WRITING ASSIGNMENT

Temperate Food Forestry:

A review of productivity, design principles, and management practices

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Literature Review

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Plain language summary

Over the past century, the growth of industrial agriculture and monocultures of a small number of annual crops has led to alarming environmental problems like soil erosion, a decline in biodiversity, and greenhouse gas emissions. As a result, there is growing interest in reintroducing productive, multifunctional perennial polycultures modeled after natural forests into rural and marginal agricultural landscapes as well as urban settings. These diverse food forest systems integrate trees, shrubs, vines, and groundcovers to provide ecological benefits while meeting human needs in a sustainable manner. Most scientific research has concentrated on the tropics, with little data from temperate regions. This review examines evidence on temperate climate food forest productivity, design principles, and management strategies in order to identify research priorities.

There is very little data on long-term yields from mature temperate food forests. According to some optimistic theoretical modeling, potential productivity is very high. However, actual yields are dependent on a number of complex factors that require further investigation through comparative field trials across the entire developmental lifecycle. These could help determine whether diverse perennial polycultures can match or exceed conventional monoculture yields in a sustainable manner. Some preliminary data indicate that satisfactory productivity is achievable with proper planning and management, but comprehensive empirical yield data across diverse mature systems and climates remains scarce.

Although there are general design guidelines, more applied research is required to tailor scientifically validated plans to regional conditions. Natural forest structure is mimicked by incorporating vertical stratification and beneficial species interactions. Selecting species that are adapted to the local environment and maximizing density and arrangement for growth and light, as well as ecological synergies and ecosystem services, are also crucial. Case studies demonstrate how participatory co-design in community food forests combines ecological principles with social priorities.

Developing customized management aligned with each food forest's developmental stage is vital. Some research suggests that simplified initial designs may improve productivity, whereas smaller systems incorporate more diversity to meet community goals. Priorities for research include developing adapted techniques for a wide range of perennials, such as propagation protocols, density planning, and integrated pest control. Documenting practitioner experiences can reveal useful principles and knowledge gaps. Innovative, specialized equipment could also boost crop yields.

In conclusion, there are currently major knowledge gaps that make it difficult to systematically optimize the productivity, design, and management of food forests in temperate climates. However, if carefully established and managed, the preliminary evidence suggests that these multifunctional perennial polycultures have the potential to provide favorable productivity levels, ecological regeneration, and community resilience. Priority knowledge gaps could be effectively filled by focused collaborative research projects that enable controlled comparative trials, multivariate ecological modeling across a range of sites, climates, and production scales, and rigorous long-term monitoring. It is imperative to establish partnerships that furnish the necessary resources for coordinating experiments that monitor soil changes, yields, biodiversity, and ecological interactions throughout the entire developmental lifecycle. Communities of practitioners, specialists, scientists, and farmers could significantly advance practical scientific knowledge on site-specific establishment and optimization of temperate food forests by working together in networks to address these research priorities. If knowledge gaps are filled, these integrated systems modeled after natural forests could help transform local food systems, agriculture, and community resilience in the face of climate change disruptions. Multifunctional temperate climate food forests have the potential to be further developed into workable regenerative models for sustainable localized agriculture throughout temperate regions, given the proper cooperative efforts and research priorities.

Abstract

This literature review synthesizes current scientific knowledge on temperate climate food forests, identifies critical gaps, and proposes priority research needs for optimizing establishment and management. Food forests incorporate productive multipurpose trees, shrubs, vines, and groundcovers mimicking natural forest structure. Despite being ancient practices, recent interest aims to adapt food forestry for modern regenerative agriculture. However, few controlled scientific studies have systematically optimized these complex agroecological systems for modern contexts. Currently, empirical data is insufficient to reliably quantify relationships between long-term productivity, design configurations, species selections, and management techniques across diverse mature food forest sites. Monitoring growth, yields, interactions, and ecosystem services across developmental lifecycles is vital. Comparative trials can reveal trade-offs between chemical-intensive orchards and organic polyculture methods. Collaborative experimental networks spanning climatic, edaphic, and management gradients have the potential to significantly advance context-specific scientific guidelines for establishing productive, multifunctional temperate food forests that balance ecological regeneration with community priorities. Participatory research aimed at filling key knowledge gaps can help accelerate the adoption of thoughtfully designed and responsibly managed food forestry systems. If these integrated perennial models are applied using adaptive science-based methods, they may favorably impact localized transformative food system transitions.

Introduction

Throughout the past century, multifunctional agricultural practices that incorporate productive perennial trees and shrubs into annual croplands have become less common in many temperate industrialized nations. Instead, a few annual commodity crops grown in extensive monoculture plantings have taken over, with the sole goal being to maximize yields and economic efficiency (Crawford, 2010). For instance, according to research, agroforestry land cover in Europe has declined significantly over the past century, from 13 million hectares in 1900 to 2 million hectares in 2000 (Eichhorn et al., 2006). This trend towards simplified, homogeneous agriculture has contributed to concerning environmental issues such as soil erosion, water pollution, greenhouse gas emissions, biodiversity decline, and reduced community food security (Crawford, 2010). As Grebner et al. (2021) and Jose et al. (2009) discuss, interest has emerged in adapting traditional food forest principles that diversify and enhance agriculture through biodiverse, multifunctional perennial polycultures. By growing ecologically linked trees, shrubs, vines, and groundcovers in vertically stratified layers, food forests aim to mimic the structural makeup and species richness of natural forests while providing a variety of regenerative ecological benefits (Jacke & Toensmeier, 2005). The concept of food forestry strategically reintroduces multifunctional perennial tree crops to agricultural landscapes. Building on several ancient agroforestry practices that are still in use today, including multistory tropical home gardens; the taungya technique (Menzies, 1988) of planting trees within agricultural crops that rotate; alley cropping techniques that interplant trees with annual crops; and the oak-grazed dehesa ecosystems that have been preserved for centuries in Spain and Portugal (Crawford, 2014; Joffre et al., 1988; Jose et al., 2004; Vicent & Alés, 2006). Within more temperate regions, productive trees and woody perennials were similarly important components of many Indigenous communities' traditional land use practices and livelihoods, as well as the agroforestry-based agricultural systems that predominated in much of Europe and North America prior to the large-scale industrialization and specialization of agriculture during the twentieth century (Erickson et al., 2011; Herzog, 1998). By managing diverse farms, orchards, and agricultural landscapes in harmony with the flows and functions of surrounding forest ecosystems, food forest systems aim to sustainably meet a wide range of human needs and values, including nutritional, material, cultural, aesthetic, and spiritual (Munsell et al., 2017). In comparison to tropical regions, there has been relatively little formal scientific research focused on developing adapted, optimized food production systems for temperate climates that are modeled after the structure and ecological functions of local forest ecosystems.

An awareness of the immense damage caused by an over-reliance on narrowed, mechanized agricultural monocultures has grown interest among farmers, communities, and sustainability scientists to resurrect and adapt traditional temperate food forestry principles through the use of ecologically regenerative, perennial plant-based design (Jose et al., 2009; Grebner et al., 2021; Smith, Pearce, & Wolfe, 2012). According to Crawford (2010), visionary pioneers such as Robert Hart and Bill Mollison first developed small-scale forest gardening models, which then inspired others to adopt sustainability practices. Their work illuminated pathways for food forests to provide community resilience. In recent years, public urban food forests have started emerging in cities globally (Allen & Mason, 2021; Beacon Food Forest, 2016; Clark, Kimberly, & Nicholas, 2013). These projects incorporate localized organic food production and ecosystem services into public greenspaces, together with social amenities such as trails, classrooms, and facilities for community events (Clark, Kimberly, & Nicholas, 2013; Schafer, Lysák, & Henriksen, 2019). For instance, the public Beacon Food Forest in Seattle (Beacon Food Forest, 2016) and the Picasso Food Forest in Parma, Italy (Riolo, 2019) demonstrate emerging models of community-oriented urban food forestry initiatives. Adapting food forests for modern use can improve sustainability and resilience. These systems enrich degraded lands with diverse, multifunctional perennials tailored to meet community needs ranging from food security to cultural connection (Frey & Czolba, 2017).

With a particular emphasis on areas with humid continental, oceanic, and Mediterranean climates, such as portions of North America, Europe, and Australia, the purpose of this literature review is to synthesize current knowledge, evaluate key gaps, and identify research priorities needed to advance scientifically-informed establishment and management of temperate climate food forests. The analysis takes into account preliminary findings from field trials and pertinent qualitative case studies of small-scale food forestry operations. Although there has been a lot of empirical research on tropical food forestry (Pumariño et al., 2015, for example), there have been comparatively few controlled, replicated field experiments conducted in temperate environments. To fully assess food forests as alternatives to conventional agriculture, repeatable long-term trials under a range of soil types, climates, and management regimes are needed, along with detailed ecological and economic metrics for comparison. The primary goal of this study is to survey the current body of evidence and identify critical research needs in order to support the wider establishment of carefully adjusted, multifunctional food forest ecosystems across temperate agricultural regions that balance productivity, ecological regeneration, and community well-being through participatory research initiatives.

Section 1: Yields and productivity potentials

Very few reports in the peer-reviewed scientific literature at this time offer thorough, quantitatively documented yield records from mature food forest systems in temperate climates that have been tracked over the course of their multi-year developmental lifecycle after initial establishment (Eichhorn et al., 2006). Some exploratory modeling has projected temperate food forest productivity by speculatively extrapolating yield benchmarks from conventional fruit orchards or woody crop monocultures (Clark, Kimberly, & Nicholas, 2013). However, productivity depends on complex factors, which these simplified models cannot account for. A geospatial modeling study in Burlington, Vermont, USA, explored hypothetical scenarios for transforming vacant public parks and open spaces suitable for agriculture into dense food forest orchards centered on apple cultivation. Based on assumptions, the study estimated that converting half the available public parcels to food forest apple orchards could theoretically provide over 3,200 metric tons of fruit a year. This could potentially supply over 100% of the recommended per capita fresh fruit needs for Burlington's whole municipal population if yields match the optimistic estimates (Clark, Kimberly, & Nicholas, 2013). Although these preliminary modeling efforts suggest that turning some underutilized urban and peri-urban spaces into multifunctional food forests could greatly increase community food security in localized resilient systems, there are significant uncertainties and gaps in knowledge that limit the ability to reliably extrapolate such optimistic productivity projections across larger geographic areas and climate regions. This is due to the fact that the actual yields and total ecosystem service values that any food forest system may eventually prove sustainably attainable in real-world settings over the long term are dependent on intricate interactions between a wide range of site-specific environmental variables, design configuration factors, and adaptive management techniques and intensities (Eichhorn et al., 2006). For example, research on apple trees has shown that fruit yields per hectare remain relatively constant across a six-fold range of planting densities (Robinson, 2008). This indicates flexibility in balancing production intensity with land area needs. While it is true that nutritionally and economically important woody perennials like walnuts, chestnuts, or apples generally have higher per-acre productivities when grown in specialized intensive monocultures optimized through regular fertilizer, pesticide, and herbicide additions to maximize annual yields, some ecological research suggests that more complex polycultures incorporating diverse, complementary species across vegetative layers may potentially have higher per-acre productivities (Wartman et al., 2018). For example, strategically incorporating nitrogen-fixing leguminous shrubs and groundcovers could reduce reliance on synthetic fertilizer amendments. Mixed species diversity may also improve system resilience to disturbances such as pest outbreaks. Some recent ecological research indicates that more on-farm plant diversity may be linked to higher total yields, possibly by decreasing crop damage and losses resulting from pests (Bedimo et al., 2008). To determine with certainty, however, whether the proposed synergies between food forests and polycultures can lead to measurable gains in net productivity, economic profitability, and ecological sustainability when compared to monocultures of conventional woody crops will ultimately require large-scale, replicated, long-term comparative experiments conducted in matched conditions across a wide range of geographical locations with varying climatic and soil gradients.

Productivity outcomes are significantly impacted not only by inherent uncertainties about the best combinations of species diversity, density, and spatial configuration but also by management intensity and the overall agroecological approach that is applied over time. In a 21-year systems trial, rows of the same individual apple and pear cultivars grown conventionally with standardized additions of synthetic fertilizers, pesticides, and herbicides were contrasted with an organic fruit tree guild agroecosystem based on permaculture principles emphasizing ecological diversity and relying solely on natural soil building techniques. According to this replicated trial, the organic guild system produced fruit yields for both apples and pears that were statistically similar to those of the parallel conventional monoculture rows following the establishment phase (Reganold et al., 2001). However, long-term empirical side-by-side productivity comparisons between perennial food crop polycultures managed organically and conventional orchard monocultures remain remarkably scarce in peer-reviewed horticultural literature. Commercially simplified apple or walnut orchards grown as conventional row monocultures represent highly optimized systems for maximizing annual yields of a target crop through regular external additions and chemical controls. Therefore, much more comparative research is required to elucidate the yield stability, ecosystem service provision, and ecological sustainability dynamics potentially attainable in thoughtfully designed diverse food forest agroecosystems. Accordingly, as accelerating climate change brings more frequent extreme weather perturbations such as damaging storms, flooding, droughts, and pest outbreaks, food forests with greater planned complexity and biodiversity may potentially exhibit superior yield stability and resilience under such biotic and abiotic stresses in comparison to ecologically simplified conventional orchards or plantations. To generate the necessary controlled experimental data to definitively evaluate this hypothesis, however, large-scale replicated comparative trials monitoring chemical-intensive and diversified agroecological management systems in parallel across gradients of geography, soils, and climate are still urgently needed.

Apart from providing an understanding of intricate management relationships, creating extensive longitudinal datasets that follow the productivity potentials of food forests from the time of initial planting to the point at which trees reach mature stability is crucial (Crawford, 2010). This is because the yields that can be measured and the resulting cost-benefit ratios for the products that are produced will vary significantly during the various stages of establishment, development, and maturity over the course of a perennial cropping cycle. For example, while the Beacon Food Forest multifunctional permaculture research site near downtown Seattle, Washington (USA), is likely still years away from reaching peak projected productive capacities as planted trees, shrubs, and perennial vines continue developing, noticeable increases in harvestable fruit, berry, and nut yields have been documented during its third year after the initial establishment phase, suggesting quantifiable outputs can be generated prior to full canopy closure and successional maturation (Beacon Food Forest, 2016). Björklund, Eksvärd, and Schaffer’s (2018) Swedish polyculture trial demonstrated the need for long-term yield data, as short-term records proved insufficient to predict mature productivity. Their work reveals an opportunity to expand monitoring durations to accurately assess food forest lifecycles. Food forest planting trials should extend monitoring beyond a single season or early years to document yields over the full cropping cycle. This would significantly improve predictive empirical data to clarify relationships between development phases and realized productivity outcomes.

According to some researchers, a number of sufficiently mature food forest sites and commercial operations offer initial proof that satisfactory levels of productivity, profitability, and ecosystem services can likely be attained through proper planning, species selection, and sustainable practices (Rebisz, 2019; Wartman et al., 2018; Schafer et al., 2019). For example, the fairly mature De Bruuk food forest research sites in Ketelbroek, the Netherlands, offered comprehensive quantitative evaluations of cumulative yields over time (Rebisz, 2019). By the seventh year, harvested products across monitored sections had an average annual productivity of approximately 5 metric tons of fruits, nuts, mushrooms, and other miscellaneous products per hectare. Additionally, this system demonstrated improved soil quality, as evidenced by a two-fold increase in soil organic carbon content from 4.4% in 2010 to 8.8% in 2019. Another well-documented commercial food forest system, New Forest Farm, developed over the last 15 years in Wisconsin, USA, by sustainable agriculture expert Mark Shepard, covers approximately 44 hectares and includes a highly diverse polyculture of multifunctional hazelnuts, chestnuts, apples, berries, and other fruits, vegetables, vines, mushrooms, herbs, and assorted woody crops. As an ecological model, New Forest Farm utilizes oak savanna and successional brushland. Ongoing monitoring shows that this diversified agroforestry landscape consistently produces total annual yields ranging from 4 to 11 metric tons per hectare (t/ha) of various products (Wartman et al., 2018). When compared to regional averages, researchers discovered that the overall productivity of this system is as high as or higher than typical yields obtained through less integrated agricultural practices that heavily rely on synthetic fertilizers and chemicals to maintain output levels. Furthermore, during experimental crop trials conducted across food forestry test sites by the Badgersett Research Corporation cooperative in Minnesota, USA, isolated yields for chestnut and hazelnut shrub plantings exceeded 2.7 t/ha, significantly outperforming the corresponding regional yield averages for these species under conventional orchard management (Rutter & Shepard, 2002).

While existing assessments are useful, comprehensive empirical productivity data across the lifecycle and diverse geographies remain limited. Productivity modeling has relied heavily on extrapolating expected yields from conventional woody crop monoculture benchmarks rather than extensive direct field documentation of long-term records capturing the progression of actual food forest sites under active cultivation (Clark, Kimberly, & Nicholas, 2013). However, as Eichhorn et al. (2006) note, current yield assessments rarely account for how variables like soil properties, weather, species differences, and management practices interact to impact food forest productivity. This presents an opportunity for more rigorous empirical research documenting these complex interacting effects on yields. While preliminary yield studies provide initial data, they are limited by the insufficient duration, replication, and geographic constraints needed to accurately quantify long-term patterns across diverse mature food forest systems. To meet research needs, significant collaborative efforts will be required for coordinated monitoring of food forest species selections across numerous test sites spanning climatic, edaphic, and management gradients. Findings from such vast networks could significantly advance knowledge in developing regionally optimized food forest practices through experiential learning. Agricultural experiment stations (AES) in the U.S. could play an important role in long-term temperate food forestry research. These stations maintain the goal of advancing agricultural science and productivity, with proposals for identifying perennial crops for regional conditions, developing long-term projects, and implementing tree crop use through outreach. Adopting these goals could help to advance multifunctional systems as viable alternatives, with far-reaching implications for agricultural adaptation to climate variability. Woody polycultures that stabilize soil and retain nutrients can thrive on lands with the same marginal qualities that make them unsuitable for annual row crops. Multifunctional systems could be integrated into farms through federal conservation programs (CRP) targeting marginal lands (Lovell et al., 2017). Standardized monitoring of growth, fruiting, stress tolerance, and other indicators across species, configurations, and techniques could strengthen long-term understanding of maximizing food forest potential compared to conventional systems.

Section 2: Design factors and considerations

Many generalized guidelines, principles, and best practices have been proposed in seminal texts and reference manuals on the establishment of food forests in temperate climates (Gold & Hanover, 1987; Frey & Czolba, 2017). These recommendations are primarily based on conceptual modeling of idealized structural characteristics and concepts of species diversity observed in natural temperate deciduous forest ecosystems. To effectively translate these theoretical constructs into quantifiably optimized configuration templates that are tailored to local environmental and social contexts, however, much more rigorous applied experimental research is still required (Crawford, 2010). Major knowledge gaps persist, particularly with regard to the systematic development of scientifically validated food forest plans that are regionally customized to match the distinct climatic conditions, landscape variables, hydrological resources, common soil types, solar exposure patterns, and community socio-economic needs and interests. A growing number of observational case studies documenting the completed adaptive co-design processes and ultimate implementation outcomes for several real-world community food forests provide some useful qualitative models and perspectives, even if they do not provide truly universal system templates (Erickson, Lovell, & Méndez, 2011; Riolo, 2019; Beacon Food Forest, 2016). Picasso Food Forest, for example, was created on a public parkland plot in Parma, Italy. It incorporates a carefully planned diversity of productive fruit and nut trees that are well-suited to the Mediterranean climate, interspersed with smaller berry shrubs, different vining crops, nitrogen-fixing leguminous shelterbelt trees, multipurpose ground cover layers, and flowering herbs for beneficial insects (Riolo, 2019). In order to mimic the vertical stratification and advantageous species diversity features of a natural forest ecosystem, students and community members involved in the participatory design process carefully planned this species arrangement and structural configuration. The site-specific species selection and placement for Picasso Food Forest had several goals. One goal was to enhance local habitat complexity to support birds and beneficial insects, particularly pollinators. Another goal was to improve long-term soil health and fertility by incorporating plants that accumulate nutrients and fix nitrogen. The design also aimed to ensure year-round visual appeal by integrating flowering species and fall colors. Identifying potential niche opportunities for generating value-added wood chip biomass through coppicing was another goal, with plans to compost the wood chips on-site. Finally, the species selected were resilient fruit and nut varieties capable of providing substantial community food and economic outputs. In addition, the Beacon Food Forest project in Seattle, Washington, USA, was guided by a participatory process incorporating input from local residents on desired uses like fruit and nut tree clusters, recreational trails, event spaces, and more (Beacon Food Forest, 2016). These community-driven urban food forests showcase integrating both biophysical and social priorities through collaborative regional sessions creatively applying permaculture and agroecology design principles. As Riolo (2019) explains, these principles aim to optimize beneficial species interactions through increased complexity in vertical stratification as well as positive plant-plant and plant-microbial relationships. Urban environments also present distinct opportunities and constraints for design compared to rural farms, necessitating consideration of aspects like integration of stormwater catchment, enhancing wildlife habitat connectivity, mitigating problematic urban heat island microclimates, and ensuring equitable access to vulnerable neighborhoods (Guitart et al., 2012). Adaptive co-design strategies that engage communities in monitoring outcomes over 5–10 years can refine designs to balance priorities from ecological health to accessibility.

In addition to community-oriented urban food forests, some rural food forest case studies and experimental trials also demonstrate key design principles. For example, Restinclieres Estate Farm in France combines alley cropping of culinary and medicinal herbs between contoured hedgerows of multifunctional woody species on sloped terrain. The Agroforestry Research Center (HARC) in Missouri, USA, conducts long-term agroforestry research on its 270-hectare research farm adjacent to the Missouri River. Established in 1953, HARC has studied the science of agroforestry systems combining trees and shrubs with crops and livestock utilizing orchard intercropping, silvoarable, and silvopastoral systems (Lovell et al., 2018). In the Netherlands, the De Bruuk food forest research sites have established productive polycultures modeled after local oak forest ecosystems (Rebisz, 2019). In rural agricultural areas, ecologically complementary crops, community needs, and marketability for income are important design factors to consider (Mudge & Gabriel, 2014). In addition, harvesting lanes, access roads, and multifunctional sorting and storage facilities are thoughtfully integrated infrastructure that enables mechanized management and efficient distribution logistics. For instance, Mark Shepard developed his highly diversified New Forest Farm perennial farming model on 45 hectares in Wisconsin, USA, through a comprehensive co-design process that included the intentional integration of cattle grazing lanes between contoured hedgerows of multifunctional woody species like apple, hazelnut, and chestnut, as well as the selective biomass harvesting from coppiced nitrogen-fixing trees and alley cropping of organic culinary herbs (Wartman et al., 2018). Although regional baseline differences in climate patterns, landscape topography, hydrology, prevalent soil types, solar exposure, and community interests may all inform localized customization of food forest planning and implementation, universally ideal "one-size-fits-all" templates are unlikely to emerge. Collectively, these case studies reveal how participatory design processes can help integrate ecological principles with community priorities and values in the design of food forests.

These rural research farms and commercial operations demonstrate how food forests can integrate strategic design principles such as contour hedgerows, alley cropping, polycultures mimicking natural forests, and agroforestry combinations of woody perennials with herbaceous crops and livestock (Mudge & Gabriel, 2014). Their long-term studies across diverse contexts provide valuable data to guide the adaptation and optimization of multifunctional food forests. However, extensive experimental optimization of food forest design across contexts has not yet occurred. Based on the available literature, some key generalized design considerations for temperate climate food forests include the selection of tree, shrub, vine, and understory species that are adapted to local climate conditions based on ecological niche modeling projections. Choose plants that are appropriate for the soil drainage qualities, textures, pH, salinity, and nutrient levels at the location based on spatial grouping informed by soil microsite variability testing. Incorporation of permanent water features such as ponds and streams and a focus on drought-tolerant, hardy plants in areas with sporadic rainfall. In addition to the use of growth modeling of shading effects to configure density and arrange different species to optimize light interception for understory plants. Symbiotic combinations and configurations that effectively make use of both horizontal and vertical growing space through advantageous interactions, like those with nitrogen fixers, are also utilized (Gold & Hanover, 1987). Additional complexity in habitats can improve ecological control over pests and diseases (Bedimo et al., 2008; Pumariño et al., 2015). Providing additional resources to support birds, pollinators, and other desirable wildlife is key (Crawford, 2010; Rivera, Quigley, & Scheerens, 2004). Selecting species combinations that provide targeted ecological services such as erosion control, nitrogen fixation, and slope stabilization are additional priorities (Nico, 2020; Montagnini, 2022). Thoughtful design can help food forests meet community needs. As Erickson, Lovell and Méndez (2011) describe, participatory processes can identify these priorities and incorporate them. In general, an alignment of management objectives and species with subsistence, income, or yield priorities as established by market research is advised. In all, more thorough comparative research across various climates, locations, communities, and production scales will likely be needed to translate broad food forest concepts from theory into workable, region-specific designs for temperate climates. Both scientific and traditional ecological knowledge systems have complementary roles in participatory design processes aiming for balanced solutions. Though definitive guidelines have yet to be established, monitoring long-term outcomes from participatory approaches in a variety of contexts can assist collaborative networks in refining balanced guidelines that integrate productivity, ecosystem regeneration, and community priorities.

Section 3: Management techniques and practices

The establishment, productivity, and realization of ecological benefits from temperate food forests will be heavily reliant on site-specific agroecological management strategies that are carefully aligned with the developmental stage, complexity, and evolving objectives of each cultivated system. However, synthesizing documented experiences and collective lessons learned by early pioneering food forest practitioners and specialists can still illuminate some useful general considerations, trade-offs, and core principles that can serve as a roadmap guiding collaborative efforts to iteratively develop, critically evaluate, and gradually improve adaptive place-based management techniques over time. For example, one insightful comparative case study tracked the introduction and participatory monitoring of small-scale forest garden polycultures on 12 family farms in Sweden over four years. Researchers discovered that the significant intra- and inter-specific plant diversity deliberately incorporated for multifunctionality poses challenges. Maintaining the desired vegetation structure, species balance, and productivity efficiently required intensive labor for pruning, trellising, coordinated harvesting, and other hands-on tasks (Björklund et al., 2018). However, planting some compatible annual vegetables, culinary herbs, and cut flower species in between rows of young fruit trees and shrubs did result in modest supplemental yields during the first three years of establishment prior to full canopy closure. The authors advised beginning with a moderately simplified composition centered on priority multifunctional crops that are relatively easy to cultivate and harvest efficiently. When first establishing temperate climate food forests, especially in rural contexts, the goal of this pragmatic initial approach would be to optimize labor efficiency, yields, and profitability (Björklund et al., 2018). On the other hand, although managing higher complexity on a small scale requires more extensive hands-on labor inputs that must be feasible within the context, smaller-scale or communal food forests might benefit from the incorporation of a broader diversity of edible, medicinal, or otherwise beneficial plant species to better fulfill varied subsistence goals, community priorities, and cultural practices.

Some recommendations for rural food forests needing machinery suggest wider initial spacing between rows of woody perennials and fruiting shrubs to accommodate equipment access (Jacke & Toensmeier, 2005). Also, periodic selective thinning as the forest matures maintains adequate room for equipment maneuvering. In order to maintain tractor access lanes, certain creative food forest operations in the American Midwest have even modified specialized mobile canopy lift equipment from silvopasture grazing systems to prune back lower tree branches as needed (Wartman et al., 2018). A balanced approach to labor inputs, cultivation efficiency, ecological sustainability, profitability, and yield stability will be the main objectives of temperate food forest management. Adaptive techniques can ultimately be gradually improved by practitioners through cycles of deliberate experimentation, monitoring assessments, and iterative system improvements. In contrast to simplified annual cropping, food forests are inherently more diverse and complex, with perennial lifecycles and woody plants. This highlights the necessity of developing customized innovations suited to their distinctive attributes. Therefore, there are probably a lot of opportunities to advance the cultivation of food forests by applying lessons learned from traditional forms of agroforestry forest gardening, by creating innovative specialized infrastructure that is suited to their dense, multi-layered vegetation structure, and possibly by utilizing newly developed digital monitoring technologies and mechanization tools that are suited to their high biodiversity. As an illustration, specialized equipment for pruning, harvesting, and cultivation is commonly utilized in conventional apple orchards and vineyards to notably improve management efficiency (Robinson, 2008). The development of specialized equipment and tools optimized for the complex configuration of food forests represents an important area for agricultural innovation and technology development.

During the first one to five years following site preparation and planting, recommended management priorities are primarily focused on promoting healthy growth of trees and understory plants, achieving optimal architectural development, and facilitating early fruiting (Gold & Hanover, 1987; Jack & Toensmeier, 2005; Rutter & Shepard, 2002). To help achieve these goals, a combination of techniques are employed, such as regular additions of organic soil amendments, natural organic mulches spread around planting zones to suppress competitive weeds and conserve moisture, supplemental irrigation during drought conditions to minimize plant water stress (Gold & Hanover, 1987), early formative and structural pruning regimes to shape the architecture of woody scaffolds (Thevathasan & Gordon, 2004), and integrated biological strategies for pest and disease prevention or control (Jose, Gillespie, & Pallardy, 2004). Significant knowledge gaps remain regarding the optimization of propagation techniques, density planning, integrated pest control, understory design and planting schedules, soil improvement practices, and water management strategies for the wide diversity of fruits, nuts, vines, shrubs, and herbs used in multifunctional temperate food forests. Understanding the best complementary combinations and cultivation methods to manage each species and cultivar will require extensive participatory on-farm trials and coordinated data exchange within cooperative networks of growers, specialists, and researchers, as various species and cultivars exhibit unique needs and stress tolerances. Similarly, systematic replicated trials and three-dimensional growth modeling would be very helpful in optimizing formative pruning regimes and training protocols for maximizing architectural development and light interception of various food forest crops. Controlled experiments could gradually develop indexed response standards, assisting in the determination of ideal crop density balances, appropriate species proportions, and optimal spatial configurations for achieving yield goals while minimizing unnecessary competition for nutrients, moisture, and sunlight. Techniques effective in simplified annual cropping may not suit food forests, which emphasize ecological, organic solutions over synthetic chemicals (Jose et al., 2004). In order to develop integrated solutions that are optimized for the greater biological diversity and structural complexity inherent to multifunctional food forest ecosystems, systematic replicated trials comparing various techniques, such as complex polycultures, organic mulches, permanent no-till living groundcovers, beneficial insectary plantings, biological control introductions, and other options, could be very beneficial in established food forests.

After canopy closure in maturing forests, managing canopy architecture becomes key for manipulating light and growth (Gold & Hanover, 1987). Early corrective structural pruning contributes to the development of strong tree scaffolds capable of supporting productive fruiting for many years (Thevathasan & Gordon, 2004). Recommended techniques aiming to maximize light exposure and productivity include: shortening excessively elongating extension shoots and reducing upright crown height to encourage more horizontally oriented lower scaffold branching; thinning out congested areas to improve air circulation and light exposure deep within the canopy (Albrecht & Wiek, 2021; Gold & Hanover, 1987) proactively removing narrow branch unions predisposed to failure under heavy fruit loads along with suppressing undesirable vertical water sprouts that compete with more productive lateral fruiting wood; containing excessive peripheral lateral spread through heading back outward-reaching branches; optimizing light exposure through espalier, cordon, or fan-shaped canopy training against trellises or fencelines (Thevathasan & Gordon, 2004); and periodic coppicing or pollarding of select species to stimulate productive rejuvenation while generating useful wood products (Crawford, 2010). Although pruning during dormancy reduces hydraulic stress, over-pruning may unintentionally increase the risks of sunscalding damage and decrease yields, so a balanced, moderate approach is recommended (Thevathasan & Gordon, 2004). However, many specifics remain unknown regarding how to optimize cultivation techniques and tools for the high diversity and perennial lifecycles inherent to food forests (Frey & Czolba, 2017). Overall, ideal context-specific practices can be improved with more adaptive research quantifying interactions between canopy light dynamics and pruning regimes and disease and pest resistance for various food forest species, configurations, and management goals.

Conclusion

Despite growing interest from farmers, communities, and sustainability scientists, this review of the literature on temperate climate food forests concludes that there are still significant geographic, disciplinary, and methodological knowledge gaps that limit the ability of current scientific research to provide definitive, systematic guidance on optimizing food forest productivity, design, and management. However, collaborative efforts enabling systematic documentation could fill gaps. These efforts could include participatory research on farms, replicated field trials comparing conventional practices through land equivalent ratios (LER), ecosystem service value, and return on investments over time, long-term monitoring and surveys, and multivariate ecological modeling across networks. They could document productivity, soil changes, hydrological impacts, biodiversity, and ecological processes over the full developmental lifecycle. Further long-term interdisciplinary studies on productivity, soil changes, and ecological interactions over the full developmental lifecycle are urgently needed across a diverse range of contexts. Multiple replicated sites spanning climatic and edaphic gradients and diverse management regimes can contribute vital data to address priority research needs.

This research synthesis reveals opportunities for collaborative networks to share costs and resources in establishing replicated food forest trials. Partnerships can provide the scale needed for rigorous system-level experiments that individual projects lack the feasibility to implement independently. Comparative studies using consistent protocols across a collaborative network could obtain empirical evidence on site-specific factors influencing real farm productivity. Findings would support refining monitoring-informed adaptive management interventions tailored to local conditions through experiential learning. In addition, controlled experiments and simulation modeling guided by agroecology and permaculture theory could identify integrated design combinations enhancing food forest performance across contexts. While inadequate data presently prevents broad generalizations, documented yields from maturing demonstration food forests suggest that favorable productivity levels may be achievable under appropriate conditions, helping to mitigate some skepticism. Nevertheless, expanded rigorous data tracking priority species' growth, yields, stress responses, and interactions across diverse scenarios can strengthen our understanding of maximizing temperate multifunctional food forestry potential. Targeting these research gaps through collaborative networks can significantly advance scientific knowledge on optimizing temperate climate food forest establishment and management. Reimagined this way, these ancient integrated systems could positively contribute to localized transformative and regenerative food transitions.

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