Scaling Up Nursery Production for Agroforestry

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Abstract

The agricultural industry will become increasingly vulnerable in the coming decades as the impacts of climate change intensify, putting farmer livelihoods and food security at risk. To mitigate the impacts of increased drought, flooding, and unpredictable climatic regimes, scaling up methods of sustainable agricultural production is critical. Agroforestry—the integration of perennial trees, shrubs, and herbaceous plants into productive agricultural landscapes—is rooted in traditions of Indigenous land stewardship and subsistence farming. Agroforestry has the potential to store greater amounts of carbon than annual cropping systems, improve soil and water health, increase on-farm biodiversity, and reduce nutrient inputs and outputs. In temperate regions, scaling up agroforestry is challenged by barriers to farmer adoption, including lack of technical service assistance, economic pressure toward large-scale, monoculture cropping systems, and limited supply of appropriate planting stock. Despite these barriers, agroforestry is of great interest among farmers and agricultural support organizations, evidenced by the ample representation of agroforestry-related projects funded through the U.S. Department of Agriculture's Partnerships for Climate-Smart Commodities program. This article addresses the limited supply of planting stock for agroforestry and emphasizes the importance of coordinating efforts between agroforestry and reforestation, especially within the nursery industry. This paper was presented at the Joint Annual Meeting of the Northeast Forest and Conservation Nursery Association and the Southern Forest Nursery Association (State College, PA, July 17–20, 2023).

Introduction

In the coming decades, ecological disruptions will intensify, requiring increased development of new and transformative climate adaptation and mitigation strategies (Anderson et al. 2020, Diaz et al. 2019, Lobell and Gourdji 2012). Building a more sustainable and just global food system will necessitate multifaceted, varied methods of adaptation and mitigation (Wezel et al. 2009). Agriculture faces the specific challenge of making revolutionary changes to the way we grow food while also maintaining a dependable food supply and mitigating carbon emissions.

In North America, vulnerabilities are compounded by decades of intensive agricultural practices that degrade soils and water resources, reduce biodiversity, and rely heavily on the production of monoculture crops (Kramer et al. 2019). Dominant agricultural practices rely heavily on annual cropping systems, which often underutilize strategies that could potentially store greater amounts of carbon in soil, improve the health and diversity of ecosystems, and reduce nutrient inputs and outputs (Chenyang et al. 2020, Lal et al. 2007). In addition, agriculture accounts for approximately 18 percent of global greenhouse gas emissions (figure 1), fueling an interest in agricultural practices that store, rather than emit, greenhouse gases (Ritchie and Roser 2023). No single solution exists to these challenges, but approaches exist that can minimize negative outcomes while supporting productive agricultural systems.

Agroforestry is an approach to climate change mitigation and adaptation that involves integrating trees, shrubs, and herbaceous perennial plants into agriculture (figure 2). By intentionally combining trees and shrubs with crops or livestock, agroforestry can offer economic, environmental, social, and cultural benefits to farmers looking to diversify their farm offerings (Gold and Garrett 2009). Aligned with principles of agroecology and regenerative agriculture, agroforestry is a contemporary term for methods of producing food, fiber, fuel, and medicine that are rooted in Indigenous knowledge and have been practiced for thousands of years (Elevitch et al. 2018, Miller and Nair 2006, Rossier and Lake 2014, Wezel et al. 2009).

Implementing agroforestry practices on productive agricultural landscapes can increase soil organic carbon stocks, improve food security and crop yields, increase biodiversity, provide wildlife and pollinator habitat, and mitigate acute effects of climate change, such as heat stress, drought, and flooding (Cardinael et al. 2021, Chenyang et al. 2020, Schoeneberger et al. 2012). As a method of carbon sequestration, agroforestry has the potential to store carbon aboveground and belowground in plant biomass and soil carbon at greater rates than

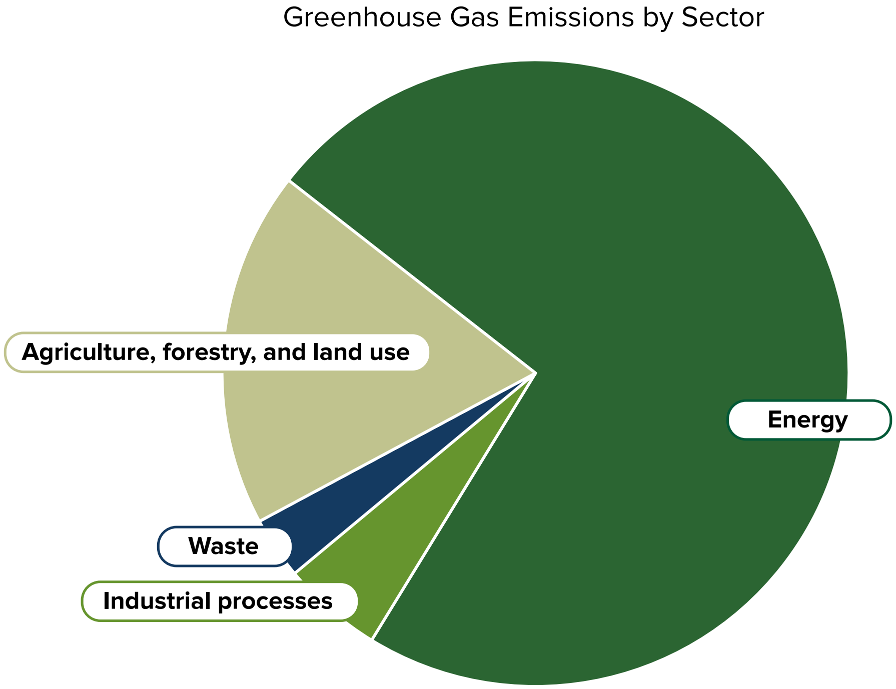

Figure 1. Agriculture, forestry, and land use sectors (beige) account for 18.4 percent of greenhouse gas emissions (not including associated transportation, food processing, packaging, and refrigeration). Electricity, heat, and transportation (dark green), industry (light green), and waste (blue) account for 73.2, 5.2, and 3.2 percent of emissions, respectively. Source: Richie (2020).

climate mitigation strategies used in annual cropping systems, such as cover cropping and no-till (Chenyang et al. 2020). In addition to the important ecological benefits it confers, agroforestry competes economically with conventional farming when the long-term environmental benefits and the cost of negative externalities associated with agriculture are integrated into economic models (Thiesmeier and Zander 2023).

Currently, agroforestry is commonly practiced in tropical regions, where using perennial cropping systems is part of longstanding agricultural traditions (Miller and Nair 2006, Smith 2010). In contrast, modern agricultural production in temperate regions of North America is currently dominated by annual row crop systems. Consequently, agricultural financing programs, crop insurance, education, economic markets for crops, and Federal support programs are shaped

Figure 2. Early silvopasture establishment necessitates protection from both livestock and wildlife. A combination of tree tubes and portable electric fencing can be used to protect tree seedlings (left). The tree tubes protect the tree from rodent girdling and deer rubbing and encourage vertical growth, allowing the tree to get above browse height sooner. Integrating livestock can be an economically viable method of vegetation management during the establishment phase as seen here with Katahdin sheep grazing alongside apple (*Malus* spp.) seedlings (center). Katahdin sheep utilize the shade from naturally established conifer trees intentionally left by the farmer (right). Photos by Alex Caskey, Barred Owl Brook Farm.

to fit large-scale, annual crop production (Carlisle et al. 2022). To scale up agroforestry adoption, current systems of agricultural advising, financing, and market development must be adapted to accommodate perennial crops and diversified farming systems (Valdivia et al. 2012).

This article outlines specific challenges associated with scaling up agroforestry at different stages of the "plant material pipeline," with a focus on the role of plant nurseries. Access to consistent, well-adapted, diverse sources of planting material is not a unique issue; scaling up efforts along the reforestation pipeline are also challenged by limited nursery capacity (Fargione et al. 2021). To better understand the interface between plant production for agroforestry and reforestation, it is important to consider the specialized knowledge, partners, industries, and supply chains of each. Greater collaboration between concerned parties is necessary at every stage of plant production, including ensuring seed supply, producing healthy plants, and generating demand for a diverse range of species. As agroforestry and reforestation scale up, it is mutually beneficial to identify areas where needs overlap and to prioritize collaboration.

A Brief History of Agroforestry

Agroforestry is not a new concept; Indigenous knowledge-holders have been familiar with the practice of combining trees and crops to provide food and ecological benefits for centuries in both tropical and temperate ecosystems (Steppler and Nair 1987). Currently, agroforestry is more widely practiced in tropical and subtropical ecosystems and is less widespread in temperate regions. Even a low level of adoption in temperate zones is impactful. Despite the variability in carbon sequestration estimates, which are influenced by factors such as site characteristics, species composition, system age, management practices, and climate, agroforestry systems have a carbon sequestration potential ranging from 0.12 Pg carbon per year to 0.31 Pg carbon per year (petagram = 10^{15} g) (Terasaki Hart et al. 2023). This potential is comparable to other prominent natural climate solutions, such as reforestation, which has an estimated sequestration potential of 0.27 Pg carbon per year. The U.S. Department of Agriculture (USDA) defines five agroforestry practices: windbreaks and hedgerows, riparian buffer zones, forest farming, silvopasture, and alley cropping or intercropping. To fully conceptualize the versatility of agroforestry, it is helpful to describe the principles that underlie these practices.

Agroforestry is guided by the goal of creating an agroecological system that is mutually beneficial for crops, livestock, the surrounding environment, and the people and cultures who steward the land. Gold and Garrett (2009) describe four key criteria to distinguish agroforestry systems from other land use practices. The first defining principle is that the system must be *intentionally* designed, established, and managed. Secondly, the different elements of the system, including crops, livestock, and trees or shrubs, are *integrated* both structurally and functionally. Integrating physical forms and biological functions creates beneficial relationships between elements of the system. Third, agroforestry systems are *intensively* managed to maintain the functions that the system was designed to fulfill. And fourth, the system cultivates *interactive* relationships among the different components. For example, rows of apple trees planted in an orchard are not considered an agroforestry system; but if livestock were integrated and intensively managed in an interactive manner between orchard rows, that system could be considered agroforestry.

Agroforestry creates a working landscape that provides both economic and environmental benefits to agricultural producers (Van Der Wolf et al. 2019). Goals may vary widely between different agroforestry systems, making it difficult to measure success or provide a simple guide to establishment (Jose 2009). Similar to ecosystem restoration and reforestation, agroforestry can be implemented on marginal farmland, in pastures, or areas that provide multiple ecosystem services such as riparian zones or sensitive ecosystems. For example, an area seasonally inundated with water may not be appropriate for vegetable production but could be suitable for creating a hedgerow of harvestable crops such as elderberry (*Sambucus* spp.) or hazelnut (*Corylus* spp.). Or, depending on the farmer's goals, this same area could be used to establish a riparian buffer to reduce nutrient runoff or to plant living fences to keep livestock out of streams. Agroforestry can also be integrated into annual cropping systems, though there is potential for reduced yields if competitive interactions are not intentionally managed (Reynolds et al. 2007). To ensure beneficial impacts, the integration of perennial crops must be designed to fit into the local context, which includes accommodating local environmental conditions, farmer priorities, and relevant local markets (Brown et al. 2018).

Scaling Up: The Agroforestry Plant Material Pipeline and Associated Barriers

Scaling up agroforestry in the United States is limited by a range of factors, including a shortage of professional consulting agroforesters and technical support staff, costs associated with establishment and management of plantings, and insufficient knowledge of tree crop management among landowners and farmers (Kronenburg et al. 2023, Stanek & Lovell 2020). A growing interest in implementing agroforestry practices in agricultural systems exists, demonstrated by an increasing number of organizations advocating for policy development, increased financial and educational resources, and improved coordination among agroforesters, farmers, nurseries, and researchers. Through the Partnership for Climate-Smart Commodities program, USDA has placed greater emphasis on promotion of agroforestry practices by distributing approximately $802 million in the program's first year to support 39 projects that include an element of agroforestry. Though not specific to agroforestry, the Inflation Reduction Act of 2022 pledged $18 billion toward climate-smart agricultural practices, enacted through conservation programs such as the Environmental Quality Incentives Program, Conservation Stewardship Program, and Conservation Reserve Program. While this support has generated huge opportunities, these programs are often criticized for their inflexibility and must be adapted to support multifunctional agricultural systems (Stanek and Lovell 2020).

Limited access to appropriate plant material is one of the primary barriers to scaling up agroforestry, which is a familiar logistical barrier to conservation professionals across the United States who must procure a wide variety of plant materials for use in restoration and reforestation plantings (Fargione et al. 2021, Jalonen et al. 2018). Current nursery production levels are inadequate to meet expanded reforestation goals, which estimate 128 million acres of land available for increased tree cover (Chizmar et al. 2022, Fargione et al. 2021, McCormick et al. 2021, Piñeiro et al. 2020, Sow et al. 2018, White et al. 2018). Similar to the challenges faced by reforestation projects, which use many of the same plant species as riparian buffer, windbreak, or hedgerow plantings, procuring plant material that is both appropriately adapted to regional conditions and can be purchased in the specific quantities and varieties necessary for a desired planting can be a significant hurdle for agroforestry adopters. As reforestation and agroforestry efforts are scaled up, nurseries will need to dramatically increase production to meet the projected demand for trees, shrubs, and herbaceous perennials (Cardinael et al. 2021, Chenyang et al. 2020, Fargione et al. 2021).

To better understand the barriers in the plant material pipeline, it is helpful to describe the four stages of the pipeline (figure 3). The pipeline begins by (1) sourcing germplasm—gathering appropriate propagative material; (2) plant production—the collected germplasm is used to grow

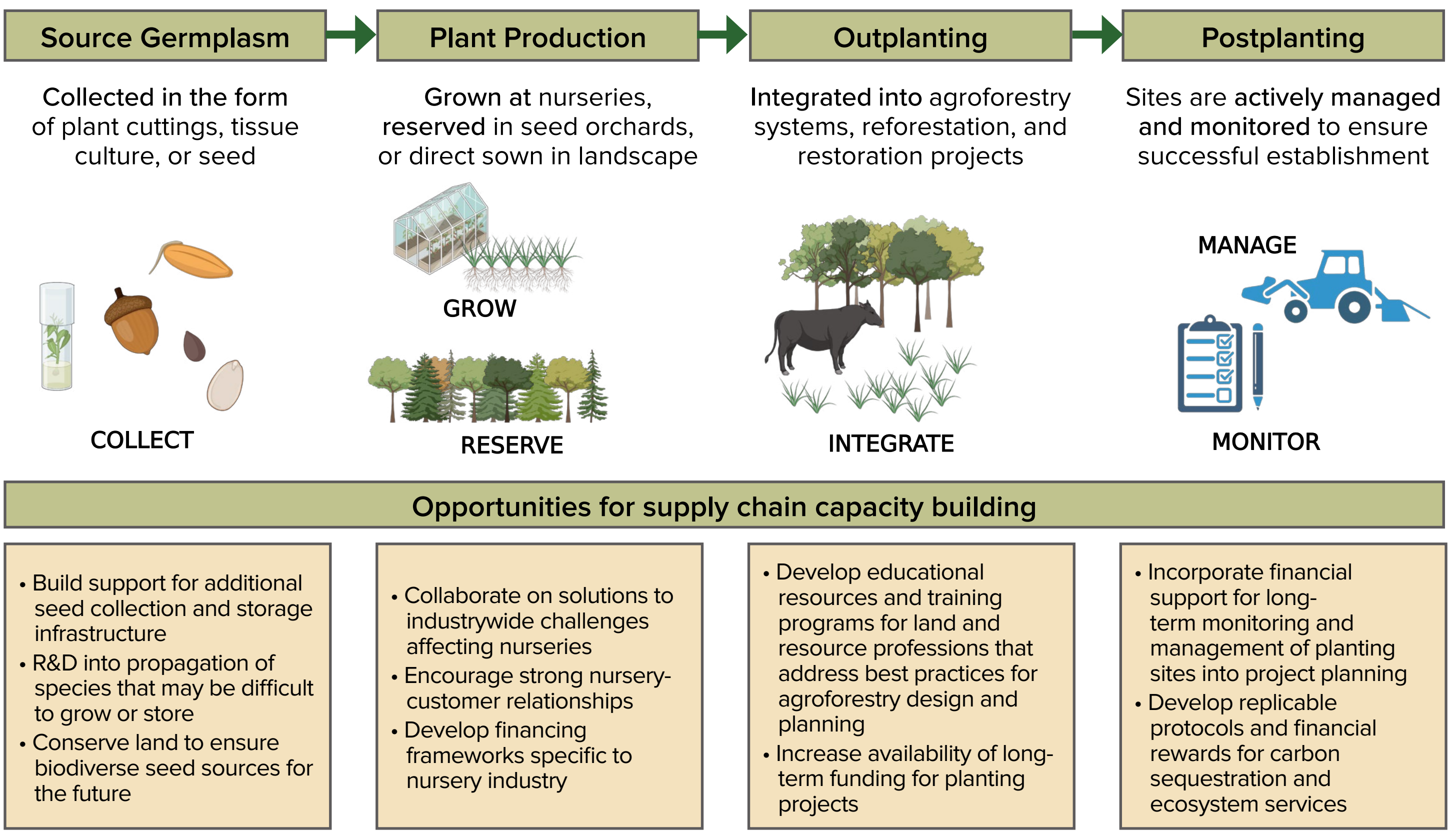

Figure 3. At each stage of plant material flow within agroforestry, reforestation, and restoration projects, opportunities exist for collaboration across these disciplines. These opportunities are not exhaustive but offer a starting point for future conversations.

plants at a nursery or is seeded directly onto a landscape to be conserved or used as a seed orchard; (3) outplanting—species are selected based on project goals, local landscape, and availability and then established in the landscape; and (4) postplanting—plants are monitored and maintained to ensure successful establishment and production and to help producers access markets for their products (from carbon credits to fruit and nut crops). These four stages are described in more detail in subsequent sections.

The process of species selection weaves itself into every stage of the plant material pipeline. The diversity of plant material needed for agroforestry presents a unique challenge for scaling up production. For example, a crop-oriented system may require specific cultivars that can produce a commercially viable fruit or nut crop. On the other hand, an agroforestry system oriented towards improving water quality and wildlife habitat may require native species from regionally sourced seed. Most nurseries can grow a wide range of plants, but it often requires sourcing young plant material from other nurseries. In addition, based on the plant material being grown, the inputs, equipment, and knowledge needed to grow specific plants can vary. For this reason, it is important to communicate project needs to regional nurseries far in advance to give growers adequate time to source and grow plant material.

When sourcing germplasm, propagative material may be collected by the nurseries, independent contractors who specialize in seed collection, or via federally funded programs like Seeds of Success. These collectors often make choices about where seed is collected from and what plant genetics will be represented based on specific project objectives (Harrison et al. 2023). Nurseries make decisions about what species to grow based on customer demands. The Target Plant Concept (TPC) (Dumroese et al. 2016, Rose et al. 1990) emphasizes the importance of feedback and communication in a nursery-client partnership to guide choices for species selection and stock specifications and to improve plant performance in outplanting sites. The TPC, though developed for forest restoration, can be applied to agroforestry as well.

Selection of species, genetic sources, and stock types are as diverse as the environments where agroforestry or reforestation are implemented, and decisions made by those who supply and purchase plants can have huge impacts on long-term ecosystem health (White et al. 2018). For reforestation, restoration, and agroforestry projects, plant selection should be based on site conditions and planting goals (Jalonen et al. 2018). Careful consideration of impacts on native plant communities and potential for invasiveness must also be factored into selections. Due to the specific needs of each project and site, it can be challenging to form lists or guides that detail the appropriate species to use in agroforestry and reforestation. To help better inform efforts to scale up production and adoption, there is currently a list of popular species for agroforestry in development by the National Agroforestry Center, a program run jointly by USDA's Forest Service and Natural Resources Conservation Service in Lincoln, NE. Additionally, a list of potential agroforestry species was developed for the State of Vermont through Vermont Farm-to-Plate, which may be useful to growers in plant hardiness zones 3, 4, and 5 (Toensmeier 2023).

Sourcing Germplasm

Plant material may be generated from (a) stem or root cuttings, (b) tissue culture, or (c) seed (figures 4 and 5). Some species used in agroforestry systems may need to be clonally propagated or improved for commercial agricultural production. For example, if the goal of the agroforestry system is to produce a fruit crop such as pears (*Pyrus* spp.) or black currant (*Ribes nigrum* L.), the parent plant is often a cultivated variety that reliably produces a consistent, robust crop. To clonally propagate (through tissue culture, grafting, cuttings, or carefully controlled

Figure 4. Northern pecan (*Carya illinoinensis* [Wangenh.] K. Koch) seeds beginning to sprout (left). This variety of pecan was selected for its short growing season, cold hardiness, and culinary attributes. These unique characteristics come at a cost of $2.20/seed to the nursery grower. Seed collection and sourcing are important for agroforestry; here (right), workers collect black walnuts (*Juglans nigra* L.) from mature, naturally established trees on a farm in Parks, AR. Photos by Alex Caskey, Barred Owl Brook Farm.

Figure 5. Cuttings, such as willow (*Salix* spp.) (left), and grafted plants, such as honey locust (*Gleditsia triacanthos* L.) (center) and mulberry (*Morus* spp.) (right), grown at Barred Owl Brook Farm in Westport, NY, are common propagative material for agroforestry plants. Photos by Alex Caskey, Barred Owl Brook Farm.

seed production) and breed plants that can be used for food production, the equipment, material supply chain, skill set, and labor needs differ from growing plants from seed. For example, hazelnuts can be propagated clonally through stooling, but there are production limits to this approach. Producing large numbers of clonal plants for commercial use requires the establishment of breeding programs, variety trials, and access to facilities such as tissue culture labs for clonal propagation.

While the development of improved plant varieties is a unique challenge, a robust, genetically diverse seed supply is a vital aspect of the plant supply for agroforestry, especially for practices like hedgerow or riparian buffer establishment. For production-oriented agroforestry systems, the conservation and use of landrace varieties, which have high levels of genetic diversity, play a crucial role in developing resilient crops that can adapt to a wide variety of environmental conditions (Martín et al. 2017). Presently, insufficient native seed is available to satisfy current and projected demand (Harrison et al. 2023). This bottleneck is exacerbated by the increasing loss of areas used for seed production due to urban development and other disturbances such as wildfires (Harrison et al. 2023, Jalonen et al. 2018). Due to the specialized skills, knowledge, and equipment associated with tasks like seed cleaning, tissue culturing, and plant breeding, a single nursery will often focus on filling a specific demand category. As agroforestry and reforestation are scaled up, it is vital to support a wide variety of nurseries, both big and small, to facilitate a diverse plant supply.

Plant Production

Propagative material may be grown at a nursery facility, in a seed orchard, or sown directly into the landscape (figure 6). Not all plant material is grown to be sold. A subset of

Figure 6. Chestnut (*Castanea* spp.) burr (left) and hybrid chestnut seedlings (right), shown here at the East Hill Tree Farm nursery in Plainfield, VT, is an example of a plant being produced for agroforestry. Photos by Nicko Rubin, East Hill Tree Farm.

propagated plants may be conserved to be used as a future source of propagative material (Harrison et al. 2023). No national studies, quantitative or qualitative, have assessed the extent of nursery production for agroforestry systems. However, nearly any woody perennial can be used in an agroforestry system, assuming it provides food, fiber, fuel, or ecosystem services in the landscape. Consequently, many nurseries are already growing, or equipped to grow, appropriate species for agroforestry (Gold and Garrett 2009). For example, in the Northeast United States, elderberry is often grown for berry production, landscaping, and riparian restoration projects, and can benefit farmers who may want to establish an alley cropping system that produces a fruit that can be harvested and sold.

Figure 7. Improved willow (*Salix* spp.) and poplar (*Populus* spp.) trees were planted at Barred Owl Brook Farm (Westport, NY) to establish living fence posts that will restrict livestock access to the adjacent drainage channel (left). The trees will also provide shade and tree fodder for sheep in addition to myriad ecological benefits for wildlife (right). Photos by Alex Caskey, Barred Owl Brook Farm.

Studies evaluating nursery production of perennial trees and shrubs can give us broad insights into the ability of nurseries to produce plants for agroforestry. Forest and conservation nurseries in the United States produced 1.27 billion tree seedlings specifically for reforestation and conservation plantings (Haase et al. 2020). A portion of those seedlings were likely used to establish windbreaks, riparian buffers, or silvopasture or intercropping systems. Reforestation, restoration, and agroforestry plantings often rely on the same State, Tribal, Federal, and private nurseries to supply plant material and are equally affected by industrywide challenges. Enhancing nursery production for multiple purposes and connecting producers to demand can foster progress toward the protection of both natural and agriculturally productive ecosystems.

When asked about constraints to expansion, workforce and uncertainty about demand were reported as the most ubiquitous challenges facing nurseries. After labor, market risks and financing were the most common limitations (Fargione et al. 2021). NurseryMag's 2022 "State of the Industry" report corroborates this, with nurseries reporting that labor issues (65 percent of participants reported), increased expenses (63 percent), and the economy (67 percent) as their biggest challenges (NurseryMag 2022). While these surveys can give broad insights into challenges faced by the nursery industry, there is a need to generate more indepth information about specific barriers.

Outplanting

After plants have been propagated, they must be integrated into agroforestry, restoration, or reforestation plantings (figure 7). The success of outplanting in an agroforestry system is dependent on many of the same factors as those in a reforestation project: compatibility of plant species and the specific environment, use of proper planting techniques, and appropriate care and monitoring after they establish. In addition to these challenges, planning an agroforestry system can be a complex endeavor, and successful outplanting requires specialized knowledge about agroforestry system design. Careful and knowledgeable planning must be done to manage interactions between trees, shrubs, crops, and groundcovers. Successful outplanting requires careful consideration of root interactions, allelopathy, nutrient cycling, water requirements, ecosystem services, and potential complementary or competitive relationships among species. A shortage of knowledgeable technical service providers and land use professionals, who may not be familiar with agroforestry practices and have limited opportunities for agroforestry training, can have a negative effect on outplanting success (Stanek and Lovell 2020, Workman et al. 2003).

Based on the goals and design, successful plant establishment in an agroforestry system may require more intensive management than restoration and reforestation projects. For example, irrigation systems, tree tubes, and deer fencing may need to be installed to protect the landowner's investments. Agroforestry plantings may also require additional materials, such as mulch, fertilizer, and compost, that raise the cost associated with the project. Procuring plants can be a challenge, especially when there are limited local sources of plant material or a project uses specific cultivars from a variety of specialized nurseries. While conservation-oriented plantings often rely on large amounts of low-cost plants, this contrasts with many agroforestry plantings, where plants may have been selected for improved genetics and often come at a higher cost per plant.

Postplanting

For an agroforestry system, the work has only just begun once roots are in the ground. One of the key principles defining agroforestry systems is that they must be intensively managed. Short funding timelines and lack of planning can often result in low survival rates in reforestation and restoration plantings. In an agroforestry system, where plants may be used for agricultural production, growers must be able to financially support themselves until the system begins producing a crop, which could take 5 to 7 years for some fruit and nut trees.

Establishing agroforestry systems involves entering a long-term relationship with the management and evolution of that system. As the plants grow, the system will need to be maintained and adjusted to adapt to changes in light, water, and maintenance needs. This maintenance may include pest and weed control, nutrient management, pruning and thinning, and water management. The intensity of management may range based on the system. For example, a riparian buffer zone may only require periodic removal of invasive species, while an alley cropping system with both annual and perennial crops will require frequent management typical in agriculture.

Beyond maintenance considerations, the long-term success of agroforestry systems requires access to developed markets for agroforestry products, monitoring of environmental benefits and potential carbon sequestration, and access to continuing education and training for landowners and technical service providers. For systems that do not produce a crop, it is vital to provide landowners with incentives to maintain plantings on their land, which may include payment for ecosystem services or carbon sequestration. A significant knowledge gap in the carbon sequestration potential of both reforestation and agroforestry exists currently (Terasaki Hart et al. 2023).

Conclusion

The challenges associated with obtaining well-adapted sources of plant material is documented in literature surrounding reforestation but less well-documented for agroforestry. Preliminary research indicates that barriers to scaling up are similar for reforestation and agroforestry, and that expanding access to planting stock would be beneficial for both communities. Both communities are affected by the need for diverse, regionally adapted planting stock as well as the overarching challenges of finding skilled laborers, high market risk, and poor financing opportunities (Fargione et al. 2021, Haase and Davis 2017, NurseryMag 2022).

While plant production for agroforestry and reforestation differ in significant ways, they both engage with similar players, notably the nursery industry. Moreover, they share the common goals of sequestering carbon and improving ecosystem resilience at a time when the health and resilience of the planet's forests and agricultural systems are threatened by a rapidly changing climate. While pursuing the restoration of natural and agro-ecosystems amid significant ecological change, it is beneficial to collaboratively develop frameworks to incentivize reforestation and agroforestry plantings and to support the growers that make these projects possible.

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References

Anderson, R.; Bayer, P.E.; Edwards, D. 2020. Climate change and the need for agricultural adaptation. Current Opinion in Plant Biology. 56: 197–202. https://doi.org/10.1016/j.pbi.2019.12.006.

Brown, S.E.; Miller, D.C.; Ordonez, P.J.; Baylis, K. 2018. Evidence for the impacts of agroforestry on agricultural productivity, ecosystem services, and human well-being in high-income countries: a systematic map protocol. Environmental Evidence. 7: 24. https://doi.org/10.1186/s13750-018-0136-0.

Cardinael, R.; Cadisch, G.; Gosme, M.; Oelbermann, M.; van Noordwijk, M. 2021. Climate change mitigation and adaptation in agriculture: why agroforestry should be part of the solution. Agriculture, Ecosystems & Environment. 319: 107555. https://doi.org/10.1016/j.agee.2021.107555.

Carlisle, L.; Esquivel, K.; Baur, P.; Ichikawa, N.F.; Olimpi, E.M.; Ory, J.; Waterhouse, H.; Iles, A.; Karp, D.S.; Kremen, C.; Bowles, T.M. 2022. Organic farmers face persistent barriers to adopting diversification practices in California's central coast. Agroecology and Sustainable Food Systems. 46: 1145–1172. https://doi.org/10.1080/21683565.2022.2104420.

Chenyang, L.; Currie, A.; Darrin, H.; Rosenberg, N. 2020. Farming with trees: reforming U.S. farm policy to expand agroforestry and mitigate climate change. Ecology Law Quarterly. 48. https://doi.org/10.2139/ssrn.3717877.

Chizmar, S.; Parajuli, R.; Frey, G.E.; Bardon, R.E.; Branan, R.A.; MacFarland, K.; Smith, M.; Ameyaw, L. 2022. Challenges and opportunities for agroforestry practitioners to participate in state preferential property tax programs for agriculture and forestry. Trees, Forests and People. 7: 100176. https://doi.org/10.1016/j.tfp.2021.100176.

Diaz, S.; Setelle, J.; Brondizio, E.; Hien, N.; Agard, J.; Arneth, A.; Balvanera, P.; Brauman, K.; Butchart, S.; Chan, K.; Garibaldi, L.; Ichii, K.; Liu, J.; Subramanian, S.; Midgley, G.; Miloslavich, P.; Molnar, Z.; Obura, D.; Pfaff, A.; Polasky, S.; Purvis, A.; Razzaque, J.; Reyers, B.; Chowdhury, R.R.; Shin, Y.J.; Visseren-Hamakers, I.; Willis, K.; Zayas, C. 2019. Pervasive human-driven decline of life on Earth points to the need for transformative change. Science. 366. https://doi.org/10.1126/science.aax3100.

Dumroese, R.K.; Landis, T.D.; Pinto, J.R.; Haase, D.L.; Wilkinson, K.W.; Davis, A.S. 2016. Meeting forest restoration challenges: using the target plant concept. Reforesta. 1: 37–52. https://doi.org/10.21750/REFOR.1.03.3.

Elevitch, C.R.; Mazaroli, D.N.; Ragone, D. 2018. Agroforestry standards for regenerative agriculture. Sustainability. 10: 3337. https://doi.org/10.3390/su10093337.

Fargione, J.; Haase, D.L.; Burney, O.T.; Kildisheva, O.A.; Edge, G.; Cook-Patton, S.C.; Chapman, T.; Rempel, A.; Hurteau, M.D.; Davis, K.T.; Dobrowski, S.; Enebak, S.; De La Torre, R.; Bhuta, A.A.R.; Cubbage, F.; Kittler, B.; Zhang, D.; Guldin, R.W. 2021. Challenges to the reforestation pipeline in the United States. Frontiers in Forests and Global Change. 4. https://doi.org/10.3389/ffgc.2021.629198.

Gold, M.A.; Garrett, H.E. 2009. Agroforestry nomenclature, concepts, and practices. In: Garrett, H.E., ed. Madison, WI: American Society of Agronomy and Soil Science Society of America: 45–56. https://doi.org/10.2134/2009.northamericanagroforestry.2ed.c3.

Haase, D.L.; Davis, A.S. 2017. Developing and supporting quality nursery facilities and staff are necessary to meet global forest and landscape restoration needs. Reforesta. 4: 69–93. https://doi.org/10.21750/REFOR.4.06.45.

Harrison, S.P.; Atcitty, D.; Feigner, R.; Goodhue, R.; Havens, K.; House, C.C.; Johnson, R.C.; Leger, E.; Lesser, V.; Opsomer, J.; Shaw, N.; Soltis, D.E.; Swinton, S.M.; Toth, E.; Young, S.A. 2023. An assessment of native seed needs and the capacity for their supply: final report. Washington, DC: National Academies Press. 228 p.

Jalonen, R.; Valette, M.; Boshier, D.; Duminil, J.; Thomas, E. 2018. Forest and landscape restoration severely constrained by a lack of attention to the quantity and quality of tree seed: insights from a global survey. Conservation Letters. 11: 12424. https://doi.org/10.1111/conl.12424.

Jose, S. 2009. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems. 76: 1–10. https://doi.org/10.1007/s10457-009-9229-7.

Kramer, A.T.; Crane, B.; Downing, J.; Hamrick, J.L.; Havens, K.; Highland, A.; Jacobi, S.K.; Kaye, T.N.; Lonsdorf, E.V.; Ramp Neale, J.; Novy, A.; Smouse, P.E.; Tallamy, D.W.; White, A.; Zeldin, J. 2019. Sourcing native plants to support ecosystem function in different planting contexts. Restoration Ecology. 27: 470–476. https://doi.org/10.1111/rec.12931.

Kronenberg, R; Lovell, S; Hall, D; Harmon-Threatt, A. 2023. Missouri natural resource professionals share key insights for supporting agroforestry practices through cost-share funding available from USDA conservation programs. Renewable Agriculture and Food Systems. 38. e18, 1–9. https://doi.org/10.1017/S1742170523000054.

Lal, R.; Follett, R.F.; Stewart, B.A.; Kimble, J.M. 2007. Soil carbon sequestration to mitigate climate change and advance food security. Soil Science. 172(12): 943–956. https://doi.org/10.1097/ss.0b013e31815cc498.

Lobell, D.B.; Gourdji, S.M. 2012. The influence of climate change on global crop productivity. Plant Physiology. 160: 1686–1697. https://doi.org/10.1104/pp.112.208298.

Martín, M.A.; Mattioni, C.; Cherubini, M.; Villani, F.; Martín, L.M. 2017. A comparative study of European chestnut varieties in relation to adaptive markers. Agroforestry Systems. 91: 97–109. https://doi.org/10.1007/s10457-016-9911-5.

McCormick, M.L.; Carr, A.N.; Massatti, R.; Winkler, D.E.; De Angelis, P.; Olwell, P. 2021. How to increase the supply of native seed to improve restoration success: the US native seed development process. Restoration Ecology. 29: e13499. https://doi.org/10.1111/rec.13499.

Miller, R.P.; Nair, P.K.R. 2006. Indigenous agroforestry systems in Amazonia: from prehistory to today. Agroforestry Systems. 66: 151–164. https://doi.org/10.1007/s10457-005-6074-1.

NurseryMag. 2022. 2022 state of the industry report: research. Nursery Magazine. 30–38. https://www.nurserymag.com/magazine/september-2022/. (February 2024)

Piñeiro, V.; Arias, J.; Dürr, J.; Elverdin, P.; Ibáñez, A.M.; Kinengyere, A.; Opazo, C.M.; Owoo, N.; Page, J.R.; Prager, S.D.; Torero, M. 2020. A scoping review on incentives for adoption of sustainable agricultural practices and their outcomes. Nature Sustainability. 3: 809–820. https://doi.org/10.1038/s41893-020-00617-y.

Reynolds, P.E.; Simpson, J.A.; Thevathasan, N.V.; Gordon, A.M. 2007. Effects of tree competition on corn and soybean photosynthesis, growth, and yield in a temperate tree-based agroforestry intercropping system in southern Ontario, Canada. Ecological Engineering. 29: 362–371. https://doi.org/10.1016/j.ecoleng.2006.09.024.

Ritchie, H.; Roser, M., eds. 2020. Sector by sector: where do global greenhouse gas emissions come from? Our World in Data. https://ourworldindata.org/ghg-emissions-by-sector. (December 2023)

Rose, R.; Carlson, W.C.; Morgan, P. 1990. The target seedling concept. In: Rose, R.; Campbell, S.J.; Landis, T.D., eds. Target Seedling Symposium: Proceedings of the Combined Meeting of the Western Forest Nursery Assoc. Gen. Tech. Rep. RM-200. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 1–8.

Rossier, C.; Lake, F. 2014. Indigenous traditional ecological knowledge in agroforestry. Agroforestry Note 44, General 14. Lincoln, NE: U.S. Department of Agriculture, Forest Service, Washington Office Research and Development, National Agroforestry Center and U.S. Department of Agriculture, Natural Resource Conservation Service. 8 p.

Schoeneberger, M.; Bentrup, G.; Gooijer, H.; Soolanayakanahally, R.; Sauer, T.; Brandle, J.; Zhou, X.; Current, D. 2012. Branching out: agroforestry as a climate change mitigation and adaptation tool for agriculture. Journal of Soil and Water Conservation. 67: 128A–136A. https://doi.org/10.2489/jswc.67.5.128A.

Smith, J. 2010. The history of temperate agroforestry. Gloucestershire, UK: The Organic Research Centre. 17 p.

Sow, M.D.; Allona, I.; Ambroise, C.; Conde, D.; Fichot, R.; Gribkova, S.; Jorge, V.; Le-Provost, G.; Pâques, L.; Plomion, C.; Salse, J.; Sanchez-Rodriguez, L.; Segura, V.; Tost, J.; Maury, S. 2018. Epigenetics in forest trees: state of the art and potential implications for breeding and management in a context of climate change. Advances in Botanical Research. 88: 387–453. https://doi.org/10.1016/bs.abr.2018.09.003.

Stanek, E.C.; Lovell, S.T. 2020. Building multifunctionality into agricultural conservation programs: lessons learned from designing agroforestry systems with central Illinois landowners. Renewable Agriculture and Food Systems. 35: 313–321. https://doi.org/10.1017/S1742170518000601.

Steppler, H.A.; Nair, P.K.R. 1987. Agroforestry, a decade of development. Nairobi, Kenya: International Council for Research in Agroforestry. 335 p.

Terasaki Hart, D.E.; Yeo, S.; Almaraz, M.; Beillouin, D.; Cardinael, R.; Garcia, E.; Kay, S.; Lovell, S.T.; Rosenstock, T.S.; Sprenkle-Hyppolite, S.; Stolle, F.; Suber, M.; Thapa, B.; Wood, S.; Cook-Patton, S.C. 2023. Priority science can accelerate agroforestry as a natural climate solution. Nature Climate Change. 13: 1179–1190. https://doi.org/10.1038/s41558-023-01810-5.

Thiesmeier, A.; Zander, P. 2023. Can agroforestry compete? A scoping review of the economic performance of agroforestry practices in Europe and North America. Forest Policy and Economics. 150: 102939. https://doi.org/10.1016/j.forpol.2023.102939.

Toensmeier, E. 2023. Agroforestry resources: 2023 Vermont agroforestry species report. Montpelier, VT: Farm-to-Plate. https://www.vtfarmtoplate.com/agroforestry. (December 2023)

Valdivia, C.; Barbieri, C.; Gold, M.A. 2012. Between forestry and farming: policy and environmental implications of the barriers to agroforestry adoption. Canadian Journal of Agricultural Economics. 60: 155–175. https://doi.org/10.1111/j.1744-7976.2012.01248.x.

Van Der Wolf, J.; Jassogne, L.; Gram, G.; Vaast, P. 2019. Turning local knowledge on agroforestry into an online decision-support tool for tree selection in smallholders' farms. Experimental Agriculture. 55: 50–66. https://doi.org/10.1017/S001447971600017X.

Wezel, A.; Bellon, S.; Doré, T.; Francis, C.; Vallod, D.; David, C. 2009. Agroecology as a science, a movement and a practice: a review. Agronomy for Sustainable Development. 29: 503–515. https://doi.org/10.1051/agro/2009004.

White, A.; Fant, J.B.; Havens, K.; Skinner, M.; Kramer, A.T. 2018. Restoring species diversity: assessing capacity in the U.S. native plant industry. Restoration Ecology. 26: 605–611. https://doi.org/10.1111/rec.12705.