact subsoil; inadequate infiltration

Growers should look for sites having the following soil properties:

Soil properties	Indicators
Deep, well drained	Bottomland; >5' deep red-brown color
Limestone-derived soil	
Yellow, brown, or reddish brown subsoils	Without mottles and >3' deep

Knowing the relative productivity of soils in potential planting areas and existing walnut stands will enable the walnut grower to locate new plantations on the best available soils. Growers are urged to use state foresters, soil survey information, and research data in their search for suitable black walnut planting sites.

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THE SIGNIFICANCE OF ALLELOPATHY IN BLACK WALNUT CULTURAL SYSTEMS

W. J. Rietveld[1]

Abstract.--The importance of allelopathy in black walnut cultural systems was evaluated. Laboratory tests showed that 18 species being considered for mixed plantings with walnut were all sensitive to juglone. In mixed, even-aged plantations containing walnut, there is a buildup period of approximately 12-15 years before allelopathic effects become noticeable, if they occur at all. This allows ample time for growing short-term co-crops, nurse crops, and cover crops with walnut. Walnut's phytotoxic activity may even be beneficial in effecting its own release. Long-term mixed walnut/pine plantings are not recommended. The long-term allelopathic effects in mixed walnut/hardwood plantings are uncertain, and may be subtle. Potential allelopathic effects of plantation weeds on growth of walnut seedlings and saplings are considered, along with the need for vegetation management in plantations.

Through evolution, plant species have developed an array of intricate adaptations to ensure survival and perpetuation. One of these schemes--called allelopathy[2]--involves the production of chemical substances which, when released into the environment, directly or indirectly harms selected neighboring plants. Allelopathic chemicals may control the sequence and rate of plant succession, cause changes in species composition, and alter plant productivity. Allelopathy should not be confused with physical competition, because allelopathy involves a chemical compound being added to the environment, whereas competition involves the removal or reduction of some growth factor (light, water, nutrients, space) required simultaneously or sequentially by some other plant sharing the environment. The term "interference" refers to the overall deleterious effects of one plant on another, encompassing both competition and allelopathy (Muller 1969).

Black walnut (*Juglans nigra* L.) is the most notorious of allelopathic trees. However, that notoriety needs qualification. Most of the reported occurrences of walnut allelopathy (with the important exception of conifers) involves toxicity between existing large walnut trees and vegetables, field crops, fruits, and ornamentals. However, a subject that has not yet been addressed directly in the literature is: What are the implications of walnut allelopathy in forestry? As silviculturists, we are more interested in knowing the significance of allelopathy in forest and plantation situations. This paper will explore the documented and suspected allelopathic relationships that may occur in walnut plantations, assess their importance to walnut culture, and recommend silvicultural treatments to avoid or overcome their effects.

HISTORY OF BLACK WALNUT ALLELOPATHY

According to Gries (1943), the first written record of walnut toxicity can be traced back to the first century A.D., when Pliny the Elder, in his *Naturalis Historia* wrote: "the shadow of walnut trees is poison to all plants within its compass, and it kills whatever it touches."

Up to the present time, and especially during the past 50 years, walnut has been reported to be toxic to a wide variety of organisms including herbaceous and woody plants (Brooks 1951), fungi (Hedin *et al*. 1979), microorganisms (Krajci and Lynch 1978), insects (Gilbert *et al*. 1967), fish (Marking 1970), and mammals (Auyong *et al*. 1963). The principal

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[2]Recent reviews on allelopathy include those by Sondheimer and Simeone (1970), National Academy of Sciences (1971), Whittaker and Feeney (1971), Rice (1974, 1979), Fisher (1976, 1979), Horsley (1976), and Rietveld (1979).

chemical responsible for walnut allelopathy has been identified as juglone (5-hydroxy-1,4-naphthoquinone) (Davis 1928), which is found in the leaves, fruit hulls, inner bark, and roots of walnut (Lee and Campbell 1969). Rain washes it from living leaves and carries it to the soil; it is released also, along with tannins, from dead leaves and fruits to the soil. Juglone has been isolated from many plants in the walnut family, including black walnut, butternut (J. cinerea L.), Persian walnut (J. regia L.), Siebold walnut (J. ailantifolia Carr.), Manchurian walnut (J. mandshurica Maxim.), shagbark hickory (Carya ovata (Mill.) K. Koch), mockernut hickory (C. tomentosa Nutt.), Caucasian walnut (Pterocarya fraxinifolia (Lam.) Spach), and pecan (C. illinoensis (Wangenh.) K. Koch) (Thomson 1971, Graves et al. 1979).

Not all reports have supported the existence of walnut toxicity, for in many cases species thought to be sensitive were observed co-existing with walnut. A controversy developed in which the key issue was whether root contact was necessary for toxicity to occur. The divergent results were best explained by Gries (1943) as follows:

> "Juglone, as such, occurs probably only in minute quantities in the inner root bark and in the green husks of the nuts. These regions, are, however, rich in a substance known as hydrojuglone. This compound, the colorless, non-toxic reduced form of juglone, is immediately oxidized to its toxic form upon exposure to the air or some oxidizing substance from the roots of other plants. Upon standing in the air, juglone again disappears, being either changed back to hydrojuglone or broken down into other non-toxic substances.... It now becomes possible for us to understand some of the discrepancies in the studies on walnut toxicity. If walnut bark or other plant parts are allowed to become desiccated, no toxicity may be found. If the roots of plants do not contact plant parts containing juglone or hydrojuglone, their oxidizing ability cannot produce the toxin."

Thus, the occurrence of toxic effects in sensitive species growing near a walnut tree depends on whether they are exposed to juglone as such. Juglone is a highly reactive substance and readily breaks down in well-aerated soil. Some plants may avoid exposure to juglone because their root systems are too shallow to contact the roots of walnut, while others may be capable of withstanding the strong oxidizing power of juglone.

PLANT ASSOCIATIONS INVOLVING BLACK WALNUT AND ALLELOPATHY

Four types of plant associations involving black walnut can be identified:

1. Natural forest stands containing walnut as a component.
2. Various species planted within the influence zone of existing large walnut trees.
3. Sapling plantations containing an even-aged mixture of walnut and one or more other woody species.
4. Walnut seedlings planted admidst herbaceous vegetation.

The first two types of plant associations are listed for completeness, but they are not the subject of this paper and will be mentioned only briefly.

A comprehensive survey of the association of native vegetation with black walnut trees was published by Brooks in 1951. His extensive tables list over 218 species growing within and outside the root and crown spreads of walnut trees. While some species (e.g., blackberry, blueberry, heaths, pines) are rarely associated with walnut, others (Kentucky bluegrass, black raspberry) grow better within the root zone of walnut than outside. The potential roles of allelopathy in differentiation, patterning, and composition of natural forest stands were discussed in a previous paper by the author (Rietveld 1979).

The majority of existing literature on occurrence of walnut allelopathy involves the second type of plant association. These numerous reports of toxicity between existing walnut trees and vegetables, field crops, fruits, and ornamentals are largely responsible for walnut's reputation as an allelopath. The literature on these associations was reviewed by Brooks (1951) and more recently by MacDaniels and Pinnow (1976).

The latter two plant associations involving black walnut in plantations are the subject of this paper and are discussed at length in the following sections.

ALLELOPATHIC POTENTIAL OF BLACK WALNUT ON PLANTATION VEGETATION

Recent research has shown that mixed plantings of certain nitrogen-fixing species with black walnut in plantations can substantially boost growth, and possibly quality (Funk et al. 1979a, Van Sambeek and Rietveld 1981). Other species are being considered as possible co-crops with walnut to diversify vegetation and increase overall product yields. However, we know nothing about the sensitivity of these species to juglone.

The experiments reported here were conducted to assess the allelopathic potential of black walnut juglone to several herbaceous and woody species which are being considered for co-crops, nurse crops, and cover crops in intensively cultured black walnut plantations.

Effects of Juglone of the Growth of Coniferous Seedlings

In an earlier experiment reported elsewhere (Funk et al. 1979b), seedling growth of four conifer species was tested in the laboratory for sensitivity to juglone. Seedlings of Japanese larch (Larix leptolepis (Sieb. and Zucc.)), Norway spruce (Picea abies (L.) Karst.), eastern white pine (Pinus strobus L.), and Scotch pine (P. sylvestris L.) were established in a hydroponic system installed in a growth chamber. The seedlings were grown for 8 to 10 weeks in a nutrient-plus-juglone solution at juglone concentrations ranging from 10^{-2} Molar (M) to 10^{-10} M.[3]

At concentrations at 10^{-2} M and 10^{-3} M, juglone was lethal to all species; Scotch pine and Japanese larch seedlings were killed at a concentration of 10^{-4} M. Juglone caused no visible injury to white pine at concentrations of 10^{-6} M and less, and 10^{-5} M and less for the other species, but seedling growth was inhibited by solutions as dilute as 10^{-7} M.

All of the conifers tested were quite sensitive to juglone and death resulted when the juglone concentration exceeded 10^{-4} M. Short-term exposure to intermediate concentrations resulted in measurable reductions in plant dry weight without the appearance of toxicity symptoms. However, the effects of long-term exposures to low and moderate juglone concentrations in the field are unknown.

[3]Equivalent percentage concentrations ranged from 0.2 to 0.000000002 percent, respectively.

Effects of Juglone on Seed Germination and Seedling Growth of Several Herbaceous and Woody Species

The following recently-completed experiment tested the effect of juglone on several plant growth processes in a variety of species. The experiment consisted of two parts: (1) seed germination and radicle elongation in various juglone concentrations, and (2) shoot elongation and dry weight accumulation in hydroponic cultures containing the same juglone concentrations.

Materials and Methods

The following species were tested:

Herbaceous legumes:

- Crimson clover (Trifolium incarnatum L.)
- Crown vetch (Coronilla varia L.)
- Hairy vetch (Vicia villosa Roth.)
- Korean lespedeza (Lespedeza stipulacea Maxim.)
- Sericea lespedeza (Lespedeza cuneata (Dumont) G. Don)

Shrubs:

- Ginnala maple (Acer ginnala Maxim.)
- Siberian peashrub (Caragana arborescens Lam.)
- Russian olive (Elaeagnus angustifolia L.)
- Autumn olive (Elaeagnus umbellata Thunb.)
- Amur honeysuckle (Lonicera maackii Maxim.)

Trees:

- White oak (Quercus alba L.)
- White ash (Fraxinus americana L.)
- Yellow poplar (Liriodendron tulipifera L.)
- European black alder (Alnus glutinosa (L.) Gaertn.)
- Eastern white pine (Pinus strobus L.)
- Scotch pine (Pinus sylvestris L.)

Certain species were not included in both tests because of problems in obtaining, stratifying, or germinating seed. Seed was collected and stored until needed. Germination tests were run in a laboratory germinator using standard recommended pregermination treatments, test conditions, and germination criteria (Association of Official Seed Analysts 1970, International Seed Testing Association 1976, USDA Forest Service 1974). Four trays of 100 seeds each were germinated in each of four juglone concentrations: 10^{-6} M, 10^{-5} M, 10^{-4} M, and 10^{-3} M, plus a control (0 concentration). Identical tests were run on two media, blotter paper and soil.

When germination was occurring at a rapid rate, 10 germinants were retained on each tray for measurement of radicle elongation. Radicle length was measured initially and again after 10-15 millimeters of elongation had occurred in the controls, usually 2-6 days.

In the second part of the experiment, seedlings were grown in hydroponic culture to test the effects of juglone on shoot elongation and dry weight accumulation. Seedlings were grown in sand to the first true leaf stage, then transferred to nutrient solution containing the same juglone concentrations used in the germination tests. The apparatus was the same unit described in the conifer growth experiment. Solutions were changed weekly. Tests ran 4-6 weeks, depending on rates of growth and symptom development. Seedling height was measured initially and repeatedly during the tests. At the end of each test, seedlings were harvested and plant dry weight determined.

Results

Seed germination.--Only the results using forest soil as the germination medium are reported, since the results using the blotter medium were similar. Percent germination was significantly affected by juglone in only three of the 14 species tested: sericea lespedeza was inhibited by the 10^{-6} M and 10^{-3} M concentrations, and white oak and amur honeysuckle germination were stimulated by the 10^{-6} M concentration (fig. 1A).

Radicle elongation.--Radicle elongation was more sensitive to juglone than was seed germination, with six of the 14 species tested significantly affected (fig. 1B). The pattern of response varied by species, but the 10^{-3} M concentration caused the most consistent and marked reduction in elongation. Radicle elongation of amur honeysuckle and black alder was stimulated by the 10^{-6} M and 10^{-5} M concentrations, respectively.

Shoot elongation.--All species were killed by 10^{-3} M, and severely inhibited by 10-4 M juglone. Five species (crimson clover, sericea lespedeza, amur honeysuckle, white ash, and black alder) were significantly inhibited by the 10^{-5} M concentration, and amur honeysuckle seedlings were also inhibited by 10^{-6} M juglone (Fig. 2A). Only severely inhibited seedlings (10^{-3} M, 10^{-4} M) showed visible symptoms (chlorosis) of juglone toxicity. Crown vetch was omitted because of its tendency to form a basal crown rather than elongate.

Plant dry weight.--Juglone effects on plant dry weight accumulation were greater and more distinct than on shoot elongation. Dry weight of white oak seedlings was not significantly affected by juglone. In the remaining species, however, concentrations of 10^{-5} M and greater significantly inhibited dry weight accumulation in all species except ginnala maple, Russian olive, and yellow-poplar (fig. 2B). Plant dry weight accumulation was also significantly inhibited by 10^{-6} M juglone in sericea lespedeza and autumn olive. In three species (Siberian peashrub, Russian olive, and yellow-poplar), dry weight of seedlings grown in 10^{-6} M and 10^{-5} M juglone was higher than in the control, but not significantly so. These responses are attributed to exceptional growth of a few individual seedlings. More vigorous seedlings are apparently more resistant to juglone.

Discussion

Every species tested was found to be sensitive to juglone. All species were killed by 10^{-3} M juglone, and in most species many seedlings were killed by 10^{-4} M juglone. The species varied independently in the growth processes affected and in their degree of sensitivity. Of the species included in all of the tests, the five most sensitive to juglone were sericea lespedeza, amur honeysuckle, hairy vetch, ginnala maple, and autumn olive; the least sensitive species were white oak and Russian olive.

Data from these short-term tests are useful for comparing species sensitivity to juglone and the relative sensitivity of different growth processes. However, biological assays are insufficient as a means of identifying the occurrence of allelopathy and the concentrations of chemicals responsible for allelopathy in the field (Stowe 1979). It is unlikely that 10^{-3} M juglone occurs under field conditions because it is difficult to prepare in the laboratory, and some juglone usually precipitated out in hydroponic culture. More likely, the allelopathic effects observed in the field are the result of longer-term exposures to low and moderate juglone concentrations under soil conditions which favor juglone persistence and increase plant susceptibility. The juglone toxicity experiments also suggest that low juglone concentrations may inhibit (or stimulate) growth for a period of time before any toxicity symptoms appear.

Significance of Black Walnut Alleopathy in Plantations

Although every species tested was found to be sensitive to juglone under short-term

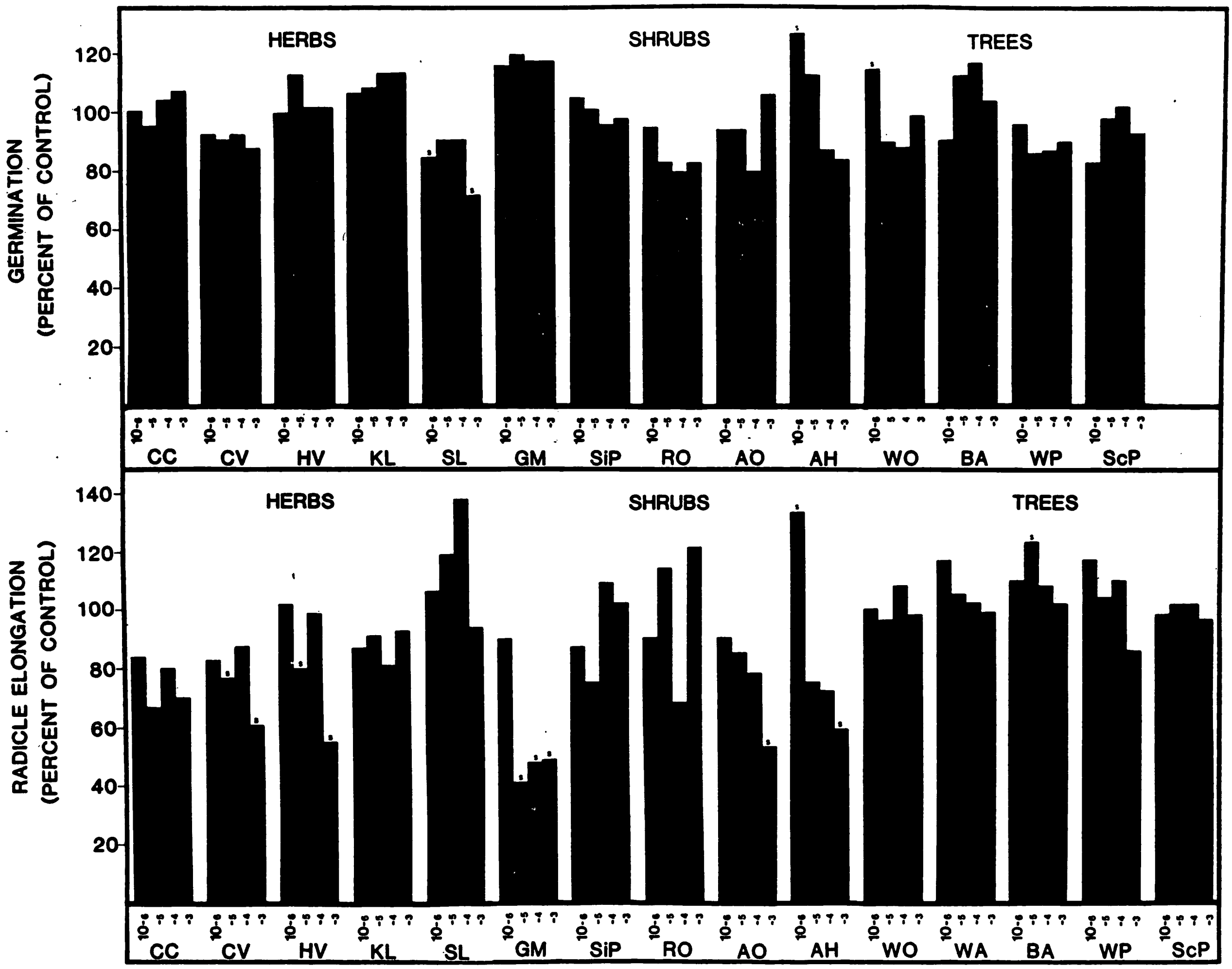

Figure 1.--Effects of juglone on: (A) seed germination and (B) radicle elongation of germinated seed of several herbaceous, shrub, and tree species. Responses to the four juglone concentrations are given as a percentage of the control (0 concentration). Species abbreviations: CC = crimson clover, CV = crown vetch, HV = hairy vetch, KL = Korean lespedeza, SL = sericea lespedeza, GM = ginnala maple, SiP = Siberian peashrub, RO = Russian olive, AO = autumn olive, AH = amur honeysuckle, WO = white oak, WA = white ash, YP = yellow-poplar, BA = black alder, WP = eastern white pine, ScP = Scotch pine. Each value is the mean of four trays of 100 seeds on forest soil.

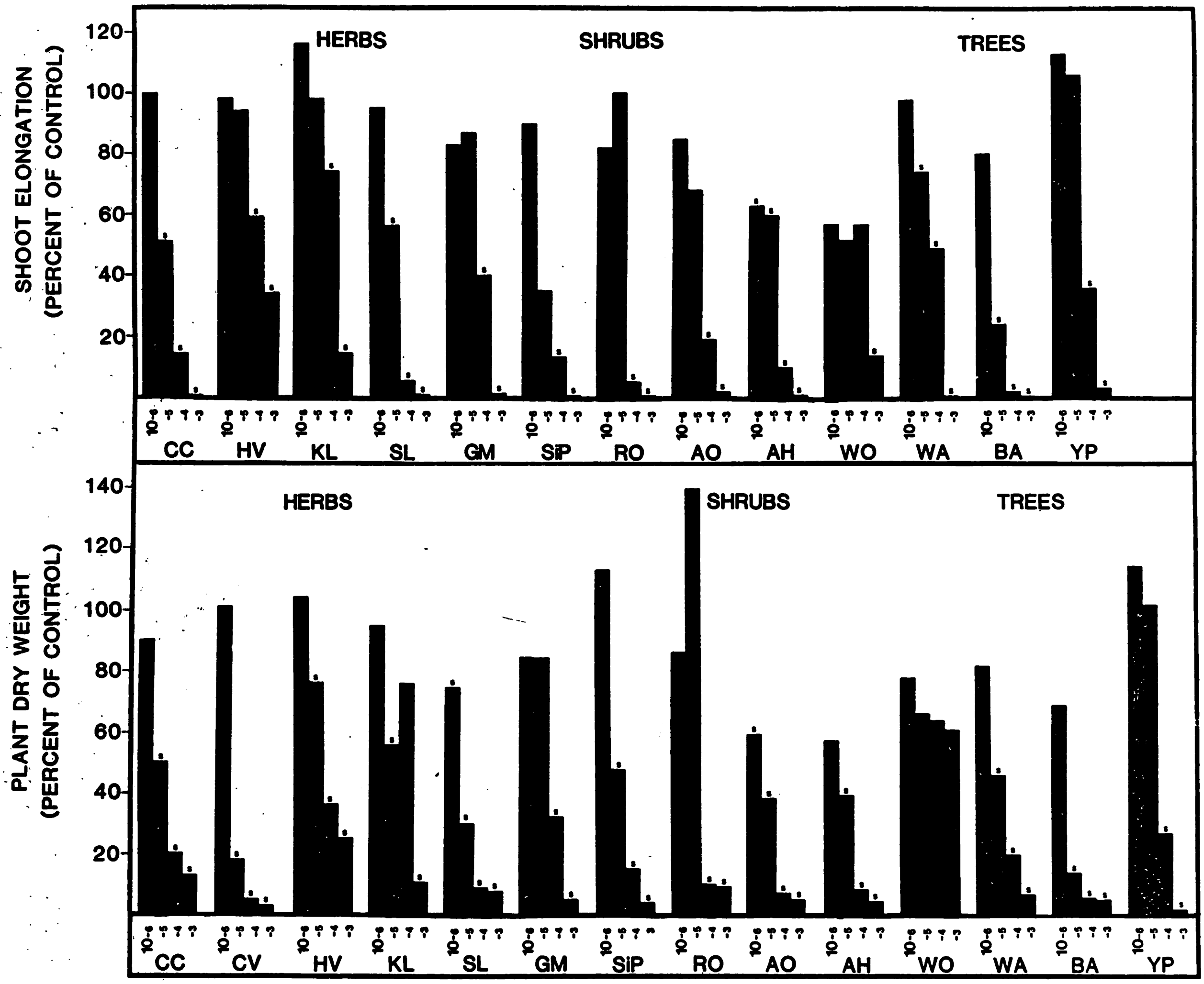

Figure 2.--(A) Seedling shoot elongation and (B) plant dry weight of several herbaceous, shrub, and tree species grown for 4-6 weeks in aerated nutrient solutions containing juglone. Growth responses to the four juglone concentrations are given as a percentage of the control (0 concentration). Species abbreviations are the same as in figure 1. Each bar is the mean of 12 seedlings.

laboratory conditions, the occurrence of allelopathy under field conditions depends on several important factors: (1) size and density of the walnut trees; (2) the sensitivity of associated species to juglone; (3) soil conditions which control the disposition of juglone, and (4) management objectives--the intended purpose and duration of co-planted species.

Information on several mixed, even-aged walnut plantations obtained from the literature and gathered through personal contacts is summarized in table 1. Although specific information on the compatibility of walnut with other species and the factors that affect it is not available, some general observations from the table and speculations will be discussed in the following sections.

The Buildup Period

There is a distinct difference between allelopathy resulting from planting species near existing large walnut trees and allelopathy in mixed, even-aged plantations containing walnut. In the former case, toxicity may occur within months or a few years, while in the latter case there is a buildup period--the time required for walnut trees to grow to sufficient size and density to have a significant chemical effect on the environment. Knowledge of the relative length of the buildup period and of factors that affect it are useful for silviculturalists wanting to grow short-term crops of other species with walnut.

A buildup period of approximately 12-25 years is needed for planted walnuts to reach a sufficient size and density to produce and release enough juglone to result in noticeable allelopathic effects (table 1). It is unknown when and for how long toxicity occurred before symptoms appeared, since moderate juglone concentrations may inhibit growth without visible injury. On the other hand, allelopathy may not occur at all, even in sensitive species, if they are growing vigorously on well-drained sites.

Species Sensitivity

There is no doubt that species vary in their sensitivity to black walnut juglone, as evidenced by Brooks' extensive surveys (Brooks 1951), the juglone toxicity experiments reported here, and table 1. Of the plantations summarized in table 1, walnut/pine mixtures were the most frequent and showed the most consistent occurrence of allelopathy. Pines are commonly planted and are especially sensitive to juglone. Although data are scarce for species other than pines, conifers as a group appear to be more sensitive to juglone than deciduous species.

European black alder has received increasing interest as a nurse crop species with black walnut in plantations. It is interesting to note in table 1 that allelopathy occurred in three out of seven mixed walnut/black alder plantations. With close spacing, the alders started dying in as little as 7-8 years. In the juglone toxicity experiments reported in this paper, black alder was one of the most sensitive species tested (figs. 1 and 2). However, autumn olive, a recommended nurse crop species (Funk et al. 1979a), was nearly as sensitive to juglone (figs. 1 and 2) but has not yet shown any noticeable allelopathic effects in the field (table 1).

Soil Factors

The principal factor affecting the length of the buildup period appears to be soil conditions, specifically soil moisture and soil aeration. Fisher (1978) found a strong relationship between soil moisture and the allelopathic activity of walnut trees. As soil moisture increased from dry to wet, the amount of extractable juglone and allelopathic activity increased. High soil moisture creates anaerobic reducing conditions that are unfavorable for the chemical and biological oxidation of juglone. Although there is no direct evidence of microbial breakdown of juglone, it seems most probable that it occurs (Fisher 1978). Soil conditions also influence growth rates and vigor, which in turn determine tree size and juglone production by walnut, and are related to susceptibility of associated species to juglone toxicity.

The relation between soil drainage (and interrelated soil factors) and the occurrence of allelopathy is evident in table 1. Eastern white pine planted on well-drained, coarse-textured soils in Wisconsin, Ontario, and Michigan are growing well with walnut after 15, 20, and 44 years, while the same species growing on moderately-drained, finer-textured soils elsewhere were killed in as little as 13 years. On some well-drained sites in Ontario, white pine has actually shaded out the walnut over a period of 20 years (personal communication with Dr. Richard F. Fisher). This implies that walnut interference to the growth of other species is due both to competitive and allelopathic factors, and the effectiveness of the latter factor is controlled by soil conditions.

Table 1. Summary of available data on compatibility of various species with black walnut in mixed, even-aged plantations. The age and size of walnut trees are those when toxicity was first noted, or current data where no toxicity has occurred

State	Associated species	Black walnut trees: Age (years)	Black walnut trees: Diameter[1/] (inches)	Soil drainage class[2/]	Condition associated species	Source
Illinois	Red pine	24		well	Dead and dying	Mr. Howard Fox (retired)
	White pine	24		well	Dead and dying	Sinnissippi Forest
	Red pine	16		well	Yellowing	Oregon, IL
Ontario	White pine	35			Dead and dying	Fayle (1976)
	White pine	4			Growing well	
Ontario	White pine + Red pine	30		well	Growing well	Fisher (1978)
	White pine + Red pine	20		moderate	Poor survival and growth	
	White pine + Red pine	20		poorly	Dead	
Ontario	Red pine + N. red oak	21		moderate	Dead and dying Growing well	von Althen (1968)
Indiana	White pine	23	8.4	moderate	Yellowing and declining	Dr. Clair Merritt
	White pine	17	2.5	moderate	Growing well[3/]	Dept. Forestry and Natural Resources
	Yellow-poplar + Red oak	19	6.3 1.2	moderate	Growing well[3/] Growing well	Purdue University
	Jack pine	16	5.1	moderate	Growing well	W. Lafayette, IN
Indiana	White pine	13	4.2	moderate	Dead and dying	Mr. Robert D. Burke
	White pine	13	3.6	well	Yellowing	Pierson-Hollowell Co.
	Black alder	12	7.0	moderate	Dead and dying	Martinsville, IN
	Autumn olive	14	5.5	moderate	Growing well	
	Autumn olive	14	4.4	moderate	Growing well	
	Autumn olive	14	4.8	moderate	Growing well	
Missouri	Black alder	8	2.9	well	Dead and dying	Dr. Richard C. Schlesinger
	Autumn olive	11	4.6		Growing well	Dr. Felix Ponder, Jr.
Illinois	Black alder	11	1.8		Growing well	North Cent. For. Exp. Stn.
	Autumn olive	11	4.2		Growing well	Carbondale, IL
	Black alder	11	3.0		Growing well	
	Autumn olive	11	4.9		Growing well	
	Black alder	7	2.7		Dead and dying	
	Autumn olive	11	6.1		Growing well	
	Black alder	15	6.0		Growing well	
	Black alder	14	3.1		Growing well	
Wisconsin	White pine	15	4.8	well	Growing well	Mr. Ken Ellis, Brooklyn, WI
Michigan	White pine	44	10.0	well	Growing well	Mr. Walter Lemmien
	White pine	35	9.0	well	Pines close to BW dead	Michigan State University East Lansing, MI
	Red pine	44	12.0	well	Growing well	
	Honey locust	40	7.0	well	Growing well	
	White oak	39	7.0	well	Growing well	
Iowa	Silver maple	16	4.0	moderate	Dying back and dead	Mr. John L. McSweeny Iowa State Conservation Comm.
	Red pine	8	2.5	moderate	Yellowing and declining	McGregor, IA
	Red pine	24	5.0	moderate	Dead and dying	
	White pine	13	3.0	moderate	Growing well	
Kansas	Black locust	31	7.0	well	Growing well[3/]	Mr. Nelson Rogers (retired)
	Bur oak + Green ash + E. red cedar + Sycamore	32	7.0	well	Growing well	North Cent. For. Exp. Stn. Salem, MO
Iowa	White ash	12	4.0	moderate	Growing well	Mr. Ed Gardiner Iowa State Conservation Comm. Anamosa, IA
Kansas	Ash + hackberry	11		--	Growing well	Mr. Gary G. Naughton Kansas State University Manhattan, KS
North Carolina	Black alder	10	6.5	well	Possibly declining	Mr. Dwight L. Brenneman North Carolina Forest Service Morganton, NC
Indiana	White pine + Japanese larch + Red ak + Red gum	12	--	well	Growing well	Mr. Richard Rambo
Missouri	Scotch pine + Blue spruce	12	3.5	moderate	Growing well	Mr. John P. Slusher University of Missouri Columbia, MO

1/ Diameter at breast height, 4.5 feet above the ground.

2/ Soil drainage class gives an indication of soil texture and organic matter content, and is related to the degree of aeration and moisture availability. Classes used are well-drained (well), moderately drained (moderate), and poorly drained (poor).

3/ Most black walnut trees shaded out.

Management Objectives

The importance of black walnut allelopathy is greatly influenced by the silvicultural goals and the duration of the species co-planted with black walnut. Allelopathy does not appear to be a problem for growing short-term crops of various herbaceous and woody species with black walnut in plantations. Such short-term crops should be either harvested or expendable after 15 years. Even sensitive species can be considered for nurse crops or co-crops, if the benefits are worth the investment.

Pines can be given serious consideration as a short-term nurse crop for black walnut on well-drained sites. Pines produce dense side shade needed to encourage height growth and good form in the walnuts, provide wind protection (especially in winter months), and help shade out plantation weeds. If their shape and color are good, some of the pines can be harvested after 7-10 years and marketed as Christmas trees, permitting recovery of plantation establishment costs and thus increasing returns on the investment in walnut.

When nurse crops are grown with walnut, the phytotoxic activity of walnut may prove to be a benefit by providing release from overcrowding.

The potential of allelopathy in long-term mixed plantings with walnut is more uncertain. Long-term mixed walnut/pine plantings are not recommended because it is too uncertain whether the pines will survive to maturity. The compatibility between black walnut and other hardwood species is unclear. While on the one hand several tree species (white ash, yellow-poplar, black alder) were found to be sensitive to juglone in the experiments reported here, walnut is commonly found associated with these and many other important forest tree species of the eastern hardwood region (Brinkman 1957). If allelopathy is involved, then it is reasonable to suggest that the influences are a matter of degree--i.e., relative effects on the abundance, vigor, and growth of other species. This may help explain why black walnut, a rather poor competitor, is able to exist in mature forest stands. Apparently, the species and individuals present are those that have successfully (at least for the present) adapted to accommodate each other. The unsuccessful species and individuals have disappeared inconspicuously over a period of time.

The situation in mixed, even-aged plantations may be different. Walnut is usually planted at higher density and/or favored in thinnings because it is a preferred species. Many changes will eventually occur in these artificially created stands, both competitively and allelopathically induced, that will result in the less competitive, intolerant, and juglone-sensitive species and individuals being eliminated. These changes are likely to be more abrupt and noticeable. Although juglone sensitivity of most eastern hardwood species appears to be less than that of conifers, the potential for allelopathy in mixed plantations is greater than in natural stands.

ALLELOPATHIC EFFECTS OF PLANTATION VEGETATION ON BLACK WALNUT

Black walnut plantations are commonly established on ex-agricultural land and old fields. The vegetation consists of: (1) black walnut and nurse crop (if any) seedlings, and (2) a diversity of volunteer herbaceous vegetation. The herbaceous component is by far the most abundant; thus, young tree plantations are essentially old fields for several years. Herbaceous plant succession occurs fairly rapidly, following a general pattern of broad-leaved weeds giving way to annual grasses, then to perennial grasses (Rice 1974). Recent research has shown that allelopathy is an important factor causing plant succession in old fields (Rice 1974, 1979).

Many of the same genera shown by Rice's group to be allelopathic to associated vegetation and microorganisms have been reported by other investigators to interfere with tree seedlings (table 2). Because of a lack of research, there are no specific reports of herbaceous vegetation allelopathically inhibiting the growth of black walnut seedlings. The implications are: (1) there is an increasing number of reports of certain herbaceous species releasing substances inhibitory to tree seedlings; (2) many of these herbaceous species are abundant in black walnut plantations; (3) thus, the potential for interference with black walnut seedling growth is great.

Weed control is a necessary and highly recommended practice for establishing black walnut plantations (Schlesinger and Funk 1977), for without it seedlings are typically suppressed for many years. Recent evidence suggests that more is accomplished by weed control than controlling competition; allelopathic interactions may also be controlled without knowing they exist. Weeds around individual seedlings should be controlled for 2-3 years after transplanting to allow the tree seedlings to become established. After weed control is curtailed, the surrounding herbaceous vegetation closes back in, and the trees are susceptible to interference from herbaceous vegetation until

Table 2.--Summary of literature on allelopathic effects of herbaceous vegetation on tree seedlings

Producing species	Receiving species	References
Bracken fern Wild oak grass Wrinkled goldenrod Flat-topped aster Hay-scented fern New York fern Short husk grass Club moss	Black cherry	Horsley, 1977a, 1977b
Broomsedge	Loblolly pine	Priester and Pennington 1978
Aster Goldenrod	Yellow-poplar Virginia pine	Haney 1969
Ragweed New England aster Daisy fleabane Hawkweed Timothy Tall buttercup Canada goldenrod Grass-leaved goldenrod	Sugar maple	Fisher *et al*. 1978
Orange hawkweed	Balsam fir White pine	Dawes and Maravolo 1973
Mountain muhly Arizona fescue	Ponderosa pine	Rietveld 1975
Tall fescue	Sweetgum	Walters and Gilmore 1976
Giant foxtail	Loblolly pine	Gilmore 1980
Tall fescue	Loblolly pine	Wheeler and Young 1979
Tall goldenrod Broomsedge Crownvetch Wild carrot Tall fescue Timothy	Black locust	Larson and Schwarz 1980

they attain sufficient size to be unaffected. That period may extend for 10 years or more.

Of the herbaceous species listed in table 2, those considered to have the greatest allelopathic potential to inhibit growth of black walnut seedlings are asters, goldenrods, fescue, and broomsedge. There is a growing body of evidence on the allelopathic activity and competitiveness of tall fescue (*Festuca arundinacea* Schreb.). Besides the reports summarized in table 2, fescue has also been reported to be toxic to the legumes birdsfoot trefoil (*Lotus corniculatus* L.) (Peters 1968) and Ladino clover (*Trifolium repens* L. cv. Tillman). Fescue is common in established walnut plantations. When heavy fescue sod in part of a 9-year-old pure walnut plantation was rotovated in June 1980, a noticeable growth response occurred the same season. With exceptionally good rainfall early the following summer, the released walnuts greatly expanded their foliage and were dark green, compared with unreleased trees which grew only modestly and were light green in color (personal communication with Dr. Richard C. Schlesinger).

Besides possible allelopathic effects, fescue is especially competitive to black walnut seedlings and saplings. Todhunter and Beineke (1979) reported that tall fescue is acutely competitive with walnut seedlings for soil water, phosphorus, and potassium. They suggested that fescue's competitiveness is due to its dense and deep rooting habit and heavy infection of vesicular-arbuscular mycorrhizae. Holt and Voeller (1975) found that removing fescue cover increased diameter growth and nut yield of 10- to 12-year old walnut trees. This evidence justifies the recommendation that fescue not be used as a cover crop in black walnut plantations.

Allelopathic chemicals from herbaceous vegetation may also inhibit certain microorganisms essential to the growth of tree seedlings. Persidsky et al. (1965) found that water extracts of prairie soils significantly inhibited oxygen uptake by mycorrhizal short roots of Monterey pine (Pinus radiata D. Don.) and red pine (P. resinosa Ait.), compared with extracts of forest soils. Theodorou and Bowen (1971) found that decomposition products of grass roots reduced the number of infections of an ectotrophic mycorrhizal fungus on Monterey pine. Rice (1972) found that broomsedge inhibits Azotobacter and Rhizobium, two important nitrogen-fixing bacteria. Since broomsedge is known to compete vigorously and grow well on soils of low fertility, he suggested that inhibition of nitrogen-fixing and nitrifying bacteria would keep the nitrogen supply low and give broomsedge a selective advantage over species that have higher nitrogen requirements.

Soil conditioning is needed on sites that have been dominated by herbaceous vegetation for a number of years. In the forest-prairie ecotone of north-central Oklahoma, Petranka and McPherson (1979) found that bottomland forest trees were unable to invade climax tallgrass prairie without the prior invasion of sumac (Rhus copallina L.) and other shrubs. Upland forest trees were able to invade climax prairie, but the invasion was enhanced by the prior invasion of shrubs. Carmean et al. (1976) found that growth of planted hardwood seedlings was strikingly better on areas that had recently supported some kind of tree cover, versus areas dominated by herbaceous cover. They attributed the differences to several physical, biological, and chemical soil factors, including allelopathy.

An alternative method to achieve both weed control and soil conditioning is to establish companion crops in plantations, i.e., woody nurse crops and herbaceous cover crops that are compatible and soil-building. Ideally, the species selected (e.g., pines, successional woody species, exotics, and leguminous cover crops) should tolerate allelopathic chemicals in the soil. They should quickly develop into dense stands which exclude weeds (possibly allelopathically), enrich the soil through nitrogen fixation and/or addition of organic matter, create a favorable microclimate, and minimally compete with the planted trees.

Our initial research on establishing herbaceous, nitrogen-fixing cover crops in black walnut plantations has been successful (Van Sambeek and Rietveld 1981). Hairy vetch has been especially promising because it effectively suppressed weeds and stimulated walnut seedling growth. However, it overtopped and deformed some of the shorter walnut seedlings. Korean lespedeza was not effective in suppressing the tall summer weeds. Crimson clover with Korean lespedeza suppressed the tall summer weeds, but not the warm season grasses, especially giant foxtail (Setaria faberii Lamb.). Sericea lespedeza and crownvetch were slow to establish, but suppressed weeds beginning the second year. Their effects on seedling growth remain to be determined.

Another potentially important role of certain companion crops is their ability to colonize soil microorganisms essential for tree growth. Kormanik et al. (1980) found that seeding corn, millet, sudex, and sorghum as nursery cover crops increased inoculum density of vesicular-arbuscular fungi (Glomus spp.) in nursery soils. These are the same fungi that form entotrophic mycorrhizal associations with black walnut roots, which are considered to be important for tree growth. Companion crops that colonize essential microorganisms in the soil need to be tested in plantations to determine the potential benefits to transplanted black walnut seedlings.

Vegetation Management

The planting of nurse crops and cover crops in plantations, orchards, etc. is not a new concept in agriculture and forestry. The obvious benefits of weed suppression and nitrogen-fixation have long been known. But companion crops have not been utilized for years because inexpensive and more conventional chemical fertilizers and pesticides were available to do the job.

Recent escalation of costs of materials and labor, and environmental concerns, have necessitated a renewed interest in companion planting. However, besides renewed interest there is increased awareness. It is becoming increasingly clear that plantation weeds do more than compete with tree seedlings. Our increasing knowledge of plant/plant and plant/microorganism allelopathy has made us aware that besides direct inhibition of plant growth there may be indirect effects on growth through inhibition of beneficial and essential soil microorganisms. The term "interference" appropriately describes the situation, because it encompasses the overall deleterious effects of both competition and allelopathy in interplant relationships (Muller 1969).

While weed control with chemical herbicides may eliminate interference, companion plantings of appropriate species have the additional potential to condition and enrich the soil physically, chemically, and biologically to make it more favorable for tree growth. The modern version of companion planting in black walnut cultural systems is vegetation management. The concept of vegetation management in plantation establishment recognizes that there will be vegetation present that competes with the trees. However, rather than dealing with volunteer successional vegetation (by repeated herbicide spraying and mowing), selected compatible herbaceous and woody species are co-established with the tree seedlings. The companion species should be non-allelopathic (to walnut), minimally competitive, and should suppress weeds and enrich the soil. The overall potential benefits are soil conditioning and enrichment, elimination of allelopaths, reduction of competition, reduction of disease and insect damage, growth stimulation, and improvement of tree quality. Our continuing research will determine the extent of benefits and cost effectiveness of plantation vegetation management and will provide this information to landowners and managers.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The principal points made in the paper are summarized as follows:

1. There is a great deal of literature on the toxic effects of black walnut that creates the false impression that few species can be planted with walnut. Most of these reports involve toxicity to vegetables, field crops, fruits, and ornamentals, which are of lesser interest to foresters. This paper evaluates the importance of walnut allelopathy in forestry.

2. Four types of plant associations involving black walnut and allelopathy were identified: (a) natural forest stands containing walnut as a component, (b) various species planted within the influence zone of existing large walnut trees, (c) mixed, even-aged sapling plantations containing walnut, and (d) transplanted walnut seedlings establishing admidst herbaceous vegetation. The latter two plant associations are the subject of this paper.

3. Laboratory tests of juglone sensitivity of 18 species being considered for mixed plantings with walnut showed that all were sensitive to juglone. Seed germination and radicle elongation were inhibited mainly by high juglone concentrations, which were unlikely to occur in nature. However, shoot elongation and dry weight accumulation were sensitive to juglone concentrations as low as 10^{-7} M. Symptom development and death occurred only at very high concentrations (10^{-4} M and 10^{-3} M). Conditions which result in allelopathic effects in the field are unknown, but are likely to be a combination of longer-term exposures to moderate juglone concentrations combined with soil conditions that favor juglone persistence and increased plant susceptibility.

4. When walnut and other species are established together in plantations, there is a buildup period of approximately 12-25 years before allelopathic effects become evident, if they occur at all. The length of the buildup period depends on the age and density of walnut trees, juglone sensitivity and vigor of associated species, and soil conditions. Allelopathy is more likely to occur on imperfectly drained soils where chemical and microbial oxidation of juglone is restricted.

5. The importance of walnut allelopathy depends on silvicultural objectives: where the intention is to grow crops with walnut beyond 12-25 years, the tree grower should be cognizant of possible allelopathic effects; but where walnut is grown as the only eventual crop, there is little reason to be concerned about allelopathy. Moreover, walnut's selective toxic effects may be beneficial for bringing about its own release. Allelopathy does not appear to be a factor discouraging the planting of nurse crops, even pines, during the early part of the rotation.

6. There is a growing body of evidence which suggests that interference from plantation weeds may inhibit growth of tree seedlings during the establishment phase. It is quite possible that walnut will joint the list of species affected. It is already known that plantation grasses, especially fescue, are severely competitive to walnut. Fescue is not recommended as a cover crop in walnut plantations.

7. Besides eliminating competition, controlling weeds may also avoid allelopathic influences for the first 2-3 years after planting. After weed control is curtailed, herbaceous vegetation re-establishes, and the extent of allelopathic activity is unknown. Recent research on woody nurse crops and herbaceous cover crops in plantations has shown that these associations smother weeds and stimulate tree growth.

8. The concept of vegetation management involves co-establishing compatible and beneficial companion species with tree seedlings in plantations. The potential benefits are soil conditioning and enrichment, elimination of allelopaths, reduction of competition, reduction of insect and disease damage, growth stimulation, and improvement of tree quality.

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PRUNING FOR QUALITY

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Abstract.--Artificial pruning can improve tree quality but can reduce growth and quality if incorrectly done. Pruning causes wounds and pruning of live branches may reduce growth. Corrective pruning is not generally useful for the development of high-quality plantations. But lateral pruning is needed and should be done in stages beginning when the trees are small. By understanding tree responses to pruning, we can improve tree quality and plantation value through proper pruning practices.

Black walnut (*Juglans nigra* L.) veneer logs generally command prices 8 to 9 times higher than saw logs. But without some artificial pruning, few black walnut trees develop the straight, clear boles needed for veneer unless we are willing to extend the growing period beyond 80 to 100 years. Although artificial pruning can improve tree quality, it can also reduce growth and quality if carelessly or incorrectly done. By understanding tree response to pruning, the grower can determine how best to prune an individual tree.

TREE GROWTH AND RESPONSE

The tree has been likened to a tower supporting an array of solar collectors (Wilson and Archer 1979). But it is much more supple than a tower, especially when small. Many young walnut trees develop straight, single stems, but others may become crooked or multiple-stemmed as the result of insect, animal, or weather damage. Yet, there is a tendency for such trees to straighten and for one leader of a multileader tree to gain dominance (Schlesinger and Bey 1978). Thus, many trees will overcome apparent form defects by themselves if left alone.

Removing some of the tree's solar collectors can reduce growth. Basically, pruning of live branches is a dwarfing practice (MacDaniels 1973). The greater the proportion of the live crown removed, the greater the chance of an undesirable response by the tree. This response could be reduced growth or the tree's attempt to compensate for the loss of its solar collectors by excessive height growth or by production of new branches on the bole (sprouting).

Pruning also causes wounds (Shigo *et al*. 1979). While the wound is open, disease organisms may gain entry and cause decay or discoloration of the wood. Wound healing involves the isolation of the wounded area (compartmentalization) and the closure of the wound by new wood overgrowing the wound. This process may result in zones of weakness in the wood that can lead to ring shake.

Black walnut does not prune itself well, even under the crowded conditions that are best for natural pruning. Especially under short-rotation intensive culture, artificial pruning of live branches or dead branches and stubs will be needed for veneer production. However, only those selected as potential crop trees will need to be pruned.

PRUNING PRACTICES

Corrective pruning.--Correcting potential form defects, especially multiple leader problems, is usually the first use of pruning in walnut plantings (Bey 1976, Beineke 1977, Clark 1966). The objective is to produce trees with straight, single stems. If two or more leaders are competing for dominance, all but one are removed. When no high-quality leader is present, the tree can be cut (coppiced) near the groundline, and the best leader can then be selected from the resulting stump sprouts. The major concern with corrective pruning is that removing too much of the live crown of a small tree may reduce growth or create new stem-form problems.

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The immediate, apparent benefits from corrective pruning may not last. von Althen (1977) found that seedlings severely injured by a June frost benefited from pruning or coppicing. Three years after treatment, 42 percent of the coppiced trees and 31 percent of the pruned trees were classified as excellent or good, but only 11 percent of the untreated trees were so classified. However, a study in southern Illinois[2] showed that the apparent improvement in tree form soon after treatment may disappear. Trees planted in 1967 were coppiced in 1969, 1970, and 1972, or not at all. Half of the trees were correctively pruned as needed beginning in 1967 and continuing until 1975. Tree form ratings in 1976 showed no significant effects of corrective pruning but trees coppiced in 1972 had significantly better form. However, by 1978 there were no significant differences in tree quality or between any of the treatments (table 1).

Corrective pruning can have a dwarfing effect. In von Althen's study (1977), the coppiced trees were 11 percent shorter and 20 percent smaller in diameter than the control trees after 4 years. The pruned trees were 3 percent shorter and 4 percent smaller. In the southern Illinois study, both tree height and diameter were significantly reduced by coppicing in 1972 but not by corrective pruning (table 2). Moreover, potential crop trees, identified on the basis of both size and quality, were more numerous within the untreated group than within any of the other treatment groups (table 3).

Table 2.--Average tree size in 1978 for Illinois study.

Year coppiced	Tree size: Diameter breast height, Not pruned	Pruned	Height, Not pruned	Pruned
	- - - cm - - -		- - - m - - - -	
Not coppiced	6.6	6.7	4.7	4.5
1969	6.8	5.9	4.6	4.3
1970	6.0	6.3	4.1	4.3
1972	4.9	4.8	3.8	3.7

Table 3.--Potential crop trees within each treatment group

Year coppiced	Crop trees[1]: Not pruned	Pruned
	- - - - Percent	- - - -
Not coppiced	44	37
1969	26	32
1970	32	32
1972	16	16

[1]Trees that were average or above average in quality and size.

Table 1.--Comparison of tree quality in 1978 for Illinois study

Year coppiced	Tree quality: Excellent and good[1], Not pruned	Pruned	Fair, Not pruned	Pruned	Poor and impossible, Not pruned	Pruned
	- - - - - - - - -	-	Percent	- - - - - -	- - - - -	-
Not coppiced	44	37	26	33	30	30
1969	37	37	47	16	16	47
1970	58	37	26	42	16	21
1972	58	53	26	15	16	32

[1]The trees were rated on a scale of 1 to 10 as to their potential to develop into high-quality trees.

Thus, corrective pruning should be practiced with restraint, if at all. Generally not all trees are needed for crop trees.

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[2]Study No. NC-1108, CH-422, data on file at the Forestry Sciences Laboratory, Carbondale, IL.

Because many trees will "correct" themselves within a year or two after developing a form problem, delay in pruning may result in the disappearance of the need for it. If a tree is pruned, the least amount needed to do the job should be done. And coppicing in March, April, or early May will result in less growth loss than if done in June or July.[3]

Lateral pruning.--The objective of lateral pruning is to remove obstacles (branches or stubs) to the formation of clear, defect-free wood on the lower stem of a tree. Basic to the development of pruning recommendations are the following considerations: (1) tree growth should not be reduced by the removal of too many live branches at any one time, and (2) wound healing should be encouraged.

Clark and Seidel (1961) found that 14-year-old trees could be heavily pruned once without significantly reducing growth. Ten years after treatment, trees pruned of 75 percent of their live crowns had grown as much in diameter as trees pruned by lesser amounts or left unpruned. However, annual pruning for 6 consecutive years reduced tree diameter when 80 percent of the bole was cleared (table 4). Trees planted in 1969 were first pruned in 1975. Three years of annual pruning did not reduce tree size (Funk 1979). However, continued treatment for an additional 3 years resulted in smaller diameter trees when 80 percent of the bole was cleared, although tree height was not significantly affected. Diameter growth at breast height during the sixth year was significantly less for the 80 percent pruned trees than for lesser treatments (table 5).

Table 4.--Tree size after 3 and 6 years of annual pruning

Percent of height pruned	Height		Diameter at 0.3 m		Diameter at breast height	
	3 years	6 years	3 years	6 years	3 years	6 years
	---- m ----		--------- cm	---------		
0	3.3	4.5	7.8	11.0	4.9	7.8
20	3.2	4.3	7.2	10.0	4.3	7.3
40	3.4	4.5	7.5	10.4	4.8	7.7
60	3.6	4.9	7.5	10.3	5.3	8.0
80	3.6	4.8	6.5	8.6	4.5	6.6

Table 5.--Treatment response during third and sixth years of annual pruning

Percent of height pruned	DBH growth 6th year	No. sprouts 3rd year	No. sprouts 6th year
	cm		
0	1.2	0.1	0.1
20	1.0	0.2	0.0
40	0.9	0.6	0.4
60	0.8	1.3	2.9
80	0.6	6.7	10.7

The tree may respond to heavy pruning by producing sprouts. Clark and Seidel (1961) noted sprouts on 50 percent of the trees pruned of 75 percent of their live crowns, but only 6 percent of the trees pruned of 25 percent of their live crowns produced sprouts. Funk (1979) found an average of 6.7 sprouts per tree for the 80 percent treatment in the third year, and 10.7 new sprouts were produced during the sixth year of the study (table 5). This rebuilding of the live crown may help a tree maintain its growth rate, but it negates the potential benefits of pruning for the production of clear wood.

The wounds that result from either natural or artificial pruning must heal cleanly if the objectives of pruning are to be met. The extent of internal defects (staining and ring-shake zones) is related to the size of the wound, the number of wounds within a segment of the bole, and the season of year when the wounds are made (Shigo et al. 1978, Shigo et al. 1979, Smith 1980). Branch collars that form around dead or dying branches are part of

[3]Data on file at the Forestry Sciences Laboratory, Carbondale, IL.

the healing process, and thus removing these collars rewounds the tree (Shigo et al. 1979). Open wounds are infection courts for disease organisms such as wood decay fungi.

Heavy pruning can also lower tree quality, primarily because of the additional wounds created by the pruning of sprouts. In the southern Illinois study, annual, repeated pruning to clear 80 percent of the bole resulted in significantly fewer high-quality trees and more lower quality trees (table 6). On the other hand, no pruning and clearing only 20 percent of the bole also resulted in fewer high-quality trees than the 40-percent and 60-percent treatments (table 6).

Table 6.--Tree quality[1] after 6 years of annual pruning

Percent of height pruned	Excellent and good	Fair	Poor and impossible
	- - - - -	Percent	- - - - - -
0	33	57	10
20	28	62	10
40	54	33	13
60	47	35	18
80	23	42	35

[1]See footnote for table 1.

For best results, lateral pruning should be done in stages, beginning when the trees (and thus the branches) are small (3 to 4 m tall). Between 40 to 50 percent of the tree height should remain with branches. If clusters of branches are present, not all branches should be removed at one time. Pruning in the spring just before bud break avoids the fall spore production period of many disease organisms and minimizes the time before the wound begins to close. And spring wounds result in less discolored and abnormal wood than fall wounds (Smith 1980). If branch collars are present, pruning should remove the branch flush to the outer edge of the collar, not flush to the main stem.

Periodic pruning should continue until the desired clear length is obtained. Theoretical economic analyses generally support a 5.2 m clear length for veneer production and a 2.6 m clear length for nut production (Schlesinger and Funk 1977).

SUMMARY

Patience and understanding are the keys to pruning for quality. Generally, corrective pruning appears to be of little or no value in intensive culture, although there may be a few exceptions. Allowing trees to straighten naturally if possible and removing the low-quality trees in thinnings will normally result in a high-quality plantation. Careful, timely lateral pruning of potential crop trees will result in the development of clear wood and high-value trees.

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PRINCIPLES OF MANAGING BLACK WALNUT IN NATURAL STANDS[1]

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Abstract.—The management of black walnut in natural stands is basically the combination of strategies normally employed in managing natural stands and the intensive cultural practices developed for plantations. These dual strategies, if carefully thought out in the planning process and then implemented, can result in the successful regeneration, growth and development of black walnut trees in natural woodlands.

INTRODUCTION

The intensive culture of black walnut plantations tends to dominate the discussion at a walnut meeting. However, timber production from natural woodlands as a management objective provides significantly more income to private, nonindustrial woodland owners than plantations.

Black walnut trees are usually a very small component of natural stands, generally appearing as scattered single trees or in small isolated groups. However, because of its potential high timber value, full consideration should be given to the possibility of incorporating the intensive culture of individual black walnut trees into the management of natural woodlands.

The objectives of this paper are two-fold. First, I wish to briefly review the steps necessary in developing a forest management plan for a natural woodland and the special considerations that can be made for black walnut tree management. Secondly, I will comment on several cultural practices for black walnut tree management in natural stands.

Management Planning

Most "forest management" in natural woodlands has been custodial in nature. That is, timber is harvested when it is merchantable and desirable for the owner, a new stand is then allowed to regenerate and grow as it will, and timber is again harvested when it becomes merchantable and advantageous to the owner. This type of management requires little, if any planning and results in very few timber management expenditures for the woodland owner. However, custodial management usually results in relatively few, widely spaced (in time) financial returns for the woodland owner. Also, such management generally does not favor the regeneration, development and growth of black walnut trees. This is particularly true when the forest management practiced is "partial cutting", where a residual stand of small and/or lower quality trees is left.

Managing timber, whether in natural stands or plantations, is a major project requiring a high degree of planning. This planning should result in the development of a forest management plan for the woodland and the consideration of the position of the woodland in relation to the other activities (investments) of the woodland owner. Both of these steps are of vital importance because of the extended time period resources are tied up before either a return is realized or the accumulated wealth in the timber and land is passed on.

A forest management plan is essential if the woodland owner is to maximize current income and wealth accumulation within the forest's biological constraints and site

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limitations, and his landownership objectives. As with the management of any investment, professional guidance and assistance is strongly recommended. Unless the landowner is trained in forestry he should seek the advice and skills of professional foresters. Foresters working for the State, Cooperative Extension Service, Soil Conservation Service, forestry consultants and industrial foresters can all be helpful.

The development of a forest management plan can be explained as a four step process. The first and continuing step is that made by the woodland owner in clearly defining his ownership objectives. Foresters and other professionals can aid in this decision making process by proposing different alternatives and projected potential incomes from the forest. However, it must be emphasized that the final objectives be those of the woodland owner and not the assisting forestry professional.

Second is the completion of an inventory. This is simply the gathering of the data necessary to evaluate the woodland potentials and opportunities, so that timber management strategies such as thinning schedules, cutting budgets, planting regimes, improvement cuttings, logging road construction, timber tax management, and individual black walnut tree culture can be developed. The data gathering can be divided into two parts. The first part, sometimes called a reconnaissance cruise, consists of the determination of property boundaries, an accurate calculation of acreage, determination of soil and topographic conditions, procurement of maps and aerial photos of the woodland, an accounting of property taxes and other nonmanagement costs of holding the land and a description of the land-use history of the woodland. The more completely this first part of the inventory process is carried out, the more successful the data collected in the "timber cruise" in the second part of the inventory can be interpreted and utilized in developing the forest management plan.

To the person interested in black walnut two aspects of the reconnaissance cruise are of particular importance. First is the soil survey. By delineating the differing soil conditions for a woodland, the woodland owner can determine which sites are suitable for black walnut trees. This should prevent future errors in establishing and managing black walnut "off-site". The second aspect is that of land-use history. A thorough analysis of past timber sales, and management activities may indicate if the woodland previously contained higher populations of black walnut than at present.

The second part of the inventory process is the "timber cruise". The sampling intensity of the timber cruise is related to the ownership objectives and characteristics of the woodland. The timber cruise should be conducted by a forestry professional. In a timber cruise the forester determines the species, diameter, height, quality, vigor and past growth rate of sample trees. The data collected on the timber cruise can be utilized in determining the structure (tree size distribution), stocking (density), pulpwood and/or sawtimber volume, present value, growth potential and earning potential of the whole woodland as well as for separate portions (stands) of the woodland.

Because of the potential high market value and increased management activity directed toward black walnut trees it may be wise to more intensively sample the walnut tree population in a natural woodland. The ultimate would be to identify and record each walnut tree and its location in the woodland. This intensity may not be justified in many situations but careful consideration should be given to sampling intensity by a woodland owner and his forester. For example, intensively inventorying the more valuable trees would be of great help in establishing the financial basis should a loss of trees occur.

The third step is the actual development of a forest management plan. This written plan is the combining of the ownership objectives and inventory data. The final plan should include a description of the woodland, a statement of ownership objectives and goals, maps and aerial photos, summaries of inventory data, a timber/cash flow analysis, and a 5 to 10 year annual plan of work. A separate portion of the plan may be devoted to the more intensive cultural management of individual or groups of black walnut trees. Most woodland management plans appear rather standardized with little individuality, such as a separate walnut portion. This usually means the landowner has not identified his objectives but followed the ideas of a forester. Finally, additional provisions for updating and revising the plan, as well as for additional inventory data should be clearly indicated.

The fourth and final step is a continuing task for the woodland owner. He must implement the plan. Also on a regular basis he must record work progress, all expenses and incomes, review and plan for future work schedules, and evaluate the plan's continued desirability.

As the woodland owner evaluates his woodland management operation he should continue to include and consider the woodland investment as part of his total investment portfolio. This will require the woodland owner to review his present and projected returns and expenses with his tax accountant and financial advisors. This will allow for the woodland owner to balance the long-term and asset accumulation aspects of his timberland with his investment portfolio and estate planning for maximum efficiency and profitability.

Cultural Practices

Timber production inherently implies growing trees for harvest. Forest management proceeds on the basic assumption that the vegetation on any site normally tends to extend itself aggressively to occupy the available growing space. If the vegetation fills the growing space, the only way that the forest can be changed or controlled is by removing (i.e. cutting) trees. Thus, cutting is important not only as a means of harvesting trees for income, it is the means by which forests are re-established and tended.

Basically, cuttings are made to either promote the growth of desirable trees already in existence - an intermediate cutting, or provide room for the establishment of new trees - a reproduction/ harvest cutting. Both of these types of cuttings can be used to increase the numbers and growth of black walnut trees in a natural woodland.

Black walnut require nearly full sunlight to survive and grow as a seedling or sapling. In fully stocked forests it must be in a dominant or codominant crown position to maintain itself. Thus, cultural practices directed towards growing existing black walnut or the establishment of new seedlings must be concerned with this intolerance to shading (Schlesinger and Funk 1977).

Intermediate Cuttings

Intermediate cuttings are made during the long time period between the establishment of a new stand of trees and its eventual harvest. Intermediate cuttings vary in objectives. Thinnings primarily regulate stand growth by varying stand density. Release and improvement cuttings are designed to regulate the species composition and improve the quality of very young and older stands. Pruning of branches results in improved future individual tree stem quality.

Thinnings are desirable to control stand density, particularly in even-aged stands. Studies have shown that trees, even in older sawtimber sized stands, respond with increased diameter growth after thinning (Hilt, 1979). Stocking guides for a number of species including black walnut are presently available (Schlesinger and Funk 1977).

Release cuttings, particularly to stimulate the growth of selected hardwood crop trees in stands less than 10 years old, are of questionable value. Such release cuttings have not significantly improved height or diameter growth or length of clear stem, nor prevented crown-class regression in black cherry and yellow poplar following treatment (Smith, 1979). Some researchers now suggest that entry into young even-aged hardwood stands less than 20 years old may be unsuccessful in stimulating growth response. However, if the objective to enter young stands is to change species composition (i.e., remove dominant undesirable species) then such a treatment may still be possible.

Also, grapevine control in such young stands may be required to reduce damage and allow future crop trees to develop. Grapevines can be a significant hinderance to young stands, particularly on very productive sites (Trimble and Tryon, 1979; Smith 1979).

Improvement cuttings (commonly called TSI if not a timber harvest) are generally made in previously unmanaged stands and take the form of removing cull trees or low-value species. The goal of such an operation is to increase future stand value by removing trees of little or no economic value and by providing space in which higher quality and high-value species can develop. Black walnut trees have been shown to be an excellent "candidate" tree to favor in TSI (Phares and Williams, 1971).

A concern that has recently arisen with TSI is the potential problem of "flashback" when using picloram (Tordan 101R) in stands. Flashback refers to the herbicide damage to adjacent untreated vegetation via root grafts or soil moisture movement. Yellow poplar is particularly sensitive to picloram. Black walnut has generally not shown to have this sensitivity problem. Practices that may avert the problem include monitoring dosage rates so that excess amounts of herbicide are not applied to injected trees, girdling trees rather than injecting herbicides and using alternative herbicides such as glyphosate (Roundup).[3]

Many landowners have invested time and money in pruning because of the veneer and high quality sawlog potential of black walnut. Pruning in plantations is usually necessary, especially those of wider spacing (Beineke, 1977). This is less of a problem in natural stands, however, pruning can be considered as an investment alternative. In theory this is a prudent investment because as a result of pruning, veneer/lumber-grade recovery of individual trees can be improved, with a resulting value increase of pruned trees over that of unpruned trees. However, in practice the landowner may not be rewarded for his pruning costs at the time of sale and harvest, so the decision to prune, as with any investment decision, must be carefully considered. Remember, pruning does not increase the growth rate of the tree! Only the reduction of surrounding competition improves individual tree growth. Pruning is simply a cultural treatment that should increase the potential stumpage value of a tree.

Planting in Natural Stands

Natural woodlands usually contain relatively few black walnut trees. Yet, many woodland sites are capable of growing black walnut. Since the natural regeneration of black walnut is a slow and "chancy" process, many woodland owners wish to "sweeten" the mix by planting black walnut trees after removing residual trees in a regeneration cutting.

Clearcutting or at least the creation of large openings (areas larger than 2-4 tree heights in diameter) is recommended as the best site preparation method prior to planting black walnut in a woodland. Such cutting creates an area large enough that open conditions are created. This is essential for black walnut. Following the planting of black walnut, the real management begins. Studies (Krajick 1975; Hilt 1977) and field experience continue to demonstrate that cultural treatments to control the competing dense sprout, shrub and herbaceous cover on previously forested sites is required if significant numbers of planted black walnut trees are to survive and grow to a dominant crown position. A second and often fatally ignored cultural practice is the maintenance of the opening/patch clearcutting over time. Smaller dimension openings, which are generally favored by woodland owners with small land holdings, must be periodically enlarged by cutting the border overstory trees. If ignored, the subsequent growth of residual overstory trees bordering a forest opening can dramatically reduce direct solar radiation levels. Fischer (1979) projected that small circular forested openings of 0.5 and 1.0 tree height dimensions had direct solar radiation reduced 21% and 17% in 5 years and 71% and 30% in 10 years based on average height and crown width increments of perimeter trees in upland hardwoods.

[3]Personal communication with Dr. Harvey A. Holt, Associate Professor of Forestry, Purdue University.

SUMMARY

The management of black walnut in natural stands is basically the combination of strategies normally employed in managing natural stands and the intensive cultural practices developed for plantations. These dual strategies, if carefully thought out in the planning process and then implemented, can result in the successful regeneration, growth and development of black walnut trees in natural woodlands.

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GROWTH OF BLACK WALNUT IN A FERTILIZED PLANTATION[1]

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Abstract.—Height and D.B.H. growth has averaged 2.2 ft/yr and 0.44 in/yr, respectively, for a well-managed, fertilized walnut plantation located on a moderately fertile site. Growth of the best 15% of the stand has averaged 2.7 ft/yr and 0.54 in/yr for height and D.B.H., respectively. The plantation was fertilized with N, P and K three times since planting in 1968, and yearly measurements of height and D.B.H. were made through 1977 and again in 1980. Statistical analysis failed to detect any meaningful growth response associated with fertilizer treatments, and there are no significant trends displayed by the data. The evidence in this study suggests that fertilizer amendments are not needed during the establishment of black walnut plantations located on good sites. This study is also discussed briefly as a case history of the growth and management potential for a walnut plantation.

INTRODUCTION

The intensive management of black walnut (Juglans nigra L.) in natural stands and plantations is of concern to many people today as an investment opportunity. Interest in black walnut has existed for many years due to the high stumpage prices that black walnut commands. The techniques needed to intensively manage black walnut, especially in plantations, have gradually developed during the last two decades. Improvement in management factors such as site selection and preparation, planting methods, spacing, interplanting with various nurse and agronomic crops, insect, disease, and weed control, corrective pruning, as well as the economic aspects of walnut management have been researched and the results and recommendations widely disseminated. Significant strides also have been made in genetic improvement of black walnut, primarily through selection and vegetative propagation. Finally, improved nursery management has produced higher quality black walnut planting stock.

Fertilization is another factor recognized as potentially significant for improving the growth of black walnut. At the time this study was initiated, 1967, there was very little information published relative to field fertilization of black walnut. Detailed study of the effects of fertilization in young plantations was considered of paramount importance and interest. The purpose of this study was to quantify the growth responses of a young black walnut plantation to various rates of nitrogen, phosphorus, and potassium fertilization.

LITERATURE REVIEW

Despite a broad base of experience in forest fertilization in some parts of the world and in some regions of our country, practical knowledge of field fertilization of black walnut is still fragmentary. Similarly, basic information on the nutritional requirements of black walnut is incomplete.

Based on greenhouse experiments with black walnut, Hacskaylo et al. (1969) described visual nutrient deficiency symptoms, normal leaf characteristics, and the foliar nutrient concentrations associated with each condition. This basic information is particularly useful for validating the condition of normal foliage. However, since site requirements of black walnut are well known, it is unlikely that nutrient deficiencies severe enough to cause recognizable deficiency symptoms will occur in

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[1]Paper presented at the 1981 Joint Meeting of Walnut Council/Northern Nut Growers Association, W. Lafayette, Indiana, Aug. 9-14, 1981.

[2]Research Forester and Professor of Forestry, respectively; Department of Forestry and Natural Resources, Purdue University, West Lafayette, Indiana 47907.

a well-located walnut plantation. If nutrient deficiencies do occur they are more likely in the range of "hidden hunger." In this condition, nutrient deficiencies reduce growth but are not severe enough to produce distinctive visual symptoms.

Phares and Finn (1972) prepared a list of tentative critical foliar nutrient levels for black walnut trees. Foliar levels below 2.00% N, 0.10% P, and 0.75% K were classed as deficient for these elements, with the strong likelyhood of a growth response to nutrient applications. Intermediate values, where fertilizer may or may not ellicit a response were given as 2.00-2.60% N, 0.10-0.25% P, and 0.75-1.30% K. Presentation of these critical values is a definite step in the right direction, but to our knowledge these data have not received extensive field testing.

The feasibility of fertilizing black walnut at the time of planting appears to be related to the suitability of the site for walnut. Ponder (1980) studied walnut on Wakeland silt loam, a somewhat poorly drained soil, that was a marginal site for walnut. Fertilization at time-of-planting stimulated both height and diameter growth of the trees. However, growth did not equal that of black walnut planted on good sites. Other studies on sites suitable for walnut (Byrnes 1966, Schneider et al. 1970, and Williams 1974) have tested a wide range of planting methods, and weed control techniques in conjunction with various fertilization treatments at time-of-planting. The consensus opinion is that walnut seedlings planted on good sites do not exhibit significant or practical growth responses to fertilization at time-of-planting, therefore, fertilization was not recommended at this stage. Williams (1974) reported that fertilization reduced survival and growth of the planted seedlings. In this case, seedling roots probably were burned by fertilizer salts placed in the planting hole (1 ounce 8-32-8/tree). It was also apparent however that competing weeds stimulated by the fertilizer suppressed some walnut seedlings.

The Managers Handbook for Black Walnut (Schlesinger and Funk 1977) states that fertilization of pole-size trees is likely to provide the best economic returns. Schlesinger and Funk also caution, however, that "not much is yet known about fertilization," and "It is not possible to make specific recommendations for specific soils at the present time . . ."

Neely et al. (1970) examined a 22-year-old walnut plantation growing on Plainfield sand; a droughty soil low in organic matter. Three yearly surface applications of N at 2600 lb/A resulted in a D.B.H. growth response of 254% after the third year. The diameter growth rate of fertilized trees amounted to 0.26 in/yr but returned to the pre-treatment level of 0.07 in/yr within two years after the final fertilizer application. Treatment with a complete fertilizer (N, P, and K) improved diameter growth only 180% during the same period.

Von Althen (1976a) thinned and fertilized a 27-year-old plantation of black walnut growing on former agricultural land in Ontario, Canada. A complete fertilizer was applied at rates of 450-218-200 lb/A of N-P-K, respectively. Foliar N and P increased while K concentrations decreased 1-year after treatment. By the end of the third growing season, foliar nutrient concentrations returned to pre-fertilization levels. The treatment had negligible effect on trees of average basal area. However, considering only the largest 100 trees/A (the probable future crop trees), fertilization increased the average diameter and height by 27% and 22%, respectively.

Maeglin et al. (1977) fertilized two 40 year old stands of black walnut to ascertain the effects of nitrogen fertilizer on growth and log quality. They concluded high fertility bottomland sites should not be fertilized as the control trees grew more then those fertilized. On upland sites fertilization increased diameter growth, but not to a statistically significant degree. It was noted that log quality of unfertilized trees on the upland site suffered due to sprouting along the lower bole. This sprouting may have been suppressed by the fertilization which would result in a significant increase in the quality of those stems.

METHODS

This study was located on the Martell Experimental Forest of Purdue University about 10 miles west of West Lafayette in Tippecanoe County, Indiana. The soil type is Genesee silt loam (Fluventic Eutrochrept), a deep, neutral to slightly alkaline, well drained soil derived from stratified loamy and silty alluvium washed from upland areas of Wisconsin glacial till. The site is nearly level and occupies a second terrace of the Wabash River. The S.C.S. soil interpretation record for Genesee silt loam indicates that black walnut is suitable for planting. Other site selection criteria (Carmean 1966, Losche

1973a) also indicate that this soil/site was suitable for black walnut. The area had a past history of agricultural cropping and grazing, but had lain fallow for several years prior to the initiation of this study.

In early April 1968, 1-0 seedlings from the Indiana state nursery were planted in augered holes on an 8 by 8-foot spacing. The seedlings were subjected to a severe late frost in early May 1968, therefore, initial fertilizer application was delayed until the following year. Twenty-three fertilizer treatments composed of various combinations of N-P-K were applied in Spring 1969 (Table 1). Nutrient elements were applied in the following forms: N as ammoniom nitrate, P as triple superphosphate, and K as mutriate of potash. The 23 selected treatments comprise an incomplete factorial experiment in a triple cube design with four replications. Each axis of the cube can be considered to represent one of the applied nutrient elements, i.e. N, P, or K and the amount of that element applied indicates a point along that axis. This particular design, proposed by Iowa State University statisticians, was utilized because it gives good estimates of the linear and quadratic coefficients of the main effects i.e. N, P, or K response as well as the interaction between these elements.

At the time of planting, every other tree in each row and column of the plantation was designated as a buffer tree. Buffer trees remained untreated, and served to isolate the treated trees and to minimize the possibility of fertilizer movement between trees treated differently. The buffer trees were cut in January 1973, resulting in the current plantation spacing of 16 by 16-feet (fig. 1).

Repeat fertilizer treatments were applied during spring 1971 and spring 1975. The fertilizer was surface-broadcast on an 8 by 8-foot square plot (64 sq. ft.) centered on each treatment tree. Each fertilizer treatment was applied to four trees within a block (replicate).

This plantation has been intensively managed throughout its life. Prompted by the severe freeze in 1968, the plantation received frost protection during the spring of 1970 and 1971. This was accomplished by igniting petroleum-coke bricks on nights that damaging frosts were anticipated. This provided a low smoke cover and reduced back radiation from the soil. The treatment was successful in minimizing frost damage.

Mechanical cultivation several times each summer has been used to control competing vegetation. Chemical methods of weed control were not used due to possible interactions with the ferilizer treatments.

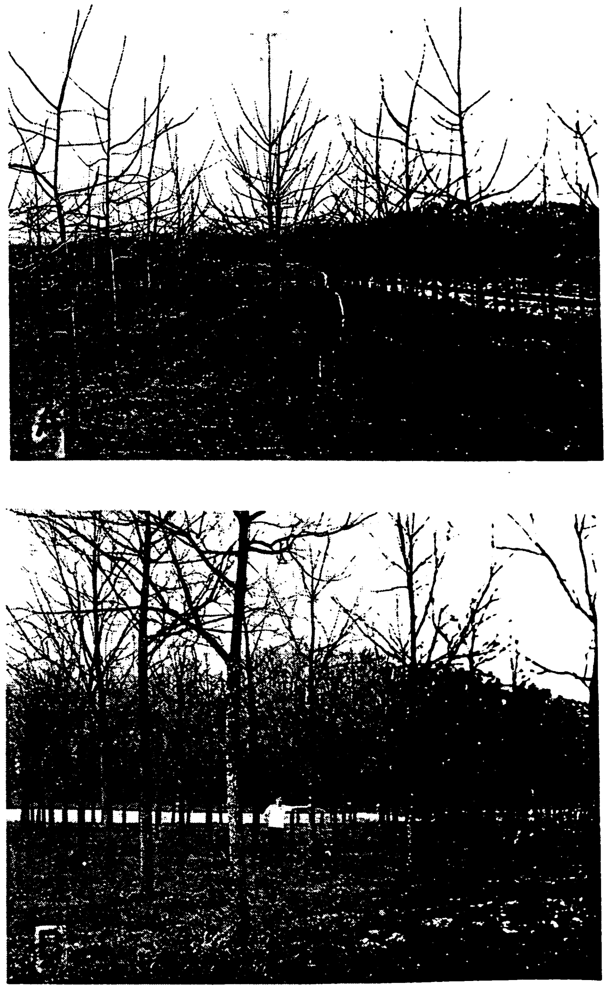

Figure 1.—Fertilized black walnut plantation located at Purdue University, Martell Forest: A Block 1, Dec. 1972, 8 x 8-foot spacing; B Block 2, March 1981, 16 x 16-foot spacing.

Corrective pruning to improve stem form has been applied periodically since 1971. Stem pruning also was initiated in 1971 to encourage development of clear bole wood. The plantation has not been irrigated at any time and no pesticides have been used for insect or disease control. Some top breakage of trees has occurred periodically during severe storms.

Table 1.--Mean[1/] survival, height, diameter-at-breast height (DBH), and total volume of black walnut by fertilizer treatment in fall 1980.

Fertilizer Applied N	P	K	Survival	Total Height	D.B.H.	Total Volume[2/]
(lbs./A)			(%)	(ft.)	(in.)	(cu. ft.)
0	0	0	94	26.2	5.4	2.1
0	0	140	94	28.5	5.9	2.6
0	60	0	100	29.9	5.7	2.4
0	60	140	100	31.2	6.3	3.0
400	0	0	100	29.9	5.9	2.6
400	0	0	100	28.5	5.6	2.4
400	60	0	100	28.5	5.7	2.4
400	60	140	94	29.9	6.2	2.8
200	30	70	100	28.9	5.7	2.4
0	30	70	100	26.2	5.5	2.2
400	30	70	87	27.9	5.8	2.4
200	0	70	100	31.5	6.0	2.7
200	60	70	94	25.6	4.9	1.7
200	30	0	100	32.5	6.1	3.0
200	30	140	100	28.9	5.6	2.4
100	15	35	100	30.8	5.9	2.7
300	45	105	100	28.5	6.1	2.7
100	15	105	100	32.2	6.3	3.0
300	45	35	100	26.9	5.6	2.2
300	15	35	100	27.9	5.7	2.4
100	45	35	100	31.8	6.3	3.0
100	45	105	100	25.6	5.2	1.9
300	15	105	100	27.2	5.5	2.2
All treatments			98	28.9	5.8	2.5

[1/] Mean of four replications

[2/] Formulae from Todhunter et al. (1979)

$$V = -2.86094 + 0.14366 \sqrt{(D^2 \times H) + 400}$$

where: V = total stem volume in cubic feet
D = DBH in inches
H = total height in feet

Soil samples were collected before the first fertilizer application in 1969, in 1970, and again prior to fertilization in 1975. These samples were analyzed for available P and exchangeable K. In addition, the 1975 samples were tested for KCl extractable NH_4^+ and NO_3^-. All tests were made by the soil testing laboratory at Purdue University.

The total height and D.B.H. of all fertilized trees were measured in the fall each year through 1977 and in 1980. The growth response of the four trees comprising an experimental unit was averaged and represents the treatment response for a given block.

RESULTS AND DISCUSSION

Data on total height and D.B.H. of the fertilized trees was subjected to statistical analysis at the P=0.05 level. The individual linear and quadratic effects for the three nutrient elements as well as their interactions were isolated by use of multiple regression. Not a single instance of a statistically significant growth response related to fertilizer treatment of black walnut was detected on these soil and site conditions.

In a similar analysis, year-by-year height and D.B.H. growth was examined. In fall 1975, the year of the last fertilizer application, a significant height growth response was noted for N and K (P=0.05). However, these responses were not of a practical magnitude, and there was no carryover into subsequent growing seasons.

Table 1 displays results of the fall 1980 measurements by fertilizer treatment. For all fertilizer levels and blocks combined, the average values for height, D.B.H., and volume are 28.9 feet, 5.8 inches, and 2.5 cubic feet, respectively. It is evident that there is a wide range of values about these means, and there is no apparent relationship between the measured values and the applied fertilizer. Survival was excellent, ranging from 87 to 100 percent among fertilizer levels, with a mean of 98 percent for all treatments and replicates combined.

There are several reasons why we believe the walnut plantation in this study did not respond to fertilization. Most importantly, the fertilizer added during this study amounted to only a fraction of the available nutrients on this fertile site. Analysis of surface samples collected in 1969 prior to the first fertilizer application indicated 54 and 168 lb/A of available P and exchangeable K, respectively. In 1970 the total soil profile was analyzed from one of the control plots, i.e. no fertilizer added. The available P and exchangeable K in the whole profile amounted to 355 lb/A and 960 lb/A, respectively. Table 2 presents the results of soil analysis from samples taken in the spring of 1975 prior to the third fertilization. Previous fertilizer additions had not materially increased the supply of available soil nutrients for any element (P=.05). Consequently, if fertilization cannot measurably alter the site, it cannot be expected to measurably influence the growth of vegetation on that site.

Secondly, as stated above, soil analysis indicated that the native site was moderately to highly fertile. Thus, despite the high nutrient demands that black walnut makes on a planting site, the site was capable of supplying these needs. The best evidence for this is the fact that the growth of the control trees has not differed significantly (P=0.05) from trees treated with any of the fertilizer combinations (Table 2).

Finally, there is a statistical explanation why growth differences were not found. The triple cube design allowed examination of all the individual factors of interest, and their interactions. This was accomplished with only 95 treatment units (a group of four treated trees within a block) whereas a complete factorial design would have required 500 treatment units. Although the design is widely used for industrial applications, the large variation inherent in biological systems reduces the ability of this design to detect treatment differences.[1] Thus, although treatment differences may actually exist, they are of such a small magnitude that they cannot be separated from the natural variation in growth of this plantation.

The main objective of this study was realized by concluding that fertilization of young black walnut stands, less than 13-years-old, planted on a good walnut site, will not yield a growth response at fertilizer levels used in this study. In addition, this study provides the basis for an excellent case history of tree growth in a well managed walnut plantation.

Figure 2 shows the total height and D.B.H. over the life of the plantation, 1968 to 1980. For both height and D.B.H., a rapid,

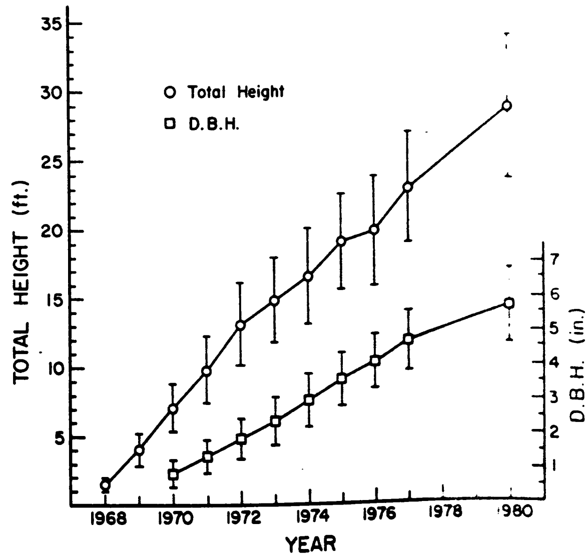

Figure 2.—Mean total height and D.B.H. (diameter-at-breast-height) for fertilized black walnut by year for the period 1968-1980, at Purdue Martell Forest.

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[1]Personal communication with Dr. Virgil Anderson, Professor of Statistics, Purdue University.

Table 2.—Soil N, P, and K, and current height, DBH, and total volume by increasing levels of applied nutrient.

Fertilizer Applied	Soil[1/] Analysis Spring 1975		Fall 1980 Height	D.B.H.	Total Volume
lb./A	lb./A		ft.	in.	cu. ft.
		Nitrogen			
0	119		28.5	5.7	2.5
100	131		30.2	5.9	2.6
200	127		29.5	5.7	2.4
300	117		27.6	5.7	2.4
400	136		28.9	5.8	2.5
		Phosphorus			
0	76		28.9	5.7	2.5
15	79		29.5	5.8	2.6
30	91		28.9	5.7	2.5
45	91		28.2	5.7	2.5
60	96		28.2	5.7	2.5
		Potassium			
0	194		29.5	5.7	2.5
35	216		29.5	5.9	2.6
70	222		27.9	5.5	2.3
105	224		28.2	5.7	2.4
140	232		29.5	5.9	2.6

[1/] Available N and P and exchangeable K, for surface samples

relatively uniform growth rate has been maintained since planting. Average annual growth rates over the 13-year period have been 2.2 ft/yr and 0.44 in/yr for total height and D.B.H., respectively. All seedlings attained the D.B.H. height (4.5 feet above the ground) by 1970. The vertical bars in figure 2 represent ± 1 standard deviation about the mean; it is evident that this variation increased as the trees grew older.

The distribution in total height and D.B.H. by 3-foot height and 1-inch D.B.H. classes, respectively, for all plantation trees in fall 1980 is shown in figure 3. Over 75% of the trees currently exceed 27 feet in height, and about one-third of the stand is taller than 33 feet. Diameter distribution indicates that over 50% of the trees have a D.B.H. greater than 6 inches.

In an effort to judge how well the Martell plantation was growing, growth data from several sources was assembled for comparison (Table 3). The sources listed represent a wide range of soil and climatic

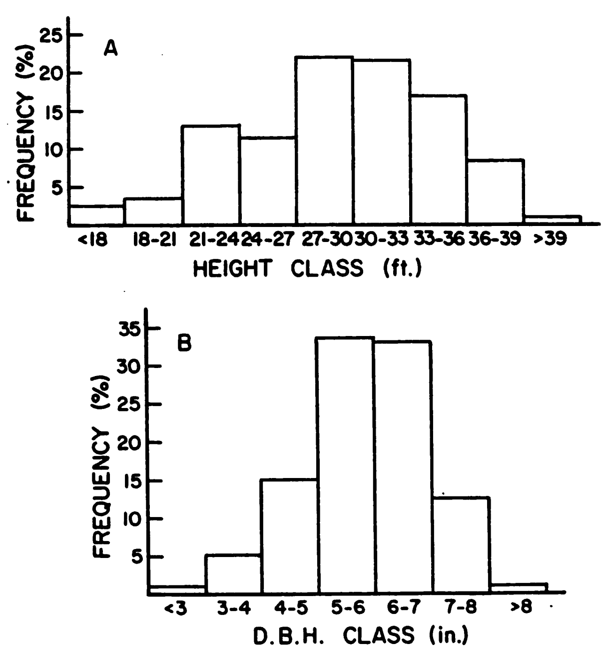

Figure 3.—Total height and D.B.H. distribution in fall 1980 for fertilized black walnut plantation at Purdue Martell Forest.

Table 3.—Average annual growth rates of trees in a fertilized black walnut plantation at Martell Forest compared to selected references.

Study	Location	Annual Growth Rate HT ft/yr	Annual Growth Rate D.B.H. in/yr	Stand Age yrs.	Comments
Martell Forest					
overall $\bar{x}$	Central Indiana	2.2	.44	13	
best 15%		2.7	.54		
Selected References					
Bey (1980)	Central States	0.9 - 2.6	.22 - .56	10	Provenance study
best 20%		1.9	.38		
Brinkman (1966)	Illinois	1.5		58	Unmanaged plantation
Byrnes, et al. (1973)	Central Indiana	1.0 - 1.7	.11 - .26	8 - 10	Weed control treatments
Carmean	S. Illinois	0.7 - 2.9	*	25	Site study
Clark et al. (1979)	S. Indiana	1.2 - 1.9	.18 - .28	12	Interplant. w/N fixers
Funk et al. (1979)	S. Indiana	0.8 - 2.5	.11 - .45	9	Interplan. w/autumn olive
Heflin (1965)	Missouri	*	.16	88	Unmanaged plantation
Krajicek et al. (1974)	S. Indiana, Iowa	0.6 - 1.7	*	3 - 5	Weed control treatments
Krajicek (1975)	Illinois	1.2 - 2.7	.10 - .31	7	Plantation on clearcut
Losche (1973b)	S. Illinois	1.4 - 2.1	.16 - .26	23 - 28	
Phares (1973)	*	*	.05 - .26	25 - 60+	Release/thinning study
Ponder (1980)	Illinois	1.0 - 1.4	*	7	Fert. rate & placement
von Althen (1976a)	Ontario, Canada	1.1 - 1.8	.16 - .28	36	Thinning & fert. study
von Althen (1976b)	Ontario, Canada	0.9 - 1.3	*	3 - 5	Planting methods study

*No data reported

conditions, stand origin, treatments, and intensity of management. Efforts were made to find and include references reporting fast growth rates. It is evident that the fertilized walnut plantation studied here is growing as well as the best walnut trees studied elsewhere. Given the intensive management this plantation has received, we believe the unimproved stock used in this study has grown at a rate close to the maximum potential rate achievable on this site.

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INTERACTION OF NITROGEN FERTILIZATION AND CHEMICAL WEED CONTROL ON FOUR-YEAR VOLUME GROWTH OF A BLACK WALNUT PLANTATION[1]

P. E. Pope, H. A. Holt, and W. R. Chaney[2]

Abstract.--Four year height, diameter and volume growth of a 16-year-old (treated at age 12) black walnut (Juglans nigra L.) plantation was significantly influenced by N-fertilization and chemical weed control. The greatest four year cumulative diameter increment (1.75 in.) and total volume growth .568 cu. ft.) occurred on trees fertilized with 100 lbs. nitrogen per acre in combination with weed control. Weed control alone resulted in a 38% increase in volume growth above untreated trees after four years whereas weed control in conjunction with 100 lbs. nitrogen per acre produced a 121% increase in volume growth. Changes in foliar nitrogen levels corresponded closely with changes in volume growth.

INTRODUCTION

Both private and industrial woodland owners have shown increasing interest in planting and growing black walnut (Juglans nigra L.). Expectations of high return on investment are certainly a stimulus for this activity. Cultural techniques to hasten growth and shorten rotation are of potential value. Considerable research has been done on genetic improvement, spacing and planting methods, weed control, pruning, and fertilization, but many questions still remain (Bey and Williams, 1976; Dickson, 1971; Holt and Voeller, 1975; Krajicek, 1971, 1975; Krajicek and Williams, 1971; Schlesinger and Funk, 1977; and Williams, 1974). This paper reports a study of the effect of nitrogen fertilization and chemical weed control on growth of 12-year-old black walnut trees for three years after treatment. Most studies on fertilization have dealt with the response of trees to nutrients applied at the time of planting. The intent of this research was to ascertain the growth response to nitrogen fertilization and weed control of established, plantation grown black walnut trees.

METHODS

The study was established in a 12-year-old black walnut plantation planted in Morgan County, Indiana in the spring of 1965. The trees were planted at 11 x 11 ft. spacing on a Martinsville silt loam soil (Typic Hapludalfs, fine-loamy, mixed, mesic). A combination of nitrogen fertilization and/or chemical weed control was applied to one-half of the plantation on May 20 and 21, 1977. The experiment was arranged in a split plot with three replications of each treatment and unequal observations per replication. Data were analyzed by analysis of variance (ANOVA) and Duncan's new multiple range test. Nitrogen treatments constituted the whole plot (0.20 acres) and chemical weed control was applied in 4 ft. bands down either side of the planted rows to one-half of each fertilized plot (0.04 acres). Nitrogen as urea was broadcast by hand at rates equivalent to 0, 50, or 100 lbs. of elemental nitrogen/acre. Weed control treatments were none and a combination of glyphosate [N-(phosphonomethyl)glycine] and simazine [2-chloro-4,6-bis(ethylamino)-S-triazine], each at 4 lb. ai/A in water. To allow for border trees, 18 trees were measured

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[2]Authors are Assistant, Associate and Professor, Department of Forestry and Natural Resources, Purdue University, West Lafayette, Indiana 47907.

in each replication of no weed control treatments whereas 12 trees were measured in each replication of weed control treatments. On May 1, 1977, prior to treatment application, trees averaged 20 ft. in height and 3.5 in. diameter at 4.5 ft. above the ground and had a per acre volume of 283.53 ft^3. Total height and diameter measurements were taken after the growing season for each of four years following treatment. These parameters were used to compute volume in cubic feet and expressed on a per acre basis with 360 trees per acre. Volume computation utilized an equation developed for seedling and sapling black walnut; $V = -2.86094 + 0.14366 \sqrt{D^2H+400}$, where V = total stem volume in cubic feet, D = diameter at 4.5 ft. in inches, and H = height in feet (Todhunter, et al., 1979).

Foliage samples were collected and analyzed for nitrogen by micro-kjeldahl distillation (Wilde, et al., 1972) prior to treatment and in mid-September for two years following treatment.

RESULTS

Average annual diameter increments and total diameter increment over 4 years are shown in Table 1. Except for the 1979 growing season, weed control alone, without nitrogen fertilization, did not affect diameter growth. Likewise, the total diameter increment for the four year measurement period was not significantly greater than no weed control. Weed control in conjunction with nitrogen fertilization did result in greater diameter growth over the four year measurement period. Except for the 1980 growing season, trees that received nitrogen and weed control grew more than those that received the same rate of nitrogen fertilization but no chemical weed control, although statistically significant differences at $\alpha = 0.05$ were evident in only two of the treatment combinations. The greatest increase in diameter growth occurred on trees fertilized with 100 lbs. nitrogen/acre with chemical weed control. These trees increased in diameter 0.82 in. more than the unfertilized trees with no weed control. For trees receiving no chemical weed control, fertilization with urea at 100 lbs/acre resulted in more diameter growth than attained by trees not fertilized or those receiving 50 lbs. nitrogen/acre. The differences were greatest for the 1980 growing season and the four year growth accumulation. Approximately 50 to 65 percent of the radial increment growth in all treatments, including the control, occurred in 1979 and 80, three and four years after treatment with 32-42 percent occurring during the wet 1979 growing season.

The data for 1980 are difficult to interpret. The diameter growth data suggest a decline in the rate of incremental growth, however, the severe drought during the 1980 growing season could have limited the growth that would have been attained under more normal conditions.

Chemical weed control alone did not affect the height growth increment of the 12-year-old (presently 16-year-old) black walnut trees (Table 2) nor did nitrogen fertilization in the absence of weed control. Trees that received 100 lbs. nitrogen/acre and chemical weed control had a significantly greater height growth increment in 1977, 1980 and in cumulative growth for the four-year period than trees in plots with no fertilizer or weed control.

Table 1.--Influence of N-fertilization and chemical weed control on the diameter growth increment of a black walnut plantation.

Fertilizer Rate (lbs N/A)	Weed Control	Diameter Increment (in.) Year '77	'78	'79	'80	Total
0	No	0.21a[1/]	0.20a	0.34a	0.18a	0.93a
	Yes	0.21a	0.33ab	0.55b	0.20a	1.29ab
50	No	0.25a	0.18a	0.48ab	0.33b	1.24ab
	Yes	0.34b	0.38b	0.51ab	0.28ab	1.51b
100	No	0.32ab	0.30ab	0.61b	0.49c	1.72c
	Yes	0.36b	0.37b	0.63b	0.39b	1.75c

1/ Column values not followed by the same letter are significantly different (Duncan's New Multiple Range Test, $\alpha = 0.05$).

Table 2.--Effect of N fertilization and chemical weed control on annual incremental height growth of black walnut.

Fertilizer Rate (lbs N/A)	Weed Control	Height Increment (ft.) Year '77	'78	'79	'80	Total
0	No	2.2a[1/]	0.8a	2.0a	1.3a	6.6a
	Yes	2.8a	0.8a	3.4ab	0.9a	7.9a
50	No	3.0a	1.3a	1.4a	2.8ab	8.5ab
	Yes	2.9a	2.0a	2.6ab	3.6b	11.10ab
100	No	3.2ab	1.4a	4.3b	2.9ab	11.80ab
	Yes	4.5b	2.1a	3.8ab	3.1b	13.50b

[1/] Column values not followed by the same letter are significantly different (Duncan's New Multiple Range Test, $\alpha = 0.05$).

Volume increase of black walnut per acre during the four-year study period, like height and diameter growth, was unaffected by weed control alone (Table 3). Generally, per acre volume increment increased with increasing levels of nitrogen fertilization and weed control. Fertilization at 50 lbs. nitrogen/acre with weed control or fertilization at 100 lbs. nitrogen/acre with or without weed control significantly increased volume growth over that of untreated trees. The largest volume increment during the four-year study period occurred on trees that received chemical weed control and 100 lbs. nitrogen/acre. This treatment resulted in an additional 311 ft^3/acre when compared to the control treatment receiving no fertilizer or weed control.

Increased growth response in the high nitrogen-weed control treatment relative to high nitrogen and no weed control was limited to the first growing season following treatment. The increased height and diameter growth combined with the multiplicative characteristic for volume calculations accounted for the increased volume of wood produced.

No differences in percent foliar nitrogen were evident in leaves collected on May 20, 1977, prior to treatment application (Table 4). At the end of the first growing season, September 1977, increased foliar nitrogen was found in response to both weed control and nitrogen application. Weed control alone resulted in increased foliar nitrogen in both

Table 3.--Effect of weed control and nitrogen fertilization applied in a 12-year-old black walnut plantation on annual and cumulative volume growth.

Fertilizer Rate (lbs N/A)	Weed Control	Per Acre Volume Increment (ft^3) Year '77	'78	'79	'80	Total
0	No	60.28a[1/]	39.87a	78.50a	78.28a	256.93a
	Yes	68.30a	59.85ab	134.46b	91.89a	354.49ab
50	No	77.57ab	43.52a	97.31ab	142.74b	361.14ab
	Yes	91.20b	85.02b	110.41ab	169.89b	456.52b
100	No	92.02b	63.64ab	158.88c	212.51c	527.05c
	Yes	117.01c	84.82b	154.76c	211.31c	567.90c

[1/] Column values not followed by the same letter are significantly different (Duncan's New Multiple Range Test, $\alpha = 0.05$).

Table 4.--Percent foliar nitrogen in black walnut in relation to nitrogen fertilization and weed control.

Fertilizer Rate (lbs N/A)	Weed Control	Date May '77	Sept. '77	Sept. '78
0	No	2.36a[1/]	2.26a	2.48a
	Yes	2.51a	2.59b	2.85b
50	No	2.63a	2.66bc	2.91b
	Yes	2.58a	2.95c	3.42bc
100	No	2.41a	2.49b	3.46bc
	Yes	2.53a	2.84c	3.61c

[1/] Column values not followed by the same letter are significantly different (Duncan's New Multiple Range Test, $P < .05$).

the first and second years after treatment. When 50 lbs. nitrogen/acre were added in conjunction with weed control, the levels of foliar nitrogen were greater than that of leaves of control trees at the end of the first season. When compared to the weed control only treatment, weed control applied with 50 lbs. nitrogen/acre did not significantly increase foliar nitrogen levels in September, 1978. At the end of the first growing season, 100 lbs. nitrogen/acre with weed control resulted in levels of foliar nitrogen that were much higher than control trees and this difference existed for two years after application.

DISCUSSION

Black walnut growth response to nitrogen application was anticipated based on results of Phares and Finn (1971). They predicted no probable growth response of black walnut trees from adding nitrogen when foliar level is above 2.6 percent, some response at foliar levels of 2.0 to 2.6 percent, and a likely response at levels below 2.0 percent foliar nitrogen. Foliar nitrogen levels for trees in this study were in the high side of the medium range, about 2.4 to 2.6% (Table 4). The first growing season after nitrogen fertilization, nitrogen levels increased to a point where no additional response was expected except in those trees that did not receive weed control. This study clearly shows that weeds are very competitive sinks for available nitrogen. Weed control treatments alone resulted in significant increases in tree foliar nitrogen levels. Nitrogen application increased foliar nitrogen levels above that of unfertilized trees around which weeds were controlled only when done in conjunction with weed control. Fertilization without weed control was no more effective than weed control alone at the end of the first growing season. The benefits of 50 lbs. nitrogen/acre and weed control were lost in the second year after treatment. This was due to the reestablishment of competing weeds on the weed control plots in the second year. On the plots that received 100 lbs. nitrogen/acre, luxuriant amounts of nitrogen were apparently still available for both weeds and trees during the second growing season.

The increased levels of foliar nitrogen in response to treatments relate closely to the volume growth increments that were found. These results support the suggestion by Russell (1961) that nitrogen generally affects leaf area of plants and that over a considerable range of nitrogen supply the amount of leaf area available for photosynthesis in proportional to the nitrogen applied. Ellis and von Althen (1973) who worked with 30 to 85-year-old natural stands of several hardwood trees in southern Ontario also concluded that nitrogenous fertilizer increased diameter growth through increased leaf area.

Nitrogen fertilization of established trees does not always produce increased growth. A 40-year-old stand of black walnut in southern Wisconsin on an upland site did not show a significant increase in diameter growth when fertilized with 500 lbs/acre of elemental nitrogen as ammonium nitrate. The same rate of nitrogen application on a fertile bottomland site reduced the rate of diameter growth below that of unfertilized trees (Maeglin, et al., 1977). Phares[2] (unpublished data) found a similar retardation of black walnut growth in Indiana. Trees of a 60 to 80-year-old stand growing on a fertile bottomland site grew less when fertilized with nitrogen than trees not fertilized. Nevertheless, Schlesinger and Funk (1977) stated that fertilization of pole-size trees is likely to provide the best economic returns and that nitrogen is the most promising nutrient to apply. They suggested that it may be necessary to refertilize approximately every 5 years to maintain growth stimulation. They also

[2] Robert E. Phares. USDA Forest Service, North Central Forest Experiment Station, Carbondale, Illinois.

emphasize that fertilization should be considered a supplement to other cultural practices, and cannot be expected to compensate for other limiting factors such as light and moisture. The results of the present study reinforce these observations since nitrogen was found to significantly increase diameter, height, and volume growth of small pole-size trees and was most effective when done in combination with weed control.

CONCLUSIONS

For the specific conditions of this study, significant increases in volume growth of a young black walnut plantation can be achieved by fertilizing with 100 lbs/acre nitrogen. The largest volume increase was recorded for plantations fertilized with 100 lb/acre N, plus weed control. While fertilization with 50 lb/acre N and/or weed control improve volume growth over the unfertilized control these growth differences were not significantly different.

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EFFECTS OF SELECTED COVER CROPS ON THE GROWTH OF BLACK WALNUT

P. L. Roth and R. J. Mitchell

Abstract.--This study was initiated to investigate the effects of selected cover crops on the growth of black walnut (Juglans nigra L.). The cover crops tested were: Poa pratensis L., Lolium multiflorum L., Phleum pratense L., Festuca arundinacea Schreb., Trifolium repens L., Lespedeza stipulacea Maxim., Melilotus officinalis (L.) Lam., Lespedeza cuneata Dumont Maxim. and a clean-cultivated control. Cover crops significantly affected the height and caliper growth of black walnut throughout the study period. Black walnut grown in clean-cultivated plots exhibited superior height and diameter. Within cover crop treatments, the height and caliper growth of black walnut grown with Lespedeza cuneata was the greatest while walnut grown in association with Festuca arundinacea showed the poorest growth.

Additional Keywords.--Height growth, caliper growth, cover crop, Juglans nigra

INTRODUCTION

Black walnut (Julans nigra L.) is the most valuable of native American woods. Accelerated reduction in the growing stock of quality black walnut, coupled with increasing demands placed upon the resource, have resulted in escalating prices for both logs and standing timber (Callahan and Smith 1974). If this shortage of black walnut lumber and veneer is to be alleviated, methods oriented toward the intensive management of this species must be investigated.

For continued good growth, walnut trees require deep, well drained, loamy soils (Losche 1973). Such sites normally have the potential to produce agronomic crops such as corn, soybeans and forage crops. Combining the management of forage crops with black walnut allows a landowner to produce short term returns to supplement income, until nut and wood crops can be realized.

A number of articles have suggested that this type of "multicropping" management is economically sound (Garrett et al. 1976, Callahan and Smith 1974), although it is warned that the data used for the economic analysis are "incomplete and slightly speculative" (Callahan and Smith 1974). This study was initiated to provide data pertaining to the growth response of black walnut grown in association with selected forage cover crops.

EXPERIMENTAL METHODS

Site Description

The experimental site was located at the Forest Tree Improvement Center two miles west of Carbondale, Illinois. The soil is classified as a Hosmer Silt Loam, a light colored forest soil, developed from loessal parent material. The soil has a fragipan at a depth of 0.6 m which restricts root depth and the movement of air and water.

Cover Crop Establishment

The cover crops consisted of: two short grasses, Kentucky bluegrass (Poa pratensis L.) and annual ryegrass (Lolium multiflorum L.); two tall grasses, timothy (Phleum pratense L.) and tall fescue (Festuca arundinacea Schreb.); two short legumes, white clover (Trifolium repens L.) and common lespedeza (Lespedeza officinalis (L.) Lam.) and sericea lespedeza (Lespedeza cuneata Dumont Maxim.). The control treatment was clean-cultivated throughout the growing season. In the fall of 1973 the cover crops were hand sown at locally recommended agronomic rates. In the spring of 1974 any areas that did not establish were resown to establish 100% cover of the specific crop in each plot.

Black Walnut Establishment

Seed for the study was collected in the fall of 1973. Parent trees were located within a ten-mile radius of Carbondale, Illinois. No standards of quality were set for the parent trees; however, all trees were judged to be of average quality as standing saw timber. Walnut seeds were pregerminated and planted in the spring of 1974. Seeds were planted on 0.9 x 1.5 m initial spacing. At the end of the 1974 and 1979 growing season trees were removed for root/shoot ratio determination so that final spacing was 1.8 x 1.5 m.

Experimental Design

The plantation was established as a split-split plot factorial design with ten replications. These replications were put in a series of five blocks. Each replication was 28.7 m wide by 19.2 m long, and contained nine randomly located treatments. The treatments were eight cover crop species plus a control that was kept free of vegetation through clean-cultivation. Each treatment was 1.5 m wide by 19.2 m long. On five randomly selected replications (one per block), the cover crops were mowed at three-week intervals during the growing season. On the remaining five replications, the cover crops were allowed to grow undisturbed.

Data Collection

Height and caliper (10 cm above ground line) measurements were recorded at the end of the 1974, 1978, and 1979 growing seasons. In late June, 1979 a team of four investigators optically estimated the percent cover by forage species in each treatment.

Data Analysis

The data were analyzed to detect significant differences by analysis of variance. If significant differences were present, Duncan's Multiple Range Comparison test was employed to perform multiple comparison among the treatments. The significance level was set at alpha = 0.05 for all statistical tests.

RESULTS AND DISCUSSION

Cover Crop Assessment

Species of cover crops varied greatly in their ability to maintain themselves in association with black walnut over the six year study period. The degree of compatibility of the eight species to the mowing treatment also varied (Table 1). Kentucky bluegrass and tall fescue were the grasses that showed the greatest compatibility with black walnut. Kentucky bluegrass (a short grass) maintained itself substantially better under the influence of the mowing while all other crop species were less abundant in the mowed replications. Apparently, the low growing morphology resulted in a competitive advantage for Kentucky bluegrass when mowing occurred. Tall fescue maintained itself well in both the mowed and the unmowed condition, and was the major invader in plots sowed to other crop species. Timothy and annual ryegrass were essentially eliminated from the plantation by stand age six. This may have been due to the susceptibility to juglone or the inability to compete with the aggressive fescue sod. Sericea lespedeza was the only legume that maintained itself well in the unmowed plots. In the mowed plots it appeared to be more susceptible to competition, especially from tall fescue. Sweet clover, white clover, and common lespedeza were unable to maintain themselves through the study period.

Height and Caliper Growth

Significant differences in mean height growth of black walnut trees associated with the various cover crop treatments were observed throughout the study (Table 2). After the 1974 growing season black walnut trees growing on the clean cultivated plots showed superior growth relative to the other cover treatments. Differences in height of black walnut among cover crop treatments after the first growing season were small, although some trends may be discerned. Timothy, white clover, sweet clover, common lespedeza and annual ryegrass tended to compete less with black walnut than did sericea lespedeza, Kentucky bluegrass and tall fescue. Differences in height growth were accentuated by the end of the 1978 growing season, with trees grown in association with annual rye exhibiting a slowing of height growth and black walnut grown in sericea lespedeza showing accelerated mean height development. This reduction in growth of black walnut in annual ryegrass plots may have been due to the failure of annual rye

Table 1.--Cover crop percentage of relative cover in 1979, six years after seeding

Cover Crop	Kentucky blue-grass	Annual rye-grass	Timothy	Tall fescue	White clover	Sericea lespedeza	Sweet clover	Common lespedeza
	Percentage of Relative Cover							
Kentucky bluegrass	29.5	8.3	7.5	5.3	6.5	-	4.3	8.8
Annual ryegrass	-	-	-	-	-	-	-	-
Timothy	-	0.5	1.5	-	-	-	0.3	-
Tall fescue	44.5	51.6	63.0	70.0	72.3	5.3	49.0	57.0
White clover	-	-	-	-	-	-	-	-
Sericea lespedeza	1.7	-	0.5	7.5	1.8	87.0	2.0	1.0
Sweet clover	-	-	-	-	-	-	8.0	3.0
Common lespedeza	1.5	-	0.5	0.3	1.5	-	-	-
Invading weedy species	22.8	39.7	27.0	16.9	17.9	7.7	36.4	30.2
Kentucky bluegrass	53.6	9.3	9.8	14.5	4.8	8.2	15.5	8.8
Annual ryegrass	-	-	-	-	-	-	-	-
Timothy	-	0.3	-	-	-	-	-	-
Tall fescue	27.2	69.8	59.5	66.5	68.0	36.0	44.8	57.0
White clover	-	-	1.0	-	1.0	-	-	3.0
Sericea lespedeza	-	-	-	-	-	31.8	10.0	1.0
Sweet clover	-	-	-	-	-	-	-	-
Common lespedeza	-	1.5	2.3	0.8	3.0	0.5	5.5	-
Invading weedy species	19.2	19.3	27.4	18.2	23.2	23.5	24.2	30.2

Table 2.--Height and caliper growth of black walnut intercropped with eight forage species and grown under clean cultivation

Cover Crop	1974		1978		1979	
	Height (cm)	Caliper (mm)	Height (cm)	Caliper (mm)	Height (cm)	Caliper (mm)
Kentucky bluegrass	20.4[1] c	2.3 c	73.6 cd	14.5 cd	96.7 cd	21.1 b
Annual ryegrass	21.6 bc	2.3 c	74.2 c	12.4 d	83.5 d	15.8 c
Timothy	24.0 b	2.6 b	95.9 b	17.8 bc	115.4 bc	22.9 b
Tall fescue	20.2 c	2.2 c	63.7 d	10.6 d	81.4 d	15.8 c
White clover	22.6 bc	2.7 b	104.7 a	20.3 b	121.8 b	26.3 b
Common lespedeza	21.9 bc	2.3 c	102.0 b	17.9 bc	116.0 bc	23.8 b
Sweet clover	22.6 c	2.3 c	102.8 b	19.0 bc	119.5 b	24.8 b
Sericea lespedeza	21.0 c	2.2 c	91.4 bc	17.2 bc	112.3 b	23.5 b
Control	30.7 a	3.9 a	123.2 a	26.0 a	148.2 a	35.2 a

[1]Each number followed by a common letter (a, b, c, d) is not significantly different at the P = 0.05 confidence level.

and the subsequent invasion of tall fescue observed in 1974. The clean cultivated control outperformed all other treatments during the 1978 and 1979 growing season. As a group, black walnut grown with sericea lespedeza, white clover, sweet clover, common lespedeza and timothy treatments performed better than walnut grown with Kentucky bluegrass, annual ryegrass, and tall fescue. The stunting of the growth of black walnut when grown in association with fescue that was observed in this study, and in a study by Todhunter and Beineke (1979), may be due to competition for mineral nutrients and water, or to an allelopathic reaction. Walters and Gilmore (1976) found that fescue suppressed the growth of sweet gum (*Liquidambar styraciflua* L.) through an allelopathic mechanism.

Mowing had no significant effect on height or diameter growth of black walnut. Although mowing did affect the ability of forage crops to maintain themselves throughout the study period (Table 1).

Data presented in Table 2 on caliper growth of black walnut show relationships similar to those observed in height growth. Clean cultivation resulted in superior caliper growth of black walnut throughout the study. The caliper growth of walnut associated with sericea lespedeza was initially retarded followed by a more rapid growth in the later stages of the study. Caliper growth of trees associated with fescue was the lowest of the cover crop treatments.

Biological and Managerial Considerations

The results of this study show significant differences in height and caliper growth of walnut among cover crop treatments. Although growth rates of black walnut in the clean-cultivated control treatment were superior, the energy necessary to maintain this condition and the potential for accelerated erosion would render this alternative less than desirable for prolonged time periods in most management situations. Sericea lespedeza was able to maintain itself well when grown in association with black walnut and walnut seedlings exhibited their greatest growth when associated with this forage species, relative to the other cover crop species. It is suspected that the early retardation of growth of black walnut when grown in association with sericea lespedeza could be eliminated by clean-cultivation during the first few years, allowing the walnut trees to grow to a height above that which the sericea lespedeza would reach (0.9 m), followed by seeding with sericea lespedeza. If the plantation is subject to moderate to high erosion potential the manager could keep an area (1 m diameter minimum) around the seedlings free of vegetation and seed with sericea lespedeza at the time of plantation establishments. Tall fescue tended to retard the growth of black walnut, subsequently it is not recommended as a cover crop in black walnut plantations during the early etablishment period.

White clover and sweet clover were unable to compete with the invading tall fescue. Fertilization and liming to adjust the fertility of the site to a more optimum level may have resulted in the clovers establishing and maintaining themselves, although more research is necessary before this species can be recommended for intercropping with black walnut.

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BLACK WALNUT SEED: FROM TREE TO SEEDLING[1]

Robert D. Williams[2]

Abstract--Recommendations are given for collecting seeds. Germination of unhulled nuts are compared with nuts hulled in large and small capacity hullers. Seed testing methods, including X-ray, are discussed; the importance of, as well as how to determine, seed moisture content is shown. Results from recent seed storage and stratification trials are presented.

Hog farmers brag that their consumers use everything but the squeal. Black walnut growers can be just as proud. They market the stem, root, and limb wood of walnut for veneer, lumber, and speciality products; the walnut kernels are food for man and animal. The walnut shells are used as abrasives for deburring, cleaning, and polishing; as additives in oil well drilling mud; and as filtering agents in smokestack scrubbers.[3] But the most important use of the nut is its role as seed, to perpetuate the species. Squirrels eat much seed, but they are also responsible for most of the natural reproduction of walnut through forgotten or unused food caches. Humans, too, consume some seed as food, but they also collect tons of seed each year (when it is available) for direct seeding or for producing seedlings at nurseries.

SEED COLLECTION

Some basic principles to remember when collecting walnut seed are:

1. Collect seed up to 150 miles south of the planting site (Bey 1980) or use the seed collection zones recommended by Deneke et al. (1980).

2. Keep records on the performance of progeny from individual seed trees. Seed and seedlings from local stands may perform very differently.

3. Choose straight, vigorous seed trees to increase chances of straight, vigorous progeny.

4. Collect after the husk begins to turn color.

5. Place collected nuts in porous bags to prevent heat buildup. Heat destroys the viability of the seed.

6. Keep seed as cool as possible until it is hulled. Hulling is not essential unless the seed is to be tested.

7. Don't waste time collecting seed from poor seed chances. Concentrate your efforts where seed is plentiful. Seed crops can be estimated by counting the number of trees that have seed in a sample of 10, and by counting the number of nuts per cluster. If 7 of the 10 trees have 1 nut per cluster or if 5 of the 10 trees have 2 or more nuts per cluster, there will be an average seed crop. If 7 or more of the 10 trees have 2 or more nuts per cluster, there will be a heavy crop.[3] Before collecting nuts, crack a few from each tree. If fewer than 6 of 10 nuts from a tree have good kernels, don't collect from that tree.

HULLING

Walnut seed should be hulled to perform the float and X-ray tests, to facilitate mechanical sowing, and to reduce bulk for seed stratification or storage. Seed may be hulled by hand or by mechanical huller.

Some hullers damage the germinative capacity of the seed. The nuts are forced up

[1]Paper presented at the joint meeting of the Northern Nut Growers Association and the Walnut Council. Purdue University, West Lafayette, IN, August 13, 1981.
[2]Robert D. Williams, Principal Silviculturist, North Central For. Exp. Stn., Bedford, IN.

[3]Personal communication with Gus Rutledge, 1981. Hammons Products Company, Stockton, MO.

against a metal grill which rubs off the hull, or they are flailed with chains to break and loosen the hulls. Probably the net effect on the seed is influenced, too, by the quantity of seed in the huller at a given time. The fewer the seed the more punishment they take and the greater the probability that the seed will be damaged and not germinate.

We conducted a study to determine whether either of the two hullers we used might destroy the germinative capacity of the seed. Our tests were conducted with small seedlots, which probably biased our findings in favor of the small huller. Because unhulled seed floats and unhulled seed was one of our variables, none of the seed was float tested. All seed was fall sown. Germination was 48 percent for unhulled seed, 60 percent for seed hulled in the small huller, and 25 percent for seed hulled in the big huller.[4] Although mechanical hullers may reduce germination, I believe germination of seed hulled in the big huller would have been higher if the huller had been run at normal capacity. Also, the float test will eliminate most of the bad seed, and hulled and float-tested seed will germinate more completely than unhulled seed.

SEED TESTING

To estimate the number of seedlings that will be produced, any sower should know what portion of his seed has the potential to germinate. Unfortunately, short of germinating the seed, only an estimate of germinative capacity is available. Walnut seed requires a minimum of 90 days' stratification, so germination tests take too long to be useful to anyone sowing seed in the fall, immediately after collection. In addition to the germination test, two standard tests and one relatively new test estimate seed viability: (1) the float test, (2) the cracking test, and (3) X-ray.

The float test separates filled from unfilled seed when hulled seed is placed in water. Air spaces in the unfilled seed cause it to float, while the filled, good seed sinks. To be effective, the float test should be conducted within 3 days after the seed is hulled. If too dry, even good seed will float.

[4]Data on file at Bedford, IN.

The cracking test is the cracking of a randomly drawn number of seeds to examine their kernels. The viability of a seedlot is estimated by determining the percentage of seed filled with firm, well-developed, white endosperm. Bad seed contain distinctly shriveled kernels, or the kernels may be buff or tan, and some may give off a rancid odor. Some bad kernels may be watery or be filled with a thick, clear, or milky oozing liquid and give off a foul odor.

X-raying seed is a useful and relatively new method to determine more precisely the quality of the seed. Every seed is X-rayed and those seeds that do not show a filled seed cavity with well-defined outlines of the seed kernel on the radiograph are discarded. X-raying walnut seed is laborious, the film and processing are expensive, and the radiologist must be a skilled technician to improve over the results of the float test. For example, in one of our first X-ray studies, germination was 64 percent for unhulled seed, 60 percent for hulled, 72 percent for hulled and floated, and 74 percent for hulled, floated, and X-rayed seed. In a later study, which contained 10 seed sources, germination was 70 percent for unhulled seed, 69 percent for hulled, 80 percent for hulled and floated, and 75 percent for hulled, floated and X-rayed seed. Germination for the ten seed sources ranged from 53 to 86 percent.[4]

Both the float test and the X-ray test must be done soon after the seed is hulled. If allowed to dry longer than 3 days, much of the seed will float and the air pockets, which are one indication of bad seed, will show up on the radiographs. In one trial, after 8 days of drying, the float test indicated that all seed in some sources were bad. According to X-ray and cracking tests done on the same seed samples, X-ray showed that 83 percent of the seed was good and the cracking test showed that 89 percent was good.[4]

The ability of the radiologist to separate good from bad seed varies by seed source and drying time. Some seed sources are more photogenic than others and radiographs are more easily discernible. If dried too long, air pockets appear in radiographs of good seed causing them to appear bad. After 28 days of drying, all seed appeared bad on the radiographs.

SEED GERMINATION

Black walnut seed is dormant when it falls from the tree, and must be stratified before it will germinate. In temperate climates, such as Indiana, overwintering in the seedbed, after fall sowing, usually satisfies the seed's requirement for stratification and the seed germinates normally the following spring. Sometimes, however, seed does not germinate until after two winters in the seedbed. Second-year germination has been observed in nursery seedbeds and by those direct seeding the nuts in the field. Seed source plays an important role in stratification, so some of the northern seed sources might not germinate promptly or completely if fall-sown in southern nurseries without prior cold room stratification.

There are three primary methods of stratification. In addition to fall sowing, a natural stratification of the seed, we have used cold stratification and pit stratification. Our cold stratification was a cold storage room at the Vallonia Nursery with a temperature of 37° F. Hulled seed was dipped in water, allowed to drain up to 15 minutes, placed in 4 mil plastic bags, and closed with a wire tie before being placed in the cold room.

Pit stratification was accomplished by placing hulled seed in pits about 3 feet deep. In normal stratification, alternate layers of seed and about 2 inches of sand would be built up to within 6 inches of the soil surface.

Fall-sown seed usually germinates more promptly and more completely than either cold- or pit-stratified seed. In a study involving 10 seed sources, germination of fall-sown seed was 63 percent; germination of cold- and pit-stratified seed was 58 percent and 52 percent, respectively.[4] Germination by seed source ranged from 43 to 71 percent. In another study germination was 46 percent for fall-sown seed, 42 percent for cold-, and 28 percent for pit-stratified seed.[4] Because fall-sown seed germinates sooner in the spring, the 1-year-old seedlings are usually larger than those from spring-sown stratified seed.

Length of stratification is important, especially for greenhouse work or for seed preparation for spring sowing. All seed sources that we tried required at least 60 days in cold stratification. However, most seed sources germinate more completely after 90 days' stratification, and seed germinates most promptly after 120 days in stratification.[4]

MOISTURE CONTENT

Moisture content plays an important role in the behavior of black walnut seed. Seed moisture content must be reduced for cold storage, and dried seed must imbibe water before it will germinate. For example, 44 percent of presoaked seed with previously reduced moisture content germinated, but only 29 percent of non-soaked seed germinated. Seed moisture content differs by seed source, too. For example, after 14 days of drying, moisture content of one seed source was reduced by 8 percent while moisture content of another was reduced 26 percent.[4]

Moisture content is easy to determine. First, weigh a sample of 5 nuts and a cloth bag large enough to hold the nuts; crack the nuts and place all pieces in the bag; place the bag of nuts in an oven preheated to 103° C; leave in the oven for 16 hours, then take out and reweigh (Bonner 1980). The formula for percent moisture content is:

$$M.C. = \frac{\text{wet weight} - \text{oven dry weight}}{\text{wet weight}} \times 100$$

To store nuts in a home refrigerator at about 40° F, moisture content should be reduced to about 30 percent. To store nuts in a home freezer where the temperature is about 0° F, seed moisture content should be reduced to about 17 percent (Williams 1971).

SEED STORAGE

Reliable, inexpensive seed storage techniques are needed for large seed quantities. Bumper seed crops occur locally in some years, but in other years no seed is produced. Walnut seed may be stored 1 full year in cold storage with little loss of viability (Williams 1971). However, walnut seed is so bulky that cold storage is too expensive for large seedlots. So we have been searching for an alternative storage method.

First, we tried ambient temperature storage.[4] Seed was sheltered from precipitation but subject to fluctuating temperatures in one location in Georgia, two locations in Illinois, three locations in Indiana, and one location in Minnesota. If kept in ambient temperature storage over winter, then placed in cold storage until it was fall-sown, some of the seed from each storage location germinated. But seed kept at ambient temperature the full year, did not germinate.

Next, we tried storing seed in root cellars.[4] Although there was a sharp loss in viability, some seed germinated after a full year in cellar storage. For example, seed collected from 10 southern Indiana seed sources in 1978 was stored in three different cellars and in pits dug at Indiana's Vallonia Nursery. After a full year in storage, the seed was fall-sown in the nursery. Germination of fresh seed from the same seed sources sown in the fall of 1978, right after collection, ranged from 58 percent for the poorest seed source to 95 percent for the best. Average germination was 81 percent. After a full year in storage, germination was 22, 23, and 24 percent for seed stored in the three cellars and 23 percent for seed stored in the pits.[4] Although 23 percent germination is not satisfactory, the cellar storage results are encouraging. If we use different kinds of bags, or manipulate the humidity, or provide some cooling, cellar storage may preserve seed viability at a satisfactory level.

SOWING SEED

Plantations may be established by direct seeding or by planting seedlings. To produce seedlings for transplanting in the field, the seedbed should be prepared in much the same way as preparing soil to sow corn or beans in a garden.

For natural stratification and best germination, sow the seed in the fall. To produce about 6 seedlings per square foot, sow 12 seeds per square foot (3 x 4 inch spacing) if seed tests indicate 50-percent germination. Adjust the sowing rate according to the seed quality. Seed should be covered with 1 1/2 to 2 inches of soil (a rule of thumb is to cover 2 times the diameter of the seed). If seed is sown in the spring, it should be stratified at least 90 days before sowing. For example, if seed is to be sown March 15, the seed should be placed in cold stratification by December 15. To protect the seed from predators, cover it with wire screening or lathe fencing.

If the seed is to be sown in the field, sow enough seed at each seed spot to ensure a seedling. If germination capacity is 50 percent, sow 2 seeds per seed spot. To protect the seed from predators, cover the seed spot with manure (Williams and Funk 1979) or with wire screen staked down over the seed. Sow the seed about 2 inches deep.

To shorten the time between sowing and seed germination, thus providing less time for rodents to pilfer the nuts, sow stratified seed in the spring. Use manure or screen wire over the seed to protect it from squirrels.

SUMMARY

There's still much to be learned about black walnut seed. But for best results we know to:

1. Collect seed up to 150 miles south of the planting site.
2. Remember that seed quality and development of seedlings from seed trees differ within local stands.
3. Collect from productive stands and high-quality trees.
4. Hull and float test within 3 days.
5. Use a huller with care because it may damage the seed and reduce its germinative capacity.
6. Sow seed the fall it's collected if possible, and never let the seed dry out excessively.
7. Stratify the seed in a cold room for at least 90 days before sowing when fall sowing is not possible.
8. Try storing surplus seed in cellars when cold storage is not available.

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A SCREENING OF VESICULAR-ARBUSCULAR (VA)

MYCORRHIZAL FORMING FUNGI ON BLACK WALNUT SEEDLINGS[1]

M. W. Melichar*, H. E. Garrett and G. S. Cox[2]

Abstract.--The effects of VA mycorrhizal forming fungi on the growth and development of black walnut (Juglans nigra L.) were studied. Percentage infection, root dry weight, stem dry weight, total seedling dry weight, stem diameter and stem height, were determined for each seedling. Seedlings inoculated with Glomus microcarpus, Glomus microcarpus+Glomus fasciculatus, and Glomus microcarpus+Glomus etunicatus+Glomus fasciculatus demonstrated superior growth and development to those inoculated with other species or left uninoculated.

INTRODUCTION

The multitude of microorganisms which live on or near the feeder roots of trees, agronomic crops and other plant types interact with the plant roots to form a functional association which plays a vital role in many physiological processes. Microbial processes involve saprophytism, pathogenism and mutualism. The most universal mutualistic relationship of plants is the mycorrhizal association which involves various root-inhabiting fungi and plant feeder roots.

The benefits of mycorrhizae to plant growth and development are well documented for ectomycorrhizal tree species (Garrett, et al., 1979; Marx, 1979; Vlasov, 1955). However, fewer studies have been made on endomycorrhizal woody types (Kormanik, et al., 1979; Starkey and Brown, 1977). In particular, little information is available on the endomycorrhizal relationships of black walnut (Juglans nigra L.), the premier timber species of the eastern United States (Ponder, 1979). This is unfortunate since black walnut is noted for poor growth and development during the first two years after outplanting (Williams, 1970) and could benefit greatly from mycorrhizae. Moreover, the chances of natural colonization of walnut root systems under nursery conditions is low due to seedbed sterilization and the fact that endomycorrhizal spores are disseminated only through the soil. At best, recolonization of nursery beds is a slow process following sterilization. Without artificial reinoculation, the benefits of a mycorrhizal relationship are not forthcoming in advance of the invasion of the walnut root system by indigenous mycorrhizal fungi at the planting site. Unfortunately, with our limited knowledge of walnut mycorrhizal relationships, at present it is impossible to recommend a specific organism for artificial inoculation.

The objective of this study was to evaluate the effects of five vesicular-arbuscular (VA) endomycorrhizal fungi on the growth and development of black walnut seedlings.

MATERIALS AND METHODS

The study was conducted within a greenhouse at the University of Missouri-Columbia. Natural light conditions were utilized and temperatures ranged from 25-29 degrees Centigrade. The greenhouse was covered with a shadecloth which transmitted 50 percent of full sunlight.

Five VA mycorrhizal fungi, Glomus caledonius (Nicolson and Gerdemann), Glomus fasciculatus (Thaxter sensu Gerdemann), Glomus microcarpus (Tulasne and Tulasne), Glomus etunicatus (Becker and Gerdemann) and Glomus mosseae (Nicolson and Gerdemann), were used as inocula.

The inoculum was produced by growing each fungus in association with soybeans (Glycine max, Merrill) of the Clark variety. Potting

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soil was steam sterilized and soybean seeds surface sterilized in a 10 percent, sodium hypochlorite solution to minimize contamination. These open pot cultures were maintained in the greenhouse for 110 days until the soybeans flowered. After flowering, the aboveground portion of the soybean plant was removed. The remaining soil-root mixture was allowed to dry, ground, and placed in sterile containers for future use as inoculum.

To minimize genetic variability among the walnut seedlings, half-sib seed of the Thomas variety were selected for uniform size and used in all treatments. The seed were surface sterilized in a 10 percent hypochlorite solution for 60 seconds, rinsed twice in distilled water and pregerminated in sterile vermiculite prior to planting.

The soil mixture consisted of equal volumes of soil, peat and vermiculite. The mixture was steam sterilized at 100 degrees centigrade for a period of 45 to 60 minutes. The mixture was then placed in five-gallon pecan cans (nine inches in diameter, 20 inches deep). The containers were watered repeatedly for a period of ten days prior to inoculation and planting to insure that the entire soil profile was saturated.

Inoculation consisted of thoroughly mixing 400 milliliters of soybean VA inoculum throughout the sterilized soil:peat:vermiculite growth medium. In addition, a cone-shaped area was formed at the surface of the soil mixture and filled with 150 milliliters of inoculum. The germinated walnut was placed directly on top of the inoculum to insure taproot-inoculum contact. Five species of fungi, used either singly or in combination, were employed as inocula. The seven treatments were Glomus caledonius, Glomus mosseae, Glomus microcarpus, Glomus microcarpus (60%)-Glomus fasciculatus (38%), Glomus fasciculatus (56%)-Glomus microcarpus (32%), Glomus microcarpus (48%)-Glomus etunicatus (28%) and a noninoculated control (Table 1) -- the percentages given for the combination treatments represent the proportion of spores present of that particular spore type. The soil was saturated every three to five days throughout the study so that seedlings were never under any degree of water stress.

A completely randomized statistical design involving the seven mycorrhizal treatments was used. Each treatment was replicated three times with five seedlings in each replication, providing 15 seedlings in each treatment. All data were subjected to analysis of variance and the means were analyzed using Duncan's New Multiple Range Test at the 0.05 alpha level.

After 198 growing days, all seedlings were lifted by immersing the entire container in water and loosening the growth medium, thus enabling it to fall away from the root system. Care was taken to insure that the fine feeder roots were retained. Percentage infection, root dry weight, stem dry weight, stem height and stem diameter were determined for each seedling. Percentage infection was assessed by a modification of the root-slide technique of Starkey (1977).

RESULTS

Inoculation of container-grown black walnut successfully produced viable VA endomycorrhizal associations. Incorporation of soybean root fragments and fungal spores grown in open-pot-cultures yielded infection percentages greater than noninoculated controls in all treatments. The percentage mycorrhizal lateral roots ranged from a high of 66 in the *G. microcarpus* (60)-*fasciculatus* (38) treatment to a low of 11 in the control (Table 2). The infection in the control seedlings was attributed to a lack of complete soil sterilization during steaming and not to reinvasion. Inoculation with *G. microcarpus* (60)-*fasciculatus* (38), *G. caledonius*, *G. fasciculatus* (56)-*microcarpus* (32) and *G. microcarpus* (48)-*etunicatus* (28) all resulted in significant increases in infection over the control. Infection percentages were 66, 61, 61 and 54, respectively.

Inoculated seedlings also produced greater root dry weights than noninoculated control stock. *Glomus fasciculatus* (56)-*microcarpus* (32), *G. microcarpus* (60)-*fasciculatus* (38) and *G. microcarpus* (48)-*etunicatus* (28) treatments resulted in significant increases in dry weights of 118, 113 and 98 percent, respectively, over the control. Inoculation with the relatively pure culture of *G. microcarpus* yielded seedlings 83 percent heavier than those produced in the noninoculated treatment.

An apparent correlation exists between percentage infection and root dry weight. Seedlings inoculated with *G. microcarpus* (60)-*fasciculatus* (38), *G. fasciculatus* (56)-*microcarpus* (32) and *G. microcarpus* (48)-*etunicatus* (28) all demonstrated increased root dry weight as a result of increased mycorrhizal infection. However, the root dry weight of *G. caledonius* seedlings was only 51 grams, even though *caledonius* produced the second highest infection percentage (61%). The increased absorptive root surface area of the mycorrhizal seedlings resulted in a significant increase in top growth.

Table 1.--Treatments consisting of six different isolates and/or combinations of VA mycorrhizal fungi (Glomus sp.) and a control which were used to inoculate black walnut seedlings.

Treatment name	Spore types and counts*					Total number of spores per 100 ml soil
	G. cale.	G. micro.	G. moss.	G. fasic.	G. etun.	
Control	-	-	-	-	-	-
G. caledonius	136	35	-	-	-	171
G. mosseae	8	-	49	3	-	60
G. microcarpus	21	89	-	-	-	110
G. micro (60)-fasic (38)	6	100	-	63	-	169
F. fascic (56)-micro (32)	12	34	-	59	-	105
G. micro (48)-etun (28)	-	63	-	33	36	132

*Number in ( ) indicates percentages of total number of spores present of that respective spore type for that particular treatment. G. cale.=Glomus caledonius, G. micro.=Glomus microcarpus, G. moss.=Glomus mosseae, G. fascic.=Glomus fasciculatus, G. etun.=Glomus etunicatus.

Table 2.--The effect of inoculation with VA mycorrhizal fungi (singularly and in combination) from the family Endogonaceae on growth of black walnut seedlings.

Treatment	Infection %	Root dry weight (gm)	Stem dry weight (gm)	Total dry weight (gm)	Stem diameter (cm)	Stem height (cm)
G. micro (60)-fasic (38)	66 a	102 ab (113)	5.5 a (53)	118.9 a (102)	.65 ab (14)	35.9 a (17)
G. fasic (56)-micro (32)	61 a	105 a (118)	5.5 a (53)	121.3 a (106)	.68 a (19)	34.9 ab (13)
G. micro (48)-etun (28)	54 abc	95 abc (98)	4.8 ab (33)	109.7 ab (86)	.64 ab (12)	32.1 ab (4)
G. microcarpus	37 bcd	88 abcd (83)	5.6 a (56)	121.8 a (107)	.65 ab (14)	30.4 ab (-1)
G. mosseae	33 bcd	70 abcd (46)	4.0 ab (11)	82.9 ab (41)	.60 bcd (5)	34.0 ab (10)
G. caledonius	61 ab	51 cd (6)	3.5 b (-3)	61.8 b (5)	.60 bcd (5)	31.6 ab (3)
Control	11 d	48 d	3.6 b	58.9 b	.57 d	30.8 ab

Means not sharing the same letter differ significantly at the alpha =0.05 level according to Duncan's New Multiple Range Test. Number in ( ) denotes the percentage difference from the control.

Mycorrhizal seedlings were consistently larger in diameter and of greater dry weight than those which were not inoculated (Table 2). The single exception was G. caledonius stock which averaged 0.1 g less weight than the nonmycorrhizal seedlings. Inoculation with G. fasciculatus (56)-microcarpus (32), G. microcarpus (60 -fasciculatus (38), G. microcarpus, and G. microcarpus (48)-etunicatus (28) significantly increased stem diameter 12 to 19 percent compared with controls.

Stem height was not affected as dramatically by inoculation as were many of the other growth features. No significant differences were observed between any of the mycorrhizal treatments and the controls. Seedlings inoculated with G. microcarpus (60)-fasciculatus (38), however, were 17 percent taller than the controls; G. fasciculatus (56)-microcarpus (32) and G. mosseae seedlings were 13 and 10 percent taller, respectively.

DISCUSSION

Endomycorrhizal inoculation of black walnut in containers is feasible under greenhouse conditions and, in all likelihood, could also be accomplished in nursery seedbeds. Our results indicate that a suitable inoculum for stimulation of the early development of endomycorrhizae on eastern black walnut may be prepared by grinding the soil and root systems of soybeans, which have been inoculated with one of several species of Glomus. Soil sterilization either by steaming or fumigation (a common nursery practice) will obviously decrease the chance of mycorrhizal development as demonstrated by the control seedlings which had only 11 percent of their root systems colonized.

The early development of endomycorrhizae on walnut seedlings in this study was associated with significant increases in growth and development. Inoculation with G. microcarpus provided an 83 percent increase in root dry weight over the noninoculated controls, while a combination of G. fasciculatus (56)-microcarpus (32) yielded a 118 percent increase. This increased root development is especially important in many Midwest soils, since it enables the seedling to better meet its moisture and nutrient needs.

A complementary relationship between inoculation, root development and shoot development was also pronounced after one growing season in this study. Inoculation with G. microcarpus, G. fasciculatus (56)-microcarpus (32) and G. microcarpus (60)-fasciculatus (38) provided increases in stem weight of more than 50 percent and increases in stem diameter from 12 to 19 percent. Although size is not necessarily a criterion of physiological condition, survival and growth after outplanting is better with larger stock. A common morphological feature used in grading nursery walnut planting stock is stem diameter. Seedlings 1/4-inch (0.64 cm) or larger in diameter survive better and grow faster than smaller ones following outplanting (Williams, 1970). Inoculation with G. microcarpus (60)-fasciculatus (38), G. fasciculatus (56)-microcarpus (32), G. microcarpus (48)-etunicatus (28) and G. microcarpus resulted in stem diameters of 0.65, 0.68, 0.64 and 0.65 cm, respectively. Control seedlings averaged only 0.56 cm which is less than the recommended 1/4-inch limit for culls.

CONCLUSIONS

This study indicates that walnut seedlings greater than 1/4-inch in diameter can be consistently produced by artificially inoculating soils with certain species of Glomus. Production of uniform nursery stock of this size could greatly reduce production costs by reducing the number of cull seedlings. In addition, such stock would exhibit greater survival and growth rates when outplanted.

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A SILVICULTURAL-ECONOMIC MODEL

FOR BLACK WALNUT[1]

Warren H. Kincaid, William B. Kurtz and H. E. Garrett[2]

Abstract.--The level of profitability from investment in black walnut production is directly related to the level of management intensity. Five different management regimes ranging from walnut timber only to timber, nuts, soybeans, winter wheat, fescue hay and grazing are evaluated in terms of internal rate of return and present net worth. Management regimes are synthesized for two sites (SI-80 and SI-65) which support different annual diameter growth rates. Internal rates of return, from least- to most-intensive management, ranged from 6.68 percent to 15.91 percent on the higher quality (SI-80) site and from 4.26 to 13.00 percent on the lower quality (SI-65) site.

Silvicultural-economic relationships within black walnut management regimes are readily examined using a systems studies approach (Johnson and Rausser 1977). Walnut has been encompassed with a comprehensive reporting of management techniques (Funk 1966, Dillow and Hawker 1971, Dillow 1975). Furthermore, much informal information is available from individuals currently growing walnut, educators and researchers. Unfortunately, useful operating data for evaluating economic aspects of walnut growth responses is rather sparse. While literature is available on growth responses to many treatments, few studies have presented adequate economic data. Moreover, few plantations of sufficient age presently exist that have undergone management techniques currently recommended. Complex interactions vary responses of many treatments and hinder the estimation of parameters so necessary for the development of a complete silvicultural-economic model of walnut management systems.

In this paper we will present an examination of several black walnut management regimes. Earlier work (Callahan and Smith 1974, Garrett and Kurtz 1980) integrating the silvicultural and economic aspects of black walnut management have provided the building-blocks for this study.

WALNUT MANAGEMENT REGIMES

The development of a complete, single silvicultural-economic model is not possible at this time due to the lack of adequate data. However, separate models for different walnut management schemes have been developed, with each model containing a number of assumptions concerning recommended treatments and expected growth rates. For the purposes of this analysis, five regimes have been selected:

1) Walnut timber (veneer logs)
2) Timber and nuts
3) Timber, nuts and winter wheat
4) Timber, nuts, soybeans, winter wheat, fescue and grazing
5) Timber, nuts and grazing

Many other regimes exist; each landowner is limited only by land quality and his management preferences.

The schedule of activities for each regime and associated costs and revenues was subjected to an investment analysis using a

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[2]Forester, Missouri Department of Conservation, New Madrid and professors of forestry, University of Missouri- Columbia, respectively.

financial return algorithm developed by Goforth and Mills (1975). Profitability indices are shown in the form of internal rate of return and present net worth. The algorithm also provides a sensitivity analysis for determining proportionate changes in present net worth and internal rate of return to changes in data inputs.

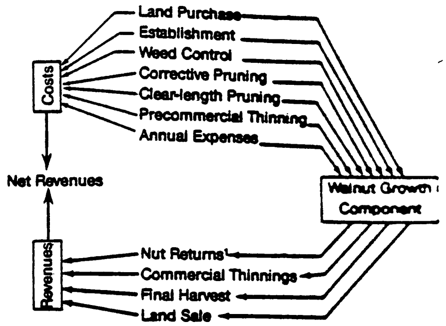
Each regime is analyzed for two different sites, medium quality (SI 65) and high quality (SI 80). The high quality site is assumed to be capable of a DBH growth rate of 1/2 inch per year, while the medium quality site is assumed to be capable of supporting a 1/3 inch per year growth rate. All regimes are carried to a rotation length of 60 years. This combination of options provides 10 different alternatives. Each analysis contains a series of assumptions about activity schedules, prices, yields, costs and benefits associated with walnut management (Table 1).

Walnut Timber

The walnut timber regime emphasizes walnut plantation management specifically for veneer logs (Figure 1). Trees are planted at a 12x12-foot spacing (300 trees per acre) to allow natural pruning and increase the potential for a straight central stem. Planting a large number of trees allows for selection gains since only 27 trees per acre will remain for final harvest. Trees are pruned to heights that allow a 16-foot log to be taken at harvest on excellent sites (SI 80). Prunings and thinnings are scheduled to yield maximum benefits, but also to minimize bole sprouting potential. Thinnings are scheduled to occur when the crown competition factor (CCF)[1/] reaches 110. Each thinning will reduce CCF to 70.

Timber and Nuts

Management techniques in this regime are similar to the walnut timber regime, except pruning and thinning schedules are changed to provide a shorter log and a larger crown to benefit nut production. The ultimate objective involves a series of nut yields beginning in year 20 and lasting throughout the remainder of the rotation; final harvest yields a veneer log that is 10 to 14 feet in length (Figure 1).



[1/]Nut returns would not contribute to the walnut timber regime.

Figure 1.--The relationship between cost and revenue activities associated with the walnut timber and nuts management regime.

Trees are planted at a spacing of 10x40 feet (108 trees per acre) allowing maximum crown development and some opportunity for selection gains. Again, following thinnings, 27 trees remain for final harvest. Thinnings occur when CCF reaches 90 and each thinning reduces CCF to 60. This CCF range, along with a reduction in pruning heights from the timber only regime, will allow maximum development of crown area.

Timber, Nuts and Winter Wheat

Multicropping management regimes include the same schedule of activities as the timber and nuts regime, plus additional agricultural activities (Figure 2). In this first multicropping regime, walnut trees are intercropped with winter wheat for the first 10 years of the enterprise. While it is possible that winter wheat could be produced longer than 10

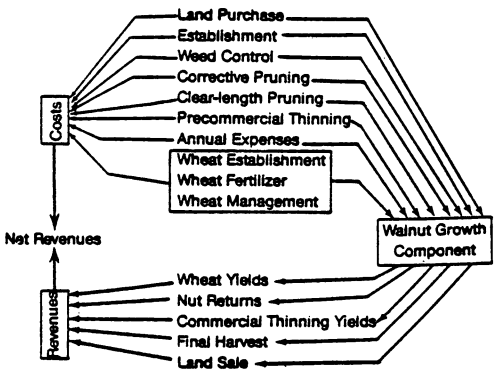


Figure 2.--The relationship between cost and revenue activities associated with the timber, nuts and wheat regime.

[1/]Crown competition factor is an index of competition between trees in a stand. It is expressed as a percentage of the ground area in the stand actually covered by tree crown area (Schlesinger and Funk 1977).

Table 1. Costs and revenues of walnut management by production categories.

Category	Description	Price per unit ($)
Land[1/]	High quality (SI 80)	1000.00/ac
	Medium quality (SI 65)	800.00/ac
	Property taxes	2.50/ac/yr
Labor		6.00/hr
Trees	Establishment (equipment, manpower, stock)	1.25/tree
	Weed control (chemicals and application)	45.00/ac
	Corrective pruning (2 hrs/ac)	12.00/ac
	Management	4.00/ac/yr
	Pruning: 7 ft (5.0 hrs/ac)	30.00/ac
	9 ft (6.0 hrs/ac)	36.00/ac
	11 ft (6.8 hrs/ac)	40.80/ac
	7-11 ft (2.4 hrs/ac)	14.40/ac
	9-15 ft (3.1 hrs/ac)	18.60/ac
	11-17 ft (3.5 hrs/ac)	21.00/ac
	Precommercial thinning:[2/] 2 inch DBH	4.86/sq ft
	3 inch DBH	3.30/sq ft
	4 inch DBH	2.31/sq ft
	5 inch DBH	1.89/sq ft
	6 inch DBH	1.47/sq ft
	7 inch DBH	1.23/sq ft
	8 inch DBH	1.95/sq ft
	9 inch DBH	.90/sq ft
	10 inch DBH	.81/sq ft
	Nuts	9.00/cwt
	Stumpage: 10 ft. log, 10.2" dibse	----
	10 ft. log, 13.8" dibse	40.00 ea
	10 ft. log, 17.0" dibse	226.00 ea
	10 ft. log, 19.8" dibse	370.00 ea
	14 ft. log, 8.9" dibse	----
	14 ft. log, 11.2" dibse	37.00 ea
	14 ft. log, 12.0" dibse	45.00 ea
	14 ft. log, 14.8" dibse	229.00 ea
	14 ft. log, 17.2" dibse	373.00 ea
	14 ft. log, 22.2" dibse	1009.00 ea
	14 ft. log, 25.9" dibse	1446.00 ea
	16 ft. log, 10.5" dibse	38.00 ea
	16 ft. log, 13.8" dibse	243.00 ea
	16 ft. log, 16.0" dibse	396.00 ea
	16 ft. log, 20.7" dibse	1089.00 ea
	16 ft. log, 24.2" dibse	1570.00 ea
Winter wheat	Establishment	31.50/ac
	Management	6.00/ac
	Fertilizer	33.50/ac
	Wheat	4.50/bu
Soybean	Establishment	39.50/ac
	Management	7.50/ac
	Fertilizer	32.00/ac
	Soybeans	11.50/bu
Fescue	Establishment	37.20/ac
	Management	7.50/ac
	Fertilizer	25.80/ac
	Seed	55.00/cwt
	Hay (deduct .15/bale when seed is removed)	.70/bale
Fencing	Perimeter fence: Establishment	42.00/ac
	Maintenance	1.25/ac/yr
	Electric fence: Establishment	49.00/ac
	Maintenance	1.15/ac/yr
	Removal	6.20/ac
Livestock	SI 65 feed costs (1-15 yrs)	26.80/ac
	SI 65 feed costs (16 yrs-rotation)	29.50/ac

SI 65 other costs[3] (1-15 yrs)	29.40/ac
SI 65 other costs[3] (16 yrs-rotation)	32.40/ac
SI 65 receipts (1-15 yrs)	77.60/ac
SI 65 receipts (16 yrs-rotation)	85.40/ac
SI 80 feed costs (1-15 years)	29.50/ac
SI 80 feed costs (16 yrs-rotation)	32.80/ac
SI 80 other costs[3] (1-15 yrs)	32.40/ac
SI 80 other costs[3] (16 yrs-rotation)	36.00/ac
SI 80 receipts (1-15 yrs)	85.40/ac
SI 80 receipts (16 yrs-rotation)	94.90/ac

[1] Land sale price equals its purchase price to synthesize its holding cost.
[2] Precommercial costs are determined using unpublished data on file at the USDA Forest Service Forest Sciences Laboratory, Carbondale, IL. Cost is a function of hourly labor rate, DBH, and the number of trees removed. It is expressed as dollars per. sq. ft. of basal area removed.
[3] Other costs include veterinary and medicine costs, labor costs, utilities and machinery.

years due to the late spring leafing characteristic of black walnut, a conservative 10-year estimate is used because of the lack of supportive data. During this period, yields of winter wheat on the medium quality site (SI 65) are expected to be 10 percent less than on the high quality site (SI 80). Furthermore, establishment of agricultural crops under a multicropping regime with black walnut requires that approximately four feet of noncropped area be left on each side of the trees to facilitate management and reduce competition. This reduces usable agricultural land area by approximately 10 percent.

Timber, Nuts, Soybeans, Winter Wheat, Fescue, and Grazing

This most intensive multicropping, management regime (Figure 3) involves a schedule that includes many aspects of agriculture -- again, these agricultural activities are performed along with the timber and nuts activities. The proposed systems of multicropping are designed with the needs of each crop in mind.

Increasing shade with increasing age of the walnut will reduce soybean yields in years 6-10 by an estimated 20 percent below that expected for years 1-5. Soybean yields are also very sensitive to changes in site quality. Yields on a medium quality site (SI 65) are reduced to 75 to 80 percent of the yields on a high quality site (SI 80). Crop free rows are maintained for the walnut trees to grow with a minimum of competition. Therefore, usable land area is reduced by about 10-20 percent.

After dual cropping soybean and winter wheat for 10 years, fescue is established in the areas between the rows of trees. Just as

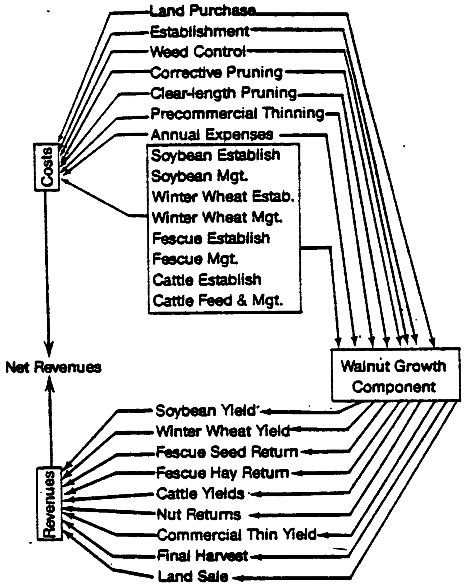


Figure 3.--The relationship between cost and revenue activities associated with the timber, nuts, soybeans, wheat, fescue and grazing regime.

soybean and winter wheat are suitable intercrops with walnut, fescue also appears to be a suitable companion crop once the trees are old enough to have a well-established root system. Research has demonstrated increases in forage quality and quantity when grown in association with walnut (Smith 1942, Garrett and Kurtz 1981). Harvest of fescue seed and hay begins in year 11 and continues until year 15, when shade substantially reduces seed yields. Differences in site quality also result in a 10 percent yield reduction for fescue seed and hay on medium quality sites (SI 65) in comparison to high quality sites (SI 80).

Cattle grazing operations begin in year 16 when fescue seed yields become too low to add revenue to the enterprise. A perimeter fence must be constructed to contain the stock and will remain to the end of the rotation. Interior fencing is not required since, by year 16 or so, walnut trees should be large enough to withstand livestock damage. Techniques of grazing management commonly employed in Missouri are used throughout the rest of the rotation.

Timber, Nuts and Grazing

Grazing operations in this regime (Figure 4) are similar to those found in the intensive multicropping regime with the exception that grazing between rows begins soon after seedlings are established. This necessitates utilization of a tree protection fence system, as well as the perimeter fence. Protective interior fencing consists of an electrically charged wire that is suspended on stakes positioned six feet on either side of a row of trees. The interior fencing remains in place until the walnut trees are sufficiently large to minimize damage from grazing stock.

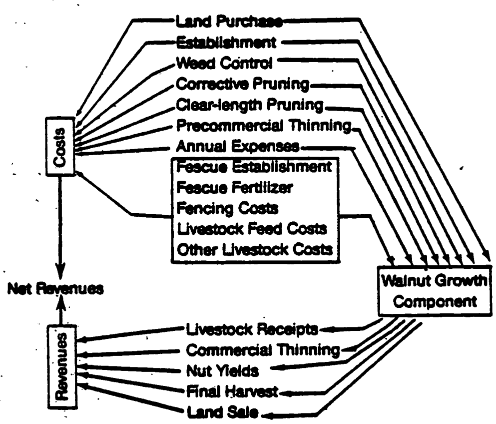


Figure 4.--The relationship between cost and revenue activities associated with the timber, nuts and grazing regime.

INVESTMENT ANALYSIS

Ranking of the five management options by internal rate of return and present net worth within identical site index and rotation age groupings is shown in Table 2. Internal rates of return for the "walnut timber only" regimes were the lowest of all regimes analyzed. This is largely due to the absence of early revenues from annual crops to help compensate for the high initial establishment costs. Establishment costs are very high for timber only

Table 2.--Walnut management regimes ranked by internal rate of return (IRR) within groups of identical site indices (SI) and rotation ages (RA). Present net worth is given for each management regime.

Regimes	IRR (percent)	PNW (7.5%) (dollars)
SI 80, 1/2 inch GR, 60 RA		
Intensive multicropping[1/]	15.91	1951.69
Timber, nuts, wheat	9.36	882.07
Timber and nuts	7.71	133.88
Timber, nuts, grazing	7.44	- 42.01
Walnut timber	6.68	- 575.28
SI 65, 1/3 inch GR, 60 RA		
Intensive multicropping[1/]	13.00	778.62
Timber, nuts, wheat	7.76	65.16
Timber, nuts	5.92	- 559.47
Timber, nuts, grazing	5.52	- 765.17
Walnut timber	4.26	-1198.83

1/ Intensive multicropping refers to timber, nuts, wheat, soybeans, fescue, and grazing regime.

regimes since 300 trees per acre are planted on a 12x12-foot spacing. Establishing 300 trees per acre and harvesting only 27 at rotation end provides an opportunity for selection gains to take place. However, the model used in this analysis did not consider increases in revenue other than those associated with an extra two feet of veneer log taken at commercial thinnings and final harvest.

Lower establishment costs and early revenues from collected nuts helped to increase the IRR of the timber and nuts regimes by about one percentage point above that observed for the walnut timber regimes. Logs taken at commercial thinnings and final harvest are shorter in length, but this allowed a larger crown to develop which increased nut yields. Nut yields are important, not only because of the additional revenue they contribute, but because of the timing of these contributions.

Internal rate of return can be raised 1.5 to 2.0 percent above that observed for the timber and nuts regime by adding a winter wheat management objective for the first 10 years of the enterprise. As with the addition of nut revenues, the additional revenues associated with wheat, and the timing of these revenues help to offset the high initial establishment costs.

The addition of grazing operations when establishing a timber and nuts regime provided very little benefit in terms of IRR. High fencing costs reduce the profitability of this regime. Grazing operations could be suspended until approximately year 16, thus eliminating the need for protective fencing due to the substantial size of the walnut trees.

Intensive multicropping is a useful practice in helping to offset high initial establishment costs that include high land prices paid for better sites. In most cases, the higher cost paid for high quality land is too extreme to be offset by added revenues from increased wood yields. However, this is not true in the timber, nuts, wheat, soybeans, fescue and grazing regimes. Here, added revenues from increased wood and crop yields more than offset the higher land price.

CONCLUSIONS

Growing black walnut either for wood products only, for both wood and nuts or in a multicropping management regime can be a profitable, as well as enjoyable, endeavor. Level of profitability is closely linked to intensity of management.

Quality of site also influences the level of profitability within respective management regimes. Obviously, the greatest influence of the higher site quality is apparent with the most intensive multicropping regime.

Multicropping management offers the greatest returns because of its more intensive use of land. While slight sacrifices might be made in agricultural crop yields and wood and nut production, the early returns from agricultural production offset the high initial cost of walnut establishment and permits substantial increases in profits.

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THE CHANGING STATUS OF PRIME AGRICULTURAL LAND: FUTURE IMPLICATIONS[1]

Luther B. Hughes, Jr.[2]

Abstract.--Losses of prime agricultural land used for food production in the U.S. continues at an alarming rate. Losses of millions of acres of land to erosion, fuel and fiber crop production and conversion to non-agricultural use, i.e. urban development, highways, etc. occur annually. Conversion to non-agricultural uses alone exceed one million acres annually. Continued losses of this magnitude of food production potential has implications of changing the U.S. to a non-food exporting country, a serious blow to world hunger demand.

INTRODUCTION

World population is increasing at the rate of more than 180,000 persons per day (Brown, 1978). The resulting annual increase in world population is equivalent to more than one-third of the entire U.S. population. This population increase has caused concern about adequate food production, especially for the future. Thomas Malthus, in the early 1800's, projected that human population would increase geometrically and food production would only increase arithmetically. Although the United States is a notable exception, the Malthusian theory has been shown to be quite prophetic. This paper attempts to point out how the potential for food production in the future is being dangerously reduced, particularly in the U.S., by large losses of prime agricultural lands due to current land use practices and changes in land use.

Food production requires many inputs, including acceptable environmental and climatic conditions, available nutrients, proper control of pests including weeds and potentially productive soils or land. Barber (1976) discussed the importance of better nutrient efficiency and availability of nutrients for future food production. Hughes (1971) stressed the importance of proper pest control for maintaining high crop yields. However, with these inputs, the availability of highly productive soils is still necessary.

LOSSES IN PRIME AGRICULTURAL LAND

Significant losses of highly productive prime agricultural lands are matters of great concern. Trends in U.S. land use are shown in Table 1. Soil, relative to length of human life, is a non-renewable resource. Yet soils are often managed as if they are quickly regenerated.

Cropping Systems Alterations

Petroleum shortages in the 1970's brought additional new pressures for land use with suggestions of crop production for alternative fuel production. Alcohol production from grain crops, use of biomass and oils from crops may eventually prove economically feasible. As production of these "fuel crops" increases, a subsequent decrease in available acreages for food production follows. Projections of over 20 million acres for grain for alcohol production alone have been reported in the National Agricultural Land Study.

Similarly, if petroleum shortages continue, the manufacture of synthetic fibers may be

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[1] Paper presented at the Walnut Council/ NNGA Symposium, West Lafayette, Indiana August 9-14, 1981.

[2] The author is Associate Professor, Agronomy Department, University of Missouri-Columbia.

jeopardized. Subsequent increases in fiber crop production may likely occur. The extent of food cropland "lost" will closely parallel the extent of fiber crop acreage increase.

Table 1.--Trends in Land Use. Includes United States, Puerto Rico, and Virgin Islands. Excludes Alaska.[1]

	1958	1977	Percent
	(Millions of Acres)		Changed
Cropland	448	413	- 8
Pastureland, native pasture, and rangeland	485	541	+12
Forest land	453	370	-18
Urban land (over 10 acres)	51	90	+76
Small areas of open water	7	9	+29
Other	60	77	+27
Total	1,504	1,500	

Accelerated Soil Erosion

The greatest pollutant of U.S. streams and rivers is soil. Most sediment originated as topsoil before detachment and removal by water. Few resources have been so badly managed or so quickly depleted. Soil is renewable only in geologic terms often requiring hundreds of years for an inch of soil development from bedrock. Conversion of land to more intensive crop use, i.e. pasture land or forest land to row cropland, often preceded accelerated erosion. One-third of the present U.S. cropland has already been lost by erosion (Pimentel, et al., 1976).

Natural processes of soil formation allow tolerable or permissible erosion to average 3-5 tons/ac/yr implying that soil formation at that rate allows no loss in productivity (Kohnke, 1969). However, soil erosion often far exceeds the "tolerable" limit. Average soil losses in excess of 10 tons per acre of cropland have been occurring in recent years in Tennessee, Mississippi, and Missouri while in the Corn Belt, cropland losses in Iowa have exceeded 9 tons/ac/yr. These soil losses can dramatically reduce productivity for the distant future. Losses of soil from the most productive lands also cause additional pressures to consider more intensive uses of more sloping marginal lands for producing food crops. Even more serious erosion may then result.

[1]"America's Soil and Water: Condition and Trends", USDA, Soil Conservation Service, December 1980.

Conversion to Non-Agricultural Uses

Few losses in agricultural lands are so permanent as losses to non-agricultural uses. Demands for land for urban, transportation and water resource development uses exceed 3 million acres each year. In many instances, these demands have chosen the very best land, prime agricultural land. Prime agricultural lands were removed at the rate of one million acres per year from 1966 to 1975 according to the National Agricultural Land Study. In most instances, buildings, concrete, asphalt or water render this land permanently useless for agricultural production.

This loss is so serious that Florida, New Hampshire and Rhode Island will lose all their prime agricultural land within 20 years if the current loss rate continues. Many other states will lose over ten percent of their best crop producing lands (Fields, 1980).

POSSIBLE SOLUTIONS

National policy decisions will play a large role in determining whether food production will be adequate to meet U.S. needs of the future. Conversion of land to fuel and fiber crops will reduce land for food production. Economics and petroleum supply may dictate that decision process.

Accelerated soil erosion cannot continue at present rates without greatly reducing the soil's productivity. Advances in conservation tillage or reduced tillage methods will hopefully play a strong role in reducing erosion. Careful management of marginal lands will be necessary. Hupe (1981) reported that walnut production had a positive effect on forage production, especially fescue. Findings of this nature may help offset yield reductions due to erosion. If voluntary soil conservation efforts do not progress, legislative action may force stringent agricultural land use; action not likely to be well-received by many landowners.

Lastly, huge losses of prime agricultural lands to non-agricultural uses will necessitate immediate action. Table 2 shows agricultural land uses in 1977 in various regions of the U.S. while in Table 3 lands with potential for conversion to cropland are shown. However, continued losses of 3 million acres of land each year will be devastating to U.S. food production and must be reduced. As with soil conservation efforts, if losses of prime agricultural land continue, legislative restrictions on land use (zoning) will likely come to fruition.

Table 2.--Agricultural land uses in 1977 in selected census regions (millions of acres).[1]

Census Regions	Crop Land	Pasture Land	Range Land	Forest Land	Other Lands in Farms	Total
West	65.8	12.6	229.3	63.2	1.4	372.3
North Central	228.6	41.6	71.1	69.1	7.2	417.6
South	101.6	72.7	113.6	181.7	2.0	471.6
North-east	16.9	5.8	———	62.3	1.5	86.5
TOTALS	412.9	132.7	414.0	376.3	12.1	1,348.0*

*Excludes 10.9 million acres of "Farmsteads."

SUMMARY

Currently, the United States is a major food exporting country. New developments in using marginal land and in technology and plant breeding will likely allow higher yields per acre if other production factors remain constant. However, losses of prime agricultural lands to erosion, fuel and fiber production, and non-agricultural uses threaten our overall food production system. Efforts through research and conservation provide some promise for stemming these losses. Otherwise, Norman Berg, chief, USDA Soil Conservation Service, may well be correct in his statement: "Ten years from now, Americans could be as concerned over the loss of the nation's prime and important farm lands as they are today over shortages of oil and gasoline" (Fields, 1980).

[1]"Agricultural Land Data Sheet, America's Land Base in 1977," National Agricultural Lands Study, Interim Report 2, 1980.

Table 3.--Agricultural land with high and medium potential for being converted to cropland, by selected census regions and by 1977 land uses (millions of acres).[1]

Census Region	1977 Land Uses: Pasture land	Range land	Forest Land	Other	Total
West	4.0	14.2	1.1	0.3	19.6
North Central	18.8	12.5	7.0	2.0	40.3
South	26.6	12.2	20.6	0.7	60.1
North-east	1.9	———	2.2	0.5	4.6
Total	51.3	38.9	30.9	3.5	124.6*

*About 2 million acres of "Other Nonfarm" has potential for conversion to cropland.

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A CASE STUDY OF BLACK WALNUT MANAGEMENT COSTS[1]

James E. Jones[2]

Abstract.--Intensive management is required to produce quality eastern black walnut trees. Weed control, fertilization and pruning are three important management practices for which the component costs are contained in this paper.

The culture of eastern black walnut (Juglans nigra L.) in a multicropping program requires intensive tree care. The tree must be cared for from its initial placement in the field to insure that weeds are controlled, soil fertility levels are adequate, and the desired tree shape is maintained.

Costs presented in this paper have been extracted from records maintained for Sho-Neff Plantation which is owned by Hammons Products Company of Stockton, Missouri. The project consists of 480 acres with 240 acres planted to trees. There is a total of 19,464 trees ranging in age from 3 to 7 years. Two thousand seven hundred and ninety are planted on a 40'x20' spacing with the remainder being on a 40'x10' spacing.

Sho-Neff Plantation is located in southwest Missouri near Stockton. The project is managed for the production of conventional agricultural crops, research, and demonstration within the multicropping framework. In Table 1 is presented costs for a one-time treatment of weed control, fertilization, and pruning.

CHEMICAL WEED CONTROL

Weed control on the project is carried out in several manners as conditions dictate. However, the only costs to be included here are for primary weed control or the application of chemicals during the spring.

Table 1.--Costs of primary weed control, fertilization and pruning in a large eastern black walnut plantation.

	Weed Control	Fertilization	Pruning
	----- (dollars per tree) -----		
Materials	$0.045	$0.063	---
Labor	0.013	0.038	$0.067
Equipment	0.024	0.004	0.004
Management	0.008	0.010	0.007
TOTAL COSTS	$0.090	$0.115	$0.078

Acceptable results have been obtained by applying a mixture of Roundup and Princep in a two and one-half foot band along each side of the row of trees. The chemicals are applied with a tractor mounted sprayer and side mounted boom. The boom is equipped with electric solenoids and no-drip nozzles to facilitate control and minimize application to crop areas.

The rate of application is 4 pints of Princep 4L and 3 pints of Roundup in a solution of 100 gallons of water. The equipment is calibrated to apply this mixture to one acre (8,712 feet of row length with a 2 1/2' band on each side).

Time used in application of the chemicals required 78 man hours and 51.7 hours on the tractor. The component costs of primary weed control are illustrated in Table 1.

[1]Paper presented at the Walnut Council/NNGA Symposium, West Lafayette, Indiana, August 9-14, 1981.

[2]Director of Forestry Practices and Management, Hammons Products Company, Stockton, Missouri.

FERTILIZATION

Individual tree fertilization has been performed only one time since tree establishment. The application was made during late winter and early spring of 1980. A fertilizer blend (N-P-K) of 12-12-12 was surface applied within the dripline of all trees at the rate of 1 pound of product per inch of stem diameter.

The fertilizer was delivered to various drop points in 50 pound bags by tractors, then distributed by hand using buckets and calibrated containers. One hundred sixty-one (161) man hours were required to fertilize 19,464 trees with 15,470 pounds of fertilizer. See Table 1 for a complete presentation of fertilizer costs.

PRUNING

Pruning is necessary for most open-grown eastern black walnut trees. To date all pruning at Sho-Neff Plantation is done with hand pruners, lopping shears, and hand saws.

Pruning is done primarily in February, March and early April. The pruning program includes both the conventional pruning and tip pruning. Consequently, the time element is greater than would normally be experienced for trees in this age and size class. However, some trees, due to their size and condition, will no longer be tip pruned.

During the winter and spring of 1981 all trees were individually inspected and treated. The time involved was 244.5 hours. Table 1 illustrates additional costs.

SUMMARY

Producing quality eastern black walnut trees requires intensive management. It is well established that weed control and pruning are essential with the jury still out on fertilization. However, from the standpoint of multiple crops, it is possible that we can justify the additional expense to maintain the plant in a high state of vigor.

There is a definite cost advantage to the operation of a large planting. For small plantings which are widely separated and operated from a central location the costs could easily double.

BLACK WALNUT MANAGEMENT COSTS: RESULTS OF THE 1981 SURVEY[1]

Timothy D. Marty and William B. Kurtz[2]

Abstract.--Costs are described for various cultural practices related to the management of black walnut. Average costs were obtained from a survey of Walnut Council members to which 91 growers responded. A cash flow for a "typical" walnut plantation was synthesized from the average costs and timing of practices reported in the survey. Our analysis indicates that a modest internal rate of return of 6.64 percent could be realized on all costs made prior to the time of investment maturity. The present net worth of the cash flow would be $519.18 per acre, discounted at a 5-percent interest rate.

Black walnut management involves many decisions within the constraints of the resource base and subject to the motivations and objectives of the individual grower. These decisions affect the amount and timing of costs and revenues and resulting profitability of the program. During the summer of 1980 a mail survey was conducted with members of the Walnut Council to further define some of the costs of walnut management. Results are reported in Kincaid and Kurtz (1981).

In the summer of 1981, a similar questionnaire was mailed to Walnut Council members seeking cost information on their walnut growing operations. Ninety-one growers responded. Many of the returned questionnaires had unanswered questions where treatments had not been applied, or costs were unknown. The cumulative usable response, however, offers some insight into black walnut management as it is being practiced by members of the Council.

MANAGEMENT CONSIDERATIONS

Responses to the 1981 survey were coded into 50 separate variables. These fall into four categories giving information on the respondents, land and timber resources, costs and revenues.

Management Objectives and Motivations

Walnut grower characterization is based on management objective and motivation. Of the respondents, 45 percent named timber production as their primary objective, 27.5 percent cited timber and nut production, resource preservation was valued highest by 11 percent, and the remaining 16.5 percent selected multicropping or a combination of objectives. Responses to the question of management motivation were divided almost evenly between three major categories; personal satisfaction (26.4%), financial return from timber and/or nuts (23.1%) and long-term investment or speculation (22.0%). This would indicate that while a large percentage of growers manage for timber or timber and nuts, less than one-quarter do so for financial return. Financial profitability does not appear to be a dominant motivating factor in walnut management for many growers.

Resource Base

The resource base is comprised of variables representing stand area and age, and land value and quality (Table 1). Areas of walnut stands generally appear to be small. More than half of the respondents have 10 acres or less of planted walnut and 90 percent have 50 acres or less. Similarily, nearly three-fourths have less than 10 acres of naturally occurring walnut stands, with 20 percent indicating no natural stands.

Most walnut stands are also relatively young. Plantation age is less than 10 years on 81 percent of the land, with over half being less than 5-years-old. Natural stand age is a

[1]Paper presented at the Walnut Council/ NNGA Symposium, West Lafayette, Indiana, August 9-14, 1981.

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Table 1.--Summary of black walnut management data, 1981 survey of black walnut growers.[1]

Category	Units	Responses (number)	Mean	Standard deviation	Range
Acres planted	acres	85	19.25	27.11	0.0 - 137.0
Acres natural	acres	69	13.54	20.22	0.0 - 85.0
Site index	feet/50 years	10	67.70	8.54	55 - 88
Land purchase price	$/acre	74	375.11	358.58	14.0 - 2000.0
Land current value	$/acre	74	1497.97	1172.91	300.0 - 6500.0
Number of trees	trees/acre	76	458.82	686.30	27.0 - 4840.0
Stock cost	$/tree	64	0.28	0.89	0.0 - 7.0
Site prep cost	$/acre	62	27.06	67.70	0.0 - 400.0
Planting cost	$/acre	56	45.48	87.60	0.0 - 500.0
Weed control	$/acre	44	21.91	28.28	0.0 - 125.0
Corrective pruning	$/acre	16	15.01	16.51	0.0 - 50.0
Corrective pruning	$/tree	--	---	---	-----
Height pruned	feet	33	10.94	5.09	3.0 - 23.0
Age pruned	years	28	12.53	8.34	2.0 - 40.0
Pruning cost	$/acre	9	48.11	55.70	0.0 - 150.0
Thinning cost	$/acre	6	32.00	25.81	5.0 - 80.0
Annual tax	$/acre/year	49	6.81	10.06	0.0 - 50.0
Management cost	$/acre	19	20.61	26.90	0.0 - 100.0
Hourly labor wage	$/hour	16	4.19	1.64	0.0 - 8.0

[1]Respondents to May, 1981 survey.

little more evenly distributed, but still only 28 percent of the stands are older than 10 years.

Only 10 respondents knew the site index[1] of their land (mean value 67.7) so the descriptive estimation of land quality provides a better estimate of the type of land being used to grow walnut. Landowners rated their land as excellent (27%), good (55%), fair (16.9%) and poor (1.1%). Most of the respondents indicated their land was used as pasture or crops before walnut production (79%), with only 19 percent indicating woods as a predecessor to walnut. Two questionnaires were returned by people growing walnut on land formerly mined.

Land purchase price varied widely from $14 to $2000 per acre, with an average value of $375. Price variation is largely attributable to time of purchase (1916-1980); over one-half of the respondents indicated their land had been purchased since 1970. Current land value was estimated at about $1500 per acre, with the most frequent response being $1000 per acre. Weighted mean land value was not calculated.

Management Costs

Costs associated with black walnut operations are incurred at many different times in the course of a rotation. Cost variables included in the questionnaire can be grouped into the general areas of site preparation, planting and establishment, weed control, pruning, thinning costs and annual taxes.

Site preparation

No dominant method of site preparation is apparent. One-fourth of the respondents used no site preparation at all, one-fourth used plow and disc, and the remainder used mowing, chemicals or some combination of these methods. Some 45 percent of the owners listed no site preparation cost, apparently either choosing to not place a cost on their labor, or only a small percentage of their land required preparation due to prior management practices (i.e., pasture/crop). Of those who did list a cost, the average value was $27 per acre.

Planting

Planting was most frequently done with a spade (38%), bar (18%), machine (15%) or auger (15%). Over 90 percent of the respondents planted seedlings. Average seedling cost was $0.25 per tree, although a large number of individuals indicated they had received free seedlings. Average planting cost was about $45 per acre. No correlation could be found between planting cost and planting method. Planting was done at an average of 458 trees per acre, approximately a 10-foot x 10-foot spacing. Only 15 percent of the planting was contracted out, the remainder (85%) was done by the landowners at an average time of 15 hours per acre.

[1]Site index represents the average height (feet) a tree will grow in 50 years.

Weed control

Weed control most often involved some combination of mowing and chemicals (49%). This was accomplished at a cost of about $22 per acre. When chemicals were used, they were usually spot applied at an average diameter of about 3 feet.

Pruning and thinning

It is difficult to draw conclusions relative to corrective pruning because of the low response rate. Landowners appear to either not have practiced or lack adequate records of these silvicultural treatments. Corrective pruning usually takes place at ages three and four years. The cost of corrective pruning averaged about $15 per acre, and about 9 hours of labor per acre were required. Cost is low in relation to the labor requirement because over one-third of those answering the question assigned no cost to their corrective pruning, apparently counting their own labor as zero. Pruning is generally done at the age of 12 years, to a height of 11 feet, at an average cost of about $48 per acre. Thinning was indicated by only seven landowners at an average age of 19 years and cost of $32 per acre. It is likely that because of the young age of many of the stands, as noted earlier, no thinning has been needed thus far.

Taxes and management

Two additional costs included in the survey were annual tax and management. Averages are $6.80 per acre for annual tax and $20 per acre for the management cost. Most landowners reported paying less than $5.00 per acre annual tax, but several respondents indicated paying in excess of $20.00 per acre which inflated the average value. Further refinement is needed in the questionnaire to more accurately determine these costs. Future questionnaires will list the specific items to be included as management costs.

ECONOMIC MODEL

An economic model was developed based on the cash flows described in the preceding section. This model represents a "typical" acre under black walnut management for veneer production utilizing the timing and dollar magnitude of the various management practices observed from the survey results. In order to preserve consistency within the model, land purchase and holding costs, annual taxes and management costs have not been included. The categories of practices in the model and their respective costs and times of application are shown in Table 2.

Table 2.--Black walnut management cash flow.

Category	Year(s) incurred	Cost
		($ per acre)
Site preparation	0	27.00
Planting stock	0	126.00
Planting	0	45.50
Initial weed control	0	22.00
Weed control	1-3	22.00
Corrective pruning	3-4	15.00
Pruning (10 feet)	10	48.00
Pre-commercial thinning	15	50.00
Pruning (17 feet)	16	48.00
Thinning	30	0.00
Thinning	40	0.00

Category	Year	Revenue
		($ per acre)
Thinning	48	520.00
Final harvest	60	6102.00

Our "typical" one acre stand is located on a low- to moderate-quality site capable of sustaining a one-third inch per year growth rate. To obtain veneer quality material over the course of the rotation, a 60-year length was assumed. Initial costs include site preparation ($27/acre), planting stock (450 seedlings @ $.25/seedling), planting ($45.50/acre) and initial weed control ($22/acre). Additional weed control would be administered in years one through three at a cost of $22 per acre. In years three and four corrective prunings would cost $15 per acre. Two prunings are planned at age 10 to a height of 10 feet, and at age 16 to a height of 17 feet.

A precommercial thinning at age 15 costs $50 per acre (225 trees removed @ $.22 per tree). Two self-supporting thinnings are planned for years 30 and 40. In these operations the revenue received from the sale of removed material is presumed to offset the cost of thinning. Seventy-five trees are removed in year 30 and 110 trees in year 40.

A commercial thinning of 13 trees occurs in year 48, returning $520. These trees should average just over 16 inches dbh and contain 60 bd. ft. per stem. A current average stumpage price of $.67 per board foot was used to calculate the value of this thinning material. Final harvest of 27 trees at rotation end in year 60 produces $6,102 in revenue. It is anticipated that these trees will average 20 inches dbh and yield around 100 bd. ft. per tree. A current average stumpage price of $2.13 per bd. ft. was used to calculate the value of the material removed during the final harvest. All revenues were inflated at a 1.5 percent annual rate to arrive at the future value of stumpage produced. This figure, based on observable trends within the walnut stumpage market, represents the average annual price increase over and above all other costs and returns (Hoover 1978).

It should be noted that no revenues from nut production were included in the model. However, as shown by Garrett and Kurtz (1981), substantial increases in profitability can accrue to a walnut producing enterprise by including nut production in the management scheme.

The internal rate of return (IRR) yielded by this "typical" plantation was 6.64 percent. This represents the average interest rate earned on all costs prior to the time of investment maturity at the end of the rotation. Present net worth (PNW) of the investment computed at a 5 percent interest rate was $519.18 per acre. This is the net value of all costs and revenues discounted back to the present time at a 5 percent interest rate. Obviously if land costs exceed $500 per acre the investment, as structured here, will not yield a 5 percent return. This finding is consistent with returns to the "basic" black walnut enterprise model developed by Callahan and Smith (1974).

CONCLUSIONS

Investment in black walnut as structured for our "typical" plantation yields modest returns. Our analysis does show that walnut is being managed in a profitable fashion. Treatment costs involve only a very small portion (less than 10%) of all costs of the walnut enterprise. These expenditures yield substantial benefits through increased size and higher quality material at harvest.

Increased returns to black walnut management can be achieved from various factors not specifically addressed in this analysis. Management for nut production and/or the adoption of a multicropping management scheme both have the potential for enhancing the profitability of the basic wood producing enterprise.

Obviously, the plantation as constructed is "typical" only in the sense that it represents an average based on the various management experiences of a group of walnut growers. It should be kept firmly in mind that the sample group has widely divergent management objectives and motivations as well as different socioeconomic characteristics. Nonetheless, this should not deter from the usefulness of our analysis in describing the responses to the 1981 survey. The relationships of the treatment cost averages we have presented are important, not only to each other but also to the overall enterprise. Black walnut growers must be familiar with their treatment costs as a matter of good business practice.

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A CRITICAL LOOK AT THE EXPECTED RETURN ON INVESTMENT FROM PLANTING BLACK WALNUT SEEDLINGS[1]

By Dwight R. McCurdy[2]

Before investing money, time, and land in planting black walnut seedlings several factors should be considered by anyone placing a positive value on their money. First, a person should realize any money spent purchasing, planting, and caring for walnut seedlings has a greater cost than the out-of-pocket expenditures for the seedlings. To illustrate, if $100 are to be spent in purchasing and planting seedlings, the owner before making the investment has at least two alternatives: (1) putting the $100 in a coffee can and burying it, and (2) placing the money in a relatively risk free federally insured savings account. Assuming 40 years passes, the amount in the coffee can (assuming it can be found) will still be $100. However, the money in the savings account would be $1,498 if the bank paid seven percent compounded annually. To be completely accurate, the investor would only have $1,048.60 after taxes if he was in the 30 percent income tax bracket. Therefore, the person planting the walnut seedlings should have at least $1,048.60 after selling the trees and after taxes (assuming no other costs). The actual amount the walnut investor will receive from his investment will depend on many factors--some of which are listed below:

1. The amount of money for which walnut trees can be sold at maturity;

2. The additional monetary costs and returns resulting from growing the walnut trees;

3. Other costs and returns (externalities) that result to the investor from growing walnut trees;

4. The opportunity for additional investment alternatives; and

5. The risks and uncertainties involved in growing walnut trees.

Table I contains the estimated costs and returns per acre for an hypothetical walnut investment. This "basic model" of a black walnut plantation was developed by Callahan and Smith in 1974. It should be recognized these costs and returns were developed for a specific site and were based on several assumptions. For example, sites vary in suitability for walnut timber production. The rate the trees grow and the survival rate for individual trees will vary between sites. These two assumptions are major factors affecting the profitability of the investment. Therefore, as a minimum a forester should conduct a site analysis to determine the expected growth and survival rates relative to the appropriate silviculture treatments needed for walnut timber production.

In critically analyzing the applicability of Callahan's basic model (for an hypothetical walnut investment) for other walnut investment opportunities we will first discuss Item One, Table I, land cost. It is well accepted that land values vary widely thereby making generalizations about the return on investment from a given site suspect. However, it is recommended that land values not be included in walnut investment analyses. Land in itself is an investment and appreciates in value regardless of use as long as its character isn't degraded. This appreciation in land value may be at a faster rate than the returns from the land's use thereby making the combined investments of land and land use appear better than the investment in land use alone. It should be pointed out this situation is nearly 100 percent valid relative to forest production investments. For example, land values may increase at a rate of 10 percent compounded annually in comparison to less than 5 percent obtained from monies invested specifically in timber production. One negative aspect of leaving out land costs (or value) is that holding or opportunity costs of the land over the investment period are not accounted for in the analysis.

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[1]Paper presented at Walnut Council Annual Meeting, Purdue University, West Lafayette, Indiana, August 13, 1981.

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The second expense item in Table I contains the initial establishment costs other than seedling and planting expenses. These expenses could vary from nothing to a relatively large amount depending on the condition of the land. For example, fencing to prevent grazing by cattle may be necessary.

The third expense item, cost of the planting stock, is a critical item since it depends on the spacing between seedlings and in turn spacing dictates the number of seedlings per acre. Spacing also affects (1) the silvicultural treatment costs, (2) expected growth rates, and (3) quality of the harvested stem. For example, spacing may vary from 10 x 10 feet (435 trees per acre) to 40 x 40 feet (27 trees per acre).

The fourth expense item, planting costs, can also vary widely between investment opportunities. For example, one site may be suitable for machine planting with no site preparation expenses while at the other extreme another site may require hand planting and then only after bulldozing a residual stand of undesirable trees.

The next seven expense items are specified by a given silvicultural prescription which should vary with site conditions. As mentioned earlier, a forester should be consulted to determine the alternative silvicultural treatments that will be needed for the specific site being considered. For example, Callahan selected his hypothetical treatments from the following alternatives:

Method 1. Completely disk the planting area and control subsequent weed growth by the application of chemicals.

Method 2. Completely disk the planting area and control subsequent weed growth by cultivation.

Method 3. Completely disk the planting area and limit subsequent weed control to spots or strips around the planted tree with weeds between treated areas controlled by mechanical means such as mowing or cultivation.

Method 4. Completely disk the planting area and limit subsequent weed control to spot weed control around individual trees using chemicals.

Not only should the silvicultural prescriptions vary between sites (investment situations), the costs of accomplishing a specific task such as pruning will differ between investors. For example, one landowner may already own the equipment needed and he might also have the skill to perform the tasks, while on the other hand, another investor may be required to hire the complete performance of the task. More specifically, one person may own "old" equipment resulting in a small capital investment while a second person may have "new" equipment with a comparatively higher capital investment but lower operation costs.

A more important consideration when calculating the expected expenses is the fact most expenses occur in the future requiring the investor to be a futurist. The model as presented by Callahan specified no increase in silviculture treatment costs for like tasks thereby assuming that today's expenses will remain parallel to inflation in amount. However, recent history has demonstrated silvicultural treatment expenses increase at a greater rate than inflation.

Expense item 12, administrative costs such as taxes, insurance, etc., which occur annually seem relatively small but when accumulated, these expenses result in a large proportion of the total. In fact, a small variation in the amount of administrative expenses can significantly effect the profitability of the investment.

The final expense item in Callahan's basic model, self-supporting thinning, was placed at zero costs under the assumption it should be done with revenues from fence posts. Here again, if there is no market for fence posts, firewood, etc., the profitability of the investment is greatly reduced. Furthermore, if proper thinnings are not performed the length of time to final harvest is significantly lengthened. The time period between planting and final harvest is one of the major elements in determining the size of the return on the investment.

On the other side of the ledger are the revenues generated from the walnut investment. The amount of revenues is dependent to a great extent on the quantity and quality of timber available for thinning and harvest. But, as mentioned earlier, timber availability is in turn dependent on site conditions, spacing, silvicultural treatments and environmental conditions (climatic, disease, insect, etc.) over the life of the treatment. All these can vary dramatically for different investment opportunities. For example, survival of planted seedlings to maturity can vary from less than 10 percent to over 80 percent. Also, the volume per acre at 50 years can vary between 2,000 and 16,000 board feet depending on the site and original spacing.

Also, similar to expenses, most, if not all, revenues occur in the future thereby making realistic estimates difficult. For example, the price received from the walnut timber varies significantly with the following:

1. The form in which the timber is sold; such as (1) on the stump, (2) as logs at the logging site, or (3) as logs delivered to the buyer;

2. The market conditions at the time of the sale. The timber industry is very cyclic relative to prices since the demand is derived from the demand for a finished product of much greater relative value; and

3. The product into which the timber will be processed; such as lumber versus veneer. Veneer walnut is the only product having sufficient value to even consider possible investment. If an export market is available the chance to receive favorable veneer prices is also enhanced since export prices generally are much higher than domestic prices.

In Callahan's basic model, prices were assumed to remain parallel to inflation as indicated by using 1974 prices. However, unlike expenses, prices over the recent past have paralleled inflation. For example, average walnut prices in Illinois between 1967 and 1976 increased 83 percent and the wholesale price index also increased 83 percent (McCurdy, 1977).

When determining the return on investment, the present or discounted value of all expenses must be equalled with the present value of all revenues (Column 5, Table I). The discount or interest rate that results in expenses equalling revenues is the rate of return on investment. For Callahan's basic model, with land values being eliminated, the rate of return was 6.5 percent.

It is this 6.5 percent that the investor should compare with his alternative opportunities such as placing his money in a can, savings account, etc. However, to be rational the following adjustments must be made to the return on investments being compared:

1. All returns should be after taxes have been deducted. Forestry, because of capital gains, has an advantage relative to land uses returning annual revenues.

2. The rate of returns should be adjusted for risk and uncertainty. For example, the probability of not receiving the estimated future revenues is generally greater with forest investments in comparison with most other land use investments.

3. The externalities from the investments should be compared. For example, forest investments often enhance the recreation values received from a tract of land.

4. If the investment is to be continued by heirs, what is the probability they will have the same time preference for their money as the original investor and an identical interest in forestry or natural resources. The rate of change in land ownership on the average indicates the above probability is very small.

CONCLUSION

When analyzing the potential return on investment from black walnut timber production, site and time specific estimates are needed relative to the expected costs and returns. Generalizations from data published from other sites and ownership conditions can lead to significant differences. In most cases, the assistance of a consulting forester is advised.

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Table 1. Basic Model of a Black Walnut Plantation Investment, Per Acre.

Item Number	Item	Year of Occurrence	Actual Value (Dollars)	Present Value (6.5% Discount Rate)
EXPENSES:				
1.	Land	0	350	N.A.
2.	Initial Establishment	0	70	70
3.	Planting Stock	0	30	30
4.	Planting	0	25	25
5.	Weed Control (Cultivation & Chemical)	0	35	35
6.	Weed Control (Chemical)	2	15	13
	Corrective Pruning		10	8
7.	Weed Control (Chemical)	3	15	12
	Corrective Pruning		10	8
8.	Weed Control (Chemical)	4	15	11
	Corrective Pruning		10	7
9.	Pruning to 8 feet	8	90	54
10.	Pruning-50 select t.p.a.	13	50	22
11.	Thinning	15	0	--
12.	Annual Charges	1-50	10	144
				439
REVENUES:				
13.	Thinning	25	50	10
14.	Thinning	35	200	22
15.	Final Harvest	50	9500	407
16.	Terminal Land Value	50	350	N.A.
				439

Source: Callahan and Smith, 1974.

WALNUT RESOURCE: AVAILABILITY AND UTILIZATION

Presented at the NNGA/Walnut Council Joint Meeting
Purdue University, West Lafayette, Indiana, August 13, 1981

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Abstract -- Walnut Resource: Availability and Utilization

High quality black walnut trees for lumber, veneer, and gunstocks are still in a somewhat short supply. The outlook for their demand is excellent. Current hardwood forestry programs need to reach more landowners; and hardwood forestry education must become more effective to insure adequate supplies of these valuable raw materials for the future. Utilization of the entire tree is likely to continue to become a reality as the use of wood as an energy source increases.

When you ask a member of the industry today about the walnut resource, he is likely to tell you "good walnut trees, or for that matter, good trees of any species, are hard to find."

In 1966 at the Walnut Workshop in Carbondale, Illinois, Steve Boyce started his speech with a statement "large diameter, high quality veneer and sawlogs - these are the walnut timber products in critical shortage." In the abstract written for a paper presented at the 1973 Black Walnut Symposium, Jim Blythe said, "rising prices with fluctuating demand indicate a scarcity of high quality walnut, a need for more efficient and complete utilization of the walnut resource, and the necessity for reducing costs in domestic manufacturing of walnut products so they can remain competitive with substitutes and foreign products."

Here we are, not quite ten years later, and we still have most of the same problems. The buyer of walnut timber, for nearly twenty years has had to buy trees that are smaller in both diameter and in total height. He has had to buy trees with more pin knots, frost cracks, spiral grain, and other factors that reduce the yield from the logs. At the same time competition for the raw material has forced the cost of logs to skyrocket upwards.

The demand for black walnut has helped motivate timber management by allowing for more profit on the part of the landowner, and the industry recognizes the necessity of landowner profits and knows it can and should result in more management. Unfortunately, all too often the landowner, or his or her heirs immediately sold the timber and failed to return any of this money back into a forest management program. Often with heirs, it is strictly a case of raping the land for whatever dollar value they can derive.

As we look into the future, we feel that walnut will continue to be readily available, but the quality problems will continue. The challenge to foresters and landowners is almost frightening. Somehow, we have to motivate the people who own the land growing hardwood timber to do a much better job of managing the trees. For nearly a hundred years we have heard the cries from the wilderness that we are going to run out of timber and that some species will become extinct. We know this can happen, but we also know there are tremendous opportunities to make sure that this does not happen.

In his report to the Indiana State Board of Agriculture for year 1880, Professor C. I. Ingersoll of Purdue University indicated that about 85% of the black walnut resource in the State of Indiana had been disposed of. Professor Ingersoll warned the people of Indiana not to destroy their forests. To quote him, "if the cornfield is destroyed, it can be restored in a single season, but when the forest is destroyed, a hundred years are required for its full restoration." To continue from Professor Ingersoll, he stated "go with me if you please to some of the countries of Europe and Asia, and read there the silent admonishments stamped by the absence of woodlands for centuries."

The lessons are well documented, unfortunately only a few eyes have seen them. It is time in America, particularly here in the midwest, when we stand up and admit that we are not doing the job in hardwood forestry. We can kid ourselves and we can say that we are growing more timber than what we are using. We can justify reasons for land clearing. We can bow down to the interests of corn, soybeans, and other row and pasture crops. We can excuse the utility right-of ways, and the home builders and the real estate people for taking our tracts of timber and making them into the finest, most expensive homes in the area. We can come up with many excuses, but if you are satellited with the responsibility of finding timber to operate a mill Monday through Friday, then you know from your own experience and in your own heart that the course we are on today will not lead us to a land of plenty.

As we sit in meetings, we hear how the wilderness and preservation people are demanding that more acres each year be locked up, never to be managed again for multiple-use purposes. Those of us in the timber business and many of you in the forestry profession, for the most part, do not go along with these theories. Yet, we sit in these same meetings and often do not speak up, and we do not move forward with programs of our own. We seem to always be defending our actions. If the preservation groups continue to insist on having single - purpose management areas set aside, then we probably should demand that single-purpose areas be set aside for timber production and timber production only. It has been said many times that the best defense is a good offense. We have got to get busy, if we are going to remain in this ball game at all.

Fortunately, it is not too late. There is still time to turn hardwood forest management in America around, but I challenge all the landowners, all the industry, all the individuals working in this field to stop fooling around and get down to the business at hand of practicing those forest management techniques which are already known. The day may come, heaven forbid, when we will have to legislate the practices that we know have to be incorporated if we are going to continue to have adequate timber supplies in America.

The other part of my assignment is to talk about utilization. I believe that we have come a long way in America, particularly in the softwoods and we are doing quite well in the hardwoods, at using almost the entire tree.

At the mill level, the progress is apparent. You rarely see the piles of bark and sawdust. In most cases you do not see the scrap that was once taken to the backside of the mill and bulldozed over the hill. We are now using the bark for landscape and mulch, if we are not burning it along with the sawdust and the other edges and trimmings as an energy source for the mill. We are working harder to find markets for all grades of hardwood lumber and veneer. At the Association level, we have for many years been involved in a character marked program to promote the use of all the grades that are developed in the manufacturing process.

In the woods we still have work to do. It is true that we find a lot of tops, limbs, and unmerchantable trees still left in the woods. This material will in time be used. We are currently seeing interest for fuelwood. I believe the day will come when the industry will have a crew to chip this material and take it back to the mill to add to the energy source. We should all be thankful for the research currently underway in this area.

To the growers of the resource I can say that the outlook is good. Raw material prices have taken only one direction in recent years, and that has been upward. Granted it has cycles, but the general trend is upward and I do not see how it can go any way other than up from now on, which is good news for you because you can make forest management investments with the confidence of a good return on your investment.

Whether the industry can keep up with the money market and the high prime rate is questionable. Whether or not anyone can keep up with the prime rate is questionable. This is one of the most serious problems facing the industry. With the high prime rate and the business slow, demand for timber is likely to soften slightly. So it is to your advantage to see the prime come down. Hopefully, at the same time inflation will be lowered, and this country will return to a somewhat stable and normal economic situation again.

I am optimistic that the future for hardwood lumber and veneer is excellent. We all know that the children of the population explosion that occurred in the late 1940's have now moved into the prime buying age bracket. They will be buying homes and they will be filling those homes with furniture, which means more demand for your timber products. With all other factors being normal, we expect excellent business throughout the 1980's. By the time the war babies move on to an older age bracket, where they may not buy so much, we will be more into a worldwide market, which again will brighten the prospects and opportunities for the timber growers of the midwest.

BUYERS PERSPECTIVE ON MARKETING WALNUT TREES

Presented at the NNGA/Walnut Council Joint Meeting
Purdue University, West Lafayette, Indiana, August 13, 1981

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Abstract -- Buyers Perspective on Marketing Walnut Trees

Marketing walnut timber is a business transaction between a willing buyer and a willing seller. The value the seller receives is the approximate difference between the end value of products produced from the tree/log mix involved in the sale and all related costs and profit. The stumpage value is determined by a buyer who estimates value based upon evaluation of location, size, and defects.

After a sale, trees are cut, bucked into logs and transported to a mill for processing or re-sale. The movement from landowner to mill may take several routes:

Landowner → Independent buyer → Company buyer → Mill

Landowner → Company buyer → Mill

Landowner or Independent buyer → Mill

Timber sales are transacted in many ways, but in all cases the timber buyer pays for a given number of trees. The most common selling methods are:

1) Lump Sum Sale--On a given piece of land the buyer pays for all usable timber within given agreed upon constraints, eg. All walnut over 16 inches, all merchantible red oak, and hackberry over 14 inches.

2) Sealed Bids--This method is essentially the same as a lump sum sale, except sealed bids are submitted by buyers. Bids are opened by the seller at a given place and time.

3) Percentage--An agreement between the landowner and buyer: the buyer cuts the trees and then sells to one or more company buyers. The buyer and seller divide proceeds based upon predetermined percentage of gross receipts.

4) Dollars Per Tree--The seller sets a dollar value per tree standard which the buyer must meet, eg. The timber sale must average $100 per tree. The buyer must then pay on the basis of $100 per tree cut (poor practice, leads to high grading).

5) Grade and Yield--The buyer cuts, bucks, scales and grades logs. The price paid to the seller equals the scaled volume by grade times the agreed upon price per grade.

6) Dollars Per MBF--The buyer cuts, bucks and scales logs. Payment is based on agreed upon price per thousand board foot. The seller and/or third party may assist in scaling logs.

7) Auction--The buyers are given an opportunity to review marked trees or the sale area, and at a given time and place an auction is held (rarely done).

8) Telephone Auction--The seller calls prospective buyers and tries to manipulate bid prices by playing buyers against each other on an individual basis. This is a common practice after the seller has accepted original bids (sealed or otherwise). Often the bids quoted in the "auction" are inaccurate.

STUMPAGE VALUE

VALUE EQUALS WHAT SOMEONE WILL PAY. No walnut buyer (at least for very long) can consistently invest more in a purchase than he receives in return. All values are based, in the final analysis, upon the market value(s) of products produced by the mill. This market value(s) minus all transportation, processing, and merchandizing costs plus a reasonable profit establishes a given average log value. This is the competitive log value paid for a given log delivered to a mill. This value minus a cutting and hauling charge, minus transportation fees (truck or rail), minus buyers expense/profit equals the stumpage value.

The stumpage value of walnut trees is a factor of volume (board feet), grade and value per board foot per grade.

The value of lumber logs is based upon size (diameter and length), quality and often general area of origin. All three factors relate back to the kind and quality of product produced. The higher the quality (end value) the greater its value to the mill. For example, larger is better than smaller, cleaner straight is better than defective crooked, and northern is better than southern.. Hence, a large, clean, straight northern log is worth much more than a small, defective, crooked southern log.

The value of veneer logs is likewise a factor of size (diameter and length), defects, area of origin (general and specific) and a rather undefinable buyer evaluation of wood quality (color, grain, pattern, etc.). I do not know of any veneer log grading system that can be applied to the value of veneer logs. For example, I commonly pay 3 times more for one log than another even though both would fall within the same general log grade. This differential is due to my evaluation of what dollar value the log will ACTUALLY YIELD after processing.

It should be apparent by now that there is no answer to the question "What is a walnut tree worth?" The question is much like asking "What is a used car worth?" There are some exceptional used cars (Elvis Presley's gold plated cadillac) just as there are some exceptional walnut trees. One must recognize that no value for any commodity, walnut trees or used cars, can remotely be based on the extremely rare individual, but rather has to be based on the average of what really exists.

AREA OF ORIGIN

All timber buyers and/or walnut companies have a tremendous backlog of experience (successes and failures). As with most businesses, they use this experience as a basis for future investment. On the AVERAGE, trees from a given spot (area of origin) have a different value than trees from another spot. For ease of discussion I have separated area of origin into four classifications.

1) REGION--Is a very general classification. Different companies/buyers will use different boundaries. In the western part of the walnut range, northern and southern is often used and the boundary is approximately an east west line from St. Louis to Kansas City. Northern logs (on the average) are better than southern logs.

2) DISTRICT--Refers to a general area within a region. I think of a district as the approximate boundaries in which a buyer usually operates. In my case, this would be western Iowa and eastern Nebraska. There is a considerable difference between the average value of logs coming from different districts.

3) AREA--Refers to units within a District. Most buyers will consciously or unconsciously differentiate between areas. I have about ten different areas within my District. On the average, trees from different areas have a different value. I pay a different price for veneer logs (lumber logs remain constant) depending upon area. I do not have a good explanation for this difference, but assume it relates to some interaction of soil, moisture and/or other environmental or genetic factors which affect quality.

4) PAST HISTORY AND SETTING--Any abuse suffered in the past by the tree lowers its quality, Grazing (type of critter and intensidy), fire, herbicides, and any type of human or natural injury (equipment/storms) have a negative affect on the health/vigor and quality of the tree. The specific setting of the tree, eg. contigious timber stand, narrow bands of trees along field or streams, or trees in proximity to humans has an affect on tree quality. On the average, trees located within contigious stands are of better quality than those in narrow bands and both are better than those in rural or urban homesteads.

SIZE

Without exception, all other variables being equal, larger diameter logs are worth more per board foot than smaller diameter logs. One would think size is the one constant in determining value, but log rules and scaling methods differ.

The walnut industry uses the Doyle Log Rule and bases scale on:

1) Length to the nearest foot. Nine feet eight inches is nine feet. Lengths on veneer logs are extremely important. A log bucked at 8'1" has a drastically different value than the same log bucked at 8'6". Critical lengths relate to the requirements of the ultimate use of produced veneer. The same critical lengths apply to standing trees. Anyone who appraises or evaluates trees and guesses at the length of veneer logs does a disservice to all concerned.

2) Diameter inside the bark (DIB) at the smallest point in the log. Where DIB cannot be directly measured (standing tree, log cut at a limb swell, or log with crotch at small end), the DIB=circumference x 0.28. This formula takes into account bark thickness. It is not always exactly accurate, but is very close. For logs/trees over 100 inches in circumference (29 inches DIB and larger), the formula is circumference x 0.30=DIB.

I have on several occasions been told that log buyers are cheating people by using the Doyle Log Rule because it underestimates the actual board footage derived from small diameter logs.

One cannot cheat anyone based on the type of log scale used. You can only cheat someone if you pay less than a fair value for the tree. It really does not matter what log rule is used. The actual price paid for a given log is independent of the log rule used to estimate volume. For example:

Log Rule	Lt.	Dia.	BF	$/BF	Total
Doyle	8	14	50	0.55	$27.50
International ¼"	8	14	65	0.42	27.30
Scribner Decimal C	8	14	60	0.46	27.60

DEFECTS

Bark characteristics, taper and width of sapwood are not actual defects, but are reliable indicators of wood quality. "Good or bad" bark characteristics are impossible to describe or demonstrate. They also vary from area to area. Most walnut buyers rely heavily on bark characteristics to determine value.

Taper is an indication of the first few years of height growth. Rapid initial height growth (less taper) normally indicates heavy competition when trees are young. With competition one would anticipate fewer low side limbs, early shedding of limbs, and fewer internal limb defects.

Sapwood width is also a reliable indication of log quality for essentially the same reasons as taper. Narrow sapwood indicates good log quality. The bark is a good external indicator of sapwood width. One should note that through bark, taper and width of sapwood the buyer tries to determine cleanness of log (lack of internal limb defects). Under proper plantation or native stand walnut management one will often have poor bark characteristics (to the buyer), average taper, and wide sapwood. As noted, these factors are not defects, but indicators of defects. Buyers/mills are interested in clean wood. My advice to owners is to properly prune trees to get clean wood and take periodic photographs to convince future walnut buyers of the quality of your product.

LIMB DEFECTS

There is a difference between limbs and limb defects. A limb is external to the bole of a tree. A limb defect is internal to the bole of a tree. A buyer only concerns himself with the internal defects. ANY indication of a limb defect is evaluated the same as an actual limb. I am often amused that many people believe pruning limbs off a tree immediately raises the value of the tree. In fact, larger limbs removed from larger trees often lowers value due to decay/discoloration/staining. The existence of a limb guarantees the presence of a limb defect, but the absence of limb does not preclude the existence of a limb defect.

HOLLOWS

I would hope that everyone recognizes a hollow tree greatly decreases in value. The hollow normally precludes any veneer and limits its value for lumber. The timber buyer is not often fooled (with experience some trees just lookhollow), but I do not know any buyer who does not occasionally get fooled. The real trick for a buyer is determining the size and extent of the hollow. Sometimes the hollow peaks out rapidly and sometimes it runs almost the length of the tree. You know you've got a problem when you stick a saw into a tree and mice come running out, but you're in real trouble when a skunk, opossum, or racoon scampers out. In all the trees we have cut, I have not seen anything that conflicts with the research of Dr. Alex Shigo's research concerning tree wounds and compartmentalization.

LIGHTNING

Lightning is one of the worst injuries a tree can sustain. It seldom kills the tree, but often opens the whole length of the bole to decay and discoloration. Even if decay has not severely progressed, it will almost always cause a ring shake. One should sell a lightning struck tree as soon as possible.

METAL

Timber buyers often feel paranoid about metal in trees. It seems people go to great lengths to nail fences, insulators, signs, deer stands and good-luck horse shoes to trees. Besides the obvious problems associated with damage to mill equipment, oron oxidizes and stains the wood a blue/black. Metal stain extends both above and below the metal site, which further deteriates the value.

BIRDPECK -- WORMS

Birdpeck and worms are hard to spot in a standing tree and are often difficult to see in a cut log. Both are severe defects, especially in veneer. One worm hole essentially lowers the veneer value the same as a limb defect. Birdpeck and worms are primarily a southern log problem but a small amount of peck and worms are found in northern logs.

COST SHARING INCENTIVES FOR BLACK WALNUT MANAGEMENT[1]

Robert W. Koenig[2]

Abstract.--Cost Sharing Incentives have been beneficial in encouraging black walnut management and where common sense is applied will yield reasonable returns on both the public and private investment. This paper presents a "Dirt Forester's" Common Sense approach on how cost sharing practices might best be applied. No attempt is made to give exact cost figures or scientifically prove what is eluded to. It is just 19 years of experience and observation speaking!

It is indeed a pleasure to return to my old Alma Mater and be able to impose a little practical, Dirt-Forestry philosophy on such a distinguished group of nut growing, nuts as you all are. The subject of cost-sharing incentives is one that has been near and dear to my heart for the past 19 years, since I have been associated with professional Forestry work in Indiana.

Let me say from the start that I am a "Die-Hard Conservative" that believes in as little Governmental intervention in private affairs as is absolutely necessary to insure the preservation of our free enterprise system of economics; but let me also make it crystal clear (that based on my experience) little or no forestry work would ever have been started in the private, non-industrial forests of Indiana without the ACP original cost- sharing program and the stepped-up application of forestry practices because of the addition of the FIP cost-sharing program in 1974. This is not to say there could not have been another way to stimulate these badly needed activities. But from recent studies conducted on the cost effectiveness of the first year of FIP practices (1974) throughout the United States[3], it certainly appears that most federal cost-sharing has been fairly cost effective with the practices involving black walnut leading the way. In fact black walnut tree planting practices showed an internal rate of return (IRR) of 14%, and black walnut timber stand improvement practices showed an IRR of 21....

The first federal cost-sharing practices specifically taylored for black walnut in Indiana were initiated in the early 1960's, ACP practices A-7(B) for establishing a stand of black walnut trees and B-10(B) for improving a stand of black walnut trees. Although we have lived through REAP (Rural Environmental Assistance Program) in the early 1970's, and have graduated to FIP (Forestry Incentives Program), and have changed practices numbers several times, we still have the two basic practices: <u>Tree Planting and Timber Stand Improvement</u> with their several component parts.

Basically all cost-shared forestry practices, whether for walnut or any species or species mix can be divided into one of two categories.

The first category includes those practices which insure the establishment of new black walnut stands such as: site prepareation, tree planting, firebreak and access road establishment and initial weed control.

The second category includes those practices which improve the quality and quantity of black walnut products grown such as: corrective pruning, side-limb pruning, pre-commercial thinning, crop tree release and maintenance of firebreak and access roads.

Undoubtedly, you have all been told that black walnut is very site specific in its requirements for surviving and maintaining reasonable growth rates. That has been proven unequivocably by the many plantation failures that have occurred over the past 25 years and

[1]Presented at the NNGA/Walnut Council Joint Meeting, Purdue University, West Lafayette, Indiana, on August 13, 1981.

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[3]"Timber Yield and Financial Return Performance of the 1974 Forestry Incentives Program", Mills, Thomas J. and Daria Cain, Research Paper Rm-204, Rocky Mountain Forest and Range Experiment Station, U.S.D.A.

before, because they were planted with no consideration for soil texture, soil depth, rooting limitations, available soil moisture, slope aspect, slope percent, accessibility for protection and cultural treatment, etc, etc. This same fact of "site specificity" affects the success of not only walnut planting but also all other cultural practices. For it does no reasonable good to try to release a walnut tree from undesirable competition such as weeds, shrubs, lower-valued trees or vines, if the walnut tree being released is growing on the wrong site! This would be a waste of both time and money for the growth response could never pay back the investment made.

Assuming that site is not a problem, then the proper sequence of component practices that go into establishing a stand of black walnut trees should be as follows:

1. Site preparation--this might be any one of the following treatments or a combination of treatments to get the land ready for the actual planting of trees. It is up to the responsible forester to determine the needs and make an estimate of cost per thousand trees to be planted using such treatment. Site preparation can run as low as just a few dollars per thousand trees planted to as high as several hundred dollars per thousand trees planted depending on the condition of the land and what needs to be remove to make it ready for planting.

   a. Plow and disc firm--good for level to gently rolling old fields--costs vary according to custom rates charged locally.

   b. Herbicide application in bands at least two weeks before planting--good for preparing old sod fields and weed invested areas where it is too steep to plow and no brush or trees are present to complete. Either Dowpon or Roundup has been used successfully. All label recommendation should be followed in handling and application rates.

   c. Bush hogging followed by herbicide application as above--use where small trees and shrubs are present and likely to be competive.

   d. Bulldozing and root raking--use only where larger trees (3" DBH and up) are the problem and only where site quality is excellent--this is too expensive to be economically justified on anything less than the best areas.

2. Tree planting-includes the cost of purchasing seedlings.

   a. Mechanical tree planting--best for larger plantings and areas that are level to gently rolling and easily accessible. Pre-emergence herbicide can normally be applied at the same time further reducing costs.

   b. Hand planting-small plantings, steep slopes or areas with poor access for motor vehicles.

3. Pre-emergence herbicide or initial weed control absolutely necessary if the plantation is to be successful. This must be applied during or immediately after planting and then at least once every spring for the first five years. Some of this may be eliminated by proper interplanting or preplanting of such species as Autumn Olive, European Black Alder, White Pine or Black Locust. Almost no corrective pruning is needed if interplanting is used.

4. Walnut as an interplanting, with pre-emergant herbicide spot sprayed around each interplanted walnut--good for rough sites, slightly doubtful landowners, etc.

   a. First plant white pine on 10'x10' spacing and let it capture the site (3 to 5 years).

   b. Then interplant walnut when the pine have their heads above the major weed competition.

Already, one can see that establishing black walnut is expensive and labor intensive and not for those who believe: "you just stick the damn things in the ground and let 'em grow!" That just won't get the job done. If you do not intend to take care of the planting, please, do not plant black walnut!

Assuming you are bound and determined to go on with it (planting and growing black walnut), then the rest of the steps fall under the category of Timber Stand Improvement and should take you up to the time when a commercial thinning is possible:

5. Fencing to keep livestock out of the plantation or out of a stand of native walnut trees is another prerequisite for growing walnut or any forest product in Indiana--this only includes interior fences and no cost sharing is allowed on boundary or road fences under either ACP or FIP.

6. Corrective Pruning - is only necessary when a tree fails to develop a straight, central stem and does not maintain a healthy, apically dominant terminal leader. Causes can be anyone of many, but usually one of these is most likely:

   a. Late frost kills terminal bud and lateral buds try to take over.

   b. Casebearer moth, shoot moth, or other insects which also kills the terminal bud.

   c. Mechanical damage such as ice, wind or birds breaking terminal leader.

   d. Genetically inferior stock--wants to be a bush rather than a tree. Usually corrective pruning won't work and the bad apple has to be removed.

7. Side Limb Pruning -- Can also be lessened by interplanting-must be done before diameter of pruned branches reach 2 inches and before bole (main stem of tree) reaches 10 inches in diameter at breast height (normally side limb pruning is done between 3 and 10 inches DBH).

8. Non-commercial thinning-means value of trees removed is less than the cost.

   a. For plantations follow the US Forest Service Guide "Quick Reference for Thinning Black Walnut" prepared by Burl Ashley of Northeastern Area State and Private Forestry, Morgantown, W.V. and Richard Schlesinger of North Central Forest Experiment Station, Carbondale, IL and published by the North Central Forest Experiment Station at St. Paul. This uses the Crown Competition Factor (CCF) to determine when to thin both for veneer-sawlog production and for nut-log production.

   b. For native or natural black walnut stands, stocking levels should be maintained 10 to 20% higher than suggested for plantation after the first pre-commercial thinning to avoid excessive epicormic sprouting and to guard against wind damage, sun scald, etc.

   By the time a second pre-commercial thinning is needed, stand density should be equal to the recommended stocking level for a plantation.

9. Maintenance of firebreaks and access roads--this usually pertains just to the practices needed to prevent erosion and sedimentation.

   a. Waterbars on steep slopes
   b. "Thankyou Mams" or drainage dips
   c. Box culverts
   d. Improved stream crossings
   e. Seeding, fertilizing, liming and mulching bare soil

So far, I have deliberately failed to mention cost-share rates and hold-down rates because in this discussion they are not important. What is important is that there is enough incentive to encourage people who have the good walnut growing sites and who have the determination to do what it takes to grow the walnut trees we need now and in the future.

U.S. Department of Agriculture, Forest Service.
Black walnut for the future. Gen. Tech. Rep. NC-74. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 151 p.

Contains 33 papers presented at the third symposium on the culture of black walnut. Papers summarize the current information on walnut timber and nut production.

KEY WORDS: Insects, disease, silviculture, tree improvement, genetics

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