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# Black walnut plantations in West Virginia: Maximizing financial returns through decision modeling and cash flow analysis

Erin Duffy Shaw
*West Virginia University*, erinshaw19@gmail.com

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**Erin D. Shaw**

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David McGill, Ph.D., Chair
Kathryn Arano Gazal, Ph.D.
Jamie Schuler, Ph.D.

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# ABSTRACT

**Black walnut plantations in West Virginia: Maximizing financial returns through decision modeling and cash flow analysis**

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The purpose of this study was to identify the management strategies that lead to maximum financial returns from a black walnut plantation. To evaluate a selection of plantation establishment scenarios, thinning treatments, and product objectives, an Excel-based black walnut financial model was updated and revised. Key updates to the model included incorporating three cash flows for 1) the collection and wholesale of black walnut sap, 2) producing black walnut syrup, and 3) leasing black walnut trees for tapping. Additionally, outputs from the Forest Vegetation Simulator were integrated into the model's growth and yield projections as a means of more accurately projecting sawtimber, nut, and sap yields over a 70-year period. Financial criteria including Net Present Value (NPV), Equivalent Annual Income (EAI), Benefit/Cost Ratio (BCR), and Internal Rate of Return (IRR) were calculated for a range of scenarios; NPV and IRR were used to rank each scenario. A discounted cash flow analysis was then performed, as well as sensitivity analyses to determine the impact of receiving cost-share funds, increasing plantation acreage and stumpage value, and adjusting the discount rate. Of the scenarios examined, NPV ranking indicated that the highest net returns are achieved by planting on 8 x 8 foot spacing without thinning, and gaining revenue through timber sales, nut harvesting, and leasing taps. The greatest losses were seen when planting on 8 x 8 foot spacing without thinning, but pursuing revenue through nut harvesting and wholesaling collected sap.

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# CHAPTER I

# INTRODUCTION

The practice of evaluating forestry investments presents unique challenges due to the long-time frames involved, the variability in supply and demand, and the opportunity to produce both timber and non-timber products, among other considerations. Nonetheless, determining the cost-effectiveness of forestry and agroforestry practices plays a key role in empowering landowners' decision-making process and helping natural resource professionals make recommendations and management decisions. Financial analysis tools - such as cash flow statements and financial models - can help estimate the feasibility of a specific enterprise and point toward the optimal management scenario in terms of financial returns. In broad terms, this research explored the costs and revenues associated with cultivating a black walnut plantation in West Virginia. Multiple establishment scenarios, thinning treatments, and product objectives were examined with the specific research goal of identifying what combination of these variables led to maximum net returns.

Black walnut (*Juglans nigra*) is a deciduous hardwood tree native to North America and distributed throughout the central and eastern United States. Common names for the species include eastern black walnut and American walnut. Noted to be "one of the scarcest and most coveted native hardwoods," (Williams, 1990) black walnut's economic value is threefold: the appearance and quality of the tree's wood make it prized for veneer, sawtimber, and a variety of specialty wood products, the tree's nuts are used in numerous food, cosmetic, and industrial products, and markets for walnut syrup have emerged in recent years. Black walnut's economic value is also driven by its relative scarcity, particularly in the eastern United States. This scarcity can be attributed to a combination of the species' specific site requirements, as well as substantial logging of the species. For the reasons described here, black walnut has long been a desirable species for cultivation in a plantation selecting where high-volume production can be achieved.

Studies examining the economics of cultivating black walnut in a plantation setting have concentrated on the Midwest (Ares & Brauer, 2004; Garrett & Kurtz, 1983; Wolz & DeLucia, 2019) and Southeast (Hatcher et al., 1993; Schultz & DeLoach, 2004), a review of the literature uncovered few studies in the Appalachian region. Furthermore, a number of studies focus on the economic contribution of black walnut in an agroforestry context - specifically as a candidate for intercropping, or alley cropping - rather than as a stand-alone tree crop. Additionally, multiple studies, sample budgets, and guidelines exist regarding the financial considerations of maple syrup production (Farrell, 2013; Hansen et al., 2010; Ober, 2017), but due to the recent emergence of the practice, little research of this kind applies the same focus to black walnut sap collection, syrup production, and tap leasing. By placing focus on managing a black walnut plantation in the Appalachian region (specifically West Virginia) for multiple product objectives, this study aimed to take a new approach toward examining black walnut in an economic context.

For landowners and forestry professionals to make informed decisions on establishing and managing a black walnut plantation as a financial investment, a greater understanding is needed of the potential costs, revenues, and management decisions associated with the multiple products black walnut can provide, especially considering relatively new product opportunities beyond timber and nuts. In order to incorporate sap and syrup-related costs and revenues into the model, the following research questions were addressed to the extent allowable based on current research: 1) What is the impact of tapping on black walnut's timber value?, 2) Can sap yield be estimated based on tree diameter?, 3) Is it feasible to tap small, young trees that would be removed from a plantation during thinning operations?, and 4) What is the sap to syrup ratio?

This last question refers to how many gallons of sap will need to be boiled down to produce one gallon of syrup, which is dictated by the initial sugar concentration of the sap. To meet legal guidelines, syrup must reach a density of at least 66˚Brix (Section 3715.24 Maple Product Standards and Grades, 1997).

As noted, the overall purpose of this research was to determine the financial feasibility of growing a black walnut plantation in West Virginia, with the research question being, "what management scenario leads to the highest net returns?" Multiple scenarios were examined involving variables including initial row spacing, thinning, receipt of cost-share funds, increase in stumpage value, and number of acres planted. These variables were adjusted to determine the impact on financial returns, along with a variety of different product objectives, including:

1. Timber
2. Timber and nuts
3. Timber, nuts, and wholesaling collected sap
4. Timber, nuts, and producing syrup
5. Timber, nuts, and lease trees for tapping
6. Nuts and wholesaling collected sap
7. Nuts and producing syrup
8. Nuts and lease trees for tapping

To simulate the scenarios summarized above and accomplish this research, an Excel-based black walnut plantation financial model initially developed by Dr. Larry Godsey at the University of Missouri Center for Agroforestry (UMCA) was revised and updated. Utilizing outputs from the U.S. Forest Service's Forest Vegetation Simulator to attain a stand structure and project timber yields - as well as specific formulas to estimate sap and nut yields based on diameter growth - a series of financial criteria were calculated for each management scenario, including Net Present Value (NPV), Equivalent Annual Income (EAI), Benefit/Cost Ratio (BCR), and Internal Rate of Return (IRR). A cash flow analysis was performed to determine the establishment, management, and product objective scenario that led to maximum profit over a planning horizon of 70-years. As noted, the long rotation periods required of many forestry investments means initial investment and maintenance costs are not recovered for a significant number of years, when a timber harvest can occur. Determining whether the incorporation of alternative revenue streams (such as nut harvesting, sap wholesale, syrup production, and tap leasing) leads to shorter payoff periods was a key objective of this research.

In combination with other financial analyses of this nature, this research is designed to serve as a reference for landowners specifically interested in cultivating black walnut in a plantation setting, or simply considering alternative land management practices. The following chapter provides an overview of the literature regarding the silvics of black walnut, its distribution and status within West Virginia, projecting its growth and yield, and examining the species' appeal as an economic resource and potential financial investment. Chapter Three provides an explanation of the black walnut financial model developed by Godsey - hereon referred to as the "original model" - presents details on the revisions and updates made to the model, and reviews steps taken in the financial analysis process. This chapter also includes a detailed synopsis of the revised model's underlying functions and assumptions. A concise summary of results is provided in Chapter Four, and Chapter Five concludes with an interpretation of the results (including potential recommendations to landowners), a discussion of the research's limitations, and suggestions for future research.

# CHAPTER II

# LITERATURE REVIEW

***Characteristics and Site Requirements of Black Walnut***

Within the forest ecosystem, black walnut is a mast-producing species that provides food for animals including rodents, birds, racoons, and bears; one study cites that black walnut makes up approximately 10% of eastern fox squirrels' diet (Coladonato, 1991). Additionally, black walnut secretes an allelopathic chemical (juglone) via its leaves, bark, husks, and roots which can adversely impact select vegetation (Williams, 1990). Though black walnut is known to grow on a range of sites, it develops best on "deep, well-drained, nearly neutral soils that are generally moist and fertile...in the orders Alfisols and Entisols" (Brinkman, 1965). On high-quality sites, black walnut can reach heights of 125 feet, though the species typically grows to a maximum of 80 feet (Coladonato, 1991). Soil characteristics shown to have a negative effect on black walnut's growth include "shallow, heavy-textured, or imperfectly drained soils" (Losche, 1973); the deep taproot and wide spreading lateral root system of black walnut necessitates an unrestricted soil profile. The preferred soil conditions of black walnut are typically found in areas associated with "deep loams, loess soils, and fertile alluvial deposits" (Williams, 1990) that one would expect to find in agricultural lands - barring the presence of a fragipan - and along streams or rivers. Aside from well-drained bottomland areas, black walnut grows best on north- or east-facing slopes and coves (Williams, 1990). Conversely, poor growing sites for black walnut include "ridgetops, south- and west-facing slopes, and swampy areas" (Beineke, 2000).

In addition to black walnut's sensitivity to soil conditions, the species' growth will also be either limited or aided by factors including stand density, water availability, temperature range, and understory competition; these factors and their impact on black walnut's growth and yield are covered more fully in subsequent sections of this chapter. However, in general, black walnut is categorized as a “light-demanding, competition-intolerant” species (Nicolescu et al., 2020). Black walnut can also be characterized as desiccation avoidant (Gauthier & Jacobs, 2011) and water stress has been shown to reduce diameter growth of black walnut (Gauthier & Jacobs, 2018).

As for black walnut’s climate adaptability, though the species exhibits a “high freezing tolerance when fully dormant” (Gauthier & Jacobs, 2011), Beineke (2000) advises against planting black walnut in areas where late spring or early fall frosts occur.. Beineke’s advice is supported by Gauthier and Jacobs’ discussion on embolism formation in black walnut as a response to freeze-thaw events, which in turn reduces xylem conductivity (2011). Lastly, multiple sources (Ares & Brauer, 2004; Coladonato, 1991; Williams, 1990; Beineke, 2000) highlight black walnut’s sensitivity to understory competition during the seedling stage. Black walnut is most susceptible to woody understory species (multiflora rose, black locust, sassafras, blackberry, poison ivy, grapevine) and bunch-type grasses (tall fescue) due to the root competition these species present (Beineke, 2000).

### *The Black Walnut Resource in West Virginia*

Though black walnut is widespread in its distribution and particularly prevalent in the Midwest, the silvics of black walnut - coupled with heavy logging of the species - have made the tree somewhat rare in the eastern U.S. (Williams, 1990). In a forested setting, black walnut is rarely found in pure stands, but rather “scattered among other trees” (Williams, 1990). In West Virginia specifically, the rarity of black walnut can be attributed to widespread logging activities at the turn of the 20th century, along with a “disregard for regeneration” (Wendel & Dorn, 1985). The Society of American Foresters lists black walnut as a common associate in five forest cover types: Sugar Maple (Type 27), Yellow-Poplar (Type 57), Yellow-Poplar-White Oak-Northern Red Oak (Type 59), Beech-Sugar Maple (Type 60), and Silver Maple-American Elm (Type 62). The species is listed as an occasional associate in four additional cover types: Chestnut Oak (Type 44), White Oak-Black Oak-Northern Red Oak (Type 52), Northern Red Oak (Type 55), and Sassafras-Persimmon (Type 64) (Eyre, 1980).

In West Virginia, oak/hickory (74%) and maple/beech/birch forest-type groups dominate the state's forest land (Morin et al., 2016). Black walnut is more prolific in the northwestern, north central, and eastern areas of the state, which encompass the Southern Unglaciated Allegheny Plateau and Northern Ridge and Valley ecoregions, respectively (Figure 1). Black walnut is less prominent in the Allegheny Mountains and Northern Cumberland Mountains likely due to the higher elevation ranges of these ecoregions and associated colder, wetter climatic conditions.

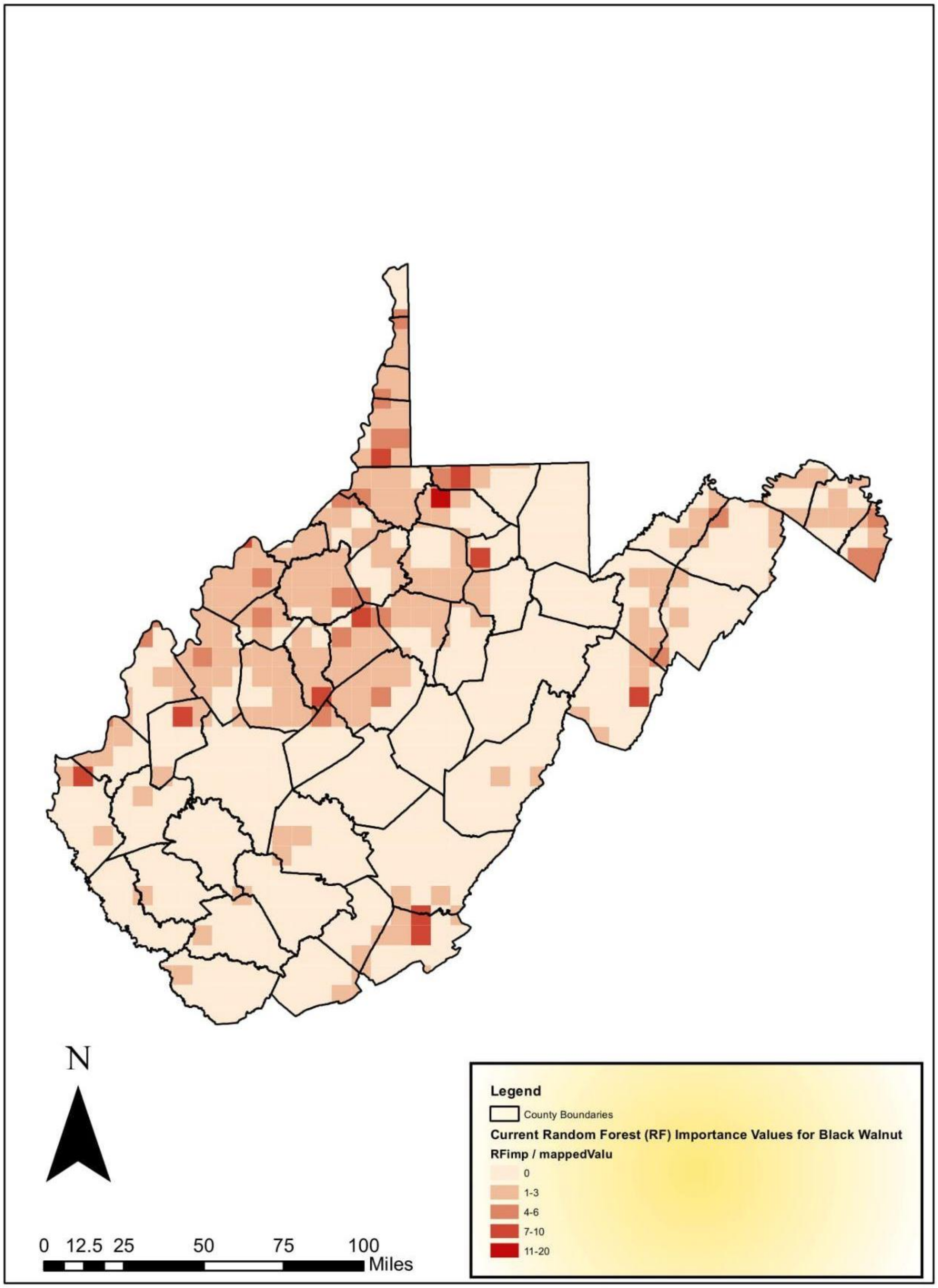


**Figure 1.** Map depicts a combination of Random Forest (RF) predicted and imputed mean and median importance values for black walnut habitat suitability in West Virginia, under current conditions. Importance values provide a measure of how dominant a species is in a given forest area and are calculated based on relative frequency, density, and basal area. Importance values can range from 0 (not present) to 300 (monoculture) (Peters et al., 2020).

Of the major commercial hardwood species growing in West Virginia, black walnut is one of the scarcest (Figure 2), making up 0.29% of live trees in the state according to 2019 USDA Forest Service Forest Inventory and Analysis (FIA) estimates. Seedling and sapling inventories suggest that black walnut will remain relatively sparse in West Virginia's forests, as black walnut in the 1.0-4.9-inch diameter class makes up only 0.12% of live saplings and 3% of total seedling abundance, in combination with hickory (USDA Forest Service, 2020).

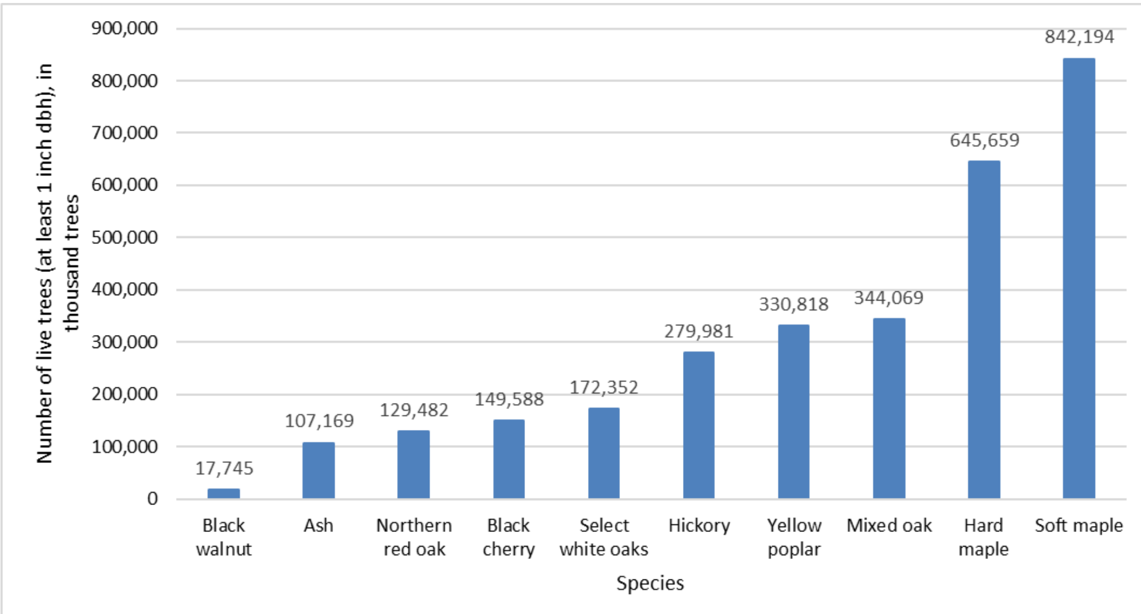


**Figure 2.** Number of live trees (all diameter classes, 1.0 to 41.0+ inches dbh), in thousand trees, on forest land by species in West Virginia, 2019 (USDA Forest Service, 2020).

It is uncertain how black walnut will respond to the process of "mesophication" (Abrams, 1992), in which mesic, shade tolerant (i.e., maple) species replace more xeric, disturbance-adapted species (i.e., oak). Mesophication is noted to be occurring in West Virginia, supported by data showing maple/beech/birch forest-type groups have increased by 26% since 1989, while oak-hickory forest-type groups have decreased by 3% (USDA Forest Service, 2020). As noted, though black walnut is associated with mesic forest types, it is also a known shade intolerant species (Williams, 1990) that requires ample sunlight and a lack of competition to grow well (Beineke, 2000).

Climate change is another factor contributing to the uncertainty around black walnut’s future distribution. A 2011 study by Gauthier and Jacobs discusses black walnut’s ability to withstand climate change, with the takeaway that black walnut may decline under a changing climate due to prolonged periods of drought, as well as potential frigid temperatures resulting from extreme weather conditions at unexpected times of year; as noted, black walnut is susceptible to water stress and prone to embolism formation in response to freezing (Gauthier & Jacobs, 2011; Gauthier & Jacobs, 2018). However, this research also concluded that “there is considerable uncertainty” over how exactly black walnut will be impacted by climate change, with some studies indicating a negative impact and others pointing toward an increase in the species’ suitable growing region due to temperature increases (Gauthier & Jacobs, 2011).

A comparison between Figures 1, 3, and 4 supports the concept that black walnut’s range may increase under a changing climate and rising temperatures. This is likely due to projected increases in temperature and precipitation, which would allow black walnut to expand into areas previously too cold or dry to support the species. Under a lower greenhouse gas concentration scenario (Figure 3), black walnut’s range shows an increase from current conditions (Figure 1), but not as drastically as the potential increase seen in a higher greenhouse gas concentration scenario (Figure 4). However, the authors who published the datasets used to create Figures 1, 3, and 4 rank the climate model reliability for black walnut as “low,” meaning there is more ambiguity as to how black walnut will respond to a changing climate than exists with other species, due in part to the species’ scarcity (Peters et al., 2020).

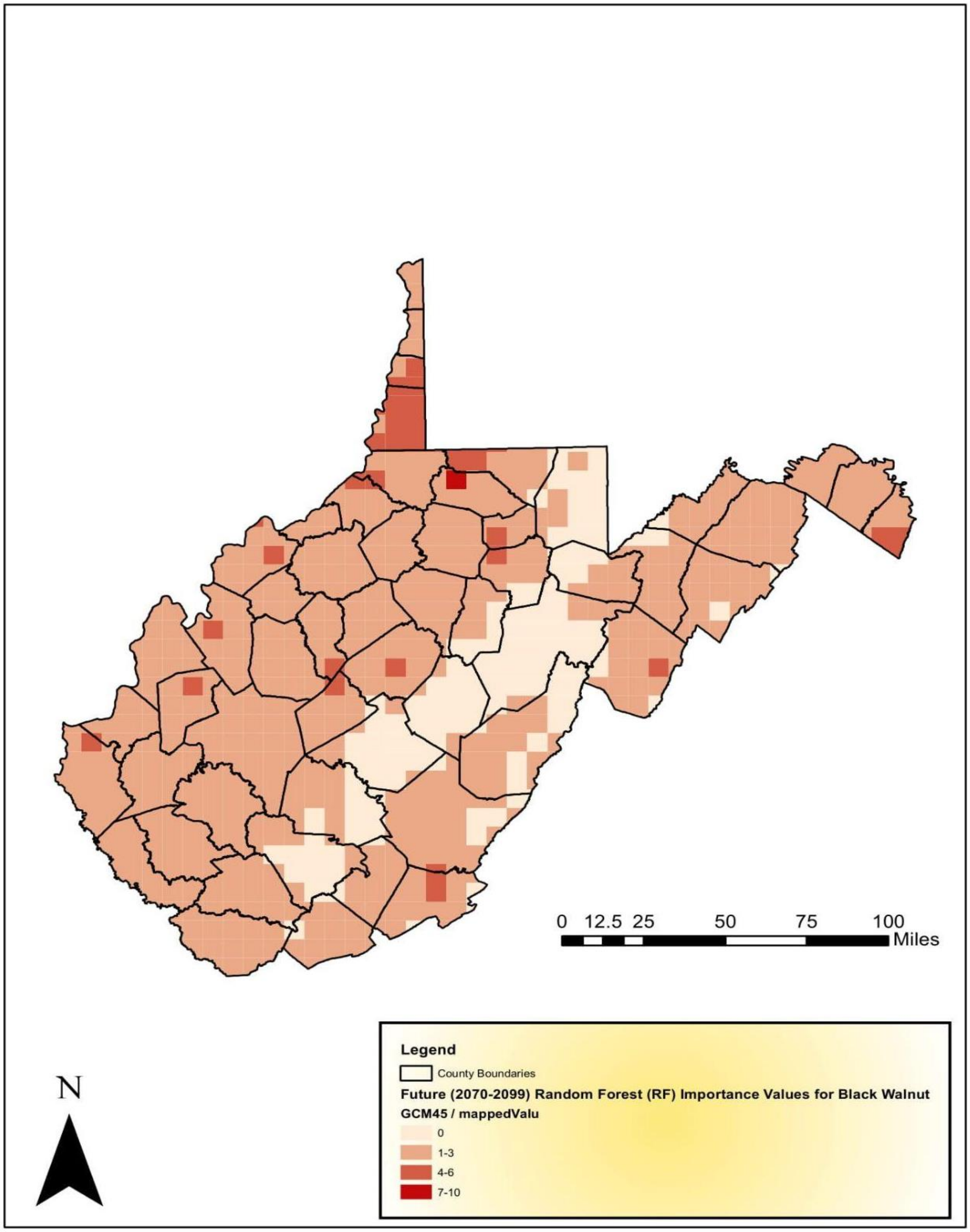


**Figure 3.** Map depicts the average combined mean and median importance values for black walnut habitat suitability in West Virginia, among the three general circulation models (NCAR Community Climate System Model, Gent et al. 2011; NOAA Geophysical Fluid Dynamics Laboratory Coupled Model 3, Donner et al. 2011; Met Office Hadley Global Environment Model 2 - Earth System, Jones et al. 2011) under the 4.5 Representative Concentration Pathway (i.e., a greenhouse gas concentration trajectory adopted by the Intergovernmental Panel on Climate Change) (Peters et al., 2020).

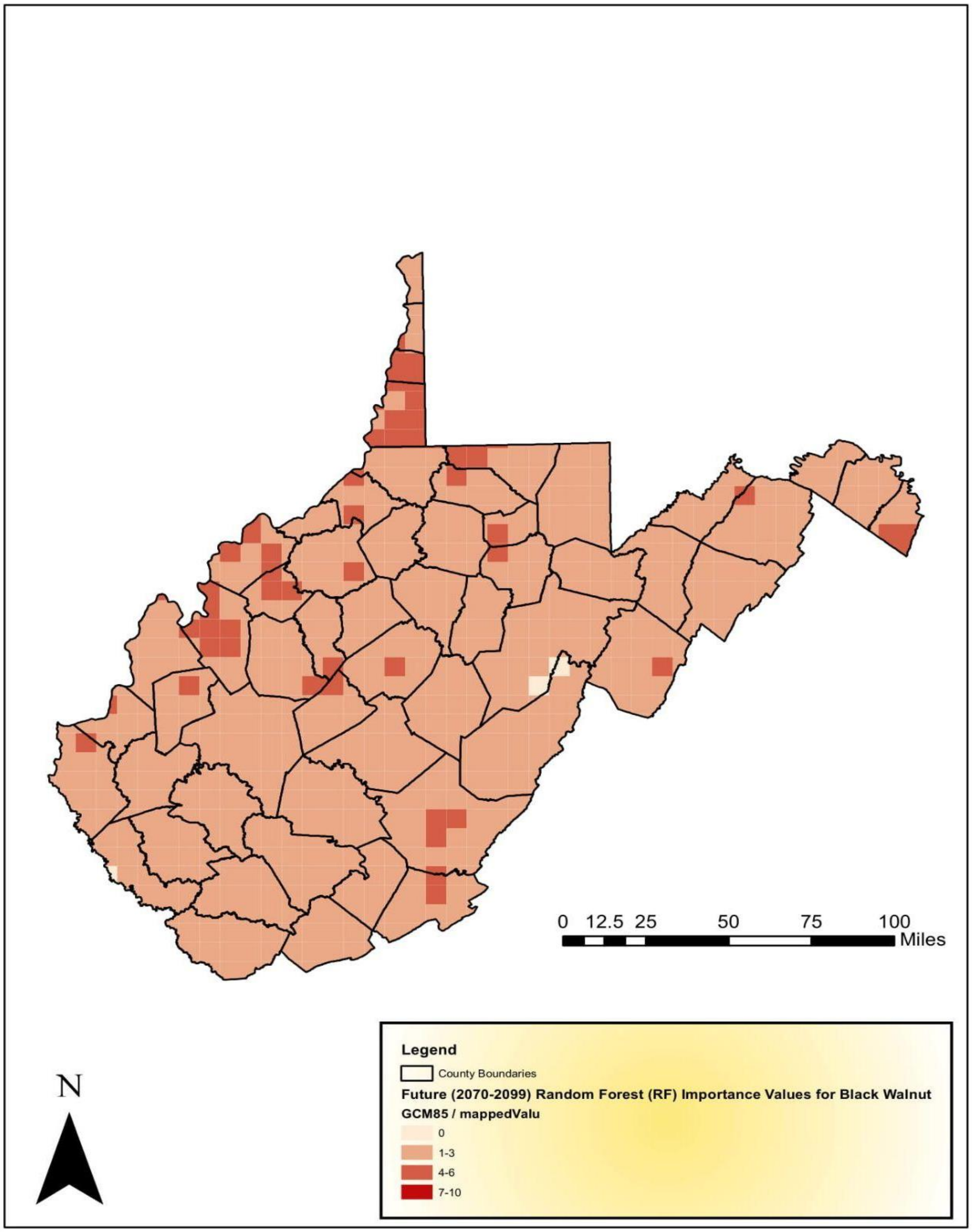


**Figure 4.** Map depicts the average combined mean and median importance values for black walnut habitat suitability in West Virginia, among the three general circulation models (NCAR Community Climate System Model, Gent et al. 2011; NOAA Geophysical Fluid Dynamics Laboratory Coupled Model 3, Donner et al. 2011; Met Office Hadley Global Environment Model 2 - Earth System, Jones et al. 2011) under the 8.5 Representative Concentration Pathway (i.e., a greenhouse gas concentration trajectory adopted by the Intergovernmental Panel on Climate Change) (Peters et al., 2020).

A study published by Purdue University highlights research efforts focused on helping black walnut withstand the effects of climate change. Genetic breeding programs are seeking to identify trees that are adapted to potential “heat or cold stresses” by examining seeds from mature black walnut trees to see if “defense mechanisms” against existing climatic changes have developed (Wallheimer, 2011). Additionally, climate modeling projects are focused on identifying growing regions where black walnut may be especially susceptible to changes in temperature and precipitation (Gauthier & Jacobs, 2011). The results of these two research efforts will impact forest management guidelines in several ways, including recommendations on which cultivars to plant for increased resistance to climate change stressors, where black walnut may need to be salvage harvested due to significant decline within the growing region, and what (likely northward) areas black walnut will migrate into and be utilized as an economic and ecological resource (Gauthier & Jacobs, 2011). Suggestions for future research in this area include further investigation into black walnut’s response to increases in $CO_2$ and $O_3$ emissions, heat stress, extreme weather events, and flooding (Gauthier & Jacobs, 2011).

***Projecting Black Walnut’s Growth and Yield***

Accurately projecting a tree species’ growth and yield over time plays an important role in assessing a forestry-related financial investment. This section presents and describes a selection of equations and models used to project the growth and yield of black walnut. Studies were chosen for their focus on one or more aspects of black walnut growth and yield modeling, such as projecting overall and bole volume growth, nut yields, and annual height/stem diameter growth rates. Comparisons were drawn to identify which variables are useful in predicting growth rates and production curves, as well as which factors may be adverse to black walnut’s productivity. The equations used in the Northeast and Central States variants of the Forest

Vegetation Simulator (FVS) to project the incremental growth of black walnut are also highlighted.

Two studies conducted by researchers in the Czech Republic explored black walnut's potential for timber production, with the overall goal of developing volume tables for black walnut growing in Central Europe. In their first study, the authors measured and compared dbh and height values for black walnut growing "in pure stands in two riparian forests" (Salek & Hejcmanova, 2011). Their results indicated that slight variances in dbh and height between the two sites under study could be attributed to differences in soil subtypes. As noted, black walnut is known to grow best on well-drained "deep loams, loess soils, and fertile alluvial deposits" (Williams, 1990). Additionally, this study confirmed that dbh and tree height are highly correlated with age, and tree height is positively correlated with dbh.

This first study seems to have served as a basis for a second article published by Salek et al. in 2012, entitled "Black walnut (*Juglans nigra* L.) standing volume in the riparian forests of the Czech Republic." After conducting a stem analysis and obtaining age, dbh, and height values for 63 black walnut trees, the authors projected standing volume using two different methods. The first method (Korf1) used "fitted mean diameter, mean height, form height, and fitted number of trees" as inputs, while the second method (Korf2), considered "the real standing volumes on sample plots by summarizing the individual tree volumes that were calculated according to their basal areas and form heights," which were derived from the measured dbh and height values (Salek et al., 2012). Both methods utilized the following Korf growth function, in which A, k and n are parameters and t represents age. The parameters and fit statistics utilized in the growth functions are noted in Table 1.

$$y(t) = A \times \exp((k/1-n) \times t^{1-n})$$

**Table 1.** Parameters and fit statistics of the Korf equations (Salek et al., 2012, p.633).

| | A | k | n | Coefficient of determination | Standard error of estimate | Mean bias |
|---|---|---|---|---|---|---|
| Mean diameter for Korf1 | 9624.6079 | 1.4228 | 1.1408 | 0.5965 | 7.6384 | 0.0819 |
| Mean height for Korf1 | 91.7060 | 1.6921 | 1.3491 | 0.7198 | 3.1500 | 0.00080 |
| Number of trees for Korf1 | 0.2455 | 4.2458 | 1.2888 | 0.8428 | 0.00053 | 0.00038 |
| Observed volume for Korf2 | 59104.2807 | 1.6799 | 1.1724 | 0.5809 | 78.1278 | 0.3682 |

After comparing the results of each method, it was found that both methodologies resulted in nearly identical standing volume calculations, indicating that either method could be used for yield modeling. In their discussion, the authors suggest the use of the Korf growth function “as a base for the creation of black walnut yield tables” (Salek et al., 2012). An additional result of this study - which may be especially pertinent in promoting the planting of black walnut - was that in comparison to tree species including oak and ash, black walnut production was significantly higher; only poplar “out-performed” black walnut on alluvial soils.

A 2004 paper co-authored by Adrian Ares and David Brauer presents two equations, one for predicting black walnut’s overall and bole volume growth and one for projecting nut yields. Utilizing field sites in Missouri, measurements including dbh, total tree height, and height to the first branch were recorded, and tree ages were obtained from landowners’ records. These measurements were then used to calculate values for dominant height and to generate site curves. Following are the equations generated to predict bole volume and nut production:

Bole volume equation, where V is measured in $m^3$, dbh and height are measured in meters, $a_1$ (0.6502) and $a_2$ (1.9984) are model coefficients, and $\epsilon$ is the error of estimation (residual mean square = 0.0182):

$$V = a_1 DBH^{a_2} H + \epsilon$$

Nut production equation, where NY represents nut yield in kilograms per tree (also important to note that the authors determined 14.5 cm to be the minimum dbh necessary to generate a significant nut harvest):

$$NY = -36.91 + 2.55DBH(cm)$$

The authors found that mean annual increments in dbh and height were positively related and nut yields were highly variable, but were related to dbh in native stock, though not in improved varieties.

The literature review process uncovered just one study on black walnut growth specific to West Virginia, published in 1985 by the U.S. Forest Service's Northeastern Forest Experimental Station. In the "Survival and Growth of Black Walnut Families After 7 Years in West Virginia," Wendel and Dorn (1985) examine the following characteristics of black walnut planted in the Fernow Experimental Forest: average survival, 7-year stem diameter (measured at one inch above the ground), stem diameter growth, average total height, and height growth. The focus of this study was to identify potential differences between 34 families of seedlings that had been collected from various locations in Appalachia, but of particular interest are the recorded annual height/stem diameter growth rates. After 7 growth years on plots with an oak site index of 80-85, average survival for the seedlings was 84%, average height was 6.4 feet with a range from 4.6-7.4 feet, and average stem diameter was 1.1 inches with a range from 0.7-1.4 inches. In terms of growth, annual height growth over the seven-year period averaged 0.77 feet per year; average stem diameter growth was calculated at 0.8 inches per year.

In a brief section of this paper, the authors touch on the stem form of the black walnut seedlings. At 7-years old, the seedlings had already developed “widely divergent forks” (Wendel & Dorn, 1985) caused by breakage of the apical meristem due to frost events, deer, and insect damage. Preventing lateral branching and maintaining good stem form is a key consideration in growing black walnut for sawtimber or veneer. Understanding that pruning needs to be undertaken early on - which as the Wendel and Dorn paper indicates, may be within the first five years of establishing a black walnut plantation - is an important consideration in the black walnut growth and yield discussion.

The Forest Vegetation Simulator (FVS) is a model developed and maintained by the U.S. Forest Service which can be used to predict the growth and yield of various trees under a variety of conditions. For a better understanding of how forest managers currently project the volume and growth of black walnut in West Virginia, it is worth briefly discussing the Northeast (NE) variant of FVS, which covers thirteen northeastern states including West Virginia (Dixon & Keyser, 2008). The NE variant of FVS utilizes several equations and site index curves to produce outputs, and coefficients for each species are listed in the “Northeast Variant Overview” published in 2008 and revised in October 2021. For black walnut, the Wykoff equation (Wykoff et al., 1982) is used to determine the periodic diameter growth of small-trees (<5.0” dbh), a growth model adapted from Teck and Hilt (1991) is used to predict large-tree (≥5.0” dbh) diameter growth, and site index curves presented in a 1989 report by Carmean et al. are used to estimate potential large-tree height growth. Site index is of particular importance because it serves as an input in both the Wykoff equation and Teck and Hilt model. An illustration of site index values for black walnut can be seen in Figure 5.

This study incorporates FVS outputs using the NE variant, as well as the Central States (CS) variant, which encompasses areas in Illinois, Indiana, Iowa, and Missouri. The CS variant was used as a means of comparison, as black walnut is more abundant in the area covered by the CS variant, hence, a larger portion of black walnut trees were likely used as the basis for the variant's growth projections. The NE variant assigns black walnut to a general species group comprising over 25 different tree species, while the CS variant allocates black walnut to its own specific species group (Dixon & Keyser, 2008). Accordingly, the CS variant utilizes black walnut-specific coefficients for site index, bark ratio, and crown ratio equations, while the NE variant uses coefficients for the "other hardwoods" species group. The other key difference between the two variants lies in how large-tree diameter growth is calculated. The CS variant incorporates a model from Deo and Froese (2013), which also uses a black walnut-specific coefficient. Comparisons between the two variant's outputs are outlined in additional detail in Chapter Four.

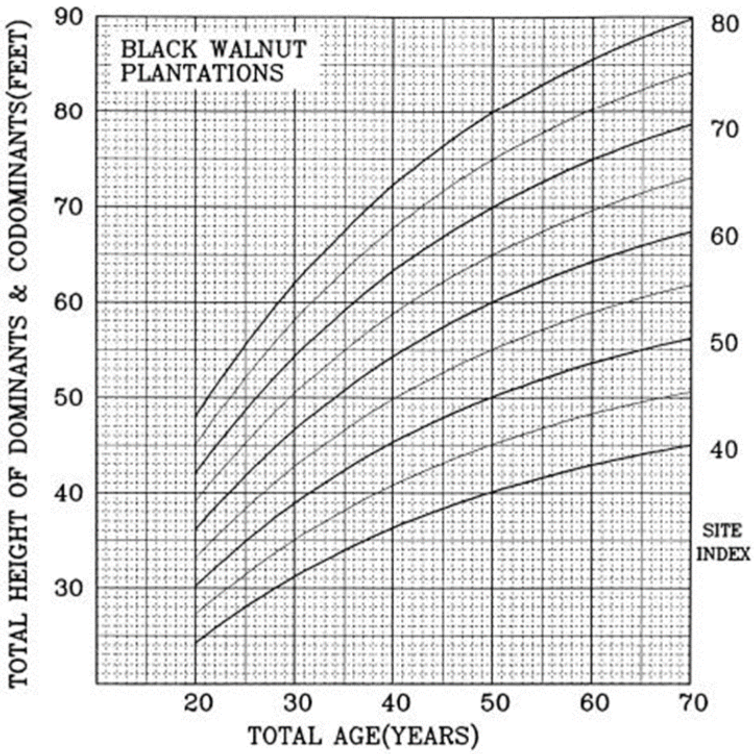


Figure 16.—Black walnut plantations (Kellogg 1939b)
Central States
188 plots, number of dominant trees not given
Total height and total age, anamorphic, equation not given
Determine total age from stumps or planting records (do not damage trees by using an increment borer) (BH = 0.0)

| | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | $R^2$ | SE | Maximum difference |
|---|---|---|---|---|---|---|---|---|
| H | 1.2898 | 0.9982 | -0.0289 | 0.8546 | 0.0171 | 0.99 | 0.44 | 1.7 |
| SI | 0.7875 | 0.9963 | -0.0281 | -0.7823 | 0.0353 | 0.99 | 0.49 | 2.1 |

**Figure 5.** One of the three site index curves for black walnut presented in Carmean et al. (1989).

A main takeaway from the literature discussed herein is that suitable soil type and characteristics play a major role in the productivity of black walnut, supporting conclusions that black walnut is highly "sensitive to soil conditions" (Williams, 1990). Soil treatments such as applying nitrogen may be helpful, but past studies have revealed that fertilization of black walnut "provides little growth improvement," (Beineke, 2000) confirming the importance of initial site selection. Cultural practices that may be more effective in improving the growth and yield of black walnut include controlling understory vegetation and pruning.

As discussed in the Ares and Brauer study, understory competition was detrimental to site index values for black walnut, particularly when tall fescue (*Festuca arundinacea*) was present, which suggests the need for weed control in the form of herbicide application, mowing, intercropping with a complimentary understory species, or some combination of these treatments. A final factor affecting the growth and productivity of black walnut - specifically in regard to the tree's timber value - is discussed in the Wendel and Dorn paper: the development of lateral branches and forking caused by breakage of the apical meristem. As suggested in "Black Walnut Plantation Management," a report produced by the Cooperative Extension Service at Purdue University, pruning of black walnuts should begin when trees are 2 years old to ensure the best growth form (Beineke, 2000).

As for the variables used to project growth, the papers by Salek et al. and Ares and Brauer both note a positive correlation between dbh and tree height, which shows that dbh growth rates may be useful in estimating long-term stand growth potential (Ares & Brauer, 2004). These papers also presented three equations applicable to modeling black walnut growth and yield. The Korf growth function used by Salek et al. demonstrated potential for calculating the standing volume of black walnut, and the two equations illustrated in the Ares and Brauer paper - one for estimating potential bole volume and one for estimating nut yields - also proved useful in predicting the economic value of individual trees. Lastly, though the Wendel and Dorn study did not utilize any specific models or equations, the annual growth data presented in the study is useful for understanding the growth of black walnut in West Virginia.

***Black Walnut as an Economic Resource***

Black walnut's ability to produce both valuable timber and non-timber forest products makes it an especially appealing species to examine from an economic perspective and consider as a financial investment. The price of black walnut exceeds that of every major timber species currently sold in West Virginia (Table 2).

**Table 2.** The average stumpage price ($/mbf, Doyle scale) of major timber species in WV for the quarter ending March 2021 (Source: Appalachian Hardwood Center at West Virginia University).

| Species | Region 1 | Region 2 | Region 3 | Region 4 | Region 5 | State Average |
|---|---|---|---|---|---|---|
| Red Oak | - | 295 | 286 | - | - | 289 |
| White Oak | - | 257 | 397 | - | - | 350 |
| Mixed Oak | - | 191 | 212 | - | - | 205 |
| Black Cherry | - | 315 | 331 | - | - | 326 |
| Yellow Poplar | - | 167 | 217 | - | - | 200 |
| Hard Maple | - | 271 | 356 | - | - | 327 |
| Soft Maple | - | 196 | 223 | - | - | 214 |
| Ash | - | 145 | 212 | - | - | 190 |
| Hickory | - | 120 | 112 | - | - | 115 |
| Walnut | - | 763 | 950 | - | - | 887 |

Additionally, black walnut has exhibited a relative increase in value over the past decade, even when prices are adjusted for inflation (Figure 6). Although prices for all hardwood lumber declined sharply between 2005 and 2009, black walnut was the last species to decline in price, declined for the least number of quarters, and demonstrated the greatest price increase after hitting a low point in 2010 in comparison to eight other hardwood species (Luppold & Bowe, 2010). This historic market information indicates that black walnut may be less susceptible to price fluctuations than other hardwood species, increasing its appeal as a financial investment.

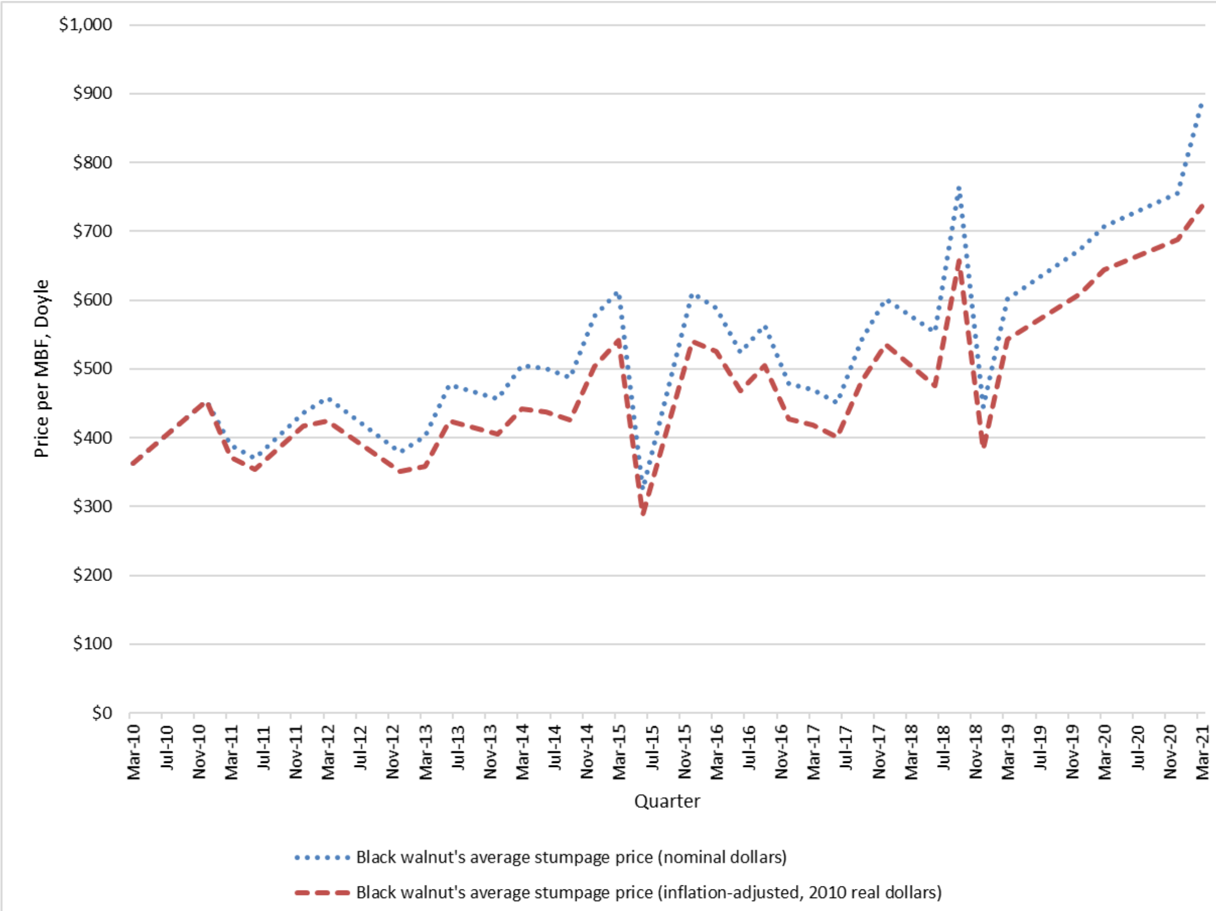


**Figure 6.** The average stumpage price ($/mbf, Doyle scale) of black walnut sold in West Virginia from March 2010 to March 2021, in both nominal and 2010 real dollars (Appalachian Hardwood Center, 2021; U.S. Bureau of Labor Statistics, 2022).

The two main categories of black walnut non-timber forest products are nuts and syrup. Jacob Basecke, Vice President of Sales and Marketing for the Hammons Products Company – the largest processor and supplier of black walnuts in North America – cited the 2020 bulk price of dehusked black walnuts as $15-16/100 lbs. (J. Basecke, personal communication, January 21, 2021). However, this pricing applies to the uncultivated – or “wild crop” of black walnuts – which make up the bulk of Hammons’s collections. Hammons purchased improved varieties of black walnut at an average of $76.73 per 100 lbs. between 2006-2019, suggesting that cultivar selection plays a significant role in estimating the profitability of black walnut, particularly if nut production is the main objective. Hammons’s focus on black walnuts is for use in food products, but the byproducts of nut processing also offer market opportunities. Shells are frequently ground for use in cosmetics (Small, 2013) and have several industrial applications, including as a “nonslip agent in automobile tires, as an air pressure propellant in strip paints...a filtering agent for scrubbers in smokestacks” and as a highly abrasive cleaner (Coladonato, 1991).

Black walnut is a semi-ring porous species, giving it a similar ability as diffuse-porous trees – such as maple and birch – to produce syrup. A study by Matta et al. (2005) found no significant difference in consumer liking of walnut versus maple syrup, indicating that black walnut could play a supplemental role in existing sugaring operations or provide a new market opportunity. However, in contrast to the various aspects of nut cultivation, harvesting, and processing, the production of black walnut syrup is a significantly underexplored area of research; a review of the literature identified three articles on the subject (Farrell & Mudge, 2014; Matta et al., 2005; Naughton et al., 2006); although there is a significant amount of unpublished discussion and informal research existing in forums such as Facebook. However, the 2006 article by Naughton et al. discusses the “substantial amount of sap flow” young black walnut trees produce, which was found to be dictated by the width of trees’ sapwood rings. As black walnut trees mature, sapwood width is reduced while heartwood volume increases, which suggests that the tapping of black walnuts could begin at a relatively young age, but potentially plateau when the tree reaches larger diameters. The production of walnut syrup could be a value-added commodity for landowners while they wait for their trees to mature (Farrell & Mudge, 2014), or recoup costs of pre-commercial thinning activities.

A report from Future Generations University quotes the 2020 wholesale price for black walnut syrup between $150-250/gallon (Rechlin & Herby, 2020), and a recent survey of black walnut syrup producers conducted by the University found the average 2021 sale price to be

$321.60/gallon (K. Fotos, personal communication, June 10, 2021). Though variable from year to year, for comparison, the average price per gallon of maple syrup in West Virginia was $30.20 per gallon (West Virginia Department of Agriculture, 2021). This significant pricing difference could be attributed to the lower sap yields provided by black walnut in comparison to maple (Farrell & Mudge, 2014). Additional research is needed to determine the economic trade-off of tapping black walnut and growing the species for veneer or sawtimber. Research of this kind has been conducted regarding the maple syrup industry (Farrell, 2012), and the methodology followed in this study could potentially be replicated with black walnut as the focus. However, for the purposes of this research, potential timber revenue for tapped trees was reduced by a flat rate of 39.5%.

This number was derived from the default value for “Value of Tapped Logs as a % of Untapped Logs” used in the NPV calculator described in “The Economics of Managing Maple Trees for Syrup or Sawtimber Production” (Farrell, 2012). The reduction in value is driven by damage occurs within the taphole area; this damage can include split bark, cambium dieback, and discolored or decayed internal wood (Walters & Shigo, 1978). While the percent reduction value may be higher or lower depending on a multitude of factors - such as the timber buyer, market conditions, the intensity of tapping, and the physiological response of the black walnut to tapping - enough research has not been conducted on these considerations in regard to black walnut to produce a more species-specific estimate.

The background information presented in this chapter served as guidance during the revision and update process of the black walnut financial model, discussed more thoroughly in Chapter Three. Literature covering the characteristics and site requirements of black walnut informed decisions on how to structure the input data used for Forest Vegetation Simulator runs, while the growth and yield-related studies helped to verify the values used to project growth and yield within the revised model. Additionally, knowledge concerning the current and future status of black walnut in West Virginia - as well as the species' proven value as a tree crop - lends justification to this research effort. As discussed, black walnut is a scarce species likely to remain sparse in the forested landscape; however, climate change modeling projects a possible increase in the range of habitat suitability for the species in West Virginia. These factors, coupled with the relatively steady economic value of black walnut, support the appeal of cultivating a black walnut plantation in West Virginia and reinforce the need for the financial analysis described and discussed in the remainder of this study.

# CHAPTER III

# METHODS

## *Original Financial Model*

As mentioned, the initial basis for this research was a black walnut financial model developed by Dr. Larry Godsey at the University of Missouri Center for Agroforestry (UMCA), identified during the literature review process. The model was first developed in 2002 to determine the "highest and best use" of a black walnut plantation, or orchard, with an objective of deciding whether sawtimber production or nut harvesting was more financially lucrative (L. Godsey, personal communication, November 10, 2021). Described as a "simplified decision model" intended for landowner use (Godsey, 2002), the Excel-based financial model requires the user to answer ten input questions found on the model's 'Inputs' worksheet:

1. What is your initial spacing? - Within row and between row spacing (in feet) is used to calculate the initial number of trees per acre.
2. Do you plan to harvest the nuts? - A "yes" answer incorporates a nut harvest cost at 50% of the nut income, while a "no" answer removes any expected nut harvest cost from the model.
3. Grafted/improved trees? - A "yes" answer incorporates an improved seedling cost, while a "no" answer incorporates an unimproved seedling cost.
4. What is the expected growth rate of the trees per year? - This input and its function is explained in more detail later in this chapter, but essentially, the model uses an algorithm to reduce the expected growth rate when crown competition begins to negatively impact the growth of the trees.
5. How much will the nuts sell for?

6. How much will the timber sell for on a board foot basis at final harvest?
7. What return would you like to earn on your investment?
8. How long will the future marketable log be? – This input is meant to reflect the length of the first branch free log on the tree that has the potential of being sold as veneer quality or as a FAS sawlog. This input serves three purposes within the model: 1) determines the market value of the final harvest of the trees, 2) helps to estimate the reduction in expected nut yield as more of the lower branches are removed, 3) helps to estimate if it is more profitable to grow the trees for timber, nuts, or both.
9. What will the diameter of the tree be at final harvest? - In conjunction with the growth rate indicated in Question #4, the model uses this input to identify what year the trees will reach the final harvest diameter. When the final harvest diameter is identified, the model calculates the income from a timber sale on the number of trees that are remaining in that year.
10. What percentage of the trees will be removed at each thinning on average? - Each time the model determines that a thinning is needed, it uses this input to calculate how many trees are removed. How the model determines a thinning is needed is explained later in this chapter.

Four additional user inputs located in the model's 'Calculations' worksheet were designed to increase the model's accuracy in terms of projecting growth and yield and developing a realistic cash flow. These additional inputs include:

1. Cost of improved seedlings: This input – as well as the following "Cost of unimproved seedlings input" – allow for current seedling prices to be incorporated into the model's cash flow.
2. Cost of unimproved seedlings
3. Alternate bearing factor: The alternate bearing factor input is meant to integrate the idea that black walnut trees produce heavy nut crops in some years, and lighter nut crops in others. This input value reduces the expected nut yield by the amount of the factor. Per Godsey, "trees that produce a large crop of nuts every other year would have an alternate bearing factor of 0.5…this would reduce the nut crop over the life of the trees by half in order to reflect the years that the trees do not produce a heavy crop. Trees that do not have the alternate bearing characteristic would have an alternate bearing factor of 1" (2002).
4. DBH @ Year 5: As discussed in more detail later in this chapter, the original model uses a simplified linear growth model not designed to estimate the growth of young trees. This variable is meant to correct the growth error caused by the simple linear growth model.

With the stated goal of decision modeling, the answer to each input question was designed to provide "an indication of the direction of change for certain management decisions…and a basis for determining which strategy would work best for a certain site" (Godsey, 2002). For example, by adjusting answers to the model's input questions, a user could identify if the resulting increase in nut yields justified the cost of improved seedlings, or if nut harvesting provided better financial returns than a timber sale on a low-quality site where diameter growth was menial. Based on communication with Dr. Godsey, as well as multiple trials with the original model, a good quality site with high growth rates favors timber production, while the reverse is true for nut harvesting.

Answers to the input questions listed above are used as formula references in five subsequent worksheets (‘Calculations’, ‘Enterprise Budget’, ‘Cashflow’, ‘Cost Calculations’, and ‘Growth Rates’). A variety of financial equations and growth and yield-related formulas are used to produce outputs that include a per tree and per acre cost summary for establishing the plantation, revenues and costs for pre-commercial/commercial thinning operations, the number of years needed to recoup establishment costs, a 100-year cash flow, and a variety of financial criteria. If the model determines timber to be the most profitable product objective, the year, volume, and monetary value of a final timber harvest is returned. Conversely, if nut harvesting is most profitable, the revenue stream from nut harvesting in perpetuity is returned. The final timber harvest year is returned using a match function to identify the user inputted answer to “What will the diameter of the tree be at final harvest?” in the model’s ‘Growth Rates’ worksheet. A ‘Financial Analysis Summary’ located on the model’s ‘Inputs’ worksheet provides an overview of the black walnut plantation’s Net Present Value (NPV), Internal Rate of Return (IRR), Annual Equivalent Value (AEV), and the Modified Internal Rate of Return (MIRR), utilizing the desired rate of return indicated by the user. Net Present Value is used as the basis for determining if growing the trees for timber, nuts, or both is most profitable.

Though the model “does not claim to accurately show tree growth characteristics at future points in time” (Godsey, 2002), it does employ a linear growth model to project average DBH of the stand, which serves as the key variable in calculating Diameter Inside Bark at small end of log (DIB), expected nut yield per tree (in lbs.), number of merchantable logs per tree, and thinning revenues/costs for each year in the 100-year cash flow. As noted, the model’s user enters the expected growth rate of the trees per year (inches DBH). This inputted growth rate - along with the number of trees per acre - is then used to calculate Crown Competition Factor (CCF) following Čavlović et al. (2010), where $SD_{m,y}$ is the number of trees per acre in year *y* -1 and $CD_{m,y}$ is a calculated crown diameter factor ($CD_{m,y} = 0.311 + 0.177 \times DBH_{m,y}$):

$$CCF_{m,y} = (SD_{m,y-1} \times (\pi \times CD_{m,y}^2/4) / 10000) \times 1.27 \times 100$$

The returned CCF value is then used to calculate a growth ratio (GR) ranging from 0-1 via an equation developed by Schlesinger (1996):

$$GR_{m,y} = \min(1, 1.411 - (0.00485 \times CCF_{m,y}) - (7.643 / CCF_{m,y}))$$

Using the following equation, diameter growth is reduced when CCF exceeds 115 and subsequently, growth ratio drops below 0.8 (i.e., when crown competition has an adverse effect on tree growth). In this equation, $DI_{m,y}$ is held constant and represents the user inputted "expected growth rate of the trees per year":

$$DBH_{m,y+1} = DBH_{m,y} + DI_{m,y} \times GR_{m,y}$$

The model also calculates a thinning operation when growth ratio drops below 0.8, as a means of maintaining a CCF level under 115. Thinning volumes (expressed in number of trees per acre removed) are estimated utilizing another input entered by the model's user: the average percentage of trees to be removed at each thinning. A thinning cost is applied if tree DBH is less than 15 inches, while a thinning revenue is applied if tree DBH is greater than 15 inches. This thinning revenue is based on a percentage of how much the timber will sell for on a board foot basis at final harvest (another user input). The equations used to calculate CCF, growth ratio, and other key outputs of the model were largely referenced from Warren H. Kincaid, Jr.'s master's thesis, "Silvicultural Economic Assessment of Black Walnut Management Alternatives" (1982).

### ***Updates and Revisions to the Model***

#### *Costs and Revenues*

To streamline the financial analysis process, the original Excel model was reformatted from six to four worksheets: 'Inputs and Financial Summary', 'Budget', 'Cash Flow', and 'Growth and Yield'. Because the black walnut financial model had not been significantly updated since its initial development in 2002, extensive revisions were made to reflect current costs and revenues more accurately. Additionally, when possible, costs and revenues specific to West Virginia were included to increase the robustness of the model's projections for state landowners. All cost updates are reflected in the model's 'Budget' worksheet. The list of establishment and maintenance activities was also redone, based on the guidelines of Walter F. Beineke's manual "Black Walnut Plantation Management" (2000) and Schlesinger and Funk's "Manager's Handbook for Black Walnut" (1977).

Costs for these activities were referenced from the West Virginia Natural Resources Conservation Service's (NRCS) Practice Scenarios Fiscal Year 2022 document, which summarizes the costs of conservation activities funded by the agency. These costs are evaluated and updated each year, and factor in current material, labor, and opportunity costs within the specified state, depending on the scenario. When appropriate NRCS practices could not be found for the cost updates, other sources were used, such as Alabama Cooperative Extension System's "Costs & Trends of Southern Forestry Practices" (2020) document. Costs of nut harvesting were estimated at 50% of the nut crop income. This set percentage was utilized in Godsey's 2002 black walnut financial model, based on information from Harper, 1998. Estimated per tree, per acre, and total costs for the two establishment scenarios evaluated are summarized in Appendix

A (Table 7). Costs were verified by referencing other sample budgets for establishing and maintaining a black walnut plantation (Basu & Gallardo, 2021; Grant et al., 2013).

Revenue estimates for each black walnut product were drawn from various sources. The most recent Timber Market Report (March 2021) from West Virginia University's Appalachian Hardwood Center was used to estimate the sale price of black walnut sawtimber per board foot. However, because the Timber Market Report provides prices based on the Doyle scale, but FVS timber volume outputs are in International ¼" scale, the following calculation was performed to align the log rule and pricing information:

International ¼" price = Doyle price ÷ 1.695 (Ray, 2022)

Doyle price = $887 per MBF, $0.89 per BF

$887 per MBF ÷ 1.695 = $523 per MBF, $0.52 per BF

Information provided by the Hammons Products Company – the largest processor and supplier of black walnuts in North America - was used to estimate the sale price of black walnuts per pound ($0.16). As an emerging product, pricing information for black walnut sap, syrup, and tap leases is not well established; however, efforts were made to identify the best estimates of current pricing. The sale price of syrup was set at $322 based on Future Generations University's unpublished 2021 walnut producer survey data (K. Fotos, personal communication, June 10, 2021); it should be noted that while 42 producers responded to the survey, just 10 reported their sale prices. The wholesale price of black walnut sap was estimated based on guidance from a Virginia syrup producer who has offered to purchase wholesale black walnut sap for $1.00 per gallon (C. Herby, personal communication, January 24, 2022). Though no black walnut tap leasing operations were identified during the research process, the lease price of trees was estimated at $1.10 per tap based on the average tap lease price for maple trees ($0.50 per tap per year) (Farrell, 2013). Both the sap wholesale and tap leasing prices were inflated to account for the higher value of black walnut syrup. All costs and revenues are adjustable within the model's 'Inputs' and 'Budget' worksheets, but the default values described herein represent the best available current estimates.

The remaining finance-related updates to the model focused on incorporating costs related to three distinct product/management objectives: 1) collecting/wholesaling unprocessed black walnut sap to syrup producers, 2) leasing trees for tapping, and 3) producing and selling black walnut syrup. Prior to these updates, the model accounted only for the costs and revenues associated with harvesting timber and nuts. The goal of incorporating these emerging practices into the model was to obtain a more complete outlook on black walnut's financial prospects - as well as the associated costs - further strengthening the model as a decision-making and financial analysis tool. Costs for these cash flows were obtained from sample budgets for maple syrup enterprises (Hansen et al., 2010; Ober, 2017), maple syrup production suppliers (Leader Evaporator, 2022), cost analysis research conducted by the U.S. Forest Service on processing maple syrup products (Huyler, 2000; Huyler & Garrett, 1979), and personal communication with Dr. Michael Farrell, CEO of The Forest Farmers, LLC, and former Director of Cornell University's Uihlein Forest (January 28, 2022). It should be noted that replacement costs were not incorporated into this analysis, although items such as tubing and syrup processing equipment would likely need to be replaced every 10 years.

*Inputs and Default Values*

Seven input questions not previously included in the original black walnut financial model were added to the 'Inputs' worksheet:

1. How many (approximate) acres will you plant?

2. Do you plan to conduct a timber sale?
3. Do you plan to collect/wholesale sap?
4. Do you plan to produce syrup?
5. Do you plan to lease trees for tapping?
6. Per acre, what percentage of the trees will be tapped/leased each year?
7. What is the approximate sugar content of sap in °Brix?

While the following input questions were eliminated due to lack of application in the model's updated format:

1. What is the expected growth rate of the trees per year?
2. How long will the future marketable log be?
3. What will the diameter of the tree be at final harvest?
4. What percentage of the trees will be removed at each thinning on average?

Four additional input questions were added to the updated model's 'Budget' worksheet, Question #1 was added for the purposes of a sensitivity analysis, while the remaining three questions are support the original model's intent of decision modeling:

1. Percentage of cost-share funds received for establishment
2. Intensive maintenance activities? (A "yes" answer incorporates additional costs for lime, nitrogen, and herbicide application, as well as insect and disease treatment.)
3. Hired labor used?
4. Labor rate ($ per hour)

Like the model's original input questions, each of the new input questions were included to indicate the direction of change caused by various management decisions and determine the overall impact on financial criteria. The eliminated input questions were no longer needed once outputs from the Forest Vegetation Simulator were incorporated; the use of these outputs is discussed in more detail in subsequent sections of this chapter.

In the original model, an assumed 54-acres is used to calculate per acre costs, however, the addition of the input question regarding how many (approximate) acres will be planted was intended to make per acre costs - as well as revenues - more specific and realistic; this input also allowed for a limited economies of scale analysis. Like the original model's input question of, "Do you plan to harvest the nuts?", if the answer is "no" to the timber sale or any of the sap/syrup-related questions, these product objectives will have no bearing on the financial analysis. The question regarding what percentage of trees per acre will be tapped or leased for tapping was included with the intent of analyzing the effect of retaining the timber value of some "tappable" trees. Lastly, the °Brix value is used to calculate an approximate sap to syrup ratio, which in turn is used to estimate the plantation's potential syrup yields, using the following modified "Jones Rule of 86" formula:

$$S = 87.1/X - 0.32$$

Where: S = the initial volume of sap (or concentrate) required to produce 1 gallon of syrup, and X = the starting sap sugar concentration in °Brix (Perkins & Isselhardt, 2013). The default value of 1.7 °Brix is an average taken from collected data, as well as data presented in the literature (Naughton et al., 2006; Rechlin & Fotos, 2021).

*Growth and Yield Projections*

A key limitation of Godsey's original model was the linear growth function used to estimate the plantation's average DBH. Using this method, the expected DBH growth rate of the trees remains relatively constant, which leads to the model underestimating the size of young trees, potentially overestimating the size of mature trees, and lacking the feature of a diameter distribution. Additionally, the "percent of trees to be removed at each thinning" input was held constant regardless of stand density, resulting in some instances in 12 trees per acre remaining at the end of the rotation and CCF values dropping below 75; thinning guidelines for black walnut advise 20-25 trees should remain per acre at final harvest (McKenna & Farlee, 2013; McKenna & Woeste, 2004) and that CCF values should not drop below 100, the level at which each tree is theoretically reaching its maximum growth rate (Schlesinger, 1989). As a means of overcoming these limitations of the original model, the Forest Vegetation Simulator was used to produce a Stand Composition Table and Summary Statistics Table for a variety of management scenarios, from which the following data was utilized: diameter distribution, quadratic mean diameter, average top height, number of trees per acre removed via thinning, sawlog board foot volume per acre removed via thinning, and total sawlog board feet volume per acre in the entire stand. The inclusion of these FVS outputs made it possible to determine stand structure over time, which provided more accurate estimates of nut yields, and made the projection of sap/syrup yields possible.

The data input into FVS was designed to simulate eight unique establishment and management scenarios (Table 3). All data points were derived from a 100% tally taken at a privately owned, approximately 6-acre black walnut plantation located in Harrison County, West Virginia. Located in a riparian area formerly in agricultural use, the site quality is relatively high. The plantation was established in 2014 with both 1- and 2-year-old bareroot seedlings. DBH measurements taken in the plantation's seventh growing cycle (2021) were used, and a sample of trees from the plantation's interior were selected as a means of controlling for edge effect. Trees were selected from a block in which 2-year-old seedlings had been planted; accordingly, stand age was set to nine in FVS. As Table 3 shows, a consistent site index of 75 was used, representing a relatively high-quality planting area. Because FVS is intended to process inventory data based on point sampling or fixed-area plots in which plot size is less than one-acre - as opposed to a 100% tally for a plot larger than one acre - the number of tree records in each FVS dataset was scaled to simulate 8 x 8 (approximately 680 trees per acre) and 17 x 17 (approximately 150 trees per acre) row spacing on a 1/10th acre plot, therefore, 68 tree records were entered to simulate 8 x 8 spacing, while 15 were used to simulate 17 x 17 spacing. The row spacing values were chosen based on guidelines for establishing a sawtimber or veneer plantation (8 x 8), or a nut orchard (17 x 17) (Schlesinger & Funk, 1977).

**Table 3. Details of each input dataset used for FVS runs.**

| Dataset # | FVS Variant | Location Code | Site Index Value | Thinning Schedule | Number of thinnings Year 10-70 | Number of commercial thinnings Year 10-70 | Initial Row Spacing | Initial Trees per Acre |
|---|---|---|---|---|---|---|---|---|
| 1 | Central States | 911 (Wayne-Hoosier) | 75 | No thinning | - | - | 8 x 8 | 680 |
| 2 | Central States | 911 (Wayne-Hoosier) | 75 | Thin to CCF level ≤115 | 8 | 2 | 8 x 8 | 680 |
| 3 | Central States | 911 (Wayne-Hoosier) | 75 | No thinning | - | - | 17 x 17 | 150 |
| 4 | Central States | 911 (Wayne-Hoosier) | 75 | Thin to CCF level ≤115 | 7 | 2 | 17x17 | 150 |
| 5 | Northeast | 911 (Wayne-Hoosier) | 75 | No thinning | - | - | 8 x 8 | 680 |
| 6 | Northeast | 911 (Wayne-Hoosier) | 75 | Thin to CCF level ≤115 | 9 | 3 | 8 x 8 | 680 |
| 7 | Northeast | 911 (Wayne-Hoosier) | 75 | No thinning | - | - | 17 x 17 | 150 |
| 8 | Northeast | 911 (Wayne-Hoosier) | 75 | Thin to CCF level ≤115 | 6 | 1 | 17x17 | 150 |

For comparison purposes, both the Northeast (NE) and Central States (CS) FVS variants were used to produce outputs. Differences in outputs using the two variants are examined in

Chapter 4, but generally it was found that outputs from the CS variant better estimated large-tree diameter growth, and were therefore used as the growth and yield component of the financial analysis. Regardless of the variant used, the location code entered for each dataset remained consistent throughout (Table 3). The Wayne – Hoosier National Forest location code utilizes a latitude and longitude of 39.33, 82.10 and an elevation of 900 feet. Of the ten other location codes listed in both the Central States and Northeast variants, the location parameters used align most closely with potential areas where black walnut would be planted.

The decision to periodically thin to maintain a CCF level ≤115 was made based on the prevailing guidance for thinning black walnut plantations (North Central Forest Experiment Station, 1981; Schlesinger, 1989), as well as the methodology followed in Godsey's original black walnut financial model. Thinnings were scheduled in FVS through an iterative process of thinning from below - without lower or upper diameter limits - to a target level of residual trees per acre while ensuring that CCF did not fall below 100 or reach above 115 by referring to the CCF field in the outputted Summary Statistics table. Once FVS runs for each dataset were completed, the following outputs were copied and pasted into the updated model's 'Growth and Yield' worksheet. Table 4 summarizes the FVS output field and its corresponding field within the 'Growth and Yield' worksheet.

**Table 4. Fields obtained from Forest Vegetation Simulator outputs and their corresponding location within the updated black walnut financial model's 'Growth and Yield' worksheet.**

| Output Table | Field(s) in Output Table | Field in 'Growth and Yield' worksheet | Unit in "Growth and Yield' worksheet |
|---|---|---|---|
| Stand Composition | DBH class (1-inch class), Live trees per Acre | Number of trees per acre for diameter classes 1-24 inches | Trees per acre |
| Summary Statistics | Quadratic mean DBH | Average DBH | Inches, centimeters |
| Summary Statistics | Average dominant height | Average height | Inches, centimeters |
| Summary Statistics | Removed trees per acre | Number of trees per acre removed in thinning | Trees per acre |
| Summary Statistics | Removed sawlog board foot volume | Sawlog board foot volume per acre removed in thinning | Sawlog board foot volume per acre calculated using equations from the National Volume Estimator Library (Dixon, 2022) |
| Summary Statistics | Sawlog board foot volume | Sawlog board foot volume per acre in plantation | |

The diameter distribution made possible using FVS outputs was used to project nut yield and sap yield per acre for each 1-inch diameter class. Nut yield was estimated using the nut production equation presented in Ares and Brauer (2004). Where NY represents nut yield in kilograms per tree (for the purposes of this research, kilograms were converted to pounds):

$$NY = -36.91 + 2.55DBH(cm)$$

Projecting the sap yield of black walnut trees is an underexplored area of research and little information exists regarding how sap yield changes over time. However, a regression analysis was run using sap yield measurements taken from trees with an average dbh of 2.89, 3.39, 16.87, and 17.87 inches. Two sets of sap yield data were collected from 15 trees growing in the same privately owned black walnut plantation described above. In 2021, 15 trees were tapped with an average dbh of 2.89 inches; in 2022, an additional 15 trees were tapped with an average dbh of 3.39 inches. Data was collected in 2021 over a seven-week period, and tapped trees ranged from 1.17 to 4.55 inches dbh; average sap yield per tree was 0.21 gallons. In 2022, data was collected over a four-week period, and tapped trees ranged from 1.50 to 5.30 inches dbh; average sap yield per tree was 0.60 gallons.

The datasets reflecting sap yield for larger-diameter trees were collected in 2016 (average tree dbh = 16.87) and 2021 (average tree dbh = 17.87) from 24 and 26 trees, respectively. These trees were grown in a natural forest setting, located at West Virginia University's University Farm Woodlot. Average sap yield per tree for the 2016 data was 5.93 gallons, and 4.42 gallons for the 2021 data. Diameter at breast height (dbh) accounted for 92.9% the variance seen in average sap yield per tree ($R^2 = 0.929$). Sap yield increased by 0.331 gallons for every one inch of dbh growth. The regression analysis produced the following equation, which was then applied within the model to calculate sap yield. Where SY represents sap yield in gallons per tree:

$$SY = -0.611 + 0.331\mathit{DBH(in)}$$

All trees equal to or greater than 6 inches dbh were considered "tappable". Research into tapping maple trees has led to the following "conservative tapping guidelines" for maximizing long-term maple sap production: one tap for a 10-inch tree, and up to two taps for a 20-inch tree (Farrell, 2013). Though similar guidelines have not yet been established for black walnut, current research indicates that black walnut can likely be tapped at smaller sizes and more "aggressively" (M. Farrell, personal communication, January 28, 2022). This statement is supported by a study that highlighted black walnut's superior response to wounding, noting that mechanically induced wounds made to fifty black walnut trees closed after a single season's growth (Armstrong et al. 1981).

***Assumptions of the Model***

The financial model includes multiple assumptions as to how the black walnut plantation will be established and managed. Though these assumptions can be altered by changing the answer to various input questions described above, they were set as follows to attain comparable results:

1. The intended planting area is non-forested, relatively flat, and uncompacted. As a result, heavy disking and tree removal are not needed. The extent of site preparation is mowing using a brush hog mower.
2. The planting area is approximately 5-acres in size. Five-acres was chosen based on previous research indicating the financial viability of small acreage tracts (Hatcher et al., 1993). This same research also highlighted the appeal of cultivating black walnut plantations as a "profitable alternative on tracts that are not conducive to shorter rotation tree crops" and incompatible with "more traditional southern agricultural enterprises" due to their size (Hatcher et al., 1993).
3. Bareroot, unimproved seedlings are planted; replacement seedlings are planted in the year following establishment with an expected 20% mortality of initial trees per acre. (The cost of improved seedlings can be incorporated via one of the input questions but was not used in this analysis).
4. Seedlings are established using machine planting.
5. Herbicide is applied in the establishment year only; weed control is addressed by mowing from Years 2-10, at which point crown closure should reduce the need for mowing.
6. Lime and fertilizers such as nitrogen, potassium, phosphorus, calcium, and magnesium are not applied at any point.

7. Tree shelters are not used, but a polywire fence with a solar charger is installed to address potential damage from deer and other ruminants.
8. Pruning with hand tools is planned for Years 2-10 in scenarios that include timber as a product objective; pruning costs are removed in scenarios with no timber product objective.
9. No irrigation or pest management occurs at any time.
10. Hired labor is used, with a labor rate of $15.00 per hour.
11. 100% of the "eligible" trees (greater than 6 inches dbh) will be tapped. One tap is placed per tree.

***Cash Flow and Sensitivity Analyses***

An individual Excel workbook containing the finalized financial model was created for each of the eight datasets summarized in Table 3, incorporating the appropriate FVS outputs (Table 4). Then, within each of these workbooks, values from the following input questions were adjusted to ascertain financial criteria for the specific product objectives of 1) timber, 2) timber and nuts, 3) timber, nuts, and collect/wholesale sap, 4) timber, nuts, and produce syrup, 5) timber, nuts, and lease trees for tapping, 6) nuts and collect/wholesale sap, 7) nuts and produce syrup, 8) nuts and lease trees for tapping:

1. Do you plan to conduct a timber sale?
2. Do you plan to collect/wholesale sap?
3. Do you plan to produce syrup?
4. Do you plan to lease trees for tapping?

The 70-year cash flow was organized by 3-year periods, necessitated by the format of the growth and yield-related FVS outputs; if growth projections exceed 40 years, the output's period length cannot be less than 3-years. The ‘Cash Flow’ worksheet of the model was set up to discount all per acre costs and revenues to their present value for each year of the cash flow, using the Present Value of a Single Sum formula:

$V_o = V_n / (1+i)^n$

In which,

$V_o$ = Value in year 0 (present value)
$V_n$ = Value in year n (future value)
i = interest rate (in this case, 4%)
n = number of years

Present values of all per acre costs and revenues were then summed for the entire project. NPV was then calculated by subtracting the total Present Value of Costs from the total Present Value of Revenues. A 4% interest rate - or discount rate - was chosen because the U.S. Forest Service uses this rate for assessing long-term forestry investments, with the justification being that “this rate approximates the long-term measures of the opportunity cost of capital in the private sector of the U.S. economy” (Row et al., 1981). Further, 4.1% was found to be the preferred discount rate in a 2018 survey of German foresters (Sauter & Mußhoff, 2018). BCR was determined by dividing the total Present Value of Revenues by the total Present Value of Costs. IRR and EAI were calculated using the built-in Excel functions for IRR and PMT. Year 70 was used as the year of comparison, based on the time when a timber harvest would likely occur.

Lastly, sensitivity analyses were performed by altering the following inputs in order to determine the impact on financial criteria if 1) cost-share funds were received, 2) acreage of the plantation was increased, 3) stumpage value of the timber increased, 4) the discount rate was lowered/raised:

1. Percentage of cost-share funds received for establishment - This value was changed from 0% - which reflects a scenario in which a landowner pays to establish a plantation completely out of pocket - to 75% of the total establishment costs, the typical Natural Resources Conservation Service (NRCS) cost-share percentage provided to landowners (K. Aldinger, personal communication, March 28, 2022). Potential conservation practice scenarios a West Virginia landowner may qualify under to establish a black walnut plantation include Riparian Forest Buffer (Code #391), Tree/Shrub Establishment (Code #612), Tree/Shrub Site Preparation (Code #490), and more (West Virginia Natural Resources Conservation Service, 2022).
2. How many (approximate) acres will you plant? - Acreage was increased from 5 to 55 acres to perform a limited economies of scale analysis (i.e., to ascertain the proportionate saving in costs gained by increased level of production).
3. Sale price of timber at final harvest ($ per board foot) - Timber prices are variable from year to year, and an increase in current pricing would likely be seen by the time a timber harvest takes place. Stumpage price was increased from $0.52 to $2.50 to estimate how an increase in the value of black walnut sawtimber would impact the optimal product objective.
4. Desired return on investment - This variable is the discount rate used to calculate present value. It was changed from 4% to 2%, and from 4% to 6%.

# CHAPTER IV

# RESULTS

## *Forest Vegetation Simulator Outputs*

A comparison between FVS outputs using both the Central States and Northeast variants is presented in Table 5. Though values are generally similar, on average, use of the CS variant resulted in slightly higher production volumes in terms of trees per acre (TPA) in Year 70, average tree diameter and height in Year 70, the average number of trees tapped per acre Year 10-70, and sawlog board foot volume. Year 70 is used as the point of comparison because that is when a timber harvest is assumed to occur for the purposes of this model. In contrast, use of the NE variant resulted in slightly higher production volumes in terms of average nut and sap yields per acre. These minor differences can be explained by variances in trees per acre and diameter distributions.

For both variants, average marketable nut yield per acre, average sap yield per acre, and average number of trees tapped per acre, were all maximized with an initial 8 x 8 row spacing, without thinning. However, the CS variant produced the largest trees - based on QMD in Year 70 - when trees were planted on 8 x 8 spacing and periodically thinned to maintain a CCF level equal to or less than 115, while 17 x 17 spacing with thinning produced the largest QMD under the NE variant. Similarly, maximum board foot volume production was achieved with 8 x 8 spacing, no thinning for the CS variant, and 8 x 8 spacing with thinning for the NE variant. Because differences between the two variants were not considerable, coupled with the fact that the CS variant likely calculates large-tree diameter of black walnut more accurately due to its species specificity, outputs from the CS variant were used as the basis for financial analyses.

**Table 5. Comparison of growth and yield outputs for a simulated black walnut plantation between the Central States (CS) and Northeast (NE) variants of the Forest Vegetation Simulator.**

| | CS variant | | | | NE variant | | | |
|---|---|---|---|---|---|---|---|---|
| | 8 x 8 spacing, no thinning | 8 x 8 spacing, CCF thinning | 17 x 17 spacing, no thinning | 17 x 17 spacing, CCF thinning | 8 x 8 spacing, no thinning | 8 x 8 spacing, CCF thinning | 17 x 17 spacing, no thinning | 17 x 17 spacing, CCF thinning |
| TPA, Year 70 | 137 | 54 | 112 | 59 | 123 | 60 | 111 | 59 |
| QMD (in), Year 70 | 13.28 | 17.35 | 13.94 | 16.35 | 14.00 | 14.90 | 14.01 | 15.14 |
| Average top height (ft), Year 70 | 82 | 82 | 80 | 80 | 80 | 81 | 80 | 80 |
| Average marketable nut yield/acre (lbs.), Year 10-70 | 4,709 | 2,666 | 2,991 | 2,196 | 5,294 | 2,569 | 2,589 | 2,326 |
| Average number of trees tapped/acre, Year 10-70 | 226 | 81 | 105 | 71 | 218 | 82 | 99 | 72 |
| Average sap yield/acre (gals), Year 10-70 | 506 | 227 | 273 | 193 | 524 | 224 | 246 | 199 |
| Total sawlog board foot volume removed in thinnings, Year 10-70 | - | 1,482 | - | 1,827 | - | 1,320 | - | 728 |
| Total sawlog board foot volume/acre, Year 70 | 15,496 | 15,585 | 15,398 | 13,282 | 17,659 | 11,089 | 15,036 | 10,877 |

***Results of the Cash Flow and Sensitivity Analyses***

Net present values (NPV) and internal rates of return (IRR) for the initial (full cost) financial analysis, as well as the five sensitivity analyses, are summarized in Appendix B (Table 8). With the full amount of establishment costs incorporated into the cash flow, 10 of the 32 scenarios evaluated were found to be feasible. Based on NPV ranking, the highest net returns were seen on 8 x 8 spacing without thinning, and selecting timber, nuts and leasing taps as the product objectives (NPV = $1,694 per acre). The greatest losses were also seen on 8 x 8 spacing without thinning, but setting nut harvesting and wholesaling collected sap as the product objectives (NPV = -$7,124 per acre). Though the number of financially feasible scenarios differed in each analysis, a commonality between all analyses was that some combination of timber, nut harvesting, and leasing taps contributed to profitability, while product objective combinations involving sap wholesale or syrup production led to financial losses. Along those same lines, each analysis resulted in the same management scenario and product objective combination leading to the highest net returns and greatest losses, except for the 6% discount rate sensitivity analysis. In the 6% discount rate sensitivity analysis, 8 x 8 spacing without thinning and selecting timber, nut harvesting, and syrup production as the product objectives resulted in the greatest losses, while planting on 8 x 8 spacing without thinning and selecting nut harvesting and leasing taps as the product objectives led to the highest net returns.

Results of the sensitivity analysis when a 75% cost-share of establishment funds was applied indicated that 12 of the 32 scenarios evaluated were feasible, and NPV values collectively increased. An increase in acreage resulted in 11 feasible scenarios, and some differences were noted in the overall rankings of most to least profitable; in general, scenarios involving producing syrup moved up in the rankings, though they remained unprofitable. For a third sensitivity analysis, stumpage value was increased to $2.50 per board foot, and 16 financially feasible scenarios were identified. As expected, scenarios involving timber harvesting became more profitable and consequently, resulted in differences among the overall rankings of most to least profitable.

Two additional sensitivity analyses focused on the impact of lowering and raising the discount rate. When the discount rate was changed from 4 to 2%, 16 scenarios were financially feasible, while only two scenarios were feasible in the 6% discount rate sensitivity analysis. Figure 7 provides a comparison of the highest and lowest NPV values (USD/acre) in Year 70 for each financial analysis described above. As noted, though all analyses identified the same scenarios and product objective combinations as the most and least profitable (with a single exception), receipt of cost-share funds, increases in acreage and stumpage value, and alterations to the discount rate, impacted financial criteria. As expected, the highest and lowest NPV values were observed in the 2% discount rate sensitivity analysis; this is an expected result because a lower discount rate results in higher present values of future cash flows, since future cash flows are reduced by the discount rate.


**Figure 7.** The highest and lowest NPV per acre values of all scenarios evaluated, in Year 70, for each financial analysis. With the exception of the 6% discount rate sensitivity analysis, all analyses identified the same scenarios as most and least profitable. Establishing the plantation on 8 x 8 spacing without thinning, and setting timber, nut harvesting, and leasing taps as the product objectives resulted in the highest net returns; 8 x 8 spacing without thinning, and setting nut harvesting and wholesaling sap as the product objectives resulted in the greatest losses. The 6% discount rate sensitivity analysis identified 8 x 8 spacing without thinning, and nut harvesting and tap leasing as the most profitable scenario; 8 x 8 spacing without thinning, and timber, nut harvesting, and producing syrup resulted in the greatest losses under this analysis.

To better understand the effect of each product objective on NPV, 1) timber, 2) nut harvesting, 3) leasing taps, 4) wholesaling sap, and 5) producing syrup were isolated to calculate their specific financial criteria without the influence of other product objectives. The financial model simulating 8 x 8 spacing, with no thinning, full establishment costs incorporated, and a 4% discount rate was chosen for this analysis (i.e., the initial financial analysis). All financial criteria calculated for these individual product objectives are summarized in Table 6. Standing alone, the least profitable objective was wholesaling collected sap and the most profitable was nut harvesting. Though product objectives were not analyzed independently within the sensitivity analyses, it can be inferred that wholesaling sap would likely remain the least profitable revenue source, while timber may replace nut harvesting as the most profitable revenue source when stumpage values are increased.

**Table 6. Financial criteria (Year 70) calculated for each individual product objective. Values are based on a financial model simulating 8 x 8 spacing with no thinning. Full establishment costs were incorporated, and a 4% discount rate was used in this analysis.**

| | Timber | Nut harvesting | Leasing taps | Wholesaling sap | Producing syrup |
|---|---|---|---|---|---|
| Payback period | Costs not recovered | 52 years | 43 years | Costs not recovered | Costs not recovered |
| NPV | -$652 | $355 | $250 | -$8,451 | -$6,997 |
| IRR | -2.9% | 1.7% | 1.5% | N/A | N/A |
| BCR | 0.44 | 1.15 | 1.26 | 0.21 | 0.66 |
| EAI | -$28 | $15 | $11 | -$361 | -$299 |
| Peak deficit | -$1,169 | -$970 | -$972 | -$8,451 | -$7,432 |
| Year peak deficit occurs | 10 | 10 | 10 | 70 | 46 |

Though NPV is the financial criterion widely used for evaluating the feasibility of investment projects, internal rate of return (IRR) can also be used to rank investments. Figure 8 compares the highest IRR values of all the scenarios evaluated. Differences between NPV and IRR rankings were observed. Though IRR ranking also identified 8 x 8 spacing without thinning as the most profitable management scenario, nut harvesting and leasing taps were found to be the most profitable product objective combination; NPV ranking identified timber, nut harvesting, and tap leasing as the most profitable. This conflict between NPV and IRR rankings is covered extensively in the literature, but can be attributed to inherent differences between the two economic indicators. While NPV is an absolute measure of an investment's profit or loss at a certain point in time, IRR is a relative measure of the rate of return a project offers over its lifespan (Weber, 2014).

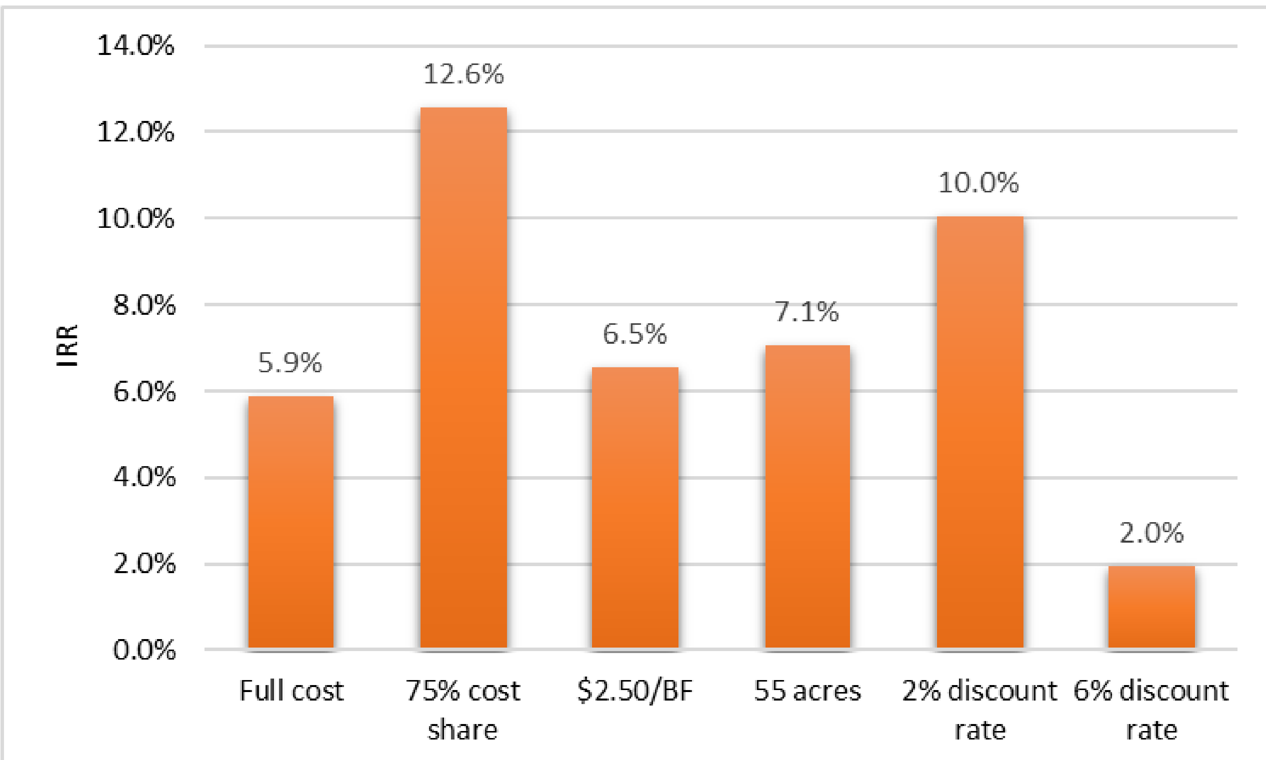


**Figure 8.** The highest IRR values of all scenarios evaluated, in Year 70, for each financial analysis.

# CHAPTER V

# DISCUSSION & CONCLUSION

## *Key Findings & Applications*

This research sought to identify what combination of establishment scenario, thinning treatment, and set of product objectives led to maximum financial returns from cultivating a black walnut plantation. Due to the lack of research surrounding the economic outlook of tapping black walnut trees, an objective of this study was to incorporate cash flows related to collecting and wholesaling black walnut sap, producing black walnut syrup, and leasing trees for tapping. Integrating sap and syrup-related cash flows into a financial model designed to project the costs and revenues of timber and nut harvesting allowed for a more comprehensive view of black walnut's economic potential as a multi-purpose tree crop.

This research suggests that the most profitable combination of product objectives is nut harvesting and tap leasing until timber matures to a merchantable size, at which point a timber sale can be completed. Across a majority of analyses, this set of product objectives consistently ranked highest in terms of NPV out of the eight options under consideration. Of particular interest is the fact that despite the inclusion of a 39.5% reduction in timber value, incorporating tap leasing still contributed to the most financially feasible option. This points toward an established concept in the field of financial analysis, which is that the sooner upfront costs (in this case, initial establishment costs) are recovered in an investment timeline, the sooner an investment can become viable and the better the return on investment will ultimately be. In this analysis, revenue from nut harvesting and tap leasing began as early as Year 10 in some instances, leading to an earlier payback period. Alternatively, in scenarios that incurred just one revenue from timber harvesting at Year 70, initial plantation establishment and maintenance costs were carried to the end of the investment period before recovery could occur, leading to a lower NPV.

It is evident from these research findings that establishment costs play a significant role in determining the profitability of cultivating a black walnut plantation. The impact of establishment costs is best illustrated by comparing results of the full cost financial analysis versus the 75% cost-share sensitivity analysis. When the full amount of establishment costs is incorporated into the analyses, there are 10 financially feasible options. On the other hand, when establishment costs are reduced via the 75% cost-share, an additional two options become financially feasible, bringing the total number of feasible options to 12. Additionally, IRR values for the 75% cost-share analysis exceed those of all other analyses (Figure 8). Another consistent finding of this research is that the least profitable combination of product objectives - regardless of establishment costs, plantation acreage, or stumpage value - is harvesting nuts and wholesaling collected sap. In every financial analysis performed, a commonality of the lowest-ranking scenarios, in terms of NPV, was the inclusion of either collecting and wholesaling sap or producing syrup. This analysis budgeted for these practices on a commercial scale, so the reason wholesaling sap and producing syrup proved to be unprofitable could be attributed to the high costs associated with these practices.

Though the price of both black walnut sap and syrup are high in comparison to that of maple, the sap yields projected by the model were not great enough to generate a substantial amount of revenue to justify the costs of investing in tapping, storage, and syrup production equipment. This finding could be interpreted as confirmation that black walnut sap yields are too low to warrant commercial potential, however, multiple considerations would need to be addressed to verify that claim. These considerations include the effect of vacuum tubing on sap yield (a factor not accounted for in this study due to a lack of research), developing walnut-specific tapping guidelines, and examining the economic outlook of black walnut tapping in conjunction with existing sugaring operations. Although this research suggests that sugaring black walnut in a plantation setting is not financially viable (outside of leasing trees for tapping), it is likely that the financial feasibility of sugaring black walnut trees would be substantially different if a resource of black walnut already existed on a landowner's property.

Many of the studies that examine the economic potential of black walnut do not incorporate a full enterprise budget (Wolz & DeLucia, 2019), or reflect out-of-date pricing information (Garrett & Kurtz, 1983; Godsey, 2002; Hatcher et al., 1993; Schultz & DeLoach, 2004), making it difficult to draw direct comparisons with the results of this research. Additionally, a research goal of some studies was to draw comparisons between the financial returns of black walnut production and other crops, such as loblolly pine (Schultz & DeLoach, 2004) or a maize-soybean rotation (Wolz & DeLucia, 2019), a question not examined in the scope of this research. However, the results of this financial analysis are in agreement with other studies that found black walnut to be a financially viable land use alternative under certain conditions.

***Limitations of the Research***

As highlighted throughout, a key limitation of this research is the lack of empirical data regarding all aspects of tapping black walnut and producing syrup from this tree species. Though the best attempts were made to gather relevant pricing information, estimate average sugar content, project sap yield based on field measurements, and approximate the effect of tapping on timber value, maple-related guidelines and standards serve as placeholders in multiple instances. If tapping black walnut trees becomes a more common practice, extensive research could be conducted following the established methodologies of maple research. The data resulting from this type of research would undoubtedly increase the robustness of this financial model's financial projections in relation to wholesaling sap, producing syrup, and leasing taps.

Additionally, the applicability of certain aspects of this research are ambiguous in regard to West Virginia. For example, distance to markets is a key consideration when it comes to nut harvesting, as no identifiable hulling and buying stations currently exist in the state. Though these stations do exist in neighboring states including Kentucky and Ohio, transportation costs are an added consideration not currently incorporated in this financial analysis due to the high variability involved. Furthermore, fixed costs are not incorporated into the revised model's (or the original model's) cash flows. This decision was made based on the high variability involved in estimating potential fixed costs, such as property taxes, insurance payments, and land value, but should be noted as an additional factor needed to project the full economic performance of a black walnut plantation.

***Recommendations and Conclusion***

Forestry-related management recommendations for landowners are highly dependent on individuals' goals and objectives; with this in mind, this study was designed to explore the financial outputs and returns for a range of potential objectives (and the management scenarios designed to meet those objectives) related to the cultivation of a black walnut plantation. One takeaway is that if a landowner is interested in this specific forestry practice, cost-share funding should be pursued, or efforts should be made to reduce establishment costs as much as possible. Additionally, if financial returns are the main goal, this specific financial analysis points toward planting on 8 x 8 spacing, not thinning the stand, and pursuing revenue through nut harvests and leasing taps until an eventual timber sale can be conducted. Product objectives to be avoided include wholesaling sap and producing syrup, based on these practices' considerable upfront costs.

However, to remain a relevant and useful resource, the framework of this research will need to be reassessed and altered as new information emerges regarding several factors, as is the case with all economic analysis. Through the inclusion of input questions, the financial model at the center of this study is designed and intended to adapt to price changes. However, factors that would require a reassessment of this analysis may involve an improved equation for projecting the sap yield of black walnut, or further validation of the model's assumptions, such as if empirical data becomes available for practices like selling tapped black walnut logs. Nonetheless, the results of this research provide a contribution to the body of knowledge on growing black walnut as a tree crop, what management strategies to pursue based on the desired product objective(s), and a current estimate of black walnut's financial outlook for West Virginia landowners.

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# APPENDIX A

**Table 7. A summary of estimated per tree, per acre, and total costs for the 8 x 8 and 17 x 17 spacing establishment scenarios. Pruning costs are removed in scenarios where timber is not a product objective, and thinning costs are removed in scenarios without thinning. Per acre costs are calculated based on a 5-acre basis.**

| | Per tree cost (17 x 17) | Per tree cost (8 x 8) | Per acre cost (17 x 17 | Per acre cost (8 x 8) | Total cost (17 x 17) | Total cost (8 x 8) | Cost estimate | Unit |
|---|---|---|---|---|---|---|---|---|
| Variable Cash Costs | | | | | | | | |
| 1. Establishment: | | | | | | | | |
| a. Site preparation | | | | | | | | |
| Tillage | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $17.46 | acre |
| Gate/fencing | $1.41 | $0.31 | $212.81 | $212.81 | $1,064.05 | $1,064.05 | $0.57 | foot |
| b. Fertilization/weed control | | | | | | | | |
| Lime | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $72.67 | ton |
| Herbicide | $0.06 | $0.01 | $8.98 | $8.98 | $44.90 | $44.90 | $8.98 | acre |
| c. Planting | | | | | | | | |
| Seedlings (bareroot) | $0.62 | $0.62 | $93.45 | $421.99 | $467.25 | $2,109.94 | $0.62 | each |
| Tree shelters | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $5.06 | each |
| d. Equipment | | | | | | | | |
| Mower | $0.22 | $0.05 | $33.44 | $33.44 | $167.22 | $167.22 | $55.74 | hour |
| Tractor | $0.20 | $0.04 | $30.35 | $30.35 | $151.74 | $151.74 | $25.29 | hour |
| Mechanical tree planter | $0.05 | $0.01 | $7.96 | $7.96 | $39.78 | $39.78 | $6.63 | hour |
| Tiller (for lime application) | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $11.35 | acre |
| e. Labor | | | | | | | | |
| Initial mowing of planting area | $0.06 | $0.01 | $9.00 | $9.00 | $45.00 | $45.00 | $15.00 | hour |
| Herbicide application | $0.06 | $0.01 | $9.00 | $9.00 | $45.00 | $45.00 | $15.00 | hour |
| Planting | $0.30 | $0.07 | $45.00 | $45.00 | $225.00 | $225.00 | $15.00 | hour |
| 2. Maintenance: | | | | | | | | |
| a. Fertilization/weed control | | | | | | | | |
| Nitrogen | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.54 | pound |
| Lime | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $72.67 | ton |

| | Per tree cost (17 x 17) | Per tree cost (8 x 8) | Per acre cost (17 x 17 | Per acre cost (8 x 8) | Total cost (17 x 17) | Total cost (8 x 8) | Cost estimate | Unit |
|---|---|---|---|---|---|---|---|---|
| Herbicide | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $8.98 | acre |
| b. Insect and disease detection/treatment | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $47.52 | acre |
| c. Mowing | $0.15 | $0.03 | $23.30 | $23.30 | $116.50 | $116.50 | $23.30 | acre |
| d. Thinning | $143.01 | $24.87 | $412.94 | $500.75 | $2,064.72 | $2,503.73 | $144.05 | acre |
| e. Replanting | | | | | | | | |
| Replacement seedlings (bareroot) | $0.02 | $0.02 | $3.74 | $16.88 | $18.69 | $84.40 | $0.62 | each |
| f. Equipment | | | | | | | | |
| Pruning tools/hand tools | $0.02 | $0.01 | $3.55 | $3.55 | $17.76 | $17.76 | $2.22 | hour |
| Tiller (for nitrogen/lime application) | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $11.35 | acre |
| g. Labor | | | | | | | | |
| Herbicide application | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $15.00 | hour |
| Pruning | $0.16 | $0.04 | $24.00 | $24.00 | $120.00 | $120.00 | $15.00 | hour |
| Replanting | $0.30 | $0.07 | $45.00 | $45.00 | $225.00 | $225.00 | $15.00 | hour |
| 3. Nut Harvesting | | | | | | | | |
| a. Crop share of 50% | | | | | | | | |
| 4. Timber Harvesting | | | | | | | | |
| a. Tapped trees' value -39.5% | | | | | | | | |
| 5. Sap Collection/Syrup Production: | | | | | | | | |
| a. Equipment | | | | | | | | |
| Tubing system | $5.57 | $5.83 | $353.19 | $398.87 | $1,765.95 | $1,994.37 | $10.00 | tap |
| Bucket/bags | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $8.37 | tap |
| Double tubing tool | $0.75 | $0.69 | $47.40 | $47.40 | $237.00 | $237.00 | $237.00 | operation |
| Wire tier | $0.25 | $0.23 | $16.00 | $16.00 | $80.00 | $80.00 | $80.00 | operation |
| Fence wire stretcher | $0.34 | $0.31 | $21.50 | $21.50 | $107.50 | $107.50 | $107.50 | operation |
| Drill w/ battery pack | $1.34 | $1.24 | $85.00 | $85.00 | $425.00 | $425.00 | $425.00 | operation |
| Tapping bit and bit file | $0.05 | $0.05 | $3.45 | $3.45 | $17.25 | $17.25 | $17.25 | operation |
| Hand tool set | $0.12 | $0.11 | $7.50 | $7.50 | $37.50 | $37.50 | $37.50 | operation |
| Tractor and trailer | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $3,750.00 | operation |

| | Per tree cost (17 x 17) | Per tree cost (8 x 8) | Per acre cost (17 x 17 | Per acre cost (8 x 8) | Total cost (17 x 17) | Total cost (8 x 8) | Cost estimate | Unit |
|---|---|---|---|---|---|---|---|---|
| Vacuum system | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $6,000.00 | operation |
| Storage tanks (sap) | $3.17 | $3.42 | $201.05 | $234.15 | $1,005.23 | $1,170.74 | $2.00 | gallon |
| Transfer pumps (if necessary) | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $300.00 | operation |
| Reverse osmosis unit (optional) | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $22,445.00 | operation |
| Evaporator feed tank | $3.78 | $3.51 | $240.00 | $240.00 | $1,200.00 | $1,200.00 | $1,200.00 | operation |
| Evaporator | $7.09 | $6.58 | $450.00 | $450.00 | $2,250.00 | $2,250.00 | $2,250.00 | operation |
| Steam hood | $0.47 | $0.44 | $30.00 | $30.00 | $150.00 | $150.00 | $150.00 | operation |
| Preheater | $5.91 | $5.48 | $375.00 | $375.00 | $1,875.00 | $1,875.00 | $1,875.00 | operation |
| Forced draft unit | $4.41 | $4.09 | $280.00 | $280.00 | $1,400.00 | $1,400.00 | $1,400.00 | operation |
| Draw-off accessories | $0.55 | $0.51 | $35.00 | $35.00 | $175.00 | $175.00 | $175.00 | operation |
| Filter press/canning unit | $4.25 | $3.95 | $270.00 | $270.00 | $1,350.00 | $1,350.00 | $1,350.00 | operation |
| Canning supplies | $0.24 | $0.26 | $15.45 | $18.02 | $77.26 | $90.08 | $4.00 | gallon |
| b. Building (optional if no syrup) | $34.04 | $31.59 | $2,160.00 | $2,160.00 | $10,800.00 | $10,800.00 | $10,800.00 | operation |
| c. Energy | | | | | | | | |
| Evaporator fuel: wood | $0.63 | $0.58 | $40.00 | $40.00 | $200.00 | $200.00 | $200.00 | cord |
| Utilities | $6.69 | $7.00 | $424.56 | $478.97 | $2,122.78 | $2,394.87 | $6.00 | tap |
| d. Labor | | | | | | | | |
| Sap collection | $1.32 | $1.38 | $83.85 | $94.60 | $419.25 | $472.99 | $15.00 | hour |
| Syrup processing | $1.19 | $1.28 | $75.33 | $87.83 | $376.66 | $439.13 | $15.00 | hour |

# APPENDIX B

**Table 8. Net present values (NPV) and internal rates of return (IRR), in Year 70, calculated for each of the scenarios and product objective combinations evaluated. Unless noted, a 4% discount rate was used. The highest and lowest NPV and IRR values identified in each analysis are marked in bold, italicized text.**

| | | NPV (USD/acre) | | | | | | IRR (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Product objectives** | Full cost | 75% cost share | $2.50 per board foot | 55 acres | 2% discount rate | 6% discount rate | Full cost | 75% cost share | $2.50 per board foot | 55 acres | 2% discount rate | 6% discount rate |
| 8 x 8, no thin | Timber | 652 | 90 | 1,319 | 495 | 785 | 979 | -2.9 | -0.6 | 2.8 | -2.4 | 1.82 | -7.4 |
| 8 x 8, no thin | Timber, Nuts | 675 | 1,237 | 2,646 | 832 | 3,922 | 368 | 2.2 | 6.1 | 5.1 | 3.0 | 6.81 | -2.0 |
| 8 x 8, no thin | Timber, Nuts, Sap | 7,008 | 6,447 | 5,816 | 6,752 | 11,076 | 4,660 | N/A | N/A | -10.7 | N/A | N/A | N/A |
| 8 x 8, no thin | Timber, Nuts, Syrup | 5,554 | 4,992 | 4,362 | 3,023 | 5,150 | ***4,732*** | -10.3 | -10.1 | -5.8 | -7.6 | -5.02 | ***N/A*** |
| 8 x 8, no thin | Timber, Nuts, Lease taps | ***1,694*** | **2,255** | ***2,886*** | ***1,851*** | ***5,517*** | 251 | 5.3 | 10.5 | 6.5 | 6.3 | 9.64 | 1.3 |
| 8 x 8, no thin | Nuts, Sap | ***7,124*** | ***6,563*** | ***7,124*** | ***6,869*** | ***12,074*** | 4,566 | ***N/A*** | ***N/A*** | ***N/A*** | ***N/A*** | ***N/A*** | N/A |
| 8 x 8, no thin | Nuts, Syrup | 5,670 | 5,109 | 5,670 | 3,140 | 6,149 | 4,638 | -12.7 | -12.6 | -12.7 | -9.9 | -7.56 | N/A |

| Scenario | Product objectives | NPV (USD/acre) | | | | | | IRR (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Full cost | 75% cost share | $2.50 per board foot | 55 acres | 2% discount rate | 6% discount rate | Full cost | 75% cost share | $2.50 per board foot | 55 acres | 2% discount rate | 6% discount rate |
| 8 x 8, no thin | Nuts, Lease taps | 1,578 | 2,139 | 1,578 | 1,735 | 4,518 | ***345*** | ***5.9*** | ***12.6*** | 5.9 | ***7.1*** | ***10.05*** | ***2.0*** |
| 8 x 8, CCF thin | Timber | 975 | 414 | 1,344 | 818 | 395 | 1,227 | -4.1 | -2.5 | 2.6 | -3.7 | 0.84 | -8.7 |
| 8 x 8, CCF thin | Timber, Nuts | 182 | 379 | 2,137 | 25 | 2,215 | 848 | -0.7 | 2.0 | 4.0 | -0.1 | 4.12 | -5.1 |
| 8 x 8, CCF thin | Timber, Nuts, Sap | 3,599 | 3,038 | 2,196 | 3,343 | 4,216 | 2,883 | N/A | -13.2 | -4.4 | N/A | -8.32 | N/A |
| 8 x 8, CCF thin | Timber, Nuts, Syrup | 3,780 | 3,218 | 2,377 | 1,249 | 2,267 | 3,678 | -7.9 | -7.5 | -3.4 | -3.6 | -2.56 | -12.8 |
| 8 x 8, CCF thin | Timber, Nuts, Lease taps | 86 | 647 | 1,489 | 243 | 2,229 | 611 | 0.3 | 3.9 | ***3.5*** | 1.1 | 4.88 | -3.9 |
| 8 x 8, CCF thin | Nuts, Sap | 3,717 | 3,156 | 3,513 | 3,461 | 5,221 | 2,789 | N/A | N/A | N/A | N/A | N/A | N/A |

| **Scenario** | **Product objectives** | **NPV (USD/acre)** Full cost | 75% cost share | $2.50 per board foot | 55 acres | 2% discount rate | 6% discount rate | **IRR (%)** Full cost | 75% cost share | $2.50 per board foot | 55 acres | 2% discount rate | 6% discount rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 x 8, CCF thin | Nuts, Syrup | 3,898 | 3,336 | 3,693 | 1,367 | 3,272 | 3,584 | -10.1 | -9.8 | -8.9 | -5.1 | -4.84 | N/A |
| 8 x 8, CCF thin | Nuts, Lease taps | 32 | 529 | 172 | 125 | 1,224 | 517 | -0.2 | 4.7 | 0.8 | 0.8 | 4.09 | -4.2 |
| 17 x 17, no thin | Timber | 327 | 3 | 1,631 | 181 | 1,107 | 659 | -1.8 | 0.0 | 4.1 | -1.1 | 3.04 | -6.4 |
| 17 x 17, no thin | Timber, Nuts | 409 | 734 | 2,367 | 555 | 3,004 | 349 | 1.8 | 4.4 | 5.5 | 2.7 | 6.57 | -2.7 |
| 17 x 17, no thin | Timber, Nuts, Sap | 2,698 | 2,373 | 1,513 | 2,473 | 3,885 | 1,898 | N/A | N/A | -4.5 | N/A | -11.51 | N/A |
| 17 x 17, no thin | Timber, Nuts, Syrup | 2,520 | 2,196 | 1,336 | 503 | 1,318 | 2,338 | -7.2 | -7.0 | -2.6 | -2.1 | -1.88 | -12.2 |
| 17 x 17, no thin | Timber, Nuts, Lease taps | 672 | 996 | 1,856 | 818 | 3,226 | 171 | 3.0 | 6.2 | 5.3 | 4.2 | 7.67 | -1.3 |
| 17 x 17, no thin | Nuts, Sap | 2,812 | 2,487 | 2,812 | 2,588 | 4,876 | 1,803 | N/A | N/A | N/A | N/A | N/A | N/A |

| Scenario | Product objectives | NPV (USD/acre) | | | | | | IRR (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Full cost | 75% cost share | $2.50 per board foot | 55 acres | 2% discount rate | 6% discount rate | Full cost | 75% cost share | $2.50 per board foot | 55 acres | 2% discount rate | 6% discount rate |
| 17 x 17, no thin | Nuts, Syrup | 2,634 | 2,310 | 2,634 | 617 | 2,308 | 2,243 | -9.7 | -9.5 | -9.7 | -3.5 | -4.41 | N/A |
| 17 x 17, no thin | Nuts, Lease taps | 558 | 882 | 558 | 704 | 2,235 | 76 | 3.4 | 8.0 | 3.4 | 5.0 | 7.80 | -0.7 |
| 17 x 17, CCF thin | Timber | 543 | 218 | 1,410 | 397 | 643 | 771 | -3.1 | -1.7 | 3.5 | -2.6 | 1.82 | -7.8 |
| 17 x 17, CCF thin | Timber, Nuts | 29 | 354 | 1,983 | 175 | 2,067 | 521 | 0.1 | 2.3 | 4.8 | 1.0 | 4.97 | -4.4 |
| 17 x 17, CCF thin | Timber, Nuts, Sap | 2,371 | 2,046 | 1,189 | 2,147 | 3,074 | 1,766 | N/A | N/A | -3.5 | N/A | -9.06 | N/A |
| 17 x 17, CCF thin | Timber, Nuts, Syrup | 2,677 | 2,353 | 1,495 | 659 | 1,894 | 2,383 | -8.3 | -8.1 | -3.0 | -3.0 | -2.97 | -13.2 |
| 17 x 17, CCF thin | Timber, Nuts, Lease taps | 175 | 500 | 1,357 | 321 | 2,001 | 393 | 0.9 | 3.6 | 4.2 | 1.9 | 5.57 | -3.4 |

| Scenario | Product objectives | NPV (USD/acre) | | | | | | IRR (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Full cost | 75% cost share | $2.50 per board foot | 55 acres | 2% discount rate | 6% discount rate | Full cost | 75% cost share | $2.50 per board foot | 55 acres | 2% discount rate | 6% discount rate |
| 17 x 17, CCF thin | Nuts, Sap | 2,442 | 2,118 | 2,282 | 2,218 | 3,898 | 1,660 | N/A | N/A | N/A | N/A | N/A | N/A |
| 17 x 17, CCF thin | Nuts, Syrup | 2,749 | 2,424 | 2,589 | 731 | 2,718 | 2,277 | -11.0 | -10.8 | -9.2 | -4.5 | -5.74 | N/A |
| 17 x 17, CCF thin | Nuts, Lease taps | 104 | 428 | 264 | 250 | 1,176 | 287 | 0.8 | 4.9 | 1.7 | 2.2 | 5.17 | -3.3 |