PERENNIAL PATHWAYS: PLANNING AND ESTABLISHMENT PRACTICES FOR EDIBLE AGROFORESTRY

BY

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Crop Sciences
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2017

Urbana, Illinois

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ABSTRACT

Agriculture faces the unprecedented task of feeding a world population of 9 billion people by 2050 while simultaneously avoiding harmful environmental and social effects. One effort to meet this challenge has been organic farming, with outcomes that are generally positive. However, a number of challenges remain. Organic yields lag behind those in conventional agriculture, and greenhouse gas emissions and nutrient leaching remain somewhat problematic. In chapter 1, we examine current organic and conventional agriculture systems and suggest that agroforestry, which is the intentional combination of trees and shrubs with crops or livestock, could be the next step in sustainable agriculture. By implementing systems that mimic nature's functions, agroforestry has the potential to remain productive while supporting a range of ecosystem services. We outline the common practices and products of agroforestry as well as beneficial environmental and social effects. We address barriers to agroforestry and explore potential options to alter policies and increase adoption by farmers. We conclude that agroforestry is one of the best land use strategies to contribute to food security while simultaneously limiting environmental degradation.

Temperate agroforestry has traditionally focused on timber species, but there is a growing interest in integrating edible trees and shrubs with vegetables, row crops, or livestock. Utilizing food-bearing trees can increase food security while also generating revenues for farmers. These systems have the potential to be scaled up and even to be mechanized, making wider adoption possible. However, as the complexity and diversity of these polycultures increases, more knowledge and planning are required to be successful.

To meet this need, we developed a practical, extension-style handbook to aid farmers and consultants in planning and establishing edible agroforestry projects. The first part of the handbook outlines the process of planning and design, walking the reader through doing a site assessment, selecting suitable species of trees and livestock, deciding on a harvest strategy, and evaluating their own goals. We include profiles of some of the most promising trees and shrubs and describe how to generate a working planting design. The second part of the handbook includes the practical steps for field preparation, tree installation, and early care of young plantings. We go over funding options and government programs that are available and highlight case studies of successful farms with diverse, perennial polycultures. The handbook will be freely available online and will be promoted through workshops and partnerships with non-profit entities working in agroforestry.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Sarah Taylor Lovell, for inviting me to be a part of the pioneering work her lab does in multifunctional perennial agriculture. Thanks also to my other committee members, Adam Davis and Gary Kling, who patiently worked with me as I developed my thesis.

Special thanks to Michael Douglass, lab tech extraordinaire, and to all my labmates— thanks for letting me bounce my crazy ideas off you, and for the help with stats. You are all world changers.

Finally, I would like to acknowledge the support of my wonderful wife, Meg, and my two kiddos. I could not have done this without you.

This work is supported by Hatch Act Funds (Project number ILLU-802-938) and Foundational Programs, Agriculture Economics and Rural Communities, Award Number 2014-68006-22041 from the USDA National Institute of Food and Agriculture; and by the Department of Crop Sciences at the University of Illinois-Urbana Champaign through the Jonathan Baldwin Turner Fellowship.

To Sylvan and Ember— we plant trees for you.

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AN IMPORTANT NOTE ABOUT FULL CONTENT

The text in chapters 1-3 constitutes only a part of the full work undertaken as part of this thesis. For a complete copy of the handbook "Perennial Pathways," please refer to appendix 1, which includes a PDF document with photos, charts, and case studies. The full document will also be available through the non-profit Savanna Institute website: www.savannainstitute.org.

CHAPTER 1: AGROFORESTRY— THE NEXT STEP IN SUSTAINABLE AND RESILIENT AGRICULTURE

INTRODUCTION

Agriculture shapes our planet in profound ways. Roughly 38% of the land surface of the earth is used to grow food, making agriculture the largest anthropogenic land use[1]. Expansion in agricultural land is the leading cause of deforestation and native habitat loss[2,3], a situation that has led to declines in wildlife, including birds[4], insects[5], and mammals[6], some of which are now considered endangered species[2]. Nutrient leaching from fertilizer results in the eutrophication of waterways, leading to oxygen-deficient "dead zones" in water bodies around the world[7,8]. Agriculture is the largest human-caused contributor to the greenhouse gas emissions implicated in climate change[1,9].

Humans are not exempt from these effects. Pesticides in measurable quantities can be found in many environments, including the human body[10,11]. In the United States alone, the human health cost of pesticide poisoning has been estimated at $1.2 billion per year[12], and excess nitrate in drinking water caused by over-fertilization can cause illness and is costly to clean up[13–15].

In addition to environmental and human impacts, there are concerning implications for the resilience of our agricultural systems[16]. Worldwide, just 15 crops produce 90% of food calories, with wheat, rice, and maize alone supplying 60% of this[17]. A majority of these crops are grown in vast tracts of annual monocultures which have a high risk for pest and disease outbreaks[18,19]. The Irish potato famine of 1845–1850 contributed to the deaths of over a million people and is a stark reminder of what can happen when disease destroys a single crop that is relied upon too heavily[20]. These monocultures require yearly replanting, high inputs, and weed control[21], and it has been suggested that this cycle of plant-fertilize-spray tends to serve the interests of the large agribusiness companies who supply the inputs for this system rather than furthering the goal of feeding the world[22].

The long-term sustainability of any agricultural system requires that soils stay productive and that necessary inputs remain available in the future. However, soil loss occurs more rapidly than soil creation in many agricultural landscapes[23], and the soil that remains tends to decline in quality[24]. Heavy reliance on fossil fuels in the form of liquid fuel and fertilizer makes agriculture subject to fluctuations in fuel costs and supply[25]. One-way fertilizer nutrient flows simultaneously cause pollution and scarcity. Phosphorus is one example: this essential plant nutrient is expected to become increasingly expensive to mine and process, while, at the same time, phosphorus runoff causes eutrophication of water bodies[26,27].

In the near future, our agricultural systems will also have to adapt to a changing climate that is expected to bring more extreme weather events like droughts and floods, in addition to increases in outbreaks of diseases and pests[28]. The changes will be more severe in the developing world, where poverty hinders people's ability to adapt[29,30]. The Dust Bowl of the 1930s is an example of destructive agricultural practices paired with an extreme drought that led to catastrophic consequences[31]. Agricultural overreach along with the inability to adapt to changes in climate has toppled civilizations, from the ancient Mesopotamians to the Mayans[32,33].

THE RISE OF ORGANIC FARMING

Organic agriculture arose as an alternative to the conventional farming paradigm, pioneered by early practitioners such as Rudolf Steiner in Europe in the 1920s, Sir Albert Howard and Lady Eve Balfour in the UK and J.I. Rodale in

the United States in the 1940s, and Masanobu Fukuoka in Japan in the 1970s and 1980s[34]. Several terms were used in these agricultural movements, including "organic", "biodynamic", "ecological", and "biological"[35]. In 1990, the United States Department of Agriculture (USDA) standardized the definition of organic production in the US, giving consumers and producers alike a common understanding of what "Certified Organic" means[35].

Although differing slightly by country and certifying agency, the main guidelines for organic management prohibit the use of synthetically produced pesticides and fertilizers, genetically modified organisms (GMOs), and the prophylactic use of antibiotics in livestock feed. Soil quality must be maintained through various practices such as crop rotation, cover cropping, or mulching[36]. Animals under organic management must be fed certified organic feed and ruminants must have access to pasture for a prescribed number of days[36]. Fertility is typically maintained by leguminous cover crops, applications of manure and compost, biologically derived inputs such as blood and feather meal, and mined mineral substances[36]. Weeds in organic grain and vegetable systems are usually controlled through tillage, though cover cropping and crop rotation also play an important role in breaking up weed cycles[37]. Pests control entails providing habitat for beneficial predators, selecting resistant plant stock, and using biologically derived pesticides as a last resort when needed[36].

The guidelines of organic production usually lead to more sustainable outcomes on the ground. Organic farms foster higher biodiversity than conventional farms, including insects, plants, soil biota, and even birds and larger animals[38–40]. Often, organic farms are more diverse in their cropping systems due to the inclusion of livestock and longer crop rotations[10]. The use of mechanical and cultural control methods for weeds and other pests can leave low levels of these populations that further contribute to biodiversity[40]. Soil quality tends to improve under organic management based on measurements of soil organic matter[39,41], though no-till conventional agriculture measured highest of all in some studies[9]. Although organic yields typically lag behind conventional yields[42], in drought years the opposite has been shown, which is attributed to the higher water holding capacity of soils under organic management[43,44]. Overall, organic production uses less energy per production unit due to the high energy costs of conventional fertilizer and pesticides[39,44,45].

Worth noting is the fact that, although organic certification makes hard distinctions about the use of pesticides, synthetic fertilizers, and GMO technology, a wide spectrum of practices are available for both conventional and organic producers that have beneficial environmental outcomes. Cover cropping, integrated pest management, application of manure and composts to build soil organic matter, crop rotation, and the integration of livestock and crops are important tools that should not be overlooked when considering impacts. Indeed, in some studies that compared organic vs. conventional crop systems, the authors conclude that improvements under organic management were likely due to practices like manure application and cover cropping that were included in the organic system which could be employed in a conventional system to similar effect[46–48].

CHALLENGES IN ORGANIC AGRICULTURE

Even with the good intentions of organic certification practices, most organic crop production systems utilize the same basic methodology as conventional farming, and therefore can have some of the same negative consequences. The pattern of cultivating annual monocultures that require yearly replanting, application of fertilizer, intensive weed control, and highly mechanized equipment to accomplish the work remains relatively unchanged, especially at scales

larger than small market gardens[49]. The undesirable conventional tools are simply swapped out for those that are more benign: organic seeds for GMO seeds, cultivation or mulch instead of herbicides for weed control, and cover crops and manure for fertilization instead of fossil-fuel derivatives[36]. Although these changes can lessen environmental impacts, they may not eliminate them.

The issue of nitrogen leaching offers a good example of environmental impacts that are not eliminated entirely. Even though some studies show an improvement in nitrate leaching under organic management, the levels may still contribute to groundwater pollution. Pimentel *et al*. compared three rotations with differing sources of nitrogen: an organic rotation with legume cover crops, an organic rotation with animal manures, and a conventional rotation utilizing synthetic fertilizers. They found that leachate samples for all three treatments sometimes exceeded the 10 ppm regulatory limit for nitrate concentration in drinking water. The organic animal, organic legume, and conventional rotations lost 20%, 32%, and 20%, respectively, of the nitrogen applied to the crops in the form of nitrate[44]. In Swedish studies, Bergström *et al.* concluded that organic sources of nitrogen leached more than conventional fertilizers. They attributed this to the fact that the manures and legume cover crops released the most nutrients during fallow periods or at times that did not sync with nitrogen demand of the crop[50].

Even though soil quality can improve under organic management relative to conventional management[39,44,51], soil loss and degradation are still risks due to the fact that tillage is required for weed control and for incorporating biomass from cover crops[37,46]. Tillage has been shown to have adverse effects including compaction, erosion, and lowering of biological activity in the soil[23,52,53]. As reported in Arnhold *et al.*, studies comparing erosion in organic and conventional systems have had variable results that depend upon the crop rotation, crops used, and tillage systems. The author's study in mountainous regions in Korea concluded that soil loss under either conventional or organic management was too high for sustained productivity[54].

Recognizing the benefits of reducing tillage, there has been interest in adapting no-till techniques for organic farming[37]. The process usually entails growing a cover crop ahead of the main cash crop, then crushing it down mechanically and planting through the residue[55]. If done correctly, weeds are suppressed by the mulch and no cultivation is needed for that crop. However, it can be a challenge to grow the necessary biomass in the cover crop to provide effective weed control, and the technique may not be possible in water-limited environments due to water competition by the cover crop[37]. Perennial weeds pose a particular problem, as they are typically able to grow through the mulch[37,42,55].

Studies exploring the impact of organic agriculture on greenhouse gas emissions have shown mixed results[35,41,56]. When measured on a per area basis, organic systems may fare better than conventional systems, but when the yield gap in organic is taken into effect, the emissions may be higher per unit of output[39,48]. Even when soil carbon increases, other gasses such as nitrous oxide are emitted by annual systems that contribute to climate change, negating potential benefits[9].

Differences in yields between organic and conventional systems may also have indirect environmental implications. Organic systems are generally agreed upon as less productive, with an average decrease in yield of around 20% to 25%, though the literature shows ranges anywhere from 5% to 50% depending upon the crop, soils, intensity of management, and how the study was conducted[38,42,57]. Critics argue that under organic management, more land would

need to be put into agricultural production in order to maintain global food security. This would result in deforestation and other habitat loss, leading to an overall negative environmental outcome[42,58].

Given these challenges within the organic/conventional debate, there seems to be an opportunity to evaluate additional tools and techniques that may yield other possible solutions. Instead of an "either-or" approach to thinking about our agricultural landscapes, a "yes-and" mentality might be more useful. Indeed, many have called for a multidisciplinary, multifunctional approach to designing agroecosystems[24,39,59,60]. In terms of feeding the world while sustaining the planet, perhaps Foley enunciates this best: "No single strategy is sufficient to solve all our problems. Think silver buckshot, not a silver bullet"[1] (p. 65).

AGROFORESTRY AS A TRANSFORMATIVE SOLUTION

One multifunctional approach for our food system is agroforestry, the intentional combination of trees and shrubs with crops or livestock. Agroforestry has been recognized for nearly half a century as a sustainable agricultural practice[61], and the concept of integrating trees into the agricultural landscape is as old as the practice of cultivating land. The beneficial outcomes of agroforestry include reductions in nutrient and pesticide runoff, carbon sequestration, increased soil quality, erosion control, improved wildlife habitat, reduced fossil fuel use, and increasing resilience in the face of an uncertain agricultural future[21,62–67]. In short, adding trees and other perennials to a landscape can help mitigate many of the harmful effects of agriculture. The fact that it can simultaneously provide economic, ecological, and cultural benefits gives agroforestry great potential as a land use strategy in both the developing and developed world[68].

AGROFORESTRY PRACTICES AND PRODUCTS

In addition to the environmental benefits, agroforestry can supply products such as timber, crops, fruits, nuts, mushrooms, forages, livestock, biomass, Christmas trees, and herbal medicine[69]. A diverse portfolio of products would allow revenue streams to be spread out over the short-term (crops, forage, livestock, mushrooms, certain fruits like currants), medium-term (nuts, fruits such as apples or persimmons, biomass, medicinal plants), and long-term (lumber, increased property value). This diversity of products can also reduce risk for farmers, though it may require creative marketing[69].

Different types of agroforestry are practiced across the world. Tropical agroforestry has traditionally enjoyed more focus and has been more widely adopted than temperate agroforestry. Systems like shade-grown coffee and tea are well developed, and the availability of hand labor make some tropical agroforestry practices more practical than in areas where machine harvesting is more common[31,70]. Culturally, agroforestry has played an important role in both indigenous tropical areas and in temperate places like Europe, though land abandonment and agricultural intensification in northern areas has led to declines in traditional agroforestry practices[71]. This review focuses primarily on temperate agroforestry.

There are five generally recognized agroforestry practices promoted in the temperate zone, especially in North America: alley cropping, silvopasture, riparian buffers, windbreaks and forest farming[67,69]. These practices fit within a variety of cropping systems, topographies, and climatic zones.

Alley cropping

Alley cropping involves growing field crops between rows of trees[72]. The trees can be grown for timber or fruits and nuts, while the alley crops can include a variety of grains, vegetables, or forages cut for hay. The crops provide short-

term income while the trees provide longer-term revenue. The tree and crop species also may interact in ways that allow increased production due to the different niches that the trees and crops occupy[73]. For example, one study in France showed walnuts and winter wheat to be good companions because they grow at different times of the year and have differing rooting depths. The researchers concluded that the system produces 40% more product per given area than if the two crops were grown separately[74].

Silvopasture

Silvopasture incorporates livestock into an intentional mixture of trees and pasture. Silvopasture is different from just "grazing the woods", because the spacing of the trees is carefully planned to allow enough sunlight for the forages below, and the livestock are kept from damaging the trees. The trees offer protection for livestock through shade during the heat of the summer and wind reduction in the cold winter[75,76]. Additionally, the pasture quality in partial shade may increase, although it is usually slightly less productive in terms of biomass[77]. Livestock grazed on silvopasture versus open pasture show equal gains[76]. If the trees are also being grown for timber, the long-term bottom line of the farmer will improve without compromising current production[76].

Riparian buffers

Riparian buffers are planted areas around waterways that are at risk from erosion, nutrient leaching, or habitat loss[78]. Usually there are two or three "zones" of vegetation that vary in composition based on the proximity to the waterway, slope, and producer needs[69]. Riparian zones tend to be marginal for agricultural production, making them prime candidates for alternative uses. There has been concerted effort by the United States Department of Agriculture (USDA) to implement conservation practices on areas around waterways due to their beneficial impact on water and soil quality. The Environmental Quality Incentive Program (EQIP) through the Natural Resources Conservation Service (NRCS) and Conservation Reserve Program (CRP) through the Farm Service Agency (FSA) are examples of some government funded initiatives[79].

Windbreaks

Windbreaks, also known as shelterbelts, were recognized early on as a useful agroforestry practice. Windbreaks prevent wind erosion, provide habitat for wildlife, and can increase water availability to nearby crops due to lower evapotranspiration and the effects of catching snow[75]. More water can mean higher production, leading to important economic benefits to farmers[80]. On a farmstead, windbreaks can decrease the heating and cooling needs for living and working spaces by reducing indoor air exchange caused by wind[81].

The Dust Bowl years in North America led to the U.S. government initiating the Prairie States Forestry Project, a massive shelterbelt stretching from Canada to Texas[75]. Another notable example is China's Three-North Shelter Forest Program, the world's largest afforestation effort[82]. Started in 1978 and expected to be completed in 2050, it is known as "China's Great Green Wall"[82]. Similar strategies have been employed in Russia, northern Europe, Australia, New Zealand and other countries[75,80,83].

Forest farming

Forest farming includes practices such as raising mushrooms, harvesting medicinal herbs like ginseng and goldenseal, and marketing woody ornamental material[69]. This agroforestry approach usually occurs in established forests that are grown for timber and allows for income generation without major disturbance[84]. Management of forest farming

systems can range from intensive to minimal, depending on the product and desired market. For example, woods-grown ginseng may involve extensive site preparation, fertilizer, tillage, and fungicides that can increase yields but are costlier and therefore riskier. Alternately, wild-simulated ginseng may involve simply raking leaves back, planting seeds, and letting the ginseng grow for several years until it is ready to harvest[69].

It is noteworthy that, of the five practices, only alley cropping and silvopasture are typically practiced on land that is suitable for conventional agriculture. Even then, conventional cropping is often continued for several years before the trees are fully grown[69]. Riparian buffers, windbreaks, and forest farming usually occur on field margins or on land not suitable for farming, although, in some cases, may require setting aside some cropland to obtain the required width to be effective[85]. These practices therefore tend to complement, rather than compete with, existing production systems and may provide ways to contribute to food security by using resources that are otherwise underutilized.

In practice, agroforestry can contribute to either conventional or organic systems. In either case, the beneficial effects of agroforestry can improve environmental outcomes beyond what is already possible within each system. In this way, agroforestry may be able to address some of the challenges outlined earlier for organic agriculture, including soil loss, greenhouse gas emissions, and nutrient leaching. The next section summarizes these benefits, as promoted in the agroforestry literature.

BENEFITS OF AGROFORESTRY

Agroforestry has positive effects on soil and water quality. Soil quality is improved by increased levels of organic matter, more diverse microbial populations, and improved nutrient cycling, which may increase crop productivity and the ability to cope with drought[65,86,87]. The water quality benefits occur as non-point source pollution from row crops is reduced by incorporating agroforestry vegetative buffer strips[88–90]. On a "paired" watershed study in Missouri, agroforestry and grass buffer strips reduced phosphorus and nitrogen loss from a corn-soybean rotation[88]. The perennial vegetation increases above-ground biomass that slows runoff and can trap as much as 95% of the sediment at risk of being lost[91], while the below-ground roots can take up 80% or more of excess nutrients as well as hosting microbial populations that can break down pesticides[68,90,92].

The increase in soil organic matter in the form of carbon not only improves the health of the soil, but it can also help reduce atmospheric carbon dioxide that is implicated in climate change [23]. Compared to a monoculture of crops or pasture, adding trees and shrubs to an agricultural landscape increases the level of carbon sequestration[65,93]. Kim *et al.* did a meta-analysis on greenhouse gas emissions in agroforestry and showed an overall mitigation of 27 ± 14 tons CO_2 per hectare per year. Biomass accounted for 70% of sequestered carbon, with the remaining 30% sequestered in the soil[94]. A North American analysis performed by Udawatta and Jose showed that agroforestry practices implemented on a modest scale could potentially sequester 548.4 Tg carbon per year, enough to offset 34% of US emissions from coal, oil, and gas[85].

The mechanisms for increased carbon sequestration include better erosion control, more carbon being stored in woody perennials, reduced organic matter decomposition, and the fact that crop biomass is not harvested in agroforestry to the degree that it is in conventional systems[94].

The link between perennial systems and climate change may be an important one. Robertson *et al.* studied the global warming potential of several annual and perennial systems. They found that none of the annual cropping systems

reduced global warming potential, whether conventional, no-till, reduced input, or organic. Although the cropping systems did accumulate carbon in the soil, the gains were offset by nitrous oxide emissions. However, the perennial and early successional forest treatments including alfalfa, hybrid poplar, and abandoned early successional sites all reduced global warming potential. Mid-successional and late successional systems stored less carbon per year as they matured. The authors concluded that the best option for mitigation was the early successional forest system[9]. Many agroforestry practices effectively mimic these early successional forests.

Reducing fossil fuel use is another important strategy for climate change mitigation[95]. Bioenergy is one avenue to reduce fossil fuel dependence, but there are concerns about using valuable cropland to grow crops for energy instead of food[16]. Currently, 40% of the U.S. corn harvest goes to producing ethanol, which seems counterproductive to the goal of reducing world hunger[16]. By producing biomass from trees in combination with food on the same land, agroforestry may be one way to contribute to a secure energy future without compromising food production capabilities[96,97].

When comparing mixes of species (i.e. polycultures) with individual crops, a useful measure is the LER, or Land Equivalent Ratio[98]. This considers the yield of the polyculture and calculates the amount of land that would be required if the crops were grown separately. For example, when comparing loblolly pine and switchgrass mixes with pure stands of each crop, Haile *et al.* noted that, although each crop yielded less in the mix, the system produced an overall LER of 1.47[99]. This means that if switchgrass and loblolly pine were grown separately, it would require 47% more land than the agroforestry system to grow the same amount of biomass.

Modeling of agroforestry systems in Europe using the Yield-SAFE (YIeld Estimator for Long- term Design of Silvoarable AgroForestry in Europe) model predicted LER values between 1–1.4 for scenarios in Spain, France, and the Netherlands, indicating higher productivity when integrating trees and crops than when grown separately[100]. In another study in Switzerland, agroforestry models focusing on walnut (*Juglans* hybrid) and wild cherry (*Prunus avium*) showed that in 12 out of 14 scenarios, mixing crops led to LER measurements higher than one. In addition, 68% of the Swiss financial scenarios were found to be more profitable than current practices[101].

When compared with conventional and organic monocultures, agroforestry contributes to the conservation of biodiversity. Adding trees, shrubs, and other perennial vegetation to an agricultural landscape provides habitat for greater numbers and more diverse populations of wildlife[68,90]. In addition to intrinsic value, biodiversity can provide useful services. More birds and predatory insects can help keep pests under control[19,102]. Habitat for pollinator species can mean better pollination of horticultural crops[103]. Even incidences of disease generally decrease in more diverse populations, for both plants and wildlife[104,105].

Livestock can benefit from agroforestry as well. Windbreaks protect animals from harsh winds, while shade provided by trees can increase comfort in the heat of the summer and may encourage more even grazing over a paddock[71]. Forest-based foraging systems for poultry and hogs can decrease the need for grain and provide surroundings closer to these species' natural habitat[106]. The cork oak *dehesas* of the Mediterranean are an example of a multifunctional landscape that has endured for hundreds of years, providing grass and acorns for grazing livestock and a valuable cash crop in the form of bark for making traditional corks[107].

Compared to annual monocultures, perennial polycultures like agroforestry are inherently more stable in the face of global market volatility and extreme climatic events[16]. In the event of fossil fuel scarcity, mature fruit and nut trees would continue to produce their products with relatively little interruption, though labor may have to be substituted for other inputs. Not only do agroforests sequester greenhouse gasses that are driving global climate change, they are also more resilient to its likely effects. Deeper rooting systems and improved infiltration and water storage lessen the impact of drought, while trees' abilities to pump excess water out of the soil as well as withstanding inundation better than field crops means they are also more resilient to floods[30].

Though often overlooked, there are additional cultural benefits to agroforestry. Many landowners value the preservation of nature, both for its beauty and for perceived benefits including a sense of improved health and the peace and quiet of a rural life[108]. Research shows that aesthetics provided by practices such as vegetative buffers are preferred by rural residents[109]. There are also opportunities for recreation, including bird watching, nature hikes, and hunting[110].

CHALLENGES TO AGROFORESTRY ADOPTION

The opportunities for agroforestry are exciting, but not without challenges. Agroforestry adoption has been surprisingly low, considering the well-documented benefits[111–113]. Barriers have included the expense of establishment[114], landowner's lack of experience with trees[108,113], and the time and knowledge required for management[115].

Many farmers learn about new agricultural practices through extension personnel or agricultural product dealers, and these professionals typically do not have training or experience with agroforestry[116]. In addition, lack of established demonstration plots makes it hard for landowners to see these systems in action[3]. Since many of the useful outcomes from agroforestry are less tangible or longer-term, it may be difficult for landowners to envision them[117].

For agroforestry systems that produce edible products such as fruits and nuts, the logistics of harvest can be challenging. For agroforestry systems to be economically competitive, mechanization may be required for larger plantings[118]. This can be complicated if multiple fruit or nut species are grown.

Non-traditional markets and delayed profits may be another deterrent[108]. The economic feasibility of some agroforestry systems such as silvopasture have been shown to be profitable, whereas other practices such as biomass plantings or riparian buffers may need the development of markets that offer compensation for the ecosystem services provided in order to make financial sense[62,97,119]. Social change and networking will also play a role as mindsets evolve to include alternatives to the norm[112,114].

MOVING FORWARD—POLICY AND RESEARCH NEEDS

Given these challenges, a number of strategies have been proposed to move agroforestry forward. Policy changes could include increased funding for government cost-share programs for installing practices and credits for environmental services rendered, such as pollination and carbon sequestration[68,97,113,116]. Current USDA programs through the NRCS and FSA often stipulate that land set aside for conservation may not be harvested, but agroforestry systems could provide a harvestable product without compromising conservation potential. A policy change to allow non-destructive harvest of consumable products from such systems might encourage more farmers to adopt agroforestry practices, leading to better conservation outcomes[68].

Although it is reasonable that the majority of government funding goes toward major cropping systems such as corn and soybean, the fact that agroforestry has the capability to remediate the negative effects of these very systems suggests it should be given more attention[68]. Some of this support could be used for education through extension and university programs[120]. In fact, education may be the most important factor for adoption, as many studies on the adoption of conservation practices cite lack of access to information and technical assistance as one of the primary barriers[3,108,116,120].

The opportunity to expand the production potential of agroforestry systems is underdeveloped. More research is needed to study the use of trees and shrubs to provide marketable products[121]. Recently, interest has grown in the development of multifunctional, edible polycultures that mimic natural ecosystems such as the native oak savannas of the Midwest[122]. These polycultures include multiple crops stacked together to take advantage of different ecological niches as well as to provide multiple streams of income[123]. For example, field trials at the University of Illinois at Champaign-Urbana were established to study a mixture of chestnuts, hazelnuts, apples, currants and raspberries. Control plots of a conventionally managed corn and soy rotation will allow for comparative analysis of a variety of environmental, ecological, and economic metrics. A large-scale, replicated study began in 2015 that will look at different spatial layouts of these polycultures compared to monocultures of each species as they might be grown in a commercial orchard, in addition to being able to compare them to a corn/soybean rotation. Included in the treatments are plantings of native trees and shrubs that also have edible products, including aronia, elderberry, pecan, pawpaw, persimmon, plum, and serviceberry. This native edible plot explores what is possible within the confines of conservation easements that mandate the use of native species[123].

CONCLUSIONS

Various pathways have been proposed to safely and sustainably feed a growing population. Organic farming shows promise for lowering the use of agrichemicals and improving certain environmental and human health metrics, while proponents of conventional systems point out the advantages of using genetic engineering, fertilizers, and pest control in improving yields.

Broader strategies include limiting the expansion of farmland via deforestation, minimizing food waste, eating less meat, closing the yield gaps for underperforming cropland in the developing world, and more efficient use of resources like water, fertilizer, and fuel[1,48]. These efforts, and others, will be needed as part of a multi-faceted approach if we are going to successfully and sustainably feed the world.

Nature produces its bounty while requiring no plowing, no fertilizer, and no pest control—in fact, no inputs of any kind. It runs entirely on solar energy and generates no harmful waste products. Its biological diversity allows dynamic adaptation in the face of external change. If our agricultural systems can more closely mimic the functionality of nature, they can become more stable and resilient. Building such a system is without a doubt a challenging task, requiring a variety of tools. Agroforestry can provide the next step in sustainable agriculture by promoting and implementing integrated, biodiverse processes to increase yields, decrease harmful effects, and advance our understanding of the complex interactions involved in increasing food production while minimizing damage.

CHAPTER 2: PERENNIAL PATHWAYS, BOOK 1: PREPARING FOR AGROFORESTRY

"A tree becomes a great deal more than just a tree when properly used."- Shibu Jose

TREES: THE FUTURE OF AGRICULTURE?

If you have picked up this guide, you have likely asked yourself one or more of the following questions:

- **"How do we grow food in a way that doesn't harm the environment?"**
- **"Is there a way for family farms to remain viable?"**
- **"What is the future for sustainable, resilient agriculture?"**

Many good agricultural techniques and technologies have arisen to help come up with answers. This guide is about an answer that has been with us all along: ***trees***.

Environmental Effects

For almost every environmental challenge facing agriculture, trees can help[89]. Their roots protect the soil by preventing erosion, and falling leaves and natural root dieback build soil organic matter[86]. Trees capture excess fertilizers and agricultural chemicals that would have ended up in waterways[88]. They pull carbon out of the air, combatting climate change[63,124]. Trees provide habitat and food for wildlife, increasing the biological diversity (and therefore, stability) of our ecosystems[102].

Social benefits

Trees are good for people too[105]. Research shows that treed landscapes contribute to mental wellbeing[110]. They provide oxygen and reduce air pollution. Their ability to keep water clean means fewer chemicals coming out of our taps. In populated areas, trees reduce temperatures during the summer and help keep buildings warm in the winter[125]. Many recreational activities depend upon trees, from hunting and birdwatching to hiking and picnicking[110].

Economic Sense

Finally, incorporating trees into agricultural landscapes often makes financial sense. Windbreaks formed by trees lead to higher crop yields and improved livestock performance in the winter[75]. In the summer, partially shaded pastures make for more comfortable animals and higher forage quality, resulting in better growth[76,126]. Adding fruit or nut trees to a farm can help diversify income, lowering financial risk. If a pest or disease wipes out one crop, the other unaffected crops can still provide revenue. Wood is a renewable source of heat, and timber can provide a long-term investment for generations to come.

WHAT'S IN A NAME?

What is agroforestry?

Agroforestry is the intentional mixing of trees with other crops or livestock. Agroforestry allows us to obtain multiple products from the same land, like timber and vegetables, or wheat and walnuts. Mixing more than one crop is referred to as a ***polyculture***, as opposed to a ***monoculture***, which is growing only one crop at a time.

Box: Polycultures: Benefits and Challenges of Diversity

In a healthy ecosystem, plant species occupy different niches and take advantage of differences in size, light and nutrient needs, microclimate variations, and susceptibility to pests and herbivores. This leads to the system being more resilient and productive overall, and it supports a wider variety of wildlife[18]. Mimicking this diversity as much as practical is the goal in agroforestry, in hopes of accruing the same benefits[71,127]. Not only that, multiple crops spread out labor needs, diversify income, and create beneficial relationships that can lead to more productivity than if crops are grown separately[74,128].

On the downside, increasing species diversity makes management and planning more complex[19]. Agroforesters must take into account harvest equipment, seasonal timing, nutrient needs, tree spacing, pest control, and livestock compatibility for each species of tree they grow. Fitting these together into a workable design is part of the art of planning edible agroforestry systems.

The United States Department of Agriculture recognizes five agroforestry practices: ***alley cropping, silvopasture, riparian buffers, windbreaks*** and ***forest farming***. Some practitioners and researchers dislike the idea of separating agroforestry into distinct parts because there is a lot of overlap among systems. We include them here so that you will be familiar with the terms.

SIDE BOX: Adapted from "Agroforestry- The Next Step in Sustainable and Resilient Agriculture"[129]

Alley cropping involves growing field crops between rows of trees. The trees can be grown for timber, fruits, or nuts, while the alley crops may include a variety of grains, vegetables, or forages cut for hay.

Silvopasture incorporates livestock into an intentional mixture of trees and pasture. Silvopasture is different from "grazing the woods," because the spacing of the trees is carefully planned to allow enough sunlight for the forages below, and the livestock are kept from damaging the trees. The trees provide the animals with shade during the heat of summer and wind protection in the cold of winter.

Riparian buffers Planted areas around waterways that are at risk from erosion, nutrient leaching, or habitat loss. Producers may choose different types of vegetation depending upon the slope and distance from the waterway.

Windbreaks have been used since their promotion and success after the dustbowl years. Windbreaks prevent wind erosion, provide habitat for wildlife, and make more water available to crops by catching snow and reducing drying winds. On a farmstead, windbreaks can lower the heating and cooling costs for living and working spaces.

Forest farming includes raising shade-tolerant crops such as mushrooms, medicinal herbs, and woody ornamental material in established forests.

Here is an example of integrating multiple agroforestry practices on a farm:

A farmer begins diversifying by planting rows of trees in a cornfield. For several years, the farmer continues growing field crops between the rows of young trees (alley cropping). When shade from the trees starts to limit crop growth, the farmer plants a forage and introduces livestock (silvopasture). Once the trees mature to the point that grass is no longer productive, the livestock are removed and mushrooms and medicinal herbs are grown in the shade (forest farming). The north side of the farm borders an open field, so the farmer decided to plant a denser row of trees there

to block wind and prevent pesticide drift (windbreak). On the other side of the field is a small creek, so water-loving tree species were planted together with a grass strip to prevent erosion and reduce nutrient runoff (riparian buffer).

Isn't this the same as…?

There are other terms used for related practices that may crop up. University researchers and publications often use the term ***agroforestry*** along with the five practices outlined above. ***Permaculture*** is a social movement based on a design philosophy that includes several aspects of agroforestry. A ***food forest*** denotes a planting that mimics a natural forest structure using edible species. ***Restoration Agriculture*** is a food-bearing, tree-based farming system that uses natural ecosystems such as oak savanna as inspiration. ***Multifunctional Woody Polyculture*** is a term used by researchers at the University of Illinois for a diverse edible agroforestry system currently being evaluated in field trials[127]. No matter what you call it, adding trees to working landscapes is a good idea!

Why this guide?

Agroforestry has been around for decades, though the approach of integrating multiple species of ***edible*** trees and shrubs with vegetables, row crops, or livestock into a farm-scale system in temperate areas is relatively recent[127]. Although homesteaders and permaculturalists have been exploring these techniques on a small scale, the systems in this handbook have the potential to be scaled up and even to be mechanized, making them practical for more farmers to implement. However, as you increase the diversity on your farm, more knowledge and planning will be required to make it work. We hope this guide will be a useful resource as you make decisions and plans.

Limitations of this guide

Some of the ideas discussed here are still on the cutting edge of sustainable agriculture. The research team has attempted to provide the most accurate info based on scientific research and the experience of farmers. However, there is much still to be learned, and we present these techniques and practices as "best bets" rather than "hard facts."

Many of the topics touched on, like rotational grazing or plant propagation, are entire disciplines unto themselves. Therefore, every effort should be made to learn as much as you can before trying a new practice on your farm. Visit farmers who are already doing what you want to do. Gather useful books, extension publications, and journal articles. Go to conferences. Listen to webinars and lectures. Understand the risks that come with undertaking a new enterprise. Make a plan to mitigate these risks and give you the best chance of achieving your goals. Then, get out there and plant trees!

SITE EVALUATION

FARMER, KNOW THY SITE

Importance of site evaluation: Grow what grows

Your site will dictate which trees and shrubs are likely to do well. A good site evaluation will allow you choose species that will thrive. It is possible to modify certain characteristics like pH, drainage, and available moisture but this takes time and money and is likely to require ongoing maintenance. Species that are inherently well suited to your site will require less upkeep and may be healthier and more productive.

This section is broken up into two parts:

Gathering info:

This part contains information you can obtain from the internet, government offices, and farm management records. It includes items like soil maps, aerial photographs, climate information, and field histories.

Field Visit:

These are observations and samples that you collect on the actual site. If you have developed a familiarity with the property, you may already know some of this information. During the field visit, you will take soil samples, scout for weeds, measure slope and aspect of fields, and note details like erosion, wind direction, and signs of flooding.

Some site characteristics can be studied beforehand and observed in the field. For example, you can look up your plant hardiness zone, but understanding and observing microclimates can only be done on site.

PART 1: GATHERING INFO

Some of the first items to gather as you begin your research are maps and photos. Mapping out your site will allow you to fill in information as you learn more about it and will be important when you start to plan where to put trees and infrastructure. You are going to want the following maps:

Aerial Photo

An aerial photo will form the base map which you will overlay with designs later. Make sure to include your whole farm. If you have a large farm, also get individual maps of each field.

Soil map

A soil map is critical to choosing appropriate species of trees. One of the easiest ways to see which soils you have is a website called ***SoilWeb***:

- https://casoilresource.lawr.ucdavis.edu/gmap/

By entering a street address, the website will display important information including:

- Soil type
- Farmland class
- Flooding frequency
- Drainage class
- Minimum Bedrock Depth
- Water Table Depth

The USDA also hosts a soil map website called ***Web Soil Survey***. Although it uses the same data as SoilWeb, it allows you to organize the information into a convenient packet for printing. You can also run custom reports about your soil's suitability for a number of crops and practices and calculate acreage of fields. It has a bit of a learning curve, but it is worth the effort.

- https://websoilsurvey.nrcs.usda.gov/

Topographical Maps

Topographical ('Topo') maps depict elevation changes across a landscape, which are important when considering general slope and aspect, but the topo maps currently available often lack sufficient detail for farm-level planning. If you plan to do any earthwork to manage water, or if because of a steep slope you want to plant trees along a contour or Keyline (discussed below), you are going to have to conduct field measurements to be accurate.

The Regrarians eHandbook (Chapter 2) has excellent directions for mapping and surveying and is available to purchase for download. It is highly recommended if you are interested in Keyline design:

- www.regrarians.org/product/regrarians-ehandbook-2-geography/

Map formats

Digital

Online Maps are available from Google or Microsoft. In addition to printing, some features allow you to measure distances or area right in your browser window.

Google Earth is a free, downloadable mapping program. For our purposes, you will want the standalone desktop version of Google Earth Pro (still free), not the web-based Chrome version launched in April 2017. The desktop version supports simple design, letting you draw lines, points, and polygons that are to scale. These can be used to mark fences, waterers, and structures, or to measure the area of a field. GPS coordinates can be imported from a hand-held GPS unit, allowing you to gather data in the field and transfer it to a map. The maps can be saved and printed out, but make sure you have a truly overhead view before printing by going to 'view' and clicking 'reset tilt and compass'. Otherwise, your scale may be incorrect, leading to problems when laying out designs. You can also set the view so that it does not tilt while navigating by clicking the following: **tools->options->navigation->Do not automatically tilt while zooming.**

- https://www.google.com/earth/desktop/

Sketchup is a free 3D design software. In Sketchup, you can import an aerial map that will be to scale (under the '**file**' menu, go to '**Geo-location**', click '**add location**' and follow prompts). You can even import models that other users have made of trees, hoop houses, fences, etc. The basics are straightforward to learn, and there are good tutorials available. Sketchup can be useful when trying different plant spacings and row layouts, but it gets complicated to do complex planting details along curved contour lines or if you are dealing with varying topography.

Print

Print maps are great for sketching out ideas and for taking to the field. You can print them using the digital resources above, or you may be able to get a copy from your county clerk's office or the Natural Resources Conservation Service (NRCS). An NRCS or county extension agent may also be able to generate a custom soil map for your farm.

Make several copies of each map, and use them in the next planning stages. You can also use one "base map" with overlying layers of tracing paper for different plans or features. If not already on the map, add the following: Existing fences, property lines, livestock waterers, infrastructure, or hazards (sinkholes, big rocks, etc.)

SIDE BOX: Getting Help: County Extension, NRCS, and FSA

On your journey into edible agroforestry, some of the most helpful folks can be those at your local government agriculture and extension offices. Their job is to help farmers, and their knowledge and expertise (not to mention cost-share funds) can really make a difference. They may be able to help you with aerial and soil maps too. After coming up with a rough plan for your farm, give them a call, set up an appointment, and ask them what items you should bring along.

- **County Extension**- The county extension office is the place to go with questions about soil testing, pests and diseases, and to gather general information on farming in your area. Some offices do soil testing, so call before you send it to a private lab. Extension offices offer workshops on a wide variety of topics, from livestock to gardening to home food preparation.
- **Natural Resources Conservation Service (NRCS)**- The NRCS is the branch of the U.S. government that helps farmers and landowners manage and install practices that protect our natural resources: soil, water, air, plants, and animals. They offer technical assistance and cost-share programs that may be able to help with your goals.
- **Farm Service Agency (FSA)**- The Farm Service Agency offers farm loans, business planning, disaster assistance, and conservation programs. The county FSA and NRCS are often housed in the same building, making it convenient to visit both. The FSA has traditionally offered payments to farmers for taking cropland out of production to install grass, shrubs, and trees. The Conservation Reserve Program (CRP) is the one most farmers are familiar with. The CRP program provides yearly payments for a contracted amount of time, easing some of the burden of establishing conservation areas.

Many practices in agroforestry fit well within the programs of the NRCS and FSA, though the local offices might be less familiar with tailoring them for agroforestry. There are different deadlines and ways to qualify for approval, and not all applications are accepted every year. The best thing to do is talk with the staff about what you want to do.

FIELD HISTORY

Previous management

Knowing how the land was managed in the past will help you correct any issues that might be present. Go over management records to see which pesticides and fertilizers were applied. Some herbicides have longer-term residual effects. If you have harvest records, they indicate areas that are particularly productive or that are problematic. Note these areas on your map and keep them in mind when deciding what to plant there.

Old orchard sites

Reclaiming an old orchard site represents an opportunity to revive the past, but it may also present unique challenges. A buildup of pathogens can cause replant disease, which can negatively impact newly planted trees for years to come[130]. Tiny, soil-dwelling worms called nematodes are one of the more important culprits. Usually, commercial growers deal with replant disease by fumigating the soil. Alternatives exist, such as cover cropping with rapeseed or

sorghum-sudangrass or applying mustard seed meal, a by-product of pressing oil for biodiesel. Choosing resistant rootstocks may be the best option[131]. For more information, check out the resources below:

Nematode control with mustard mixes[130]:

- www.goodfruit.com/new-replant-disease-treatment/

Controlling replant disease with cover cropping[132]:

- http://extension.psu.edu/plants/tree-fruit/commercial-tree-fruit-production/orchard-establishment/orchard-bio-renovations

Organic Records

If you are considering organic certification, you will need to show that the fields you wish to enroll in the program have not had any prohibited substances applied within three years of your first organic harvest. If you have not owned or managed the farm for that long, you will need a written statement from the previous farmer. Check with your certifier about which forms satisfy this requirement.

CLIMATE

Rainfall

Most of the eastern United States has sufficient rainfall for the trees and shrubs in this guide to survive. However, if there is drought or a dry spell during a time of critical fruit development, you may have to provide supplemental irrigation to have a harvestable product. Even in years with adequate rainfall, trees may need irrigation in the first year after planting. Some growers decide not to install irrigation or do not have access to a water source nearby, instead relying on a portable water tank if conditions become too dry. Mulching will help reduce water stress. Most trees will require an inch of water per week (roughly 0.6 gallons per square foot of soil around the tree). Carefully consider the irrigation strategy you will employ, and how comfortable you are with risk— do you have the time and equipment to haul water? Is there access for a vehicle? Would the cost of the irrigation system be worth increased yields and lower risk?

Tom Wahl: "Plant things that are worth irrigating, then irrigate them if they need it."

Plant hardiness Zone

Plant hardiness zones are based on the minimum temperatures an area typically gets in the winter. It is common for nurseries to list the zones where a plant will survive. Keep in mind that if you plant trees or shrubs that are right on the edge of being adapted to your site, an especially frigid winter or extended summer drought may cause damage. Plants tend to move south easier than they move north, so getting cold-hardy varieties may not be a bad idea. You can look up your climate zone on this handy USDA website:

- http://planthardiness.ars.usda.gov/PHZMWeb/

Frost pockets

Depressions and low areas in the terrain can cause cold air to pool on nights without wind that are cold and clear. It is best to avoid frost pockets for fruiting trees if possible, but later-blooming trees (black walnuts, hazels, pecans, chestnuts, persimmons) should be a safer bet[133].

Wind

Wind can dry out crops and young trees, cause erosion, and limit weight gain in livestock in the winter[75]. Avoid the tops of ridges for fruit and nut trees, as they tend to be windier. Consider putting in a windbreak if you have sustained winds in your area or if pesticide drift is expected to be a problem. If not serving as a buffer for pesticides, windbreaks can be made up of species that produce edibles and ornamentals, so they are not a waste of space[121,134]. Additionally, a real opportunity exists to explore different genetics by planting trees that were grown from the seed of good varieties. Seed-grown trees will be much less expensive than grafted ones. Although they may not be as suitable for intensive production due to the variation in harvest timing, yield, and quality, you may just discover the next promising cultivar for your area.

SIDE BOX: Defensive Farming: Pesticide Drift

Damage to non-target crops from pesticide drift has been a risk since they were introduced, but recently there have been worrying trends that anybody who is planning on planting perennials near cropland should be aware of. A new class of herbicide-resistant GMO soybeans was released in 2016 which are tolerant to either *2,4-D* or *dicamba*, both broadleaf herbicides that are more prone to volatilize and drift than other herbicides such as glyphosate (Roundup)[135]. Already, complaints and lawsuits are showing that these herbicides are reaching vineyards, orchards, and non-resistant crops[136]. Some farmers are responding by planting the patented, resistant soybean seeds just to protect themselves from neighbors who are spraying, as the herbicides will damage regular soybeans[137]. If there is the possibility that this technology will be used within 1/8 of a mile of your farm, you might want to consider a strategy for mitigating drift[136]. Since volatilization can move these chemicals beyond the typical range normally associated with drift caused by spray droplets, this might include a wide buffer of cropland or pasture that will not be damaged by broadleaf herbicide, as well as a stout windbreak made up of "sacrificial" trees like hybrid poplar and conifers. Taking legal action in the event of damage can be costly and time-consuming, ultimately making defensive action the wisest choice. Best of all is putting your new agroforestry planting well away from conventional crop production.

SITE VISIT

Soil testing

Soil testing is important for knowing your baseline fertility levels. A basic soil test will show the pH of your soil and levels of nutrients like potassium, phosphorus, calcium, and sodium. This information will give you an idea of which plants might naturally do well. For example, if you have very low pH (below 5), you might consider blueberries. A soil test will also serve as a starting point for adjusting the pH and nutrient levels. We recommend ordering a soil test that includes organic matter, as this is a major indicator of soil productivity. Other minor nutrients may be important for some tree crops, so find out if the trees you are interested in have specific requirements so that you can request for them to be included in the test.

Contact your county extension office and ask if they do soil testing, as some offices offer discounts. Otherwise, a private lab can analyze samples for you for $15-$30 for a basic test. Ask for instructions on how to collect and prepare the sample. In general, you are going to want to take separate samples for each of your fields, and perhaps for different sections of the same field if the soil type or slope varies.

Interpreting test results

When you complete the paperwork for your soil test, request that the testing lab provide nutrient recommendations for the trees you would like to plant. If they are not able to provide this, you may be able to ask your county extension agent or horticulture specialist for help. Be aware that there are several schools of thought regarding nutrient management and fertilization. It may be worth getting several opinions.

pH

Most fruit and nut trees will thrive at a pH of 6.0-6.5[138]. Some species can handle more acidic (lower pH) or more alkaline (higher pH) conditions. Consult the species profiles later in this guide for specific requirements, and plan on adjusting the pH to an acceptable range before you plant your trees.

Drainage

Good drainage is probably the most important soil characteristic for nuts and fruits[138]. A soil map will give you a general idea of the soil drainage conditions. Digging some holes on-site and examining them to a depth of 4-6 feet is even better[139]. If the soil fills with water overnight (in March or April), it could have a high water table. Soils that are gray, or have gray, yellow, or reddish-brown streaks are likely to have poor drainage[139].

Flooding

Knowing where seasonal flooding occurs within a field is critical when installing infrastructure like fences and roads. This information can be provided by soil maps or possibly obtained from neighbors if you have not managed the property for long.

SIDE BOX: Water harvesting: Swales and Keylines

Various water-harvesting techniques are employed by permaculture practitioners, including the use of ***swales*** and ***Keyline design***. Although fairly simple in concept, the installation of ditches, ponds, and other earthworks often requires heavy equipment and constitutes a major disturbance of the soil (if not the wallet!). Farmers that have installed these practices have had mixed results, and there is very little scientific literature on the subject. It is difficult to predict the consequences of altering the natural drainage patterns of a site, and disturbing the soil with heavy machinery can lead to severe compaction and changes in weed pressure if not done correctly. If you hire a professional to design or carry out the work, ask if they have installed the practices before and request references from past customers. If you can, visit the sites and ask the landowners how the water harvesting installations have performed. It is best to learn as much as you can before deciding to fire up the heavy equipment. Once you have trees in the ground, it will be difficult (if not impossible) to adjust your earthworks without damaging your planting.

Swales

In permaculture circles, a ***swale*** denotes an on-contour, dead-level ditch that is designed to catch and hold rainwater, allowing it to soak into the soil slowly[140]. Though often promoted in popular permaculture manuals, rarely are

guidelines given for considerations like annual rainfall, soil physical properties, slope, matching plant needs with available water, or how to calculate swale depth or distance apart.

Keyline

The Keyline system, developed before the advent of permaculture, integrates ponds, irrigation ditches, and a special sub-soiling plow used to aerate the soil and help water enter the soil. It was developed by Australian P.A. Yeomans throughout the 1950's and 1960's for semi-arid, pastured landscapes[141]. Keyline planning is a comprehensive methodology that takes into consideration the permanence of structures, earthworks, trees, and other aspects of a farm and prioritizes them accordingly. The main element is the ***Keyline***, which is based on the principal contour identified by observing slopes, ridges, and valleys of a landscape. The Keyline is slightly off- contour, sloping slightly towards ridges to bring water to the drier parts of the field. From this Keyline, parallel rips are made with a modified sub-soil plow, with the intention of creating channels for water, air, and plant roots.

In areas that receive adequate rainfall, complex systems of ponds and channels may not be required, but the Keyline principle of maintaining equal distance between rows of trees in sloping terrain makes mowing and managing livestock easier. Subsoiling with a Keyline plow may help break up compaction and can be used to prune tree roots to reduce competition with alley crops.

To learn more about the Keyline system, consult ***Water for Every Farm***[141] or the ***Regrarians eHandbook (Chapter 2- Geography):***[142]

- http://www.regrarians.org/product/regrarians-ehandbook-2-geography/

TOPOGRAPHY

Slope

The slope of your site is important when considering machine vs. hand harvesting, row design, water harvesting, and erosion control. It can also affect soil drainage and patterns of air movement. A tool called a clinometer (or inclinometer) is used to measure slope. There are websites that guide you through printing out and making simple clinometers out of paper and string, or you can find and download an app on your phone to do the job.

For sloping sites, the usual advice is to orient rows along contours to help prevent erosion. However, this can make for alleys of uneven widths, which can cause problems when using machinery for tasks like mowing and harvest. Using Keyline planning can maximize the number of trees while still maintaining a relatively uniform spacing between the rows of trees for mowing and other field work.

Erosion

In many agricultural landscapes, soil loss from erosion occurs more rapidly than soil can be formed, steadily decreasing the organic matter, nutrient holding capacity, and productivity of farmland[23]. Take note of any existing erosion and note it on your map. These areas will need some extra care to protect.

Aspect

Aspect is the direction a slope faces, which can affect tree dormancy, moisture levels, and disease[133].

- South- Tend to be warm and dry, and heat up earlier in the spring, which can make trees come out of dormancy sooner and may cause them to lose their blossoms if there is a late frost. Trees that bloom early are at more risk, such as stone fruits (cherries, plums, apricots, etc.), apples, and pears. Late blooming trees like persimmon, mulberry, and chestnut are less of a risk.
- North- warm up later in the spring, generally wetter. North-facing slopes recommended for frost sensitive trees and those that like cool, moist soils.
- East- morning sun can help prevent foliar disease by drying leaves (especially grapes)[143].
- West- hotter and drier

Existing vegetation: Do PRESENT species suggest a good match?

Looking at what is already growing can give you an idea of what might do well on your site without much input. For example, if you have elderberries growing on the edge of a bottomland field, you might consider planting cultivated varieties of elderberry nearby. Do you already have black walnuts growing on the field borders? It could be a good site for more. This approach is not foolproof— some pioneering species may have moved into a marginally suitable site and are just languishing along. But who knows? You might discover a previously unknown cultivar of a native fruit like pawpaw or an exemplary hickory with easy to crack nuts.

Weed Identification

It is a good idea to identify most of the weeds on your site because effective management will vary by species. A good weed identification guide can help with this, or ask someone who knows local weeds to walk your fields with you. Knowing which weeds are present will help later on when you start to prepare your site for planting. If the farm was previously in row crops like corn or soybeans, figure out if there were any problems with herbicide resistance in the weed population.

Keep an eye out for particularly troublesome weeds like Canada thistle, Johnsongrass, field bindweed, poison ivy, poison hemlock, brambles, ironweed, and multiflora rose[138]. These weeds may take special measures to control, especially under organic management. See the "Site Preparation" and "Weed Control" sections for more information.

THE TOOLBOX: SPECIES PROFILES

With your site assessment completed, you are ready to select plants that will be a good fit. Using your field assessment sheets, you can work your way through the following species pages and charts and write down suitable species for the different areas of your farm. Evaluate each field separately. For example, a poorly-drained bottomland might have a different set of compatible trees than a sloping hillside. The goal in this section is simply to create a list of which species would be suitable for each field or even parts of fields if conditions are different. Final selection and the field layout will be covered in later sections.

SPECIES SELECTION

Here we highlight species that show promise in mixed, multifunctional plantings, but this is by no means an exhaustive list. We prioritize species that can be machine harvested or those that are suitable for feeding livestock. Hand-harvested species are included if they fit well as companion plants. The majority are disease and pest resistant, low-maintenance, and hardy to at least zone 5b.

Top Picks

These species are prime candidates for edible agroforestry.

Trees

- Apple (cider)
- Black walnut
- Chinese chestnut
- Hazelnut

Shrubs

- Aronia
- Black currant
- Saskatoon/Juneberry/Serviceberry

Livestock Feed

- American persimmon
- Honeylocust
- Mulberry

Good companions

Good for adding diversity as companions or as secondary enterprises.

- Asian pear
- Elderberry
- Honeyberry/Haskap/Blue Honeysuckle
- Pawpaw
- Pecan (northern)

Challenging

We have intentionally left out certain species if they are prone to pest or disease problems, require heavy inputs, or do not lend themselves to mixed agroforestry systems.

- Cherries, apricots, plums (pests, early bloom)
- Grapes (disease, outcompete trees)

- Brambles (disease, pests)
- Blueberries (require very low pH)
- Apples- dessert (disease, pests, labor intensive)

APPLES (CIDER)

Malus spp.

Introduction

Despite being one of the more challenging perennial crops to grow, we have included apples in this guide because of the increasing interest in hard cider (hereafter referred to as "cider") by both growers and consumers. There are numerous apple pests and diseases to contend with, making it difficult to meet consumer expectations of size and appearance for apples destined for fresh eating ("dessert apples"). An alternative is to produce apples for processing into cider[144]. Because the fruit need not be visually perfect, they can be grown with fewer inputs. However, even cider apples will require careful and timely management, especially if using organic methods[145].

Requirements

Apple trees tolerate a range of soil types but prefer well-drained, sandy loam to sandy clay loams. Some rootstocks are more tolerant of heavier, wetter soils. An ideal pH would be around 6.5, but a pH of 5.5 to 7.5 is acceptable[144]. Frost pockets should be avoided to reduce the risk of losing blossoms to late spring frosts. Apples need full sun for quality fruit production. Early morning sun is particularly important since it dries the dew from the leaves, which reduces problems with disease. There are varieties of apples adapted to most of the climate regions of the United States.

Management

Apples require cross-pollination with a compatible variety, and a common practice is to hire or keep hives of honeybees to increase fruit set[144]. Apples have widely variable characteristics depending upon the variety and rootstock[145]. Choosing appropriate stock for your area will be critical for disease management, harvest date, fruit quality, and size characteristics[146]. Cider makers usually use a mix of apple varieties that have different levels of tannins, acidity, and sweetness[144]. Consult applicable guides and extension recommendations for selecting appropriate varieties to suit your location and goals.

Most commercial orchards are moving toward denser spacing with dwarfing rootstocks. Smaller trees bear fruit earlier and are easier to harvest and maintain without working on ladders or platforms. However, most dwarf and semi-dwarf trees need to be supported by staking or trellising, adding additional costs during establishment[147]. Dwarfing reduces the productive life of the orchard: Trees on dwarfing rootstocks may only produce for 15-20 years, semi-dwarfing trees can be expected to live 25 years, and full-sized seedling rootstocks will be productive for 50+ years. Larger trees are also better able to handle drought and certain pests[147].

Apples require yearly pruning to stay productive, though some growers use techniques such as training branches to grow in a downward direction to decrease vigor and reduce the need to prune[148]. While apples destined for the cider press can be less-than-perfect cosmetically, certain pests and diseases such as apple maggot and apple scab still need

to be controlled. Apple maggot flies can be caught with sticky traps, while controlling scab may require raking and composting inoculum-carrying leaves or applying sprays like neem oil, compost tea, or approved fungicides such as Bordeaux mixture[147].

Livestock

Apple orchards present an excellent opportunity for integrating livestock. Throwing feed under trees will encourage poultry to scratch and gobble up insect larvae[147]. Organic apple growers are experimenting with putting hogs in the orchard after the main harvest to allow them to glean the fallen fruit. This approach not only provides food for the animals (apple finished pork!) but has shown to reduce pests such as plum curculio in the following year[147,149]. Apples typically drop a portion of their unripe fruits in early summer (known as "June drop") which can be used for livestock feed, but you must make sure to observe appropriate waiting periods before harvest to prevent contamination by manure[149].

SIDE BOX: Sheep, Apples, and White Muscle Disease

As a young farmer, the author's family once acquired a flock of sheep from a farm that had a sizable apple orchard. Being relatively inexperienced with sheep, they were careful to follow the instructions of the previous owners of the flock for vaccinations, minerals, and feed. Nevertheless, the first crop of lambs did not thrive. The cause was white muscle disease, a disorder caused by a lack of selenium. It turned out that soils in the area were typically low in selenium and most producers learned to give a shot containing selenium to address this issue. Wondering why the previous owners never had a problem with it despite not supplementing with selenium, they concluded that the only difference was the apple orchard, where sheep were previously allowed to eat all the fallen fruit they liked in the summer and fall. A quick internet search revealed many shepherds extolling the benefits of apple cider vinegar for treating white muscle disease. Coincidence? Perhaps. But these sorts of anecdotal stories can inspire research into promising ways of making connections in multifunctional, diverse systems.

Harvest

In Europe, cider apples are shaken off the trees, then swept up with machinery. In the United States, cider apples are mostly still hand-picked[150]. Harvest labor constitutes a major cost for producers, as some cider apple varieties have small fruits that can take up to four times as long to harvest[151]. High-density, trellised orchards are becoming the norm as they provide earlier yields and higher returns, but this type of system does not work well with the shake-and-sweep method[152]. Estimates for hand-harvesting apples range from 23 to 32 hours per acre[145,151].

Human-powered

A range of smaller harvesters are available in Europe, the simplest of which use a cylinder with spikes around the outside that is rolled along the ground which stabs the apples and lifts them into a container. One of the companies that makes this type of device (Huemer Obsterntetechnik) has several models ranging in price from 1,150-2,980 Euros, not including import costs.

Sweepers

Machines that sweep fruit up off the orchard floor come in a variety of sizes and configurations. Some may be suitable for multiple types of crops. See the "Harvest and Processing" section for more information on the possibilities of this type of sweeper in mixed systems.

Straddle harvesters

Research at Washington State University explored the use of a small fruit straddle harvester (Littau OR0012) for trellised cider apples and found that the machine used four times less labor than hand picking. However, yield was only 87% that of hand picking and some of the fruit were cut or damaged, which can potentially to lead to spoilage and off-flavors if there is a delay in pressing the juice[151]. A refurbished over-the-row harvester like the one used in the study run around $70,000, with new models costing up to $225,000[151].

Storage and use of fallen fruit

In commercial cider production, fruit is often stored in open barns for up to a month before pressing the juice, a practice known as "sweating." Fruit that is damaged or punctured by machines may be more prone to rot, so prompt pressing of the juice or refrigeration is important[151].

If fruit touch the ground, there is always the risk of contamination by harmful bacteria that can cause illness. Such apples are only suitable for pasteurized juice or fermented cider. Even with heat and fermentation, some pathogens like *Listeria* sometimes survive, so testing the final product before sale is a good practice[153]. Check your state regulations before planning on using dropped apples.

Marketing and Economics

Hard cider was the alcoholic beverage of choice in the United States until the late 1800's when prohibition and an influx of immigrants who preferred beer led to declines in the cider market[151]. Today, cider production is the fastest growing sector of the apple industry. Profitability will likely depend upon having local cideries who are willing to pay well for specialty cider apples[147]. Making cider (both sweet and alcoholic) on-farm is possible but requires careful consideration of the buildings and equipment you will need, as well as ensuring that you are complying with all applicable laws and regulations.

Resources

- ***Apples: Organic Production Guide*** (ATTRA, 2011)
    - https://attra.ncat.org/attra-pub/summaries/summary.php?pub=4
- ***Growing Cider Apples*** (Michigan State University, 2016)
    - http://msue.anr.msu.edu/resources/growing_cider_apples
- ***Organic Apples*** (University of Kentucky, 2012)
    - https://www.uky.edu/Ag/CCD/introsheets/organicapples.pdf

- ***Using Dropped Apples for Cider Production*** (University of Idaho, 2017)
    - http://www.ciderassociation.org/resources/Pictures/Cider%20apple%20drop%20food%20safety%20(2)%20(1)%20(1).pdf

BLACK WALNUT

Juglans nigra

Introduction

Black walnut is one of the most common trees used in temperate agroforestry because it has very valuable timber, produces edible nuts, and has traits that make it well suited to mixing with other crops. Black walnut trees have a sparse canopy that allows more sunlight to reach understory crops, and they are one of the last trees to leaf out in the spring and first to lose leaves in the fall. A deep root system allows black walnuts to reach water and nutrients without competing with shallower-rooted alley crops or forages.

Black walnut growers tend to focus on either nut production or timber, as the management requirements and tree genetics for each goal are very different[154]. Trees grown for timber are planted at a higher density to encourage competition that results in tall, straight trees with few branches and lower nut yields. Nut bearing trees need more space and a wide, branching canopy to capture the maximum amount of sunlight, which makes them poorly suited for timber[154]. Establishment costs are another difference: for timber, it is important to keep planting costs as low as possible because of the long return on investment, so inexpensive seedling trees are used. Grafted trees of improved cultivars are used when establishing a nut orchard, which cost much more.

Requirements

Black walnuts need fertile, deep soils with good drainage and a pH of 6.0 to 7.5 if they are to perform well[154]. Walnuts are sensitive to spring frost injury, so low-lying frost pockets should be avoided if nuts are desired[154]. Although trees may grow on less than ideal sites, nut production will be lower and timber growth will be slow. Black walnut excretes a chemical from the roots and fallen leaves called juglone that can hinder the growth of some crops, but this can be managed by root pruning and leaf litter management (see section on root pruning in "Beyond Establishment").

Management

Black walnuts can self-pollinate, but it is recommended that at least four varieties with overlapping flowering dates be planted to increase nut set[154]. If nut production for human consumption is a goal, use grafted cultivars that have desirable nut characteristics such as thin shells for easy cracking. You can establish nut-bearing trees in several ways: planting already grafted trees, planting purchased seedlings and grafting after 2 to 3 years, or direct seeding stratified nuts in the final location and field grafting after 3 to 4 years[154]. You will need to protect nuts and young trees from rodents and deer.

Spacing of 30' x 30' (48 trees per acre) is suitable for nut production, but wider spacing is fine for alley cropping or silvopasture sites. Diagonal thinning of every other tree will be required around age 20 (42' x 42' feet, 24 trees/acre) and again at age 50 (60' x 60', 12 trees/acre)[154]. For intensive black walnut nut production, you may have to spray to control pests and diseases.

Livestock

Black walnut is an excellent tree for silvopastures stocked with sheep or cattle, where trees can increase forage quality and animal comfort[76,155]. There are reports that full-grown hogs can be trained to eat whole black walnuts, cracking and spitting out the shells[106]. The small fragments that do end up in the digestive system may act as a dewormer[156]. Enterprising homesteaders used to feed laying hens through the winter by smashing black walnuts with a mallet and letting the hens pick the nutmeats out[106].

Harvest

Like many nuts, black walnuts tend to bear heavy crops in some years and lean crops in others, called **alternate bearing.** Some cultivars have less of a tendency for this than others. The harvest season starts in September and goes through October, depending on the location and variety[154]. Yields can be as high as 2,000 pounds per acre with improved cultivars and intensive management[154].

For nuts that fall to the ground before being harvested (walnut, chestnut, pecan, European hazelnut, etc.), there are human-powered tools for picking them up. Rolling cage harvesters such as the Nut Wizard® (www.holtsnutwizard.net) come in various sizes and pick up most types of nuts, acorns, or even apples. It consists of a globe-shaped cage on a pole that the user rolls along the ground. The tines of the globe allow nuts to pass into the cage, but not escape. To empty the cage, you press it down on a wire wedge mounted to a bucket, which separates the tines and allows the nuts to fall into the bucket.

Commercial operations shake the nuts out of the tree when 50 percent of the nuts are ripe, though smaller producers usually wait for the nuts to fall to the ground[154]. Prompt removal of the green hulls will prevent dark stains on the nuts from the pigment in the hulls. After hulling, the nuts are washed and air dried.

Marketing and Economics

The most profitable use of black walnuts are for silvopastures and alley cropping, which can provide early cashflow while timber is maturing[157]. A typical alley cropping plan might be to grow corn for the first 7 to 10 years, then switch to more shade-tolerant wheat when the canopy starts to shade the corn, and finally pasture until the lumber is mature. Cutting hay is also a viable option. Choosing an appropriate site is very important, as the growth rate of the trees is key to profitability. Because growing a timber-sized tree can take 40-60 years or more, installation costs must be kept very low to provide a reasonable return on your investment.

Economic analysis of orchards grown solely for nut production show that it is a challenge to make money unless you process and direct market the nuts[154,158]. Most enterprise budgets show break-even points anywhere from 14 to 20+ years[157,158]. Nearly all of the black walnuts harvested for sale in the United States are collected from wild trees and sold wholesale to Hammons Products Company via local hulling stations around the eastern U.S.[157] Improved varieties of black walnuts that have larger nutmeats and crack out easier fetch a higher price per pound[157]. Processing the nuts on-farm and selling the nutmeats at retail prices can increase the value, but hulling, cracking, and sorting black walnuts requires specialized equipment that may not be feasible for the average producer[154]. For some growers, black walnut relatives like the heartnut (*Juglans ailantifolia var. cordiformis*) have proven to be more marketable because they have shells that have an interesting shape and are easy to crack[143].

SIDE BOX: Commercial Black Walnut Economics: Tough Nut to Crack

Making money by selling the nuts of unimproved black walnut cultivars may be difficult without savvy marketing and clever tinkering with home-built equipment. Consider just the cost of harvest— a good worker can pick up around 500 pounds of dehulled walnuts in an 8-hour day, working out to about 10,000 pounds over a typical 20 day harvest period[159]. At this rate, one person could harvest about 10 acres per season at a yield of 1,000 pounds per acre. At the average price of $0.10 per pound for wholesale nuts (wild cultivars), this works out to about $6.25 per hour[160]. Note that this is *just the cost of harvest labor*, and does not include any costs for establishing or maintaining trees. Machinery can be used, including modified Savage pecan harvesters and English walnut harvesters by Weiss-McNair. These machines cost from $10,000 to $40,000, not including the tractor to run them. Breaking down the economics of machine harvest indicate that in the best of conditions, harvest costs can range from $0.05 to $0.06 per pound[160]. At a wholesale rate $0.10-$0.15 paid per pound, it is difficult to justify machinery, unless it used to harvest other crops as part of an integrated system. However, improved varieties have a much higher kernel-to-nut ratio and have been bred to crack out easier. Processors will be willing to pay more per pound for these improved nuts.

Resources

- ***Black Walnut*** (University of Kentucky, 2017)
    - http://www.uky.edu/ccd/sites/www.uky.edu.ccd/files/walnuts.pdf
- ***Black Walnut Harvesting Costs— The 50 Percent Factor*** (Harper, n.d.)
    - https://www.nrs.fs.fed.us/pubs/misc/walnut/p137_142.pdf
- ***Growing Black Walnut for Nut Production*** (University of Missouri, 2009)
    - http://extension.missouri.edu/p/AF1011
- ***Hogs and Black Walnuts*** (Oregon Sustainable Agriculture Land Trust, 2012)
    - http://www.osalt.org/assets/research/hogs%20and%20black%20walnuts.pdf
- ***Honeylocust and Black Walnut Products within a Temperate Appalachian Silvopasture*** (Johnson, 2011)
    - http://theses.lib.vt.edu/theses/available/etd-02182011-102323/

CHINESE CHESTNUT

Castanea mollissima

Introduction

Chestnuts play a star role on the edible agroforestry stage. Low pest pressures, dependable high yields, strong markets, and ease of maintenance make them very attractive candidates for mixed perennial systems. The American chestnut (*Castanea dentata*) was once a major native timber species in the eastern U.S. and was a valuable source of food for both people and livestock. Unfortunately, the imported chestnut blight has all but wiped them out. The blight-resistant Chinese chestnut (*Castanea mollisima*) is now the primary species grown east of the Rockies, though some commercial hybrids utilize Japanese (*C. crenata*) and European (*C. sativa*) chestnut genetics.

Requirements

Chinese chestnuts require well-drained loamy to sandy loam soils as they are susceptible to root rots on wet, heavy soils[161]. Slightly sloping sites above frost pockets that have a pH of 5.5 to 6.5 are recommended[133]. Once mature, they are quite drought hardy, but supplemental watering will increase yields[161]. Chinese chestnuts are cold tolerant to -20°F and are hardy in zones 6a to 8, possibly even zone 5b in favorable microclimates[161,162].

Management

There is debate in the chestnut growing community over whether to use seedling trees from improved parents or grafted trees of known cultivars. Those that favor using grafted trees note the benefits of predictable harvest timing and known nut quality[161]. Other growers, especially those in colder areas, say that grafted chestnuts are more prone to be infected by blight and suffer from lower vigor and delayed graft union failure that can sometimes happen even 15 years after planting[162,163].

Chinese chestnuts can be established in several ways depending upon your goals, skills, timeline, and budget. Planting grafted trees will be more expensive, but yields will happen sooner. Another option is to plant seedlings and graft later. Finally, stratified seed can be planted in the final location and grafted (if desired) at the appropriate size. See more in the "Obtaining Plants" section about the benefits and drawbacks of these various methods.

Final spacing for Chinese chestnuts is usually around 40' by 40', or 27 trees per acre. Since it takes many years to reach this size, some growers plant at a higher density (20' x 20', or 108 trees per acre) and thin when the trees become crowded[162]. In this way, yields are higher early on in the life of the orchard, and selective thinning can remove underperforming trees[162]. Chinese chestnuts require at least one other cultivar for cross-pollination[161].

Although Chinese chestnuts suffer from relatively few pests and diseases, some growers occasionally spray to control leafhoppers, European red/two-spotted spider mites, or yellow necked caterpillars[161,162].

Livestock

Chestnuts and hazelnuts are extolled as the "corn and soybeans" of the tree world, because they serve as starch and oil sources, respectively. As such, it would seem to make sense to try to incorporate them into tree plantings intended primarily for livestock. However, the demand for chestnuts for human consumption currently far exceeds supply. Even at wholesale prices for chestnuts (at the low end, around $1.50/lb), the comparison between organic corn (around $8.00 per bushel at the time of this writing) and chestnuts is more than an order of magnitude different:

Organic Corn: $0.14 per pound[164]

Chestnuts: $1.50 per pound[165]

The estimated cost of hand-harvesting chestnuts is about $0.25-$0.50 per pound[166], so even though no labor is expended if hogs are allowed to self-harvest the nuts, the numbers still favor selling the nuts for human consumption. Of course, hogs can be run through the orchard after the main harvest to pick up any leftovers, and chestnut trees can be grown on hillsides that corn cannot. Integrating poultry into the chestnut rotation may also help gobble up chestnut weevils[167].

Harvest

Chestnut harvest occurs from September through October, with individual trees dropping nuts over a two to four week period[161]. Yields of 2,000 pounds per acre by age 12 to 15 can be expected in irrigated orchards[161]. Chestnuts are high in carbohydrates and moisture, unlike most other nuts. They therefore require refrigeration after harvest and must be stored under cold, moist conditions[168]. Harvesting for human consumption can be done manually or mechanically. Scale, markets, and the availability of labor, capital, and machinery will all be part of determining how to harvest your chestnuts.

Hand Harvest

Most chestnut orchards, even relatively large ones, rely on human labor to collect nuts[169,170]. This can be done by opening up the orchard for you-pick, hiring seasonal workers, or by working with groups to put on fund-raisers[169]. Tools such as Nut Wizards® can be made available to customers. Some growers have found that customers with a cultural familiarity with chestnuts (primarily from Eastern Europe and Asia) are very willing to travel to an orchard to collect nuts in a you-pick situation[170]. With customers at the farm, offering other products and activities can increase income, a strategy employed by many Christmas tree farms and apple orchards. In areas with chestnut weevil (see below), you will have to do a hot-water bath of the chestnuts, perhaps complicating you-pick. Chestnuts must be harvested at least every two days to keep the chestnuts from drying out and to ensure that chestnut weevil larvae do not re-infest the orchard[163].

Machine Harvest

Researchers in Michigan determined that under 2 acres of chestnuts can easily be harvested by hand, whereas more than 8 acres favors an imported commercial harvester[118]. They developed a prototype vacuum harvester for the intermediate sized farms between 2 and 8 acres, but it is not available commercially.

Another team of researchers in Missouri modified a horse paddock vacuum to harvest chestnuts, and showed that at the average yield, the paddock vacuum was more economical than hand harvest with a Nut Wizard® for greater than 6.9 acres when wages were $8/hour, but it only took 2.7 acres to make it profitable when wages were $15/hour[166]. Similar vacuums are used in sloping orchards to harvest European hazelnuts, so the same unit may be able to be modified for both crops. Backpack vacuums have been developed for smaller or very steep orchards[171].

Some chestnut growers use a modified pecan harvester to harvest chestnuts, with mixed results[162,172]. Ken Hunt at the University of Missouri outlined their experiences with a Savage Model 8042 harvester, saying that it was only about 60% effective at picking up chestnuts due to rough ground and the fact that the machine cannot get too close to the tree trunks. Systems with drip lines for irrigation require either moving the lines or using some sort of blower to move the nuts into the alleys where the harvester can get at them. Secondary cleaning is needed to separate the nuts from burrs and trash, and they had good success with a Savage 4124 pecan cleaner. All in all, Hunt concluded that with machine harvest, you end up with scratched, scuffed, and dirty nuts that require extra cleaning compared to hand harvest[172].

According to Savage, the model 8042 harvester runs around $10,000 new and has the capacity to harvest 2,200lbs/day of pecans. It can be pulled by an ATV or lawn tractor, and is self-powered by a small gasoline engine. The Model 4124 pecan cleaner is no longer manufactured, but the current model 4224 would be comparable, according to Savage.

SIDE BOX: Chestnut Weevil

"The bane of the chestnut industry in the past has been the weevil. Nearly everyone who has eaten a chestnut has met a chestnut worm under conditions of extreme and unpleasant intimacy. Neither party was pleased…" – J. Russell Smith, "Tree Crops- A Permanent Agriculture"

Chestnut growers should be aware that if they live in an area with chestnut weevils, they will have to process their chestnuts with a hot water bath before sale to kill any eggs or small larvae that may be present. If done promptly, these will remain unnoticeable and the nuts can be eaten. A couple of bad nuts here or there might be acceptable to consumers, but there is zero tolerance for ***live*** larvae in food[173].

Greg Miller of Empire Chestnuts shared his processing method in an excellent video series available on Youtube called "Bringing Back the Chestnut"[169]. After a hot water bath for 20 minutes at exactly 120 degrees Fahrenheit[173], the nuts are sorted into small, medium, and large sizes with a rotating drum. They are then graded on a conveyor by hand to remove nuts that are damaged or moldy. Damaged nuts are further processed into chestnut flour, and moldy nuts are sold to hunters as deer bait, so there is no loss. For more information and directions on how Greg Miller made his automatic hot water bath system, check out the University of Missouri document, "Chestnut Weevil":

- www.centerforagroforestry.org/weevil.pdf

Marketing and Economics

The market for chestnuts appears to be strong, with domestic production currently making up only a tiny fraction of the chestnuts consumed in the U.S[165]. Prices paid range from $1.50 per pound wholesale up to $5.00 or more per pound retail[165]. Chestnuts are primarily sold fresh in-shell but can also be frozen or dried and ground into flour. Cooperatives exist for marketing chestnuts:

- ***Prairie Grove Chestnut Grower's Cooperative*** (Columbus Junction, Iowa)
  - http://prairiegrovechestnutgrowers.com/
- ***Route 9 Cooperative*** (Carrollton, Ohio)
  - http://www.route9cooperative.com/index.html
- ***Chestnut Growers, Inc.*** (across Michigan)
  - http://www.chestnutgrowersinc.com/index.shtml

Resources

- ***The Iowa Chestnut Grower's Primer*** (Tom Wahl, 2017)
  - http://www.redfernfarm.com/wp-content/uploads/2017/01/Iowa-Chestnut-Primer.pdf

- ***Growing Chinese Chestnuts in Missouri*** (University of Missouri, 2012)
    - http://www.centerforagroforestry.org/pubs/chestnut.pdf
- ***Chestnut Farming for Profit*** (Grimo Nut Nursery, 2017)
    - www.grimonut.com/shared/media/editor/file/Chestnut%20Farming%20for%20Profit%202017.pdf

HAZELNUT

Corylus avellana (European), Corylus americana (American)

Introduction

Hazelnuts show promise as a low-input perennial source of food, oil, and livestock feed[174]. Researchers and farmers have been evaluating hazelnuts as a crop in the Eastern United States for several years[175]. The main challenges are cold hardiness and Eastern Filbert Blight (EFB), a disease which affects the European hazelnut (*Corylus avellana*) but not the American Hazelnut (*Corylus americana*). For this reason, the American hazelnut selections are used to impart disease resistance and cold tolerance to European selections via hybridization. However, improved hybrid hazelnut varieties are not yet available commercially, so genetic variation in seed-planted stock leads to noteworthy differences in yields, harvest timing, and nut quality[176]. European hazels with documented resistance to EFB (such as the variety 'Yamhill') are currently undergoing field trials in the Midwest, representing perhaps the most promising short-term option for commercial production[175,177], while American x European hybrids continue to be developed.

Requirements

Hazelnuts can withstand wetter areas than chestnuts or walnuts, but still prefer well-drained soil with a pH of 5.5 to 7.5[133,158]. Tile drainage or mounding can be used to improve conditions in poorly drained areas[178].

Management

Pollination requirements for hazelnuts are complex and variety specific, so careful planning based on the desired varieties must be done to ensure compatibility[178]. Hybrid hazelnuts are usually trained to a bush form in hedgerows, while commercial production with European genetics favors training trees into a single trunk[178]. Hazelnuts are the smallest nut tree for northern temperate regions, reaching a height of 16' for hybrids and up to 40' for European trees on good soil[139,178]. Final spacing of 16' to 18' apart is suitable for improved European genetics in the Midwest, with double-density (18' x 9') and later thinning as an option for earlier yields[178]. Hybrid hazelnuts in hedgerow plantings are planted 3' to 5' apart in rows 10' to 15' apart. Like most perennial crops, irrigation during establishment can increase success and will increase yields and nut quality in dryer years after maturity, especially for European hazelnuts, which prefer moisture to be spread out evenly throughout the year.

Other than EFB, big bud mite is another potential concern, but certain varieties show resistance. This pest is not considered a major problem, though spraying is recommended if more than 5% to 10% of buds are affected[158,178]. You may have to take measures to protect your nuts from squirrels, mice, chipmunks, and even birds like jays and crows[178]. Options include encouraging predators, trapping (for rodents), and scare tactics for birds.

Livestock

Livestock systems that integrate hazelnuts are uncommon. Until improved hybrid hazelnut varieties are available commercially, it might be best to integrate them as a component in systems that do not rely upon heavy yields to impart value, such as riparian buffers and windbreaks. Hogs (and perhaps turkeys) will eat the dropped nuts in these systems.

SIDE BOX: Using Windbreaks and Riparian Buffers to Identify New Varieties

Windbreaks and riparian buffers need high densities of trees and shrubs to be effective at blocking wind and preventing erosion. We would also like them to produce a marketable crop, but using expensive grafted planting stock would be cost-prohibitive. Not only are seedling trees more economical, they also offer an opportunity for participatory plant breeding. If seed from improved parents is used, there is a chance of growing a new individual with superior qualities that is uniquely adapted to your locale. As the windbreak or buffer is managed over the years, you can identify these promising candidates for further propagation and research.

Harvest- Hybrid Hazelnuts

A study of hazelnut yields in the Upper Midwest showed that the average yield for hybrid hazelnuts was 294 pounds of kernel per acre at a normalized spacing of 5' x 15' and a density of 580 plants per acre[174]. Individual plant yields varied a lot, with ranges of 0.03-2.58 pounds per plant. Because of this variation, growers often plant hybrid hazelnuts at a high density initially, and then thin out under-performing plants.

Most hybrid hazelnuts (*Corylus americana x C. avellana*) ripen within their involucre (the husk) on the trees, or sometimes the entire cluster will fall to the ground. For this reason, commercial hazelnut harvesters that sweep the nuts off the ground are not suitable. Most hybrid hazelnuts are harvested by hand, but several farms use a modified over-the-row blueberry harvester[174]. Time trials of hybrid-hazelnut hand harvest by the Upper Midwest Hazelnut Development Initiative indicate a typical hard-working picker can harvest about 13 pounds in-shell per hour.

Harvest- European Hazelnuts

European hazelnuts (*Corylus avellana*) fall from their husks when ripe. Worthwhile yields begin around age four. Mature orchards in the Pacific Northwest produce from 2,000 to 4,000 pounds of dry nuts per acre[139]. These orchards typically maintain smoothed, bare soil under their trees to facilitate easier machine harvest. Bare soil is not practical in the Eastern U.S., as heavy rains would lead to soil erosion and muddy harvest conditions, but groundcovers can be cut short prior to machine harvest to make it easier[178].

Many hazelnuts in other parts of the world are harvested with vacuum equipment. Research in Turkey found that shaking the nuts from the trees by hand and raking them into the rows with a garden rake, then using a backpack vacuum harvester to pick them up required 45 hours per acre, at a rate of 43.6 to 78 pounds per hour[179].

The Savage model 8042 pecan harvester mentioned in the chestnut section is also used to harvest hazelnuts. Information from Grimo Nut Nursery states that it would be suitable for hazelnut plantings 1-10 acres in size[178]. Another option may be a multifunctional sweeper like those made by Feucht-Obsttechnik, though careful orchard floor management would be required.

After harvest, nuts will need to be husked, washed, sanitized, and dried if they are to be sold directly to consumers. Various small-scale, DIY solutions have been devised for shelling and sorting if the nuts are not to be sold in-shell. See Grimo Nut Nursery's excellent guide "***Hazelnut Farming for Profit***" for more information[174].

Marketing and Economics

Currently, most hazelnuts grown in the Midwest are direct marketed, though small grower-owned businesses such as the American Hazelnut Company (http://www.americanhazelnutcompany.com/) have been established to aggregate processing and marketing. Most nuts are processed into value-added products like chocolate candies, cooking oils, and baking ingredients[158]. In the future, companies like Ferrero Roche (the maker of Nutella™) may be willing to buy Midwestern hazelnuts if the quantity and quality are adequate[178].

Resources

- ***Agroforestry of the Farm: Hybrid Hazelnuts at Hazel Acres, Fenton, Iowa*** (Trees Forever, 2014)
    - http://www.treesforever.org/AgroforestryResources
- ***A Landowners Guide to Perennial Crop Options*** (Trees Forever, 2014)
    - http://www.treesforever.org/crops
- ***Growing Hybrid Hazelnuts*** (Chelsea Green Publishing, 2015)
    - http://www.chelseagreen.com/growing-hybrid-hazelnuts
- ***Hazelnut Farming for Profit*** (Grimo Nut Nursery, 2017)
    - http://www.grimonut.com/shared/media/editor/file/Hazelnut%20Farming%20for%20Profit%202017%281%29.pdf

ARONIA

Aronia melanocarpa

Introduction

This native, up-and-coming "super fruit" is extremely productive and relatively easy to grow. Clever marketers preferred to advertise the fruit as Aroniaberry, rather than the common moniker of "chokeberry," so-called due to an unpleasant astringency when eaten fresh[180]. Juiced, it adds color and healthy antioxidants to beverages and juice blends. It can be harvested by the same machine as Saskatoons, currants, and haskap, making it a great candidate for mixed plantings.

Requirements

Aronia tolerates a range of soil conditions but prefers well-drained soils with slightly acid to neutral pH[133]. The quality of fruit can decline during droughts without irrigation[180]. Aronia grows to a height of 5 to 10 feet and produces suckers[180]. Full sun is required for optimal fruit production[181].

Management

Aronia can be propagated by seed, cuttings (softwood or semi-softwood), micropropagation, or division of root suckers[181]. Aronia is self-fruitful and therefore does not require planting more than one variety[182]. Currently, most growers plant the vegetatively-propagated variety 'Viking.' Growers have noted the critical nature of early weed control and moisture management for Aronia[183]. Mulching is recommended, as mowing or using a string trimmer close to shrubs may cause damage that can lead to disease[182]. Spacing will depend upon the harvest method and machinery. Spacing of 12 to 14 feet between rows and 3 to 4 feet between plants within the row (around 900 plants per acre) is recommended to create a hedge that is suitable for machine harvest[180]. Pruning recommendations vary. Annual pruning may be required if machinery requires a smaller height, but plant productivity can be maintained by pruning every 4 or 5 years[180,181]. Aronia is relatively pest-free, but may need protection from deer or birds[180].

Livestock

Aronia is not commonly planted for livestock, though pastured poultry may help control weeds or insects if pastured in the rows.

Harvest

Aronia berries have a harvest window of four to six weeks, ripening from late August through mid-September[182]. Yields may vary from 4,000 to 18,000 pounds per acre or more[182]. An average yield of 8,000 to 10,000 pounds per acre (yielding 600 to 750 gallons of juice) can be expected with a spacing of 4 feet by 12 feet at 900 plants per acre[182]. Harvestable quantities of fruit normally begin in the third year after planting, with full production by years five or six[181].

Hand harvest of aronia is only viable for very small plantings and direct sales at retail prices. Aronia can be harvested by hand at a rate of around 16 pounds per hour. Several companies offer mechanical harvesters that are suitable for aronia, including Oxbo® and Weremczuck®. Machine harvest is estimated at 0.3 to 0.25 acres per hour with a common pull-behind model, though total harvest labor has been estimated at 65 hours per acre[180,184]. Collective ownership of machinery or hiring a custom harvester could reduce machinery costs. See the "Multi-crop Harvesters" section for more details.

Marketing and Economics

Aronia has the greatest potential in larger markets that can handle the volume generated by machine harvest. Since fresh market sales are limited, aronia is usually frozen or processed into juice, wine, preserves, or nutraceuticals. Refrigeration will be required to store the berries until processing. Wholesale prices range from $0.50-$1.25 per pound[183].

Resources

- ***Aronia Berries*** (Agricultural Marketing Resource Center, 2013)
    - http://www.agmrc.org/commodities-products/fruits/aronia-berries/
- ***Aronia Berry at Winding Creek, Belmond, Iowa*** (Trees Forever, 2014)
    - http://greenlandsbluewaters.net/Aronia%20Case%20Study%20FINAL%20(1).pdf

- ***Culture of Aronia for Fruit Production*** (University of Maine, n.d.)
    - https://extension.umaine.edu/agriculture/home/aronia/culture/
- ***Jujube and Aronia*** (University of Kentucky, 2013)***:***
    - https://www.uky.edu/Ag/CCD/introsheets/jujube.pdf

BLACK CURRANT

Ribes spp.

Introduction

Black currants are very attractive candidates for mixed agroforestry systems because they are one of the few fruits that produce well in partial shade, making use of the shady areas under larger trees like chestnuts[185]. Currants were once more widely grown in the United States, but at the outbreak of a disease called White Pine Blister Rust (WPBR) in the early 1920's, regulations were passed to protect the white pine timber industry by prohibiting cultivation of plants that harbor this disease, including currants[186]. Since then, cultivars have been developed that are resistant to the disease[187]. Black currants remain popular in Europe, suggesting market development potential in North America.

Requirements

Black currants are not picky about soils, but you should avoid planting them in very heavy clay soils or standing water. The blossoms are somewhat susceptible to late frosts, so low-lying sites should be avoided[188]. Locations with good air circulation will help prevent mildew. The ideal pH for currants is 5.5 to 6.5[185]. Cold tolerance depends upon the cultivar, but most currants are considered cold hardy at least to zone 4, with some adaptable to zone 2 or colder[187,189]. Black currants are self-fruitful, but larger and better crops will occur with cross-pollination[185].

Management

Black currants (*Ribes nigrum and R. ussurienses and hybrids*) show the most promise for larger plantings as they can be machine harvested and are suitable for processing. Red currants (*Ribes rubrum*) have high-quality fruit that is suitable for fresh eating, but they are not suitable for machine harvest and are less hardy. Pure *Ribes nigrum* are susceptible to WPBR, so crosses were made with *Ribes ussurienses* to impart resistance, but early varieties had poor fruit quality. Newer varieties show resistance to WPBR while retaining good quality and high yields[187]. Although the federal ban on currants has been lifted, some states still have laws on the books that may or may not be enforced, so knowing your local regulations and selecting only resistant varieties is a good idea[185]. Powdery mildew is a problem for currants, so choosing resistant cultivars is important[187]. With disease-resistant varieties, black currants are a good candidate for organic management[189].

Black currants can be easily propagated by layering or cuttings as long as they are not a protected by a patent or trademark[185]. Pruning is required, usually done by removing about a third of the oldest stems each year, leaving 10 to 12 stems per bush[189]. In some commercial orchards, bushes are cut to the ground every third year on a rotation. Although this reduces yields, it also reduces pruning costs[186].

Planting is best done in the fall or late winter, as later spring planting can lead to the plants breaking dormancy and blooming early[186]. Spacing will depend upon the requirements of the harvester, with a common layout of 2 to 3 feet apart in rows that are spaced 12 to 14 apart[189].

Harvest

Black currants begin to bear in the third year, with full production by year 4 or 5. Fruit begins to ripen in late June and July further south and in August in the north[189]. Ripe fruit keeps well on the bushes, allowing some flexibility in harvest[185]. Black currants are well suited to machine harvest with a straddle (over row) or side-row harvester. See "Harvest and Processing" section for more information.

Marketing and Economics

Black currants are among the most nutrient-dense fruits, with three times the vitamin C of oranges and twice the antioxidants of blueberries, along with high levels of calcium, iron, magnesium, and potassium[190]. Although some varieties of black currant are suitable for fresh eating, most North American consumers are unfamiliar with the fruit. Therefore, the primary market is in processed products such as wine, syrups, jellies, pie fillings, dessert toppings, ice cream, candies, and juice[186,187]. Some consumer education may be required, as customers may be familiar with a small dried raisin that is also called 'currant' but which is actually a type of grape[186].

Resources

- ***Organic Black Currant Production Manual*** (Anne's PEI Farm and the PEI Horticulture Association)
    - http://acornorganic.org/media/resources/blackcurrantmanual.pdf
- ***Potential for Ribes Cultivation in North America*** (HortTechnology, 2000)
    - http://horttech.ashspublications.org/content/10/3/548.abstract
- ***Specialty Crop Profile: Ribes (Currants and Gooseberries)*** (Virginia Cooperative Extension, 2009)
    - https://pubs.ext.vt.edu/438/438-107/438-107.html
- ***Gooseberries and Currants*** (University of Kentucky, 2012)
    - https://www.uky.edu/Ag/CCD/introsheets/currants.pdf

SASKATOON, JUNEBERRY, SERVICEBERRY

Amelanchier spp.

Introduction

The *Amelanchier* family includes dozens of species that are native to North America. The most commonly grown for fruit is *Amelanchier alnifolia*, usually referred to as Saskatoon berry or Juneberry. Identification to the species level can be difficult even for experts, as this genus hybridizes freely[191]. The nutritious fruits are about the size of a blueberry but with more variation in color and a different, but agreeable, taste. Saskatoons are another highly nutritious, machine-harvestable berry that can fit well into diversified systems.

Requirements

Saskatoons are suitable for USDA zones 2 through 5 and are adaptable to a variety of soil types, though they do best on gently sloping hills with good air and soil drainage and a pH between 6.0 to 8.0[192,193]. True Saskatoons (*Amelanchier alnifolia*) may have problems with leaf spot and adapting to early spring warming periods outside of the northern U.S. and Canada, where other species such as Allegheny serviceberry (*Amelanchier laevis*) and hybrids grow better, although they tend to be larger in form, which may make harvest difficult[194].

Management

Saskatoons are considered self-pollinating[192]. Although they can be grown from seed, vegetative propagation makes for more uniform bushes and fruit maturity for commercial harvest. Cuttings are obtained through a process that utilizes darkness to form etiolated shoots that root better than normal softwood cuttings[192]. Micropropagation is also successful and ensures disease-free planting stock[192]. Recommended in-row spacing is 3 to 5 feet apart, with a between-row spacing of 12 to 16 feet for hand harvest and 17 to 20 feet for mechanical harvest[192]. Irrigation may be required during establishment, though mature orchards can be productive without supplemental watering if there is enough rainfall[192]. Bushes will require pruning to maintain productivity and make harvesting easier. There are a number of potential pests and diseases that can affect Saskatoons, so a careful monitoring and control strategy is recommended[192].

Harvest

Saskatoons can be harvested by hand or machine. Bushes begin to yield in their third year, with individual plants producing an average of 4 to 5 pounds, though some varieties have yielded up to 10 pounds per bush[193]. Yields per acre range from 2,000 to 6,000 pounds[192]. Harvest occurs over about a two-and-a-half-week period. Due to uneven ripening, machine harvest is usually done twice, four to six days apart[192]. Fresh fruit does not keep long and must be refrigerated immediately after harvest. Fruit must be sorted before sale, either on-farm or at the processing facility. Freezing is the most common processing method for commercial Saskatoon production[192].

Marketing and Economics

Saskatoons have been cultivated in the Canadian prairies for more than a hundred years, but few U.S. consumers are familiar with them. Integration with more well-known fruits in a you-pick operation is one way to increase consumer awareness[193]. The timing of fruiting is an opportunity for filling the seasonal gap between strawberries and blueberries.

Saskatoons also have broad commercial potential and are enjoyed in pies, jellies, tarts, rolls, breads, syrups and juices[193]. The berries freeze and dehydrate well[194]. Like the other bush fruits highlighted in this guide, the berries have high nutritive and antioxidant values[193].

Resources

- ***Saskatoon Berry Production Manual*** (Alberta Agriculture and Rural Development, 2013)
    - http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/agdex14362
- ***Guide to Juneberries*** (Growing Produce for Profit, 2012)
    - https://www.growingmagazine.com/fruits/juneberries/

- ***Juneberry*** (University of Kentucky, 2012)
    - https://www.uky.edu/Ag/CCD/introsheets/juneberry.pdf

SIDE BOX: The Legacy of J. Russell Smith

J. Russell Smith, a professor of geography at Columbia University, was a pioneer in agroforestry[177]. His book, ***Tree Crops: A Permanent Agriculture*** written in 1929 (with an update in 1950), is considered a foundational text for using trees in agricultural systems[177]. His goal was to protect fragile sloping hillsides from erosion by planting trees in a way that was profitable for farmers. He documented and promoted letting livestock gather their food from under intentionally planted trees, including chestnut, mulberry, honeylocust, American persimmon, and oak, among others[106]. Smith's witty writing, useful anecdotes, and visionary foresight make it well worth getting your hands on a copy of *Tree Crops*.

AMERICAN PERSIMMON

Diospyros virginiana

Introduction

This North American native fruit is enjoyed by people, livestock, and wildlife. Although this species has not yet reached commercial popularity like its cousin the Asian Persimmon (*Diospyros kaki*), it nevertheless has potential for wholesale and retail markets including as an ingredient for brewing, winemaking, and processed foods like ice creams and puddings. American persimmons may also have a role as livestock feed, especially for hogs and poultry.

Requirements

The American persimmon grows up to 70 feet tall and is adaptable to a wide variety of soils, from wet bottomland to thin ridgetops[195]. It flowers late for a reliable fruit set, making it suitable for colder microclimates where other fruit might lose blossoms to early frost. Young trees can handle partial shade, but full sun is recommended for fruit production. The American persimmon is hardy in USDA zones 5-9, while the Asian persimmon is only adapted in zones 7-10, limiting its use in the north[195].

Management

Persimmon trees are dioecious, meaning they are either male or female. Interestingly, there are two 'races' of American persimmon: a 60-chromosome type that is native to the south and a 90-chromosome type from the north. Most named varieties are of the 90-chromosome variety, as the flesh and flavor are of higher quality[196]. When 90-chromosome females are pollinated by 60-chromosome males, the fruit may have few to no seeds[197].

Cross-pollination is required by some varieties, but other varieties have shown the ability to produce fruit without a compatible male nearby. However, a 5:1 ratio of female to male trees is recommended for good fruit set[196]. Propagation is possible from seeds, though sex cannot be determined until the tree flowers, which can take several years. Vegetative propagation through cuttings, grafting, and suckers eliminates this guesswork and ensures desirable fruit characteristics. Since persimmons have a deep taproot that makes them sensitive when transplanting, seeds can be planted directly in the final orchard location and grafted onto later. For each tree desired, plant about five seeds closely together in a mound, and pick the strongest individual to graft after one or two years when the tree is pencil-sized and

around 12" tall[196]. Recommended spacing is 30' x 35', or around 42 trees per acre. Persimmons are usually trained to a modified central leader, but do not require routine pruning after they reach mature size[197]. Pests and diseases are of minor concern, though wildlife like deer, squirrels, and raccoons may eat the fruit. Some varieties contain black specks in the flesh, which is undesirable in the pulp[197]. Care should be taken not to hit the bark of the tree with mowers or string trimmers, as persimmon trees do not heal well at the base, which can leave them open to decay and insects. Keep an eye out for persimmon borer on young trees[196].

Livestock

Many animals relish the sweet fruits, and the persimmon's habit of dropping fruit throughout an extended period in the fall and early winter make it a candidate for plantings that are intended to provide supplemental livestock feed, especially for hogs or chickens[106,198]. It is one of the most reliable trees to bear, rarely failing to set fruit. It is probably best kept out of equine paddocks, as persimmons have been known to cause foundering in horses and mules in rare cases.

Harvest

Top-producing grafted trees have been known to produce 70 lb. of fruit (45 lb. of pulp) by age 5, but the average is 35 to 75 lb. per mature tree[196,197].

There is limited opportunity for machine harvest, as shaking the trees is liable to drop fruit before it is fully mature. The fruits often remain on the tree until they are very soft and liable to be damaged when they fall to the ground[195]. Jerry Lehman of Terre Haute, Indiana solves this problem by spreading clean straw under the trees before harvest, then picking the fruits up by hand. He estimates that one person can harvest around 20 lb. per hour this way[196]. Fruit should be harvested every other day and promptly processed. Fruit can be sanitized by dunking in a basin with bleach water (1 tsp. bleach per gallon of water), then rinsed in pure water. Fruit is then pulped, separated from the seeds, and frozen.

Marketing and Economics

When marketing fresh persimmons, it is important to ensure fruit is fully ripe, as unripe fruit can be very astringent[197]. In fact, the experience of eating an under-ripe persimmon can make customers unwilling to try the fruit again, so it is imperative that consumers know how to identify a ripe fruit and to be educated about proper techniques for ripening. Leaving fruit on the counter for a few days in a plastic bag with an apple slice will do the trick[195]. Commercial potential lies in marketing the frozen pulp for use in ice cream, sorbet, puddings, cookies, cakes, and preserves[199]. There is also an increasing demand for persimmon as an ingredient for alcoholic beverages[196]. Frozen pulp retails for around $5.00/lb. Dehydrated persimmons taste similar to dates and may be another avenue for preservation and added value.

Resources

- ***Persimmons, Asian and American*** (ATTRA, 2010)
    - https://attra.ncat.org/attra-pub/summaries/summary.php?pub=10
- ***Passion for Persimmons: Grower Strives to Commercialize the Seasonal Fruit*** (Hayhurst, 2012)
    - http://www.my-indiana-home.com/food/passion-for-persimmons-grower-strives-to-commercialize-the-

seasonal-fruit/

- ***American Persimmon*** (University of Kentucky, 2011)
    - https://www.uky.edu/Ag/CCD/introsheets/persimmon.pdf

HONEYLOCUST

Gleditsia triacanthos

Introduction

The adaptable, native honeylocust has excellent potential for silvopastures. Grass grows well under its dappled shade, and livestock relish the sugary seedpods. Honeylocust is a non-nodulating legume, thriving as a pioneer species that colonizes abandoned fields and forest edges. Most wild individuals have impressive, 6"-12" thorns along the trunk and lower branches that are capable of puncturing vehicle tires. Thornless trees are produced by variety selection or grafting.

Requirements

Honeylocust thrives in a wide range of soils and climate zones, with temperatures down to -34°C and as little annual rainfall as 20 inches per year[200]. Honeylocusts grow relatively quickly, reaching heights of 40 to 50 feet. Thornless varieties are popular urban trees due to their wide adaptability and tolerance to drought, compaction, and pollution. Honeylocust seedlings are intolerant of shade.

Management

Young honeylocust trees should be protected by tree shelters or fence until they are out of browse height, as the leaves and small twigs are palatable to livestock and deer. Usual tree densities range from 54 to 80 trees per acre (between 23 to 28 feet apart).

Vareities with high yields of sugary pods were identified by J. Russell Smith and others. These thorny but productive varieties can be propagated to make thornless trees by grafting the thornless branches from higher in the canopy onto seedling rootstocks. The resulting tree will grow without thorns. Breeders of ornamental varieties selected against pod production, as they can be a nuisance to clean up in a city setting. An opportunity exists to breed a truly thornless variety with high pod production. There are few reported pests for honeylocust in silvopasture settings, though overplanting in some urban areas has led to buildups of damaging insect populations.

Livestock

The main use for honeylocust is for silvopastures. Leafing out late in the spring and dropping leaves early in the fall complement cool-season forage growth, and the small leaf size breaks down quickly without smothering groundcovers. Livestock grazing under honeylocust show equal or better gains as those in open pasture. Improved cultivars of honeylocust have pods that are nutritionally equivalent to oats[201]. Sheep are better able to utilize whole pods than other livestock because they can digest not only the sugary pulp of the pods but also about 80% of the seeds, which contain much of the protein[202]. Grinding and mixing the pods into a complete ration allows other livestock to benefit from their full nutritional value.

Harvest

Honeylocust typically displays alternate bearing patterns, producing heavily one year and sparingly the next, which could complicate planning for livestock enterprises. Honeylocust pods fall over an extended period in the late fall. Stockpiling forage under honeylocust trees in late summer and grazing it in the fall or early winter would allow livestock to harvest the pods themselves and might reduce hay needs. Pods can be picked up and stored for later use. Modifying hay equipment or mechanical sweepers for use in harvesting honeylocust pods is a possibility that merits further exploration.

Marketing and Economics

The best use of honeylocust is for on-farm feed production. Currently, there are no marketing channels for honeylocust products, though there have been experiments with generating ethanol by fermenting the pods.

Cautions

The thorny offspring of honeylocust have the potential to invade neighboring areas, as thornless grafted trees may spread seeds that grow with the characteristic thorns of the parent. Improved varieties may be hard to find, and growth rate, time to bearing, and frost tolerance can be highly variable depending upon the site and cultivar. More research is needed in developing widely adapted genetics suitable for integrated farming systems.

Resources

- ***Honeylocust Agroforestry*** (website by Andy Wilson)
    - http://faculty.virginia.edu/honeylocust-agroforestry/agroforestry/
- ***Honeylocust and Black Walnut Tree Products within a Temperate Appalachian Silvopasture*** (Johnson, 2011)
    - http://theses.lib.vt.edu/theses/available/etd-02182011-102323/
- ***Honeylocust (Gleditsia Triacanthos), A Multi-purpose Tree for the Temperate Zones*** (Gold and Hanover, 1993):
    - International Tree Crops Journal, Vol. 7, Iss. 4, 1993
- ***Potential Value of Honeylocust as a Fodder Tree for Silvopastures*** (Johnson et al., 2013)
    - http://www.afgc.org/proceedings/2013/38.pdf

MULBERRY

Morus rubra (Red Mulberry), Morus alba (White Mulberry)

Introduction

In the past, farmers often planted mulberries as a source of feed for hogs and poultry[106]. As producers return to pasture-based systems for these non-ruminants, the mulberry has the potential to provide high-quality feed at very little cost.

There are three main species of mulberry grown in the United States: white (*Morus alba*), black (*Morus nigra*), and the native red (*Morus rubra*)[203]. The white mulberry is considered an invasive species in most of North America and the black mulberry cannot handle temperatures below zero, making the native red mulberry the species of choice.

However, mulberries hybridize freely, making it difficult to confirm whether a variety is truly a native cultivar. Birds enjoy the fruits and the seeds remain viable in their droppings, potentially allowing this aggressive tree to spread into sensitive areas, so spending the time to find non-invasive varieties is probably worthwhile.

Requirements

Mulberries are adaptable to a range of soils as long as they are moderately well-drained. Cold tolerance depends upon the variety. The white is the most cold hardy (up to Zone 4), but the red can also handle sub-zero temperatures. Trees can either be male or female (dioecious) or have both flowers on the same tree (monoecious). The large leaves of the mulberry cast a deep shade, so take this into consideration when incorporating it with forages or alley crops.

Management

White mulberries can grow as tall as 80 feet, while red mulberries are a little smaller[204]. Mulberries flower later in the spring than most fruits, making them suitable for planting in frost pockets[205,206]. The trees suffer from few pests or diseases and are easily vegetatively propagated.

Livestock

Urban dwellers with mulberry trees may curse the falling berries that stain sidewalks and cars, but this is an opportunity for livestock producers. Poultry and pigs will happily clean up the fallen fruit. J. Russell Smith chronicles the use of mulberry as livestock feed in the Southern U.S., noting that nearly every hog lot in North Carolina, South Carolina, and Georgia contained mulberry trees and that a single tree could support a hog or two with very little supplemental feed during the fruiting season[106]. The leaves make a nutritious and palatable browse, and mulberry is commonly used in "cut and carry" livestock systems in the tropics[203]. A system of coppice or pollarding could be a way to increase forage availability to ruminants during hot summer months when cool-season forages are less productive.

Harvest

Mulberry fruits are shaped somewhat like a blackberry, but are sweeter and usually lack tartness. Despite the name, the fruit of white mulberries can be a range of colors from white to red to purple, depending on the cultivar. Mulberries produce fruit from May to July. The fruit can be shaken from the tree when ripe, though some cultivars may cling to the branches. It may be possible to use a machine to shake and catch the fruits, though pruning might be necessary to maintain a suitable size. Birds are very fond of the fruit, so bird control measures may be required. You may be able to take advantage of this by planting mulberries to lure birds away from other fruits like cherries that are ripening at the same time[207].

Marketing and Economics

The best way to utilize mulberries may be as a livestock feed tree in frost-prone areas with marginal soils. Mulberry fruits damage easily and have a short shelf life, which is the reason for limited commercial production. However, the fruits may be processed into wine, jams, jellies, pies, sauces, and juice. They have excellent potential to mix with other fruits during processing, especially those that would add some tartness. Mulberries dry well.

Resources

- ***Mulberries*** (Agriculture Marketing Resource Center, 2016):
    - http://www.agmrc.org/commodities-products/fruits/mullberries/
- ***Mulberry*** (California Rare Fruit Growers, 1997):
    - https://www.crfg.org/pubs/ff/mulberry.html
- ***Mulberry*** (Uncommon Fruit, 2012):
    - http://uncommonfruit.cias.wisc.edu/mulberry/
- ***Protect Your Harvest with Mulberry Trees*** (Stark Bro's, 2017):
    - https://www.starkbros.com/growing-guide/article
- ***Tree Crops— A Permanent Agriculture*** (Smith, 1950)
    - Island Press, Washington DC. 55

GOOD COMPANIONS

The following species did not make it into our main crop profiles because they either cannot be machine harvested, do not fit well with livestock, or have other concerns that limit their use as a primary enterprise. However, they can make useful additions to diverse plantings.

ASIAN PEAR

Pyrus pyrifolia

Nutshell:

Asian pears, also known as apple pears, have a high value in the marketplace, especially with consumers who are familiar with their crisp, juicy texture and sweet flavor[208]. Though they have fewer issues with diseases and insects than apples or European pears, an integrated pest management (IPM) program will still be required[143,208]. Asian pears do not respond to dwarfing rootstocks like European pears and require thinning of the fruits to ensure adequate fruit size. They must be picked by hand, and the fruits bruise easily, so careful handling and storage are necessary[208].

Pros:

Tolerant of heavier soils than apples, fewer pests, good consumer demand, can be dried

Cons:

Fire blight, blooms early, hand harvest only, requires pruning and thinning

- ***Asian and European Pears*** (University of Kentucky, 2014)
    - https://www.uky.edu/Ag/CCD/introsheets/pears.pdf

ELDERBERRY

Sambucus canadensis

Nutshell:

Elderberries are tough native plants that are easy to propagate and grow[209]. The flowers support pollinators, and the fruits are high in healthy antioxidants and flavonoids[210]. The main markets are for juice, preserves, syrup, wine, and medicinal products[209]. The small berries are borne on clusters that do not lend themselves to machine harvest, and fruit must be frozen before processing[209]. Unlike most other shrubs, elderberries can be coppiced to the ground annually, which reduces yields slightly but saves pruning labor and makes for more even ripening and larger fruit clusters[211]. Birds can consume the entire crop if not controlled[209,210]. Spotted Wing Drosophila is a newer pest that may require spraying for a marketable crop[211].

Pros:

Native, tolerant of poor sites, easy to propagate, good for pollinators, health benefits, easy pruning, well-suited to mixing with other fruits, frost tolerant

Cons:

Hand harvest, birds, Spotted Wing Drosophila

- ***American Elderberry*** (Uncommon Fruit, 2013)
    - http://uncommonfruit.cias.wisc.edu/american-elderberry/
- ***Elderberry*** (University of Kentucky, 2012)
    - https://www.uky.edu/Ag/CCD/introsheets/elderberry.pdf
- ***Growing and Marketing Elderberries in Missouri*** (University of Missouri, 2014)
    - http://www.centerforagroforestry.org/pubs/2014GrowingElderberryGuide.pdf

HONEYBERRY, HASKAP, BLUE HONEYSUCKLE

Lonicera caerulea

Nutshell:

These members of the honeysuckle family are native to the cold northern regions of North America, Europe, and Asia[212]. The oval-shaped fruits vary in flavor and are suitable for fresh eating or for making into wine, ice cream, or other products. Commercial plantings exist in Russia and Japan, and farmers are experimenting with them in Canada and the United States. Recent breeding work has made this usually cold-loving plant more adaptable to warmer regions[213]. It has the potential to be harvested mechanically and would fit well into processing streams for currants, aronia, and Saskatoon[213]. However, marketing efforts will be required to increase consumer awareness, and variety trials and breeding work must continue before widespread planting can be recommended for most regions of the U.S.[214]

Pros:

Fresh eating or processing, high nutrient value, machine harvestable, few pests and diseases, fits well with other fruits

Cons:

Few variety trials in U.S., lack of consumer familiarity, best suited to colder zones (though breeding has made more varieties available)

- ***Growing Haskap/Blue honeysuckle in Canada*** (University of Saskatchewan, 2008)
    - http://www.fruit.usask.ca/articles/growing_haskap_mar2008.pdf
- ***Honeyberry*** (Uncommon Fruit, 2013)
    - http://uncommonfruit.cias.wisc.edu/honeyberry/

PAWPAW

Asimina triloba

NUTSHELL:

Pawpaws are a native understory tree with a flavor somewhat like a banana or mango[215]. In their native range (zones 5-8), pawpaws suffer from few pests or diseases. Pawpaws can produce fruit in partial shade, which makes them suitable for planting under larger trees or at the shady edges of fields, though they will yield more in full sun[215]. Although pawpaws are one of the only trees not to be browsed by deer, young trees must be protected from sun damage until they are established[216]. Poor pollination can be an issue, sometimes requiring hand pollinating[216]. Many consumers are unfamiliar with the fruit, so you may have to spend time educating and providing samples. The fruits are sold fresh locally, as they have a very short shelf life[217]. There is also a growing commercial demand for the processed pulp for use in ice creams, desserts, juices, wine, beer, and even bourbon[217].

Pros:

Native, good companion tree, frozen pulp may be marketed along same lines as persimmon pulp, few pests, no pruning, NOT browsed by deer

Cons:

Hand harvest, fruits have a short shelf life, young trees require sun protection, short-lived tree

- ***Pawpaw*** (University of Kentucky, 2012)
    - https://www.uky.edu/Ag/CCD/introsheets/pawpaw.pdf
- ***Pawpaw Planting Guide*** (Kentucky State University, 2009)
    - http://www.pawpaw.kysu.edu/pawpaw/ppg.htm
- ***Forest Production of Pawpaw*** (Kentucky state University, 2009)
    - http://kysu.edu/wp-content/uploads/2017/07/ForestPawpawPBI-0031.pdf

PECAN (NORTHERN)

Carya illinoinensis

Nutshell:

Pecans are native to the Mississippi river valley and are the most important economic nut crop in the eastern U.S[218]. For northern growers, cold-hardy varieties are required to fill nuts and avoid winter injury[219]. Pecans are alternate bearing, producing a heavy crops in some years and light crops in others[218]. The nuts fall from the trees when ripe and can be picked up by machines. Wild stands of native pecans are managed for nut production, but may require 80 or more acres to make it worthwhile to own harvest equipment[218]. Cattle are often grazed in pecan stands[218]. Pecans suffer from a variety of pests and diseases, depending upon the area where they are grown[219]. Most commercial production requires monitoring and spraying, as well as fertilizer inputs for good nut production[218,219].

Pros:

Native, high-quality nut, grows in wetter areas than most nuts, mechanical harvest and processing, minimal pruning, known to consumers

Cons:

Alternate bearing, low yields for northern cultivars, pests and diseases require intervention

- ***Sustainable Pecan Production*** (ATTRA, 2000)
    - https://attra.ncat.org/attra-pub/summaries/summary.php?pub=65
- ***Growing Pecans in Missouri*** (University of Missouri, 2000)
    - https://extensiondata.missouri.edu/pub/pdf/agguides/agroforestry/af1002.pdf
- ***Non-Timber Forest Products— Kentucky Pecans*** (Kentucky Woodlands Magazine, 2011)
    - http://www2.ca.uky.edu/kywoodlandsmagazine/Vol6_No1/Pecanspg14-17.pdf

LIVESTOCK

"When tree agriculture is established, chestnut and acorn orchards may produce great forage crops, and other orchards may be yielding persimmons or mulberries, crops which pigs, chickens, and turkeys will harvest by picking up their own food from the ground." – J. Russell Smith, **Tree Crops: A Permanent Agriculture**

INTRODUCTION

The ecosystems that we aim to mimic with edible agroforestry include not just plants, but animals. Wild herbivores keep growth in check and cycle nutrients back into the soil. With domestic livestock, we can do the same thing, only produce marketable (and tasty!) products at the same time. Cows and sheep turn forages into food in the form of meat and milk. Poultry and pigs glean rotten fruit and dropped nuts, and can be useful for other tasks such as stump removal and insect control[149]. Incorporating trees into pastures (silvopasture) can diversify income, provide fertility through animal manures, improve animal comfort, and increase the overall biodiversity of your farm[76]. Well-managed

rotational grazing can improve soil health and help control invasive species[220]. Livestock sales can help supplement income in the early years when trees are still too young to produce[221].

Adding livestock also brings challenges[222]. It will make management more complex, may increase labor requirements, and requires additional infrastructure in the form of fences, waterers, and handling facilities. If you maintain breeding stock, you may have to check on animals every day, year-round. Soil compaction and tree root damage can happen if animals are left in one place for too long. There is also the danger of damage to young trees if livestock outsmart a farmer's efforts to protect them.

The purpose of the following information on livestock is not meant to be comprehensive, but to identify some opportunities and challenges when incorporating animals into agroforestry systems. If you have never managed livestock, you should you gain as much experience as you can beforehand. Visit farms in your area with the type of animals you are interested in, go to training workshops and conferences, and consider working on someone else's farm to gain experience. There is no substitute for hands-on experience when it comes to working with livestock!

LIVESTOCK SPECIES

Poultry

Pastured poultry are inexpensive to purchase, have a short payback time, and may be handled with minimal risk of injury to the farmer. A pasture-based system of pens or electric netting are used to move birds around so that they have access to fresh forage and do not damage the grass from staying in one place too long. Being monogastric (having 'one stomach') means they cannot gain much in the way of calories from the grass, so they will still need feed to maintain growth (mature geese are an exception). However, they do benefit from the minerals and protein in green forages and gobble up any insects they can. Pasturing poultry has a measurable effect on the quality of the eggs and meat, with higher levels of healthy fats and vitamins compared to chickens raised in confinement systems without access to pasture[223].

Making money with poultry will depend upon feed prices, loss of birds to predators, and labor efficiency. In one study, only 50% of farmers with pasture-raised chickens said that they were directly profitable, but 78% noted that they contributed to indirect profits because of the increase in soil fertility and enhanced customer loyalty[223].

In agroforestry systems, poultry can be utilized to graze pasture between or within rows of trees. They do not damage young trees like larger livestock might. Exceptions to this might be if they are left too long in one place, potentially causing soil compaction or eating the leaves of tree branches within reach. Pastured poultry are one of the best ways to integrate livestock into agroforestry systems while trees are getting established.

Chickens have been proposed for use in orchards to reduce pest pressure on the trees. Studies have shown that although the number of insect pests is lower in areas with chickens, this has not affected the fruit yield or quality[224–226]. Anecdotal evidence suggests that chickens may reduce populations of chestnut weevils[167]. Turkeys have the potential to follow hogs in cleaning up chestnut orchards, or even for the planting of chinkapins solely for turkey production[106].

"The ordinary game chicken is found to be the greatest enemy of the chestnut weevil. A brood of one hundred game chickens in a grove of twenty-five acres will in the course of a few years reduce the multitude of chestnut weevils to a minimum. Sheep turned to pasture in a chestnut grove with the chickens assist in keeping the grass and undergrowth cropped close, thus aiding the fowls in their scavenger work." -1902 article in Pennsylvania Forestry Association's journal "Forest Leaves"[167]

In addition to chickens and turkeys, ducks and geese are good candidates for pastured operations and considered hardier and more resistant to cold[227]. Mature geese can thrive on grass and indeed have been successfully used to weed orchards[224,228]. Marketing goose might be a challenge, so figure out where you would sell them before you decide to buy a gaggle of goslings.

Ducks have a reputation for eating slugs and snails, and some breeds rival chickens for the number of eggs they can lay in a year. They must have access to clean water to bathe in[222].

All poultry require adequate shelter and protection from predators. Popular systems include movable pens called "chicken tractors" and portable electric netting. It cannot be stressed enough that losses to predators can make the difference between profit and loss[223], not to mention the farmer's obligation to provide for the needs of the animals in his or her care.

Hogs

Traditionally, hogs were used to gather up the acorns, fruits, and other mast in forests for part of the year. Persimmons, mulberries, apples, acorns, hickories, chestnuts, hazelnuts, and more will be happily munched by porcine jowls. The cork oak *dehesas* of southern Europe are one notable example, where hogs graze acorns under oak trees that provide natural cork material[107].

Hogs show promise in reducing pests in orchards by consuming the fallen fruit after the main harvest. In one study, hogs in apple, cherry, and pear orchards ate 100% of the fallen fruit, which broke the cycle of plum curculio and codling moth, leading to lower pest populations the following year[149].

Another practical way to use hogs is to employ them to dig up stumps in transitioning forests to silvopasture, an ingenious system outlined by Brett McCleod in "The Woodland Homestead"[229].

However, pigs have the potential to be incredibly destructive. If left in one place too long, they can completely root up young trees or pastures, and their wallowing can cause severe compaction. Healthy systems that integrate hogs move them into sensitive areas like woods and pastures only for short periods of time and when there is food on the ground to keep the animals busy so that they do not dig out of boredom. Smaller "sacrifice" areas are used for more permanent pens. Food safety is another concern when introducing livestock before the main harvest, as pathogens from manure risk contaminating fruit. However, at least one study showed that hogs were effective at controlling weeds in orchards, with levels of bacteria remaining in acceptable ranges[230].

Sheep

Sheep are well suited for agroforestry. They are small enough that handling can be done relatively safely with portable equipment, and they multiply quickly compared to cattle, bearing 1-2 lambs that will grow in a year. If trees are

protected with tree tubes (see "Tree Protection" section), sheep are unlikely to damage them[231]. Sheep need a more substantial interior fence, however, as their wool partially protects them from electric shocks. Marketing lamb might be more of a challenge than marketing beef or chicken, but many small producers are doing it successfully, often by making connections with ethnic communities where demand is higher.

Of course, most sheep produce wool, but it is difficult to make it profitable unless you have heritage breeds and are willing to market individual fleeces to hand spinners. Shearing is difficult, and shearers are not available in all parts of the country. For these reasons, some farmers choose to go with hair sheep breeds like Katahdin and St. Croix, which have been bred so that they do not need to be shorn. They also tend to handle heat and internal parasites better than some wool breeds.

Goats

Goats play a role in improving degraded forests by cleaning up invasive species like honeysuckle, multiflora rose, and buckthorn, as well as native plants that might not be desired, like poison ivy[222]. They are browsers, meaning they prefer bushes and trees over grass. They are not recommended for integration with fruit and nut trees, as they are clever at escaping and can debark and damage valuable trees surprisingly quickly. They host the same internal parasites as sheep, so careful parasite management will be required if both species are part of a system.

"Goats spend 23 hours of the day planning their escape, and the last hour executing it." -Unknown

Cattle

Beef cattle, like sheep, can get all their nutritional needs met by grass and hay alone, making them a good fit for areas that need to have grass between trees for erosion control, such as hillsides. Cattle are the easiest species to contain with temporary electric fence, often requiring only a single electrified wire for interior paddocks. However, robust equipment or facilities are needed to safely handle cattle for routine work like vaccinations and working calves, or for loading them on trailers. Alleys in some alley cropping systems may be too narrow for cattle. Cattle can also cause significant compaction if left in one place for long or if soils are wet[227]. They are more expensive to get started in than smaller livestock, and herds do not grow as fast as flocks of sheep or goats because they typically only have one calf per year and take longer to mature. However, demand for grass-fed beef tends to be strong.

LIVESTOCK SYSTEMS

Silvopasture

One way to generate money from the space between trees is to use it for making hay or grazing livestock. In the first few years, trees will need protection from livestock by tree tubes, wire cages, or electric fence[232]. Another strategy is to only cut hay until the trees are big enough not to be at risk. Note that it may not be profitable to maintain haying equipment unless you are planning on harvesting significant acreages. You may be able to hire a custom harvester to do the haying, or agree on a crop-share where the hay is split between you and the person doing the haying. When hiring anyone to do work on your farm, make sure they understand how far away from your trees you would like themto keep their machinery. Tree tubes and marking rows with stakes helps prevent accidental mowing of young trees.

In silvopastures, the tree density is managed to favor forage growth by spacing or thinning trees so that light levels remain at about 50% of open pasture[126]. Cool-season species tend to do better in the shade than warm-season grasses[233]. Trees that cast a dappled shade such as honeylocust and black walnut make good silvopasture trees, though other species can certainly be used[77,234,235].

SIDE BOX: Leave Healthy Forests Alone[222]

Integrating trees and livestock works best in forests that would benefit from thinning and extra management. If you have woods that are mature and healthy, it might be best to keep the animals out. There is the potential for damage to the trees, and it is simply not worth the risk of upsetting a healthy forest ecosystem. In mature forests, it might be a better fit to try mushrooms, syrup, or medicinal herbs like ginseng[222].

Rotational grazing

Rotational grazing is a must in agroforestry no matter what livestock species you may have. This strategy requires moving the animals based upon the condition of the forage. Moves can range from every day to a week or more depending on the season, pasture composition, and stocking density[220]. Rotational grazing has many benefits, including minimizing wasted forage, increasing pasture and animal health, and higher animal gains per acre[220]. Portable electric fencing has made rotational grazing practical, and many ingenious systems have been developed to make it easier. Rotational grazing is an art unto itself, and there are good resources available for learning more[236].

Multispecies Grazing

Including multiple livestock species in a grazing system takes advantage of the fact that each species of livestock prefers a slightly different category of available plant forage: cattle prefer grass, sheep go for broad-leaved forbs, and poultry scratch for seeds and insects[237]. They can either be grazed all together at the same time or moved sequentially through a pasture. One well-known example of this is Joel Salatin's system of moving chickens into a pasture a few days behind his cattle herd[238]. By then, flies have laid eggs in the cow pies, and the chickens happily scratch them apart to eat the larvae. Thus, the chickens gain some protein, the manure is spread out over the pasture by the scratching action of the chickens, and the fly population is reduced. This type of synergy is what agroforestry is all about, and good producers look for ways to connect elements in their farming enterprises to take advantage of it. The permaculture movement has been particularly good about promoting the stacking of multiple functions[239].

Fodder, Coppice, and Pollarding

Not only do trees offer livestock protection from wind and the sun, but the trees themselves can provide valuable fodder. Aspen, alder, black locust, poplar, honeylocust, and mulberry all have leaves that are high-quality feed for livestock[222]. Cutting tree branches and leaves to feed to animals is common in the tropics. In temperate areas, producers are experimenting with using coppicing (cutting trees near ground level) and pollarding (cutting trees higher up) to provide additional forage for animals when cool-season pastures are less productive in the summer[240]. For example, a farmer in Wisconsin who manages a hybrid poplar and sheep silvopasture culls trees in the summer during dry conditions. The sheep eat the leaves off the fallen trees and the farmer later cuts them up for sale as firewood to campers in a nearby state park. Do some research before feeding tree foliage, as a few trees like cherry can be toxic to livestock[241].

INFRASTRUCTURE

Fencing

A full description of the many fencing options is more than we can cover here, but an overview of the basics will help you plan. See the "Tree Protection" section for how fencing and tree tubes can be used to protect trees from livestock and deer.

Most rotational grazers use portable electric fences. Common systems use single or multiple strands of "polywire," which is an electrified plastic braided cord. Step-in posts with insulators are used to hold it off the ground. Cattle, hogs, and well-trained sheep can be contained with polywire. Electrified nets are available that offer better containment for goats, poultry, and flightier sheep. They are more time consuming to move and require a larger charger because the netting has more points of contact with vegetation. They also cost more.

All electrified fences will require a charger (also called an energizer) and ground rods. Plug-in chargers are less expensive, but require an outlet in close enough proximity to the fence. Chargers that run off a solar panel or car battery are available and are convenient for paddocks that are too far away from an electric line. Installing ground rods is necessary for any electric fence system, and the most common mistake for electric fencing is improper or insufficient grounding.

Waterers

Livestock require fresh water every day, so work this into your plan. Installing waterlines and waterers should be done before planting trees. Ideally, there will be water access wherever you plan to keep livestock. You can haul water in a tank, but this increases labor and uses fuel.

Feed and Storage

Cattle and sheep need hay in the winter even with the best management, so consider where you will store bales and how you will move them around to feed the animals. Poultry and hogs require supplemental feed, which either means hauling around bags or storing bulk feed in bins or wagons.

Handling Facilities

Safe handling of livestock for routine work like vaccinations, worming, and sorting into breeding groups requires appropriate infrastructure. For goats and sheep, this can mean portable electric fence supplemented with some rigid wire panels (often called "hog panels" or "cattle panels") to form a working/catch area. For cattle, a portable corral and a head gate are the bare minimum needed. Even better is to have a facility designed to reduce stress for the animals and injury for their handlers, such as those promoted by Dr. Temple Grandin[242].

HARVEST AND PROCESSING

"God gives us the nuts, but he does not crack them." –German Proverb

HARVEST PLANNING

Knowing how you will harvest your trees will be important in determining row spacing, pruning technique, species composition within a row, and target markets. Harvest makes up a significant percentage of the labor for tree crops,

so knowing the harvest labor demands for each crop will help you decide on suitable harvesting strategies and equipment. For specific harvest information by crop, consult individual tree crop profiles.

Labor availability

If it is hard to find laborers in your area, or you would like to keep the operation small enough to be handled by a few individuals, consider the harvest labor requirements per acre and plan accordingly. For example, one person can reasonably handle harvesting several acres of chestnuts by hand, but could only harvest a fraction of an acre of aronia or black currants. Keep in mind that the harvest window is limited for most crops, so one laborer will only be able to harvest a certain acreage during that time. Choosing multiple species with different harvest times can spread your labor out of over the season.

Topography and access

Topography might limit the possibility of using machinery. Road access will be important to get the harvest equipment and harvested product in and out of the field. Steep slopes may be another limiting factor. Most fruit and nut machines are designed for flat orchards, but some can handle sloping terrain. Check with the manufacturer of the machine you are considering to ensure it can be safely run on your orchard's slope.

Cooperatives and machinery pools

Cooperative ownership of machinery gives smaller growers access to mechanical harvesters without high upfront investment costs. Alternately, if you own a harvesting machine, you may be able to do custom harvesting or rent it out to generate extra income. Grower co-ops can take advantage of combined marketing and pooling of products to reach bigger markets.

MULTI-CROP HARVESTERS

Machines capable of harvesting multiple crops have exciting potential for mixed agroforestry plantings. Outlined below are two examples: one for berries and the other for fruits and nuts that fall to the ground before harvest. Both are made in Europe and represent the types of machines available from a variety of manufacturers. The mention of brand names below does not imply endorsement, and product specifications should be confirmed with manufacturers to ensure that machinery will meet your needs.

Joanna Berry Harvesters by Weremczuk

These machines will harvest currants, aronia, haskap (aka Honeyberry), Saskatoons, and even wild rose. They are pulled by a tractor and are capable of harvesting ¼ to ½ an acre per hour, depending upon the crop. They are split-row harvesters, meaning they harvest one side of the bushes at a time, requiring a pass up each side of a row.

In fact, machine harvest is probably the only way to make these crops financially viable, unless you can develop a strong pick-your-own operation. Consider the labor requirements: to harvest ***one acre*** of Aronia or black currants requires 720-778 hours, or roughly 10 full-time workers over the course of two weeks[186]! The same acre can be harvested by a Joanna-4 in 3-4 hours, though when calculating total harvest labor, some estimates put machine harvest at around 65 hours per acre because multiple people are needed to run the machine and sort the fruit[180,243].

If a machine can harvest multiple crops, it means that the harvest window can be spread out over a longer period. One machine can thus harvest more acres per year, lowering the overhead costs and speeding up the payback time. Planting two or three different crops can minimize risk and open up more marketing opportunities. It also encourages diversity, benefitting the local ecosystem. Note that not all of these berries are suitable for growing in every location.

One analysis showed that the breakeven acreage for machine harvest of aronia was around 0.66 acres, assuming a labor wage of $7.25 per hour and a basic machine cost of $30,000[244]. An updated quote that includes equipping the machine with extra features (Joanna Premium) to handle multiple crops and steeper slopes would cost more. Even at a machine cost of $60,000, this would only increase the breakeven acreage to 1.16 acres.

Larger "straddle" harvesters that can harvest a whole row at a time are available, but their larger size may limit use in mixed systems due to interference with tree branches, and the higher initial price tag and bulkier frame for transport may make them less suited to shared-use situations like machinery cooperatives.

Feucht-Obsttechnik Fruit and Nut harvesters

This German company offers a range of small- to medium-sized harvesters that can pick up fruits and nuts from a grassy orchard floor at slopes of up to 35 degrees[245]. The machines sweep up the crop, run it through a blower, and deposit it into bins or a hopper. They are used primarily for apples and pears destined for cider but will work with nuts that fall to the ground, including walnuts, chestnuts, pecans, and hazelnuts. Secondary separation may be required for chestnuts since the burrs are likely to be swept up with the crop. The dealer noted that it might be more difficult to harvest hazelnuts if the orchard is not flat or if there are a lot of leaves on the ground.

The smaller, walk-behind units can harvest 1.5-2.5 tons per hour and start around $9,000 including freight and export taxes. Medium-sized, ride-on machines capable of harvesting 4-5 tons per hour start around $30,000. Larger units that mount on a tractor are also available.

PROCESSING

Adding value to your products by processing, packaging, or marketing them yourself can mean the difference between a crop making money or losing it. However, it usually takes more time, knowledge, and equipment than simply selling a raw agricultural crop. Some fruits and nuts may not have well-developed wholesale markets available, requiring direct sales.

Some products can be sold straight after the harvest, while others may require some processing before they leave the farm. Most fruits will require prompt refrigeration or freezing if not being processed immediately. Black walnuts must be promptly hulled, chestnuts will need a hot water treatment and then refrigeration, and hazelnuts for direct sales must be sorted, washed, and dried.

Several small-scale commercial nutcrackers are available if you desire to pursue direct sales of shelled nuts. Some nut growers develop their own specialized equipment. There are also a few cooperatives that may be able to custom process your harvest.

Processing regulations

Depending upon the product you would like to produce and your state requirements, you may have to do your processing in a certified commercial kitchen. Special "incubator kitchens" are available for rent in some areas to encourage small farm entrepreneurship. Often, low-risk foods may be processed at home if certain conditions or training are met and the product is going to be sold directly to consumers. Of course, alcoholic beverages like cider or wine will require special permits and facilities. Check with your state department of agriculture for guidance.

GOALS

"A goal without a plan is just a wish." -Antoine de Saint-Exupéry

WHAT DO YOU *WANT* TO DO?

On any given piece of land, a variety of plants and animals could be put together into a workable, ecologically responsible agroforestry plan. Ultimately, the ideal system for your farm is the one that best fits your goals. Envisioning the long-term goals for your operation should take into consideration more than just your production and income targets. Your desired quality of life, family and community involvement, and environmental improvement are all important. Resources such as **Whole Farm Planning** and **Holistic Management** are available for helping you develop your goals into comprehensive management plans. Find one that fits your needs and stick with it. Although it may be uncomfortable or feel unnecessary at first, solid planning based on your desired outcomes will undoubtedly increase your chances of success.

WHOLE FARM PLANNING

Whole farm planning helps balance the quality of life desired by the farm family with long-term profitability and environmental stewardship[246]. The process can also include planning for retirement, investments, and transitioning the farm to the next generation[247].

There are four steps in whole farm planning:

1. Setting goals
2. Making an inventory and assessment of the farm resources
3. Developing and implementing an action plan
4. Monitoring on-farm progress toward goals

For more information:

- ***Introduction to Whole Farm Planning*** (Minnesota Institute for Sustainable Agriculture)
    - A good introduction to the concepts of whole farm planning. Includes a list of useful resources[246].
        - http://misadocuments.info/WholeFarmPlanning_complete.pdf
- ***Whole Farm Planning Model*** (Ohio State University Extension, 2017)
    - A concise overview of whole farm planning process, with a focus on the business and family goal setting side of things, including retirement and transition plans[247]

    - https://ohioline.osu.edu/factsheet/anr-52

- ***Whole-Farm Planning: Ecological Imperatives, Personal Values, and Economics*** (Chelsea Green Publishing, 2011)
    - This Northeast Organic Farming Association (NOFA) handbook dives into assessing the whole farm (people, assets, money) along with a consideration of the ecosystems involved when building a framework for decision making. It includes case studies from actual farmers as well as alternative business models[248].
        - http://www.chelseagreen.com/wholefarm-planning
- ***Building a Sustainable Business***
    - An excellent overall guide for developing a business plan in the context of a sustainable farm business. Includes goal setting, marketing, financing, and examples from real farms. Available as a free download from SARE:
        - http://www.sare.org/Learning-Center/Books/Building-a-Sustainable-Business

HOLISTIC MANAGEMENT

Holistic Management® is a framework developed by Allan Savory that integrates decision making and farmer values into a farm management plan. It was originally implemented in the context of grazing, but it can be adapted to other production models.

SIDE BOX: Holistic Management Decision Making (used with permission from Holistic Management International)

- Look at all you manage - your team and assets.
- Develop a holistic goal with those involved.
- Consider ecosystem processes in your decision.
- Create the mission, vision, strategies, policies, and objectives for your holistic goal.
- Identify the tools available to manage your resources.
- Consider influential factors (experience, data, peer pressure, cost, etc.)
- Apply the seven tests to make sure your decision(s) are sound and will lead toward your holistic goal.
- Before you make a decision, consider the unintended consequences that can arise within complex living systems.
- Use a feedback loop to monitor your decisions and plans. Plan, monitor, control, and replan, if necessary.
- For more information: https://holisticmanagement.org/

VALUES AND QUESTIONS

As you develop a plan based on your goals and values, consider the following topics and questions. You may have different goals than those outlined below, such as a primary focus on wildlife conservation, family food production, or education. Whatever your goals are, make sure to include them in your planning.

Marketing Strategy

Farmer's Markets/on-farm sales/you-pick

These direct sales strategies require face-to-face interaction with customers, which can be a good way to foster connection within the local community. Economically, retail sales mean higher returns per unit of product, though there may be limits to the quantities local markets can handle. Farmer's markets require labor for transport, set-up, and tear-down. If visitors are going to be coming to the farm, you will have to consider vehicle access, parking, and liability insurance.

> **Questions**: Do I enjoy interacting with people? Am I willing to spend the time to set-up, tear-down, and sell at a market stall every week? Is there a big enough customer base in nearby cities? Is direct-marketing important for my profitability? Is my product legal to sell at a farmers' market? Is my farm set up for visitors/you-pick?

Restaurants/Grocery Stores

Restaurants typically offer good prices, but they expect high quality and consistency. Seasonality may be a problem for restaurants that want a consistent menu. Grocery store sales will require appropriate packaging, labeling, ordering and invoicing. Some establishments may require you to meet GAP (Good Agricultural Practices) certification.

> **Questions:** Am I willing to seek out and maintain multiple restaurant or grocery accounts? Is it worth my time to deliver to multiple locations? Do I have a consistent enough product over a wide enough time range to satisfy restaurants and grocery stores?

Wholesale to processors, aggregators, cooperatives

Wholesaling means moving a higher volume of product with less time spent on advertising and customer service, but at the cost of lower profits per unit of product. Often, the producer has little control over what they are paid, since the market usually dictates wholesale pricing. Cooperatives can make reaching larger markets possible for smaller growers and can give some bargaining power. Shipping may be required to reach distribution points.

> **Questions:** Will I have enough product to market wholesale? Am I willing to take lower prices in exchange for moving greater volume? Do wholesale markets exist in my area? Is a growers cooperative available, or could one be organized?

Pesticides and fertilizers

Many producers are interested in limiting the use of synthetic pesticides and fertilizers. Organic certification is one avenue for this, while potentially increasing the value of your products. Others may be comfortable incorporating appropriate chemical inputs as part of an integrated pest management (IPM) plan. Becoming certified organic will typically involve some tradeoffs which each farmer will have to weigh. Organic certification usually means increased

recordkeeping, extra labor, and sometimes increased production costs. However, the organic label is familiar to consumers and can increase the value of your crops. The whole suite of resources that an individual farm and its surrounding community have may be the determining factor – is there enough capital (human, natural, and financial) readily available to meet the standards in the short term without reducing the benefits of certification through increased effort? For more information, refer to the "Pest and Disease Management" section. Organic production is better suited to some crops than others:

- **Less challenging**: pawpaw, chestnut, persimmon, honeylocust, black currant, aronia, Saskatoon, mulberry, elderberry, hazelnut
- **More challenging**: apple, pear, pecan, walnut

Questions: Am I comfortable spraying for insects and disease if needed? If not, am I willing to use organic alternatives that might be less effective or more costly? Do my customers demand organic certification or is there a strong enough market demand without it? Do my values make it worthwhile for me to follow organic practices, even if it is not strictly necessary? Can the crops I am interested in be managed successfully under organic management?

SIDE BOX: Organic Certification

What does "organic" really mean? In the United States, the term is federally regulated, requiring producers who use the word "organic" in their labeling to follow standards established by the National Organic Standards Board. In a nutshell (pun intended), organic farms must meet the following requirements:

- Fields must be managed to maintain or improve soil quality, a requirement that perennial systems usually meet. In annual crop production, farmers achieve this through longer crop rotations, cover crops, integration of livestock and crops, mulching, and other strategies.
- Synthetic fertilizers, pesticides, and GMO (Genetically Modified Organisms) or treated seeds are prohibited, and a transition period of 3 years is required from the time of last application on acreage that is to be certified.
- Seeds, seedlings, and planting stock must be organic if possible. If no organic sources are available, conventional sources may be used as long as they are not genetically modified (GMO) and have not been treated with a prohibited substance. Non-organic perennial planting stock (like trees and shrubs) must go through a 1-year transition period before being considered organic.
- Organic and conventionally grown products must be handled and stored separately.
- Records must be kept that allow a certifying agency to track the integrity of a product throughout the production and distribution chains.
- An annual farm inspection from the certifying agency is required in addition to filling out appropriate paperwork (known as an "organic system plan" or OSP).
- A processing fee varies by state and by certifying agency, but federal cost-share assistance is available:
    - https://www.ams.usda.gov/services/grants/occsp

Smaller farms that have less than $5,000 of gross sales in organic products are exempt from certification, though they must apply for the exemption and adhere to the organic regulations.

If you are considering organic certification, your state department of agriculture should be able to give you information on the certifying agencies for your area.

Fossil fuels

Most farms use fossil fuels, but recognizing that they are a limited resource is important. You may want to minimize fossil fuel use to reduce costs, increase sustainability, combat climate change, or improve the resilience of your operation.

> **Questions:** Are there ways to integrate renewable energy (solar, wind, biomass) into my plans? Where can a biological resource be substituted for a fossil fuel powered resource (for example, grazing instead of mowing, or growing N-fixing cover crops instead of using fertilizer)? Would my business model work if the availability of fuel was limited or the cost went up significantly? What are the reasonable and appropriate uses for fossil fuels on my farm?

Labor/Time

Estimating labor requirements is an important part of planning and goal setting. Time is easy to undervalue, but it is important not to sell yourself short. Likewise, good time management can help balance work and family life. Multiple enterprises can spread out labor, but also make management more complex. Livestock (other than perhaps bees) require daily care. Set aside (paid!) time for non-production activities like marketing, transportation, continuing education, planning, and recordkeeping. Interns and other "free" labor situations work best when there are clear expectations and a respectful and friendly work atmosphere.

> **Questions:** What is my time worth? Would I like to spread labor out throughout the year, or do I prefer a couple of weeks of intense work, with the option to take time off? Am I comfortable hiring employees during harvest, or would I like to keep things on a scale that my family and I can handle? Am I able to provide time, living space and emotional energy for short-term workers such as interns? Do I see fruit and nut production as a hobby, a side business, or a full-time occupation?

Equipment

Buying expensive equipment can sink a farm into debt or open doors to new levels of production. Carefully consider your need for equipment. Machinery requires maintenance, fuel, and storage space. Although mechanization can increase the scale of production significantly, it will also increase costs.

> **Questions:** Do I want to keep equipment costs low and work primarily with hand tools? Would a two-wheeled walk-behind tractor be more appropriate for my scale? Do I have the shop space and the skills necessary to maintain a larger tractor or harvester? Can I rent or hire custom operators for the equipment I need?

Infrastructure

All infrastructure (fences, refrigerators/freezers, buildings, waterers, greenhouses) requires an upfront investment and ongoing maintenance. The more you build, the more time and money you must put into taking care of it. Consider portable or mobile structures whenever possible. They allow flexibility if plans change and may be subject to fewer zoning and building regulations. Renovating existing infrastructure can be costly and time-consuming, so account for this in planning.

> **Questions:** What infrastructure will I need for each enterprise? Could it be used for multiple purposes? Would it benefit from being portable? Do I have existing infrastructure that could be repurposed?

Land

Owning a piece of land may be an important goal for you and your family. Ensuring long-term control of a piece of property is important for growing tree crops. However, a mortgage may limit financial flexibility. Long-term leases are becoming more common and can be a way to get access to land if capital is limited. Another thing to consider is that a rental payment is tax-deductible as a business expense.

> **Questions:** Is owning land required for my plans, or would rented land work? Am I ready to commit to a geographical area for the long-term? Do I require specific land characteristics for my farm plans (for example, you-pick, livestock, forest farming)?

SIDE BOX: Farmer Profile: Greg Judy

Greg Judy practices intensive rotational grazing on roughly 1600 acres in Missouri. He is a strong proponent of leasing land instead of owning it. “My number one unfair advantage is rented land,” says Judy. He makes sure to improve the land he leases, digging ponds for watering, clearing brush, and benefitting the soil through rotational grazing. He encourages investing in livestock rather than machinery, as they do not break down like equipment and increase their numbers naturally: “Who has ever gone out to the barn in the morning to discover a baby tractor?” Another strategy is the use of fiberglass posts for high-tensile fencing. It will not rot, and if his lease changes, he can take the fence with him. Greg is a popular speaker and has written two books, available on his website:

- http://www.greenpasturesfarm.net/

Money

For better or for worse, money is critically important to any farming operation. Careful enterprise budgeting and planning will avoid costly mistakes later. Access to capital in the form of savings or credit will be important when starting any new enterprise. Building or doing things yourself can save money upfront but should be part of a longer-term plan. Government funding may be available for some practices.

> **Questions:** Do I have the financial capability to begin an enterprise, or will I require outside funding to make it work? For the crops I am interested in, would it make more sense to invest heavily at the beginning to maximize potential profits sooner? Am I comfortable with debt? Would starting small and expanding as I have the means be a better option? Are there government funding opportunities that might be appropriate for what I want to do?

DESIGN AND LAYOUT

"Those who are inspired by a model other than Nature, a mistress above all masters, are laboring in vain." - Leonardo da Vinci

DESIGN: PUTTING THE PIECES TOGETHER

Design is a refining process: starting with all the possible trees that are adapted to the site, the choices are narrowed down by evaluating livestock compatibility, harvest method, and the goals of the farmer until suitable species are settled upon. Once likely candidates are identified they are arranged spatially on a field map, taking into consideration things like row spacing, temporal planning, machinery size, and pollination requirements.

At this stage, an economic analysis of the system would also be appropriate. Unfortunately, comprehensive economic resources are not yet available for complex, edible agroforestry systems in temperate North America. However, there are several good enterprise budgets for individual crops like chestnut, hazelnut, walnut, and many fruits. See the "Economics and Funding" section for more details on available resources.

SIDE BOX: The Fruit and Nut Compass

There is mounting evidence for the conservation benefits of diverse, perennial ecosystems. Increasingly, new and experienced farmers are developing these systems by growing polycultures of fruits and nuts. To support these farmers, the Center for Integrated Agricultural Systems at UW-Madison is currently developing the Fruit and Nut Compass.

The Compass, funded by a two-year SARE grant, includes an economic-planning tool, which helps farmers predict flows of revenue and expenses over a 20-year timeline for up to 15 crops at once. In addition, CIAS is collaborating with the Savanna Institute in conducting interviews to publish "Principles of Success," which includes farmer case studies and a mini-documentary on fruit and nut farming.

The Compass will be available from CIAS alongside the popular Veggie Compass and the forthcoming Pasture Dairy Compass and Livestock Compass.

TREE SPACING AND ARRANGEMENT

Consider interactions

After choosing appropriate trees and livestock for your site, the next step is to consider how these species will interact with each other. Our goal is to arrange plants in a way to minimize competition and to take advantage of differences in size, light requirements, and nutrient needs[127]. In permaculture, the term "guilds" is used to denote a group of plants that work well together. For example, Tom Wahl of Red Fern Farm in Iowa found that chestnuts and pawpaws are good companions, and notes that persimmons and black walnuts grow better together[249].

Light

One advantage of mixed species planting is the ability to stack different sizes of trees and shrubs to capture the maximum amount of light. Arrange shade-tolerant species like currants or pawpaws in the understory of larger trees. For silvopastures, space trees so that there is about 50% sunlight available for the forage[250,251].

Below-ground interactions

The below-ground interactions in mixed agroforestry systems are complex. Trees, pastures, and alley crops may compete for water and nutrients in the soil[252]. Grouping deep-rooted species with those that have shallow root systems may compensate for some of this competition[73]. Yearly root pruning with a subsoiler or similar implement is recommended in alley cropping situations to train tree roots to grow deeper[90].

Growing Fertility

Nitrogen is the most limiting nutrient in most agricultural landscapes and is the primary fertilizer applied. Leguminous trees like honeylocust (*Gleditsia triacanthos*), black locust (*Robinia pseudoacacia*), and alder (*Alnus spp.*) have the potential to increase nitrogen availability in a system, and in some circumstances can increase the growth of neighboring trees substantially[253]. Legumes are plants that have a remarkable relationship with a type of bacteria that can take nitrogen out of the air and convert it into a form that plants can use[254]. These "N-fixing" plants can increase the resilience of agricultural systems and save money because less fertilizer is required[221].

Utilizing leguminous trees in agricultural systems is more common in the tropics, where branches are cut and leaves are tilled into the soil to increase fertility. There are fewer models in temperate zones. A notable exception is Miracle Farm in Quebec where Stefan Sobkowiak has interplanted thornless honeylocust trees with apples and pears[255]. Leguminous groundcovers and pasture mixes also provide nitrogen, which is discussed more in the "Site Preparation" section.

Pollination

Pollination requirements vary by species. Some fruits and nuts require careful consideration to match varieties, spacing, and timing. Others are self-fruitful. For certain fruits or nuts, you may have to intersperse specific pollinizer varieties throughout the orchard to get effective pollination. Consult extension and nursery sources for specific variety recommendations.

Temporal planning: Design with timing in mind

Harvest dates

Designing your layout according to the date of maturity will allow greater efficiency when harvesting and integrating livestock. Variety is especially important when considering harvest dates. For example, there are some varieties of apple that are mature as early as July, while others may not ripen until November. Predictable harvest timing is one of the major advantages to using grafted cultivars instead of seedling stock, as plants grown from seed will have variable dates of maturity.

If you are planning on doing you-pick, grouping varieties by maturity into blocks will create less confusion for your customers, as unripe blocks can be roped off. Similarly, moving livestock like pigs through an orchard that is systematically grouped by maturity will make it easier to avoid problems with soil compaction or tree damage that might happen if the animals had access to the entire orchard for a longer period.

Successional Planning

In a natural ecosystem, a process of succession happens after a disturbance such as a wildfire. First, annual herbaceous plants form a quick cover that protects the soil. Perennial grasses and shrubs then start to move in, along with pioneer

trees, often legumes. Over time, longer-lived hardwoods will create a closed canopy forest that shades out the early pioneer species and favors shade-tolerant understory plants.

We can follow this progression in our temporal planning while taking advantage of the opportunity for generating income in the short, intermediate, and long-term timeframes.

For example, early cash flow can be obtained by alley cropped grains or vegetables between rows of trees in the first few years. When partial shade from the trees starts to limit the productivity of sun-loving annuals, a grass-legume forage mix can be planted and grazed by livestock[126]. Shade-tolerant plants like currants will remain productive in the intermediate term[188]. In a mature, closed-canopy orchard, mushrooms or medicinal herbs can supplement income from fruits and nuts. A cashflow analysis that accounts for this yearly change in successional cropping is a useful way to evaluate various design elements.

Tree Spacing and arrangement

Within row

The spacing between trees within the row is usually determined by the mature size of the tree. You can also plant at a higher density and plan to thin the trees later to reach the final spacing, which often done with nut trees that take longer to mature than fruit trees, as it generates higher yields early on[128].

Between rows (Alleys)

Between-row spacing is determined by machinery widths, mature size of tree species, and sunlight requirements of the alley crop[126,128]. With closer spacing, the alley will become shaded sooner, requiring an earlier change to a shade-tolerant alley crop[128]. Most alley crops are not shade-tolerant, so if the grower wishes to maintain annual income as long as possible, alleys should have a wide spacing. If you would like to grow sun-loving plants for more than 5 to 10 years, alley widths of 75 feet or more may be required[128]. For nut production, make alleys wide enough to allow trees to develop a full crown without competition[128]. For timber production, space trees closer together to maximize the number of trees per acre and encourage straighter trunk growth with fewer branches. In general, allow 8-15' between trees in the row and 24-40' between rows for silvopasture[126]. Laying out your planting on a simple grid (equal spacing between all the trees) makes it possible to mow in different directions, although it may not work if you plan on integrating shrubs into your tree rows.

Row orientation

For sloping sites, the usual advice is to orient rows along contours to help prevent erosion. However, strict adherence to contours will usually make for rows of uneven widths, which can be problematic when using machinery for tasks like mowing and harvest. Using Keyline planning can help maximize the number of trees while still maintaining a relatively uniform spacing between the rows of trees for mowing and other fieldwork. For flatter areas, east-west oriented rows will provide more sunlight for the alley crop than those oriented north-south[90]. Researchers in Canada found that a northwest-southeast orientation worked best for alley cropping at their latitude.

DESIGN LAYOUT

The next step is to finalize the planting design. This design will be used for field planting and to generate nursery lists. This step can be done on paper or digitally. If your site is relatively flat and you have straight rows, the process may be relatively simple. Keyline or contour planting for sloped terrain is more of a challenge. For complex situations, it might be worth hiring a competent designer who is familiar with the type of plans you need.

Paper

When working on paper, bigger is usually better. Print out a large aerial map and use tracing paper to denote different layers- infrastructure, alley crops, trees, etc. Try different designs. Inexpensive rulers, compasses, and templates are available to make scale drawing easier. You can even cut small templates out of cardstock that match the scale of trees and trace around them for individual tree layouts.

Digital

As mentioned earlier, free digital resources are available to help with spatial layouts. **Google Earth** will allow you to mark out and measure field boundaries (using polygons), note structures and hazards (with points), and print out maps. It will not easily accomplish scaled planting designs. **Sketchup** is probably the best free tool available for spatially explicit layout. Once the basics have been mastered, a 2D (flat) design can be drawn to scale relatively quickly. Dealing with contours and keylines on sloped terrain will take intermediate to expert level competence. Online tutorials are available to get you started.

SIDE BOX: A Note About Scale

Drawing something "to scale" is important when making your field plan. This means that the plans accurately depict the correct size for the image or map you are using. For example, if your scale is 1:100, an inch on the paper would correspond to 100 inches in real life. You can measure the scale bar on a printed map with a ruler to calculate a workable scale.

We will calculate the scale of the printed map below as an example, but keep in mind that this map is really too small for practical use. Your maps should be as large as possible. For this map, the scale bar measured 6.5 centimeters for 200'. Dividing 6.5cm by 200' gives 0.0325 centimeters per foot. If rows 30' apart are desired, we would multiply the centimeters per foot (0.0325) x 30' = 0.975, or roughly one centimeter (10mm). A ruler can then be used to mark out rows on the map one centimeter apart.

Programs like Sketchup, Google Earth, and AutoCAD allow you to work at the appropriate scale. Drawing programs like Paint or Photoshop usually do not.

Mapping step-by-step:

1. If you have not done so already, mark all existing infrastructure on a map layer. On another layer, put down future infrastructure that you plan to install.
2. Equipment will need space to turn around at the ends of tree rows. The amount of space will depend upon the type of equipment you have. A rough guideline would be to leave 30' or so. Mark this offset around the inside of the field boundaries on your map. Your tree rows should not extend past this offset.

3. Draw in tree rows, ensuring the distance between them is correctly scaled.
4. If a single row is going to be made up of different varieties of trees (i.e. for grouping by maturity or to intersperse pollenizers), note the individual trees for each row.

Nursery List

Once you have your layout finished, you can generate a nursery list with the number and type of trees to purchase or propagate. To figure out the number of trees per row, measure each row (if different lengths) and divide the length by how far apart your trees will be in the row. For example, a 250' long row with 30' spacing between trees would be 250/30= 8.3 trees, rounded down to 8 trees per row. Add up the number of each variety and compile it into a final nursery list. Adding a certain number of extra trees to make up for runts or losses should be considered.

SIDE BOX: Hiring a Designer vs. Do-it-yourself

Every person brings a unique set of skills and passions to the design process. You may really get a kick out of trying to fit everything together like pieces of a puzzle. For others, this seems like a huge barrier that must be overcome before the actual farming can start! These systems are complex, and hiring a competent agroforestry consultant to be involved in the planning process is worth considering. Some may even be able to help with economic planning and get you connected with markets or cooperatives. Even if you do most of the design yourself, an experienced set of eyes can look it over before you commit to the expensive and lengthy process of planting and caring for trees.

CHAPTER 3: PERENNIAL PATHWAYS, BOOK 2: PLANTING CROP TREES

INTRODUCTION TO BOOK 2

Book 1 in this series introduced the planning and design phases of beginning an edible agroforestry enterprise. Now that you have a design that fits your farm and goals - how do you put it into action? This book includes the practical information for installing and maintaining your trees for the first few years, and includes several profiles of farms with extensive experience raising tree crops.

OBTAINING PLANTS

"The creation of a thousand forests is in one acorn." –Ralph Waldo Emerson

BUYING VS. PROPAGATING

You can obtain your plants by purchasing them, propagating your own, or some combination such as buying rootstocks and grafting them yourself. Growing plants yourself will save money and ensure that you are getting the varieties that you want. It may present an opportunity to recover some costs if you can grow more than you need and sell the extras. However, it can delay field planting by a year or two and requires labor, space, and some skill compared to buying from a nursery. Each species has specific propagation requirements. No matter how you decide to obtain your trees, sourcing genetics that are suited to your particular location can be critical for success, especially for traits like cold-tolerance and disease resistance.

Purchasing Trees

When buying trees, it is important to find reputable sources. Nurseries that sell directly to the fruit and nut industry usually give bulk discounts. The cost savings may justify ordering more than you need and selling the excess to other growers. Some state forestry departments offer inexpensive bareroot stock, although the selection of fruit and nut trees may be limited. Prices can range from $0.50 for trees grown from seed up to $15-$25 for grafted stock. Certain varieties may be unavailable commercially, and it is not uncommon to have to order grafted trees a year in advance to get the desired cultivar and quantity needed[161].

Bareroot

Most of the cultivars used in edible agroforestry are available in bareroot form. Without the soil, plants are easier to ship and to handle when planting. Bareroot seedlings are the best choice for mechanical planting, as they do not have as large of a root mass and are planted while dormant, typically in the early spring. Some growers have noted that bareroot trees are more challenging to grow because they need careful weed and moisture management in the first few years of establishment[143]. However, once established, bareroot and containerized trees tend to perform equally well[256–258].

Containerized (potted)

Larger stock and some specialty varieties are only available in a container. Typically, trees in pots are planted by shovel or with the aid of an auger, although you can plant smaller containerized stock with a tree planter. As long as they are kept sufficiently watered, containerized trees can be planted during the growing season and may outperform

bareroot stock in situations where weed control is difficult[258,259]. Fully leafed-out trees may need to be hardened off by keeping them in a shady spot that is out of the wind for a few days. Pruning trees before planting can help the roots keep up with the top growth early on. Containerized trees are usually more expensive than bareroot, especially if you have to pay for shipping.

GROWING FROM SEED

What You Seed is What You Get?

Most fruit and nut seed will not grow true to type, meaning that even if the seed came from good parents, seedlings may or may not display the same qualities. Fruits like aronia and Saskatoons show little variation when propagated from seed, while others like apples may have tremendous variability and are almost never planted from seed[181,260]. Species like chestnuts and pawpaws are somewhere in the middle, as seedlings from improved parents often prove worthwhile, but grafting is also a common practice when precise characteristics are desired[161].

You can use seed-grown trees as rootstocks for improved varieties by grafting. Chestnuts, walnuts, persimmons, pawpaws, honeylocust, and pecans are all suited to this technique. Apples and pears were traditionally grafted onto seedling rootstocks, but the trees end up very large and vigorous, making pruning and harvest more of a challenge than trees on dwarfing rootstocks. These days, most apple and pear rootstocks are vegetatively produced by layering or micropropagation.

Growing from seed will delay the harvest by one or two years over purchasing already grafted stock, so account for this delay in revenue when deciding to use seed. Another disadvantage of seedling trees is that yield, quality, size of fruit, and harvest date can be highly variable, making harvest logistics and marketing more difficult[161].

Stratification

Many fruit and nut seeds must go through a period under cold, moist conditions to germinate, known as **stratification**. In nature, this ensures that the seeds do not germinate right after falling off the tree, which would put them at risk for winter damage. For many species, putting seed in a well-labeled plastic bag with moist sand or peat moss in a refrigerator for the required time is sufficient. Time, temperature, and moisture requirements vary by species.

Direct seeding

Plant stratified seed in the early spring. You may choose to plant seeds directly in the location of the adult tree. This strategy avoids any potential for transplant shock and ensures well-anchored root systems, which is especially important for trees like persimmon and pawpaw that do not transplant very well. One technique is to plant 4 or 5 seeds in a mound, then cut out all but the best seedling after a year or two when grafting. Weed control, irrigation, and pest management may be more difficult for small seedlings that are spread out over a field rather than consolidated in a nursery bed. Field grafting will be required if particular cultivars are desired[161].

Nursery beds

In a nursery, you can care for many seedlings in a smaller space, saving labor and potentially increasing survival over field-grown trees. A nursery can be as simple as a cultivated raised bed. Adding wooden sides and covering the bottom with wire mesh before filling it with soil keeps burrowing rodents out, while a similar cover over the top will

discourage squirrels, birds, and rabbits. Seeds can be spaced only a few inches apart as they will be transplanted to their final locations before they start to compete much. Amending the soil with compost, peat moss, or sand can make digging seedlings easier. Consider installing irrigation for dry periods, or put the nursery within reach of a hose.

Starting seed in containers

Planting seed in containers will give you more flexibility in planting, as potted plants can handle a wider range of planting conditions than bareroot plants. Trees in pots need more careful attention to watering and fertility than trees in a nursery. Plants can also become rootbound if left in pots for too long, which may affect their long-term vigor. Special pots to help prevent this condition are available.

VEGETATIVE PROPAGATION

SIDE BOX: Clonal Advantage vs. Genetic Diversity

Using vegetative techniques for propagating has advantages. Since the trees are genetically identical (essentially clones) to the parent, they will have the same characteristics for yield, flavor, harvest date, and disease resistance. Grafting lets us use rootstocks that impart disease resistance or dwarfing habits while still retaining the uniformity of harvest from tree to tree. Most fruit and nut species today are produced through vegetative means.

However, growing plants from seed introduces genetic variability that may prove beneficial— genetically identical populations may be more likely to succumb to disease than those that are very diverse, and seed-grown plantings are more likely to produce a few individuals that are especially suited to a particular place or that have superior characteristics. Several commercial fruit and nut cultivars have come from random cross-pollination or wild seedlings.

Grafting

Grafting involves attaching the vegetative bud (called a **scion**) of the desired variety to another plant (the **rootstock**). The scion is permitted to grow, while the vegetation of the rootstock is not. What results is a tree that is genetically identical to the grafted variety, though the form and vigor of the tree may differ because the rootstock also plays a role in disease resistance and size.

Grafting trees yourself can save money, especially if many grafted trees are required, but it takes some practice to develop the skill. Finding suitable rootstocks and scionwood takes time, and grafted trees often need to spend an extra season in a nursery bed before being planted out. Graft failure can be high when first learning, which means trees will have to be re-grafted or replaced. There are many grafting techniques, some more suitable to certain species than others. A hands-on lesson from someone is the best way to learn.

Cuttings

Aronia, elderberry, mulberry, and currants can be propagated by cutting off shoots or branches at the appropriate time and putting them in soil or potting media, where they will take root[188,261,262]. As these species also benefit from yearly pruning, an opportunity exists for multiplying numbers of plants very rapidly and at little extra cost or labor. Consult appropriate resources to determine the best timing and techniques for individual species.

Mound layering

Mound layering (also called 'stool layering') can be used for European hazelnuts and apple rootstocks, though with American hazelnuts layering has had mixed results[263]. The winter before laying, cut the tree or shrub to the ground. The following spring, multiple shoots will sprout from the stump. You then girdle these sprouts either by wrapping with wire or cutting the bark in a certain way. Soil, sawdust, or peat moss are mounded up around the shoots. Because of the girdling, each shoot will start to send out roots, and when they are read, you cut and transplant each shoot individually.

FIELD PREPARATION

"By failing to prepare, you are preparing to fail." –Benjamin Franklin

OFF TO A GOOD START

We cannot overstate the importance of adequate field preparation. Time and effort put into ensuring your trees are off to a good start are well worth the investment. For best results, start preparing two or three years in advance. Once trees are in the ground, it becomes much more difficult to deal with problems like pernicious weeds, subsoil compaction, or nutrient deficiencies that you could have addressed earlier.

SOIL PREP

Heavy equipment

Field prep starts by installing any fences, water lines, terraces, ponds, or other features that require heavy equipment[143]. Take care to avoid removing or burying topsoil, if possible. Remove any hazards such as old stumps or rocks that might damage a mower[138]. If utilizing deer fence, install it before planting trees. Otherwise, have tree shelters on hand for installing shortly after planting, preferably the same day. To avoid compaction, do not use machinery when the soil is wet.

Compaction

Next, evaluate the level of existing compaction. Crop fields and pastures can become compacted over time due to equipment use or livestock hoof traffic. Tree growth will be compromised if roots cannot penetrate past the compaction zone[264].

Measuring compaction can be done with a tool called a **penetrometer**, which can be purchased for a few hundred dollars or perhaps borrowed from a forester or extension agent. It is pushed into the soil while a gauge is read. Multiple readings will be required to be accurate, so sample every few hundred feet, or at least three to four samples per acre. Readings above 300psi indicate significant compaction, so if greater than 50% of the samples taken read above this threshold, you should subsoil[265]. Because the readings on a penetrometer can vary depending upon the soil moisture, the soil type and profile should also be considered[266,267]. If soils are naturally poorly drained or very clayey, subsoiling may be ineffective.

Subsoiling

Subsoiling is the practice of ripping a deep groove in the soil, breaking up compaction and creating a favorable environment for roots by allowing water and air into the soil[126]. You can also use a subsoiler after trees are established

to prune tree roots to prevent tree competition with alley crops[128].

Subsoilers are normally a set of shanks mounted to the 3-point hitch of a tractor. For orchard preparation, subsoil along the rows where the trees will be. If possible, rip in both directions, making a grid[138]. On flatter sites, plan the subsoiling rip lines so that they cross where trees are to be planted, allowing the tree roots to grow outward in four directions. On sloping sites, subsoiling should follow contours or keylines.

Getting a subsoiler set up correctly is a challenge. Research in Quebec found the most common problems were a lack of tractor power (at least 40 HP per shank is required to pull a subsoiler at 15-17" depth)[267], poor balancing, tine protection mechanisms that were too weak, or a limited working depth[266].

Although subsoiling does not create a traditional dead furrow like a moldboard plow would, be aware that it can still raise a significant divot that can create bumpy conditions for vehicle traffic or hay making activities. Coulters (disks) ahead of shanks and packing wheels behind help with reducing and breaking down clods[266]. For more information about subsoiling, consult:

- ***A Guide to Successful Subsoiling*** (CETAB, 2015)
    - https://www.cetab.org/system/files/publications/weill_2015._guide_to_successful_subsoiling._cetab.pdf

Adjusting nutrients and pH

If you have modified a field by major earthmoving, it might be worthwhile to take another soil test at this point to give a more accurate basis for adjusting nutrients[138]. If you plan on using organic amendments like compost, manure, or rock powders, they can be applied to cover crops to give time for some of the nutrients to break down into a plant-available form. The cover crops will take up the nutrients as they grow, which will help prevent them from being lost by leaching. The cover crop will eventually release these nutrients back into the soil as it breaks back down into organic matter. Again, consult your soil test recommendations, and contact your county extension agent or an agronomist when in doubt.

To increase a low pH, apply lime at the rate recommended on your soil test at least six months ahead of tree planting. Incorporating lime into the soil with tillage will allow it to start modifying pH sooner than if you spread it on the surface, which can take up to a year to take effect[251]. If less than two tons of lime per acre are required, make a single application after plowing, then disk thoroughly. If more than two tons are needed, apply half of the lime, disk once to incorporate, plow, then apply the other half and disk again. If you need to bring the pH down, elemental sulfur is most commonly used.

If you have multiple species with varying pH requirements, aim for a pH of around 6.5, or adjust your plans so that species with similar requirements are together[146].

MANAGE WEEDS BEFORE PLANTING TREES

Weed control is one of the most important things you can do to improve the survival and growth of young trees[268–270]. Making an effort to eliminate perennial weeds and deplete the weed seed bank before planting trees will make it much easier to keep weeds in check later on[146]. Choosing an effective control strategy will depend upon the species of weeds

present, availability of equipment, topography, and your goals, such as conventional or organic management. Herbicides can be used on non-organic sites, while non-chemical options include tillage, cover cropping, mulching, and solarization.

Field conditions and weed populations

If the field has been in row crops, weed management should focus on preventing annual weeds from establishing and going to seed. Sloped areas, pastures, and fallow fields often contain highly competitive perennial grasses and legumes like smooth brome, orchard grass, reed canary grass, tall fescue, alfalfa, or birdsfoot trefoil[133,254]. For these areas, you may have to remove the existing vegetation and plant a groundcover that is less competitive. Tenacious weeds like Canada thistle, Johnsongrass, field bindweed, poison ivy, poison hemlock, brambles, and multiflora rose may require more than one season of intervention for adequate control, especially under organic management[138,146].

Herbicide

Broad-spectrum herbicides like glyphosate (Roundup®) are commonly used to kill vegetation before planting. You can apply herbicides to the whole field if establishing a new groundcover or alley crop, or just in the tree rows if keeping the existing sod in the alleys[126]. Some perennials will require two or three applications for complete control[138].

If the field has been under conventional crop management that included herbicide use, there is a chance that herbicide-resistant weeds may be present. If there is a known history of resistance, adjust plans or herbicide formulations accordingly. For all herbicide use, follow label directions or hire a competent professional.

SIDE BOX: Delaying Organic Certification During Establishment

It might be worth considering taking a field out of organic management during tree establishment[271]. You can then use herbicides, synthetic fertilizer, and non-organic seed for field prep. By the time most trees are mature enough to produce fruit, the 3-year organic transition period will have ended and the field can be certified again. Of course, you will not be able to grow any certified organic alley crops or livestock during this period. Non-organic perennial planting stock requires one year before it can be considered organic, but this is rarely an issue as most perennials do not fruit during the first year[272,273].

Tillage

Tillage is the primary organic method of weed control during site preparation. Although ongoing tillage can damage soil health, it is a reasonable tradeoff to use tillage to establish a perennial planting that will remain untilled for many years to come. If a field has been in pasture or has grass species present, shallow tillage with a disk harrow or rototiller will not be adequate for control by itself. A better bet is to moldboard plow, followed by several passes with a disk or other cultivator[143].

After plowing, use shallow tillage every ten days or so for at least a month to reduce the number of viable weed seeds in the weed seed bank and deplete the nutrient reserves of perennial weeds[146]. Using this technique at various times of the year will control differing weed populations.

Perennial weeds with underground rhizomes like Canada thistle (*Cirsium arvense*) or Johnsongrass (*Sorghum halepense*) are especially difficult to eradicate, as a single tilling operation will only chop up and distribute underground pieces— each of which will sprout into a new weed. However, frequent tillage will eventually deplete the weed's nutrient reserves.

Organic site preparation on sloping fields

It is likely that sloped sites will have perennial weeds but the risk of erosion limits the possibility tilling the whole field for weed control. One option is to strip-till just the planting rows or a small area for each tree. After tilling, plant a less competitive living mulch like white clover or fine-leaved fescue, taking care during establishment to limit erosion by spreading a thin layer of straw after planting[90]. Alternately, a manufactured mulch such as weed fabric or recycled cardboard with a layer of wood chips or straw on top may be viable as long as the material and labor are available[274]. See the "Weed Control: Post Planting" section for more details.

Cover crops

Whether using conventional herbicides or organic techniques, growing cover crops during site preparation will help choke out weeds, add organic matter to the soil, and prevent erosion[146]. Cover crops can also be used in alleys after you plant trees, but they should be kept far enough apart to avoid competition between the cover crop and the trees.

Two of the best summer cover crops for choking out weeds and building soil are hybrid sorghum-sudangrass (often called 'Sudex") and buckwheat. Both are planted when the soil temperatures warm up, typically around June[275].

Cool-season cover crops include cereal rye, winter wheat, hairy vetch, tillage radish, and Austrian winter pea. These fall planted cover crops will hold the soil over the winter and grow rapidly in the spring[275].

In addition to directly smothering weeds, cover crops may have a place in generating on-site mulch. In one study, researchers planted sorghum-sudangrass the summer before establishing hybrid poplar. The sorghum-sudangrass was then cut and raked into the tree rows the following spring when the trees were planted. Trees with the mulch had higher survival rates than those without, likely due to increased moisture retention under the mulch[276].

Similar research in Illinois used a cereal rye cover crop mulch for establishing apples. Rye was planted in the alleys in the fall, and white clover was frost-seeded in late winter into the standing rye. The following spring, the tree rows were tilled, the apples were planted, and tree tubes were installed. The rye was cut with a sickle-bar mower at the flowering stage and raked into the tree rows. After one season of growth, trees with the cover crop mulch were an average of 39% taller and had a 62% larger trunk diameter than the trees grown in plots without weed control. The apple trees in the wood chip treatment in the study had the best results of all— they were 89% taller and had 120% larger trunks.

An excellent free resource for detailed cover crop information is ***Managing Cover Crops Profitably***, available from SARE:

- http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

Solarization

Solarization has been successfully used in preparing organic sites for planting pollinator habitat, and the method may be suitable for tree establishment[277]. To solarize a planting area, a spread a clear sheet of UV-stable plastic over tilled soil and bury the edges. The heat under the plastic kills weeds and some soil-borne pathogens. Remove the plastic before planting your trees. Solarization would only be appropriate for smaller orchard sites, as the cost of plastic can be high if it is not available used[277]. For more information about solarization, refer to:

- Wildflower Establishment— Organic Site Preparation Methods (Xerces, 2016)
    - http://www.xerces.org/wp-content/uploads/2016/10/Organic-Wildflower-Establishment_Oct2016_FINAL-web.pdf

ESTABLISH GROUNDCOVER OR ALLEY CROP

Groundcover

If you are not planning on cropping or grazing the alleys, plant a suitable groundcover to protect the soil and provide a surface for machine traffic. Choose a species that is low-maintenance, non-competitive, and shade tolerant. A mixture of grass and legume species is preferred, as the legume will contribute nitrogen to the system. Suggested species include turf-type perennial ryegrass, fine-leaved fescue (hard, creeping red, or Chewing's), and Dutch white clover[143]. Plant the groundcover in August or September, and either spray or till a 2'-3' strip the following spring before planting trees[131,138]. Clover can be successfully frost-seeded into a standing cover crop or groundcover in late winter.

Silvopasture

If an alley is to be grazed or cut for hay, you should choose a forage species that will remain productive in partial shade. Cool-season forages like clover, tall fescue, bluegrass and orchardgrass grow as well or even better at 35-65 percent sunlight than in open pastures[233]. If using tall fescue, consider investing in novel-endophyte seed, as the regular KY-31 tall fescue can negatively affect livestock health.

In a pasture or hayfield, mixes that contain at least 33% legumes do not require additional nitrogen fertilizer. Integrating legumes into a stand of grass can increase the total yield, even compared to stands that receive commercial nitrogen fertilizers[251].

Alley Crops

If you are actively growing grains or vegetables in the alleys between trees, you can either integrate a cover crop into the rotation while establishing trees or continue cropping. For the planting year, you will have to carefully plan how site preparation and tree planting will be accomplished without damaging the alley crops. Likewise, any management for the crops like spraying herbicide or cultivation will need to be adjusted to keep from harming young trees.

SITE PREP SCENARIO:

The following scenario is an at-a-glance plan for site prep. Adjust it according to your site and situation. This plan would only be suitable for minimally sloping sites due to erosion concerns.

YEAR 1:

1. Earthmoving: rocks, stumps, waterlines, swales, terraces
    a. Conventional: Herbicide in Fall

YEAR 2:

Spring

2. Plow, disk
3. Subsoil
4. Weed control: Spring
    a. Organic: Stale seedbed
        i. Shallow tillage every 10 days for at least a month
    b. Conventional: Herbicide

Summer

June

5. Adjust Nutrients/pH
    a. If planting sorghum-sudangrass: 75-100 lb. N/A[275]
    b. Penn State: 50 lb. N, correct P and K
6. Cover crop: Summer
    a. Sorghum-sudangrass: warm soil (2 weeks after prime corn date for your area), 35-40 lbs. (drilled) or 40-50 lbs. (broadcast), 1-2" deep[275]
    b. Buckwheat: Soil temps at least 65 degrees, 50-60 lbs. (drilled), 70 lbs. (broadcast), 0.5-1.5" deep

July-Aug

7. Mow, let it regrow/reseed
        i. Sorghum-sudangrass: mow when it is 3'-4' tall, leaving 6" stubble height[275]
            1. Option: cut and rake residue into future tree rows for mulch
        ii. Buckwheat: mow at 6 weeks before seed is viable, incorporate and plant second crop of buckwheat[277]
            1. Option: let seed mature, mow and lightly till for reseeded second crop

Aug-Sept

8. Mow and Plow cover crop
    a. Option: cut and rake sorghum-sudangrass residue into future tree rows for mulch

9. Weed control: Late summer/Fall
    a. Organic: Stale seedbed
        i. Shallow tillage every 10 days for at least a month
    b. Conventional: Herbicide
10. Add additional amendments

Sept-Oct

11. Cover crop: Fall/Winter
    a. Rye: 60-120 lb. (drilled), 90-160 lb. (broadcast), 0.5"-1.5 " deep[275]
    b. Option: Seed groundcover or silvopasture mix for alleys (August or September)

YEAR 3:

Spring

Feb-Mar

a. Option: Frost seed clover into alleys
    a. Broadcast 7-14 lb. white clover early in the morning when frost is still in the soil

Apr-May

12. Mow Winter Cover Crop
    a. Option: Strip-till/spray herbicide 2'-3' wide in tree rows two weeks before planting trees
    b. Option: cut and rake residue for mulch in tree rows
13. Flag tree locations (Layout)
14. Plant trees
15. Install tubes, irrigation
    a. Option: establish alley crop
16. Begin post-planting weed control
    a. Herbicide
    b. Mulch
    c. Tillage
    d. Mowing

Aug-Sept

17. Plant groundcover in alleys, if not already established

PLANTING TREES

"The best time to plant a tree was twenty years ago. The second best time is now." –Anonymous

PLANTING PREP

Field layout: Marking tree locations

You should mark out where your trees will go before planting them. The simplest way to transfer the plan from your map to actual flags on the ground is to identify a telephone pole, road intersection, building corner, or particularly unique tree as a reference point on your map and then measure from that point in your field. Make all subsequent measurements from this initial reference point.

You can use a long tape measure (100' or more), a measuring wheel, or a rope (look for a "no-stretch" type) with the correct spacing marked off on it with zip ties or colored duct tape. It is easier to do field layout with multiple people. Use surveying flags for marking each tree location, with different colors for each species. A professional surveyor with GPS capabilities may be justified on larger jobs to mark row ends or contours. You can then flag out individual trees later with a marked rope or tape measure. Remember to leave space for equipment to turn around at the ends of the rows.

If you are not using tree tubes, you should mark the ends of rows with something stout like a T-post as a visual reference later when mowing or spraying, as it can be difficult to spot very young trees if there is much vegetation around them.

Marking contours: The "Bunyip" level

If you need to plant on contours or keylines, various tools are available for marking out tree rows. These range from simple homemade A-frame levels up to modern surveying stations that are linked to global satellite networks. If you can rent or borrow modern equipment, by all means, do so. If your field is small or you prefer a DIY approach, a "Bunyip" level will do the job. It requires two people to operate.

Make a Bunyip level by attaching a clear, water-filled tube to two stakes. The tube is open at both ends, so the water will measure level on both sticks as long as there is a little slack in the tube. A stout string that is the desired length between measurements is tied to both stakes. Shorter lengths will lay out more accurate contours, but longer lengths will be quicker. Before starting, place both stakes on a level surface next to each other and mark the level on the stakes as a reference. You can also attach a yardstick or old tape measure to the sticks.

For marking out a 10-meter tree spacing along a contour, one person holds a stake at the starting point and the other person walks the other stake out until the 10-meter string is taut, then pivots uphill or downhill until the level of the water is the same on both sticks.

You can mark out simple grades by calculating the amount of rise or fall required on the stakes for the distance between them. For example, if we wanted a slope of 1% along our 10-meter distance, we would want a vertical difference of 10cm between the lines on our stakes (10m x 1% = 1000cm x 0.01 = 10cm). Good resources exist online for building and using Bunyip/Water levels.

Handling trees until planting

When trees are shipped from a nursery, count them, inspect them for disease, and make sure the roots have not dried out. Call the nursery if you discover a problem. Bareroot stock should be kept moist (but not wet) by wrapping in shredded paper, sawdust, or peat moss and kept in a cool, frost-free location until being planted[126]. If it is going to be more than a few days before planting, "heeled in" the trees outdoors in a well-drained location by laying the trees in a trench and covering the roots with soil, wood shavings, sand, or sawdust[278]. Just before planting, rehydrate the trees by soaking them for up to a half a day, preferably under flowing water or in a tub that has an aquarium bubbler to provide oxygen.

Inoculation

Most plants form symbiotic relationships with beneficial fungi in the soil. These mycorrhizal fungi extract minerals from the soil which they share with the plants in exchange for sugars that the plant produces. Usually, there are sufficient native populations of these fungi, but research suggests that inoculating seedlings before planting with the appropriate strains of fungus may help seedlings become established. Inoculation may be particularly important in soils that have been heavily farmed or disturbed, or if renovating an old orchard[279]. Commercial inoculants are available. Be sure to match the type of fungi (endomycorrhizal or ectomycorrhizal) with the species of tree you are planting, or just use a mixture that includes all of the strains you might need.

If you would like to explore making your own inoculant, the Rodale Institute has developed an inexpensive system for on-farm inoculant production oriented towards vegetable growers that might be able to be adapted for perennials[280,281]:

- http://rodaleinstitute.org/a-complete-how-to-on-farm-am-fungus-inoculum-production/

TIMING

Spring planting

Spring planting is best for bareroot stock, usually in March or April in the Midwest[278]. Most nurseries ship trees in the spring, and cooler temperatures and moist soil allow trees to take root before summer heat[144]. Avoid planting into overly wet or frozen soils.

Fall planting

Fall planting is also possible, but it is a bit riskier due to the possibility of winter injury[278]. Plant trees early enough to develop some roots before overwintering. Container grown stock may be planted anytime throughout the growing season but should be kept moist.

MECHANICAL PLANTERS

Auger

A mechanical auger can make quick work of digging holes. Various types are available, including single-person, two-person, and tractor-mounted. Remove the sod with a shovel before using the auger. Augers can sometimes smooth and compact the sides of the hole, making it difficult for tree roots to penetrate. To avoid this, score the sides of the hole with a shovel or use an auger with teeth welded on the outside of the auger blade[282].

Tree planter

If you have many trees to plant, it might be worth renting or borrowing a tree planting machine. Some state forestry departments have them available for use. The tree planters mount behind a tractor, and one or two operators sit in a seat and drop seedlings into a furrow cut by the planter. Closing wheels come behind and close the furrow. Tree planters work best with smaller bareroot stock, as the planting is less exact than when planting by hand.

PLANTING: STEP-BY-STEP

1. During planting, do not let tree roots dry out. For bare root trees, gels are available that you can dip roots in, or keep trees in a bucket of water or wrapped in a moist towel[278].
2. Dig a hole that is 2-3 times as wide as it is deep so that the roots of the tree can spread out without bending around the sides of the hole. If the roots are excessively long, it is better to trim them to fit the hole rather than bend them. Do not dig too deep, as this may cause the tree to settle[143].
3. For potted trees, score the roots if they seem rootbound. Spread the roots out in the hole and hold the tree at the appropriate level as you backfill, tamping the soil as you go to eliminate air pockets. Avoid bending the roots upward, known as "J-rooting," which can lead to shallow rooting that is susceptible to damage during high winds or drought[283]. If the tree is grafted, orient the graft union towards the north or northwest to avoid sunburn.
4. Backfill only with native soil: do not add any fertilizer, compost, or other amendment to the planting hole[284]. Enriching the soil in the hole may allow the tree to grow well at first, but when the roots meet the edge of your planting hole, they may bend to stay in the nutrient-rich soil mix instead of growing into the native soil, creating a "pot in the ground" effect that will stunt the tree. Do not fertilize the tree for the first year, other than with compost that is top-dressed[278].
5. One of the most important steps when planting trees is to make sure that the root crown, which is the part where the roots and trunk meet, is level with the ground or slightly higher[283]. In soils that have poor drainage or that consist of mostly silt and clay, place trees 2-4" higher than the trees were grown in the nursery[282]. If planted too low, trees can suffer from disease, and there is no way to correct this after the tree is established[126]. For grafted trees, correct planting depth ensures that the graft union stays above the soil. Otherwise, the scion may root and influence the growth of the tree.
6. Water each tree at planting and weekly after that for the first growing season unless there is enough rain (around 1" per week)[282]. Young trees have small root systems, so supplemental water will likely be required, even with fairly regular rainfall.
7. Install tree shelters or rodent guards the same day as planting. If you do not use tree tubes, young trees may require stabilization to avoid leaning from the wind. One effective method is the use of bamboo stakes with rubber tie bands. This system allows some movement of the trees but stabilizes them against permanent leaning.
8. Begin weed control strategies within a few days of planting (mulching, herbicides, etc.)
9. If planted later in the fall, mulch deeply to avoid frost heave[133].

TREE PROTECTION

Young trees are susceptible to damage from deer, rodents, rabbits, and livestock. In mature orchards, they may eat fruits and nuts before they can be harvested. Evaluating the most effective and economical way to prevent damage takes careful planning. There may be cost-share programs available for installing a fence or tree shelters. As always, do your own cost estimates and evaluate your goals before making a final decision.

DEER

Deer can cause serious damage or death to trees during establishment. Deer browse leaves and nibble off young growing shoots. Bucks rub their antlers on smaller trees, damaging the bark. In areas with high deer pressure, trees can be killed or stunted for years if not protected, which means a loss of revenue due to the cost of replacing trees and the delay of harvest. We highly recommend deer protection for all new fruit and nut plantings.

FENCE FACTORS

Deer fence may seem like a lot of upfront work and expense, but it can be the most economical and effective option in the long run. When deciding on deer protection measures, ask yourself the following questions:

Are deer likely to cause harvest losses?

If deer may eat your fruits or nuts during harvest (likely for things like apples or chestnuts), deer fence may be the best choice from the start. However, you still may have to put rodent guards on the trees if voles or rabbits are expected to be a problem.

Will livestock be a part of the system?

If you have sheep, goats, or cattle, you will need a reliable perimeter fence that separates the pasture from neighboring farms, the road, or other places you do not want your livestock to wander. Woven wire and electrified high tensile make good perimeter fences, but less secure barriers like a 3D polywire fence should not be relied upon to keep your cows off the road or pigs out of the neighbor's lawn. If you want graze livestock when trees are still young enough to be at risk, then both a perimeter fence AND tree protection will be required. Commercial tree tubes will suffice for poultry or sheep, but cattle and hogs may require a sturdier wire tree cage with two or three stakes. Another option is to use moveable electric fences or pens to keep the livestock away from the trees. Consult the 'Livestock' section for more details about planning for livestock.

How many acres and how many trees per acre need protection?

As field size increases, the amount of fence per acre required to enclose it goes down (see chart). For small fields, tree tubes may be more economical, especially at lower tree densities. If many trees per acre need protection or acreages are larger, a fence may be the most economical choice.

FENCE TYPES

There are many types of deer fence. The following three represent different levels of effectiveness and cost. Consult an experienced fence contractor or extension publication to help with estimating fencing cost. Remember to include gates, fence chargers, hardware, and labor costs.

Woven Wire

Woven wire fence provides excellent control, but it is expensive ($4.00-$6.00 per foot) and labor intensive to install. It is usually 8'-10' tall and will contain most types of livestock[285,286]. It is low maintenance and will last many years. The high cost of woven wire is usually not justified unless deer pressure is extreme and the crop is very high value.

High Tensile Electrified

Electrified high tensile fence is moderate in cost ($2.00-3.00 per foot). It provides good control of deer, although it is not impenetrable if deer are determined[285]. It will require a fence energizer you must control weeds under the fence to avoid shorting it out. It is suitable as a livestock perimeter fence.

Offset/3D polywire fence

This fence is inexpensive ($0.50-$0.70 per foot), easy to install, and moderately effective. It relies upon deer's poor eyesight and reluctance to jump over a barrier if they do not have enough space to land. It consists of two electrified wires with another single electrified wire offset 3 feet away. The offset rows provide the "3D" effect, as the deer do not have enough space to jump over or crawl under the first wire without hitting the other two. Baiting the fence with peanut butter or apple scent will help train the deer, increasing effectiveness. This fence would be suitable to contain cattle or well-trained sheep as an interior fence, but should not be relied upon as a perimeter fence for livestock.

TREE SHELTERS

Tree shelters consist of a cylinder of polypropylene or wire that is installed around a tree and held down with stakes. Height should be tall enough to allow the tree to grow above the browsing height of deer, typically 5'. Depending on the shelter, they may also prevent damage from livestock. There are a variety of manufacturers, and prices and styles vary[287]. A good resource for comparing styles of tree shelters and support stakes is the NRCS Fact Sheet ***Tree Shelter Installation and Maintenance.***

Tree tubes

Commercial tree shelters, commonly called "tree tubes," are made of UV stable polypropylene or polyethylene and protect trees from harsh winds, deer, rabbits and livestock like sheep and chickens[118,119]. Using tree tubes with cattle has a less proven track record. Oak regeneration projects in California have had success with cattle and tubes, although it required a 6' metal T-post to secure the tube, rather than the normal wooden, fiberglass, or PVC stake[159]. If using tree tubes with livestock, an extra stake is recommended to prevent the animals from spinning the tube around when they rub on it[290]. The second stake can be shorter than the primary stake.

In addition to protection from animals, tree tubes help prevent damage from herbicides and string trimmers and are useful to see the tree's location when mowing. Trees with tubes often grow more rapidly than trees without tubes at first, but unsheltered trees usually catch up and show no difference after a few years as long as they are not browsed by deer or livestock[287,291].

Tree cages

Tree cages are shelters made from welded wire. They do not modify the microclimate around the tree, acting primarily as protection from herbivores. Wind can still move the tree, which allows for stronger trunk growth, though it can

cause damage if the tree rubs on the shelter. Some producers have had success using wire cages for cattle, with 2 to 3 stakes per cage[292]. Tree cages usually take more time to install and cost more than tree tubes unless there is a recycled source of wire or stakes. However, they last longer than tree tubes and may be reused after the trees outgrow them.

DOGS

Dogs can protect orchards from deer[293,294]. A study in New York got dogs from an animal shelter and trained them with shock collars and buried invisible fence. The dogs proved to be effective at repelling deer and cost much less than traditional deer fencing[293]. Research in Wisconsin showed that the personality and breed of the dog are important factors for success[294]. Dogs should patrol the confined area, chase deer, and not be skittish. Huskies and Malamute mixes did well in their study.

REPELLENTS

Deer repellents are substantially cheaper than fencing or shelters, but results are unpredictable and they must be reapplied periodically[256]. Fear-based repellents that have a sulfurous smell may be more effective than taste-based repellents[291].

SIDE BOX: Cheap deer repellent recipe:

A dozen eggs, beaten, strained thru screen (unstrained egg will clog sprayers) mixed with 5-6 gallons water. Spray lightly on leaves. Treats about 5 acres. One egg in ½ gallon treats ½ acre. Won't wash off in rain, but wears off after 2 weeks. Keep an eye out for raccoons, who are attracted by the egg mixture and can cause tree damage. Recipe courtesy of Tom Wahl[143].

RODENTS AND RABBITS

Mice, voles, gophers, and rabbits eat the bark and roots of trees. They are more of a threat during the winter when food is scarce and tree bark is more tempting. Tall grass, cover crops, brush piles, and even tree tubes and mulches can provide hiding places for rodents. They have been known to tunnel under plastic weed barrier to get to trees. Mulches like straw, sawdust, shredded bark, or grass clippings may have to be raked away from tree trunks in the winter to prevent damage[295]. However, wood chip mulches seem to be unfavorable to them[296]. One grower observed that wood chips larger than a silver dollar prevent burrowing into tubes and under fabric.

Using a range of methods may be required for adequate control[297]. One of the best is keeping the grass mown short around trees to remove cover for the critters, making them vulnerable to predators. Physical barriers like tree tubes or wire rodent guards are effective for rabbits if they are at least 24" to 36" tall. Wire rodent guards that have a small mesh size (1/4") and tree tubes will discourage some rodents, although determined voles and gophers can dig under them[297]. Mice like to nest in the sheltered environment in tree tubes, but not wire rodent guards. You can attract raptors like hawks, kestrels, and owls by placing a tall post like an old telephone pole in the middle of a field where they can perch. Building suitable nest boxes may entice them to stick around.

Poisons and trapping show mixed results and put non-target animals at risk[298]. Domestic cats kill some rodents, but they are also a major threat to native songbirds, killing billions of birds every year, so they are best kept indoors[299].

Small working dogs like terriers may be a better option if you are interested in using domesticated animals for controlling small mammals[162,294].

BIRDS

Currants, Saskatoons, aronia, haskap, and hazelnuts may have to be protected from birds. Extreme bird pressure may require using nets at harvest time[194]. Alternately, some growers have had success with noise-making machines that mimic the distress call of the offending bird species[178]. Encouraging raptors is another option.

WEED CONTROL: POST PLANTING

"May all your weeds be wildflowers." –Author Unknown

Weed control is perhaps one of the most challenging tasks in caring for young trees, yet it has been shown to be very important for the first three to five years[133,259]. Once mature, trees have deeper roots and more nutrient reserves, enabling them to compete with weeds better[268,300]. Herbicides are commonly used in conventional orchards, while organic methods include tillage, mowing, and mulching[274]. Organic herbicides so far do not provide reliable results and are cost-prohibitive[296].

SIDE BOX: Spectrum of Intervention

There are varying philosophies regarding care for young agroforestry plantings, and finding the right balance will be up to each producer. One strategy is to opt for dense plantings and minimal weed control, hoping that genetic variation will allow trees to self-select desirable individuals through competition[301]. Other growers make considerable efforts to ensure the best possible outcome for each tree by using tree shelters, keeping the area around trees free of vegetation, and actively managing pests and fertility. Several studies and many farmers have noted the critical nature of early tree care, so that you give young trees as much attention as is practical[259].

WEED BASICS

Using multiple methods of weed control can prevent weeds that are adapted to a single management technique from taking hold[302]. No matter what method you use, a weed-free radius of 2' to 3' is recommended to prevent negative impacts on tree growth[303]. Once orchards are mature, complete weed control is not necessary, but timing can be important. For example, weed control in May and June have been shown to be the most critical in established apple orchards[131].

HERBICIDE

Once trees you have controlled the perennial weeds and planted your trees, you should limit herbicide use to a 2' to 3' wide strip in the tree rows. Recommendations differ regarding whether to focus on pre-emergence or post-emergence herbicides. Either way, taking advantage of multiple modes of action will help prevent herbicide resistance from developing[302]. To avoid accidental drift from damaging trees, consider using spray shields or wick applicators. Herbicides usually result in adequate tree survival and growth, although the quality of the soil may go down over time compared to mulching or living cover[295,304].

TILLAGE

Tillage is used in both conventional and organic orchards, typically performing better than living covers or no weed control[296,305]. If perennial weeds are present, repeated shallow tillage may be the best option for organic weed control if synthetic woven mulches are not an option[274]. Machinery for orchard cultivation is available in a variety of scales, from walk-behind tillers to tractor-mounted cultivators with pressure-sensitive arms that swing out of the way to avoid damage to tree trunks.

However, tillage is harmful to soil health, reducing both soil biological activity and levels of organic matter[46,306]. Organic standards mandate that soil and water quality be "maintained or improved," a goal which may be difficult to achieve with tillage as the primary weed control practice[36,304]. Tillage can also damage shallow tree roots, leading to lower yields and smaller fruit size[274,296].

MOWING AND GROUNDCOVERS

Mowing weeds prevents them from shading out young trees but does not eliminate root competition in the soil, which can have a negative effect on tree growth[304]. Grasses are especially competitive with trees, and mowing encourages perennial grasses to dominate[307]. Mowing can also injure trees if not done carefully, especially when tree shelters are not used[308]. However, mowing can keep weeds from going to seed, preventing future flushes of weeds[251]. Some weeds can produce tens of thousands of seeds per plant, and seeds can remain viable in the soil for years.

Intentionally growing a less-competitive grass or legume as a "living mulch" can provide improvements to soil quality and biodiversity compared to tillage, but the groundcover still competes with trees for water and nutrients[306]. Unless you move it frequently, it can also provide cover for rodents that damage trees by feeding on bark[295,309]. "Mow and blow" systems that cut the groundcover in the alleys and deliver the biomass to the tree row show promise in helping to control weeds and provide nutrients to the trees, but may not provide lasting weed-control unless combined with other approaches[304,310].

MULCH

Mulches can be either manufactured (smooth plastic, woven fabric, biodegradable fiber) or dead organic materials (wood chips, straw, bark, sawdust). Non-living, plant-based mulches like wood chips and straw are good for both the soil and trees, including encouraging a higher diversity of soil life, lowering evaporation rates, and improving soil organic matter and nutrient content[303]. Organically managed plots have higher levels of beneficial fungi than conventional plots, likely due to the use of compost and mulches for weed control[311]. Hurdles to using much can be a lack of supply, the cost of transport, or the unavailability of labor for application[303]. Larger operations apply mulch with mulching trailers or modified livestock feed wagons.

Dead organic mulches are less effective without a manufactured weed barrier underneath if there are perennial weeds present, as they can have the nutrient reserves to punch up through even thick layers of material. Even with a barrier, weeds that vegetatively spread may eventually invade straw or wood chip mulches from the side unless a strip of herbicide or tillage is maintained between the mulch and the alley[274].

Wood Chips

Granatstein et al. (2008) showed improved soil quality, fruit yield, and fruit quality for wood chip mulched apple trees compared to other treatments. In their study, the improvement justified the cost and labor for wood chip mulch application[296]. Wood chip mulches seem to be unattractive to voles, a major pest in orchards[309].

Straw

Straw mulch also improves tree growth, nutrient cycling, and fruit yield[295]. In a study comparing different orchard groundcover treatments, Merwin and Stiles (1994) noted that straw mulch showed excellent tree growth, nutrient uptake, and fruit yield[295]. Another study noted that straw mulch consistently provided among the highest weed control and the least end-of-season weed biomass[303]. Two major challenges to using straw include an increase in phytophthora root rots and vole predation[295,312,313].

Manufactured Mulches

Commercially available weed barriers are made of smooth black plastic, permeable landscape fabric, woven plastic weed mats, or biodegradable cellulose. Synthetic mulches can be applied to individual trees as 3' x 3' squares, or the entire row if tree spacing is closer[133]. Although manufactured mulches often have higher upfront costs, they typically provide good weed control and require less ongoing labor than other methods[274].

However, rodents have been observed tunneling under weed barriers, where they build nests and gnaw on tree bark and roots[256,296]. In areas that are prone to flooding, floodwaters can lift plastic and wrap it around tree trunks, causing damage[256]. Synthetic mulches may also limit your options for managing fertility, as nutrients from surface-applied composts and manures may have difficulty passing through[274]. If you plan on applying liquid nutrients through drip lines, this is less of an issue. For organic compliance, synthetic weed barriers must be removed from the field before deteriorating[273].

Biodegradable manufactured mulches made of natural fibers or recycled cellulose have interesting possibilities for organic plantings, as they can be laid under dead organic mulches like wood chips and would not have to be removed[274]. Biomass-based mulches also ease concerns over fossil-fuel derived materials and the eliminate the issue of disposal after removal.

BEYOND ESTABLISHMENT

The focus of this guide has been on the planning and establishment phases of edible agroforestry. The goal of all this planning and attention early on is to develop a low-maintenance agroforestry system that is productive and profitable. However, even well-designed, mature orchards will require monitoring and a practical approach to dealing with ongoing issues like insects and diseases, soil fertility, and pruning.

INVESTING IN SOIL HEALTH

The long-term profitability and productivity of your farm will depend upon healthy soil: not only for you, but for those that farm your soils long after you are gone. It is not an exaggeration to say that maintaining our soils is critical for the survival of future generations. Improving soil health is like putting money in the bank. The investment will pay

dividends in the form of higher yields, better quality, and fewer inputs required. Healthy soils grow healthy plants that are more resistant to droughts, disease, and insects[264].

Keep it covered

By now, preventing erosion should be on your radar as a top priority. Planting perennials is one of the best ways to do this, but a few points should be kept in mind. Avoid cultivation when possible, especially on slopes. If it is necessary to create bare soil conditions for site preparation or alley crop production, consider mulching or planting a cover crop immediately after tilling. Monitor the movement of water through ditches, streams, and gullies. If erosion is occuring, install measures that stabilize the soil, slow down the flow of water, and trap nutrients.

Minimize compaction

Compaction can occur if heavy vehicles pass over the same ground over and over, especially when the soil is wet. Some growers avoid compaction by using smaller and lighter equipment, such as walk-behind tractors. Avoid using a vehicle when walking or using a handcart or wheelbarrow will do.

Livestock can also compact soils, especially over the winter[233]. Consider installing dedicated lanes for moving livestock, and take care when feeding hay. Use small sacrifice areas to prevent damage to larger pastures during wet weather.

As discussed in the site preparation section, some types of compaction can be broken up by subsoiling. If you want to reduce competition from trees in silvopasture and alley cropping situations, subsoiling and root pruning can be done at the same time[128].

Nutrient management

The ideal model for fertility management would work like a mature forest: a mostly closed-loop system where nutrients are recycled that requires no outside inputs. If our goal is to build a similar system, it will require a bank of soil organic matter along with a healthy, diverse soil microbe population.

Inputs come in the form of synthetic fertilizers or biologically derived materials like compost, manure, wood chips, hay, straw, or other types of biomass. If you have livestock, nutrients from feed and hay can be a significant source of fertility. Rotational grazing and cover cropping are ways to increase soil health with minimal outside inputs.

Synthetic nitrogen fertilizers are made using fossil fuels (typically natural gas), which raises concerns over the long-term sustainability and environmental damage caused by extraction practices as well as their contribution to climate change. Lifecycle analyses (LCA's) show that fertilizers make up a sizable portion of the energy use for farming, so using alternatives such as nitrogen-fixing trees or groundcovers can make a big difference in overall energy use.

Composts, manures, and other organic sources contain lots of organic matter and are a good way to build soils, but they are bulky to apply and require nearby sources. These materials have a cumulative effect as they break down over several years. Be careful if you use compost or manure as your only source of nitrogen, as levels of other nutrients such as phosphorus and potassium can build up. In this case, growing leguminous cover crops or trees as a source of nitrogen can help balance nutrient levels.

You can also find nutrient sources around the farm: grass clippings can be composted, wood chips from forest improvement projects can be used as mulch, and dedicated biomass plantings from species like willow can be coppiced and chipped.

Fertilize according to the requirements of the alley crop or forage, rather than the trees[126,128]. You can figure out if trees are getting enough nutrients by taking a leaf tissue sample, which may be more useful than soil tests, especially for nitrogen[314]. Maintain pH by liming according to soil tests.

Building Soils for Better Crops is an excellent handbook for hands-on, science-based advice for improving soils. You can download an electronic version for free from SARE:

- http://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition

INSECTS AND DISEASES

We selected the species in this guide because they are good for organic or low-input commercial production. However, most fruits and nuts will require some level of pest control. You will have to decide what practices you are comfortable with. Often, non-chemical controls are very pest-specific, so you will need a good understanding of the pests present in your region and their appropriate control measures[147]. Since it is impossible to go into the array of pests, diseases, and recommended cultivars in this publication, visit with your county extension office and local fruit growers to learn about what works well in your area.

Integrated Pest Management

With chemical pesticides freely available, some producers simply spray on a schedule, whether it is needed or not. Over-application of pesticides leads to resistance in pest populations, added expense, and harm to non-target wildlife[12]. **Integrated pest management** (IPM) was developed to provide a more environmentally friendly and economically sound alternative. With IPM, you monitor for pests, compare results with economic thresholds, and take appropriate actions if those thresholds are exceeded[315]. The range of control strategies includes prevention, exclusion, pheromone disruption, providing beneficial habitat for predators, and pesticides as a last resort.

Insects

Plants do not have genetic defenses against insects that damage fruits and nuts, so we cannot use variety selection to combat these pests. Non-chemical approaches rely on the use of pheromones, applying substances like kaolin clay that physically block insects from feeding, and enlisting the help of beneficial predators to keep pest populations in check.

Providing habitat for pest predators, sometimes called **farmscaping,** helps keep pest populations lower and benefits other pollinators and wildlife. In addition to good pollinator plants, farmscaping includes using water sources, hedgerows, and cover crops[316]. Take care when choosing plants to include, as some plants can provide habitat for pests instead of beneficials. Sometimes just an un-mowed strip in the middle of the rows where existing plants can go to flower is enough to provide some benefits[147].

For more information:

- ***Farmscaping to Enhance Biological Control*** (ATTRA, 2000)
    - https://attra.ncat.org/attra-pub/summaries/summary.php?pub=145
- ***Farmscaping: Making Use of Nature's Pest Management Service*** (eXtension, 2013)
    - http://articles.extension.org/pages/18573/farmscaping:-making-use-of-natures-pest-management-services

As mentioned in the livestock section, poultry and hogs can have a role in insect pest control. Hogs will eat fallen fruit that harbor larvae of pests like plum curculio[147]. Chickens scratch up the soil, disturbing and consuming soil-dwelling pupae. To comply with organic standards, remove livestock at least 90 days before harvest[36].

Disease

Plant diseases thrive in warm, humid conditions, which is why most organic fruit is grown in California, Oregon, and Washington where humidity is low and disease can be more easily managed. Organic or low-input orchards in the Eastern U.S. will require more attention.

Choosing site-appropriate varieties with proven disease resistance and integrating them into an ecologically diverse system with an attention to soil health is the first step in preventing disease. Select sites with good air drainage and circulation. Promptly remove diseased material from orchard and burn it. Properly sanitize pruning shears in strong bleach or Lysol to prevent the spread of pathogens.

For some diseases like apple scab, raking fallen leaves and fruit from the orchard can eliminate the source of inoculum. Potential hosts of pests and diseases (for example, cedar trees that harbor cedar apple rust) should also be removed from the surrounding landscape if possible[147].

Some organic fruit growers advocate for spraying compost teas and other mixes that contain nutrients and beneficial microbes to outcompete pathogens and boost tree health, and although the scientific literature is less clear about the effects, it probably doesn't hurt[317–319].

SIDE BOX: Ugly Fruit

In the fresh fruit market, consumer expectations usually demand blemish-free fruit. Some fungal diseases on apples like sooty blotch and fly speck are purely cosmetic[147]. Since this goal can be difficult to achieve for some fruits without repeated spraying, a better approach may be to spend time re-educating your customers. Most will tolerate cosmetic variation if it means fewer pesticide applications. Another option is to find alternative ways to sell your products that do not require perfect fruit— like freezing, juicing, dehydrating, or making jams and jellies.

PRUNING AND SUNSCALD

Pruning

You will have to prune trees like apples and pears, while most nuts and some other fruit trees will only require occasional pruning to establish a basic tree structure. Pruning requires a lot of labor, so selecting trees that require

little or no pruning will help reduce costs. While advanced techniques for pruning are beyond the scope of this guide, a few general guidelines are presented below (courtesy of Tom Wahl)[143]:

- Tree shelters can encourage young trees to grow vertically towards the light at the top, reducing the number of side branches and the amount of pruning required.
- Prune and train trees to the preferred structure for the species (central leader, modified central leader, etc.) and keep the angle between the trunk and the branch to greater than 45 degrees.
- Do not cut too close to the truck— you want to prune to just beyond the collar of the branch, not flush with the trunk.
- Never use paint or wound sealant.
- It is best to prune branches when they are between ¾" and 1" in diameter.
- Never prune off more than 1/3 of a tree in any given year.

Preventing sunscald

The trunks of young trees are susceptible to sunscald, also known as "south-west injury"[162,320]. Sunscald happens on sunny days in the spring when the trunk warms and sap begins to flow. Once temperatures drop again at night, the bark can be damaged[320]. Any young, thin-barked tree can be affected by sunscald, but especially susceptible are apples, chestnuts, honeylocust, pawpaw, and stone fruits (cherries, peach, apricots, etc.)[321].

To prevent injury, paint trunks with a 50/50 mixture of white interior latex paint and water. A great tip from Grimo Nut Nursery is to apply it with a car wash mitt with a rubber glove to keep the paint off your hands[162]. White plastic spiral tree wraps also prevent sunscald[161].

ECONOMICS AND FUNDING

Unless you are farming as a hobby or as a way to provide food for your family (both worthwhile goals in themselves), getting a financial return on your efforts is necessary for the long-term viability of your operation. Any farm business requires good financial management, but cutting-edge perennial systems have unique challenges: high initial investment, long payback, non-traditional markets, untested yields in mixed systems, and complex management, to name a few. Research is ongoing, but there are still many questions about the most economically successful models for growing these crops in integrated systems. To succeed, you will need to do careful enterprise budgeting and business planning which takes into consideration your unique circumstances and goals.

ENTERPRISE BUDGETING AND BUSINESS PLANNING

There are a variety of excellent resources for developing enterprise budgets and business plans. Sample budgets for many of the tree crops in this guide are available, though they typically only include a single tree crop. You will have to work these into a comprehensive economic analysis that recognizes the synergies and challenges of multiple crops. As mentioned in the "Goals" section, an economic analysis tool for mixed perennial farming systems called Fruit and Nut Compass will be available soon from the University of Wisconsin-Madison, so keep your eye out for its release.

University of Missouri Center for Agroforestry

One of the best resources for economic information is the ***University of Missouri Center for Agroforestry***. In addition to extension publications, several interactive enterprise budgets for Excel are available, as well as a comprehensive training manual for agroforestry.

- ***Training Manual for Applied Agroforestry Practices***
    - http://www.centerforagroforestry.org/pubs/training/index.php

Economics and Funding

- ***Economic Budgeting for Agroforestry Practices***
    - http://www.centerforagroforestry.org/pubs/economichandbook.pdf
- ***Tax Considerations for the Establishment of Agroforestry Practices***
    - http://www.centerforagroforestry.org/pubs/agrotaxcons.pdf
- ***Funding Incentives for Agroforestry in Missouri***
    - http://extension.missouri.edu/explorepdf/agguides/agroforestry/af1005.pdf

Excel Budgets

- Download at http://www.centerforagroforestry.org/profit/

- ***Chestnut Decision Support Tool***
- ***Eastern Black Walnut Decision Support Tool***
- ***Black Walnut Financial Model (Version 2.0)***

ATTRA

ATTRA (Appropriate Technology Transfer to Rural Areas) is a program managed by the National Center for Appropriate Technology (NCAT). They have many articles, tutorials, and multimedia on all aspects of sustainable farming, including farm financial planning. Beginning and veteran farmers alike will find useful information here.

ATTRA— Marketing, Business & Risk Management

- https://attra.ncat.org/marketing.html#funding

Other resources

- ***Building a Sustainable Business*** (SARE, 2003)
    - This excellent, freely downloadable guide "…brings the business planning process alive to help today's alternative and sustainable agriculture entrepreneurs transform farm-grown inspiration into profitable enterprises. Sample worksheets lend a practical perspective and illustrate how real farm families set goals, researched processing alternatives, determined potential markets, and evaluated financing options. Blank worksheets help the reader develop a detailed, lender-ready business plan or map out strategies to take advantage of new opportunities."[322]
        - http://www.sare.org/Learning-Center/Books/Building-a-Sustainable-Business

- ***A Landowners Guide to Perennial Crop Options*** (Trees Forever, 2014)
    - A useful overview of several perennial crops including aronia, hazelnut, black walnut, chestnuts, elderberries, and Christmas trees. Includes enterprise budgets and production guidelines.
        - http://www.treesforever.org/crops

FINANCIAL AND TECHNICAL ASSISTANCE

Federal cost-share programs can help defray the high upfront costs of establishing perennial crops. It may seem daunting to navigate all of the government agencies, grants, and programs at first, but the benefits may be well worth it. For example, the author once got approved for NRCS cost-share assistance to build a fence on his property to keep livestock out of the creek and the woods. Although it took a few visits with NRCS personnel and some paperwork, the program paid for the majority of the project. If considered on a per-hour basis, the time spent pursuing assistance paid more than most farming enterprises!

Of course, these programs are not designed to be "free money," but they may mean the difference between being financially able to achieve an objective (in the example above, of improving the health of the forest and quality of the water) or not. Program requirements, eligibility, and practices vary by agency and from state to state. If you have not already done so, set up a meeting with your local NRCS or FSA office to see how they can help.

The Natural Resources Conservation Service (NRCS)

The NRCS is a branch of the United States Department of Agriculture (USDA) with the goal of helping landowners address natural resource concerns. It has several programs that may be compatible with edible agroforestry. Usually, an NRCS agent will visit the farm and work with the producer to come up with a plan that includes several practices. Once approved, the farmer then installs the practice according to the standards set in the agreement, and a set amount is paid to the famer once they are checked off.

Farm Service Agency (FSA)

The Farm Service Agency administers the Conservation Reserve Program (CRP) and the Continuous Conservation Reserve Program (CCRP). These programs take environmentally sensitive farmland out of production for a set period to improve environmental outcomes. Various practices can be installed that meet the requirements. Yearly rental payments to the farmer help offset production losses, and cost-share assistance or sign-up bonuses are sometimes available for the initial installation.

An in-depth resource for exploring government sources of funding is the ***National Sustainable Agriculture Coalition***. Several useful publications are available on their website:

- http://sustainableagriculture.net/publications/

- ***Grassroots Guide to Federal Farm and Food Programs***
- ***Growing Opportunity: A Guide to USDA Sustainable Farming Programs***
- ***USDA Financing Options for On-Farm Storage***

State and County

Your state department of agriculture or county agriculture board may have available grants or loans for value-added processing, watershed improvement, or alternative crop enterprises.

Grants

Finally, grants may be available for conducting on-farm research, building local food systems, or other sustainable farming endeavors. You can find these through online searches. The Sustainable Agriculture Research and Education (SARE) offers yearly grants for a variety of goals. They also publish useful guides on sustainable farming:

- ***Sustainable Agriculture Research & Education***
    - http://www.sare.org/

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APPENDIX A: PERENNIAL PATHWAYS BOOKS 1 AND 2, COMPLETE LAYOUT (PDF)

The complete version of "Perennial Pathways" is available as a downloadable PDF in the supplemental materials of this thesis. The full version will also be published through the Savanna Institute, a non-profit that supports research and education in agroforestry in the Midwest. "Perennial Pathways" will be available through the website www.savannainstitute.org.