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Review

Agroforestry Standards for Regenerative Agriculture

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Abstract: Agroforestry is increasingly being recognized as a holistic food production system that can have numerous significant environmental, economic, and social benefits. This growing recognition is paralleled in the USA by the budding interest in regenerative agriculture and motivation to certify regenerative practices. Current efforts to develop a regenerative agriculture certification offer an opportunity to consider agroforestry's role in furthering regenerative goals. To understand this opportunity, we first examine how agroforestry practices can advance regenerative agriculture's five core environmental concerns: soil fertility and health, water quality, biodiversity, ecosystem health, and carbon sequestration. Next, we review a subset of certification programs, standards, guidelines, and associated scientific literature to understand existing efforts to standardize agroforestry. We determine that development of an agroforestry standard alongside current efforts to certify regenerative agriculture offers an opportunity to leverage common goals and strengths of each. Additionally, we determine that there is a lack of standards with measurable criteria available for agroforestry, particularly in temperate locations. Lastly, we propose a framework and general, measurable criteria for an agroforestry standard that could potentially be implemented as a standalone standard or built into existing agriculture, forestry, or resource conservation certification programs.

Keywords: agroforestry; ecosystem services; measurable criteria; certification standard; biodiversity; breadfruit; agroecosystem; regenerative agriculture

1. Introduction

There is a growing movement in the USA to develop a certification for agricultural systems that are deemed not just sustainable, but regenerative in their outcomes [1,2]. This provides a unique opportunity and imperative to rethink the design and implementation of agricultural systems that not only maximize productivity, but also ecosystem and socioeconomic benefits.

Fueled by frustrations with the enforcement of the United States Department of Agriculture (USDA) organic standards [3] and proposed changes to the National Organic Standards Board governance [4,5], there has been a growing desire by many farmers and food producers in the USA to distinguish practices that "go beyond" the requirements of USDA Organic certification in terms of their beneficial impacts to the environment [5,6]. In September 2017, a consortium of food producers and farming organizations released the *Recommended Framework for Regenerative Organic Certification* [7]. While there are a handful of other efforts currently underway to certify regenerative agriculture, this paper draws upon the Regenerative Organic Certification (ROC) certification effort (the second version of which was released in March 2018 [8]).

There is currently no uniformly accepted definition of regenerative agriculture. In light of this, we provide three descriptions of regenerative agriculture and its associated practices to consider:

- "Regenerative organic agriculture is marked by tendencies towards closed nutrient loops, greater diversity in the biological community, fewer annuals and more perennials, and greater reliance on internal rather than external resources." [9].
- "Practices that: (i) contribute to generating/building soils and soil fertility and health; (ii) increase water percolation, water retention, and clean and safe water runoff; (iii) increase biodiversity and ecosystem health and resiliency; and (iv) invert the carbon emissions of our current agriculture to one of remarkably significant carbon sequestration thereby cleansing the atmosphere of legacy levels of CO_2." [10].
- "Unifying principles consistent across regenerative farming systems include: (1) abandoning tillage (or actively rebuilding soil communities following a tillage event); (2) eliminating spatio-temporal events of bare soil; (3) fostering plant diversity on the farm; and (4) integrating livestock and cropping operations on the land." [11].

While these three descriptions may present somewhat differing perspectives on the specific goals and supporting practices of regenerative agriculture, they highlight several universal themes. For the purpose of our analysis and proposed agroforestry standards, we summarize the broad regenerative agriculture goals as follows:

1. **Soil**: Contribute to building soils along with soil fertility and health.
2. **Water**: Increase water percolation, water retention, and clean and safe water runoff.
3. **Biodiversity**: Enhance and conserve biodiversity.
4. **Ecosystem health**: Capacity for self-renewal and resiliency [12,13].
5. **Carbon**: Sequester carbon.

The following section outlines the potential for agroforestry systems to achieve these regenerative goals.

2. Agroforestry as a Regenerative System

There are numerous definitions for agroforestry [14–17]. The USDA definition [18] that is frequently cited and captures many common themes of other agroforestry definitions states, "the intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits". A basic agroforestry configuration is simply the integration of suitable woody perennials into an agricultural landscape [19]. On the other end of the spectrum is the complex structure of multistory, multifunctional, agroforestry systems [17,20]. In this paper, "agroforestry system" and "agroforest" are used to refer in general to systems that fall within the USDA definition of agroforestry, while "agroforestry practice" refers to specific and recognized applications of agroforestry (e.g., windbreak, alley cropping, etc., see Section 3.1). As a "multifunctional working landscape" [21], the promise of agroforestry is twofold: (1) a diverse, multi-layer food production system; and (2) a resource conservation and/or ecological restoration land use method.

Agroforestry is seen as a holistic food production system addressing social, ecological, and economic goals [16,22], the regenerative outcomes of which have been recognized and fostered over time. While agroforestry is a relatively new term coined in the 1970s, its principles and methods have been applied for millennia throughout the world in both temperate and tropical regions [23,24]. Through careful observation of natural forests, including how forests reestablish after disturbances such as fires or severe storms, and trial and error over many generations, diverse, multifunctional agroforestry was developed traditionally as a foundation for food production throughout the world. There is an indigenous/traditional body of knowledge that substantiates the promise and potential of agroforestry as a regenerative strategy [23–26].

A testament to agroforests' ability to sustain themselves over generations is the indigenous cultivation of breadfruit (*Artocarpus altilis*), which has taken place over millennia and up to the present day in highly biodiverse multistory perennial agroforests in the Pacific Islands. The breadfruit is a signature tree of traditional agroforestry systems (Figure 1) throughout Oceania, on volcanic islands as well as low-lying coral atolls [27]. The landscape coverage, complexity, and diversity of plants grown together with breadfruit can be impressive. Breadfruit agroforests on the island of Pohnpei, Federated States of Micronesia, epitomize these systems by incorporating more than 120 useful species, as well as 50 cultivars of breadfruit [28,29]. Up until very recently, breadfruit has exclusively been grown in traditional agroforestry systems as diverse multistory polycultures [30]. The cultivation of breadfruit in commercial monocultures began approximately 10 years ago and appears to be rapidly expanding on a large scale in the Pacific Islands, the Caribbean, and to a lesser extent in Central America and West Africa. These commercial breadfruit monocultures lack the regenerative characteristics of the traditional multistory agroforest and underscore a need to understand how to measure and support agroforestry systems and practices that yield regenerative outcomes.

Figure 1. This young Samoan breadfruit agroforest integrates numerous crops including banana (*Musa* spp.), noni (*Morinda citrifolia*), cacao (*Theobroma cacao*), poumuli (*Flueggea macrophylla*), and coconut (*Cocos nucifera*). The structure and diversity of crops is an instructive model for regenerative agroforestry.

The global spectrum of agroforestry systems and practices is important to note. Climatic, physiographic, and socioeconomic variations influence the types of agroforestry practices used and systems yielded across the world [24,31,32]. For example, agroforestry is prevalent in traditional land use systems across India. Agroforestry systems of *Erythrina indica* trees shading coffee (*Coffea* spp.) and acting as a support tree for black pepper (*Piper nigra*) vines are common in the Western Ghats of Kerala, India [33]. In the northeastern Himalayan region of India, another common system is the highly productive and widely practiced intercropping of pineapple (*Ananas comosus*) and black pepper beneath the areca nut palm (*Areca catechu*) [34]. In the Hararghe highlands of Eastern Ethiopia and other areas across sub-Saharan Africa, *Faidherbia albida* (formerly *Acacia albida*) has traditionally been grown as a permanent tree crop with cereals, vegetables, and coffee underneath [35,36].

Though less diverse and widespread than the tropical agroforestry systems of lower latitudes, there is also a long tradition of agroforestry in temperate zones [32], with practices that are largely informed by the distinct seasonality of temperate climates and the existing natural systems [24,31]. In Europe, the traditional dehesa systems of Spain and montado systems of Portugal are closely related examples of temperate multifunctional agroforestry systems on the Iberian Peninsula. The Portuguese montado is internationally recognized for its agro-silvopastral system of cork, holm oak, and livestock, producing a global majority of cork [37,38].

Furthermore, the scope of and interest in temperate agroforestry continues to expand [19]. The European initiative AGFORWARD (AGroFORestry that Will Advance Rural Development [39]) conducts research on these systems and convenes stakeholders from both of these countries and systems to understand producers' needs [40,41]. In an example from the temperate regions of the USA, the University of Illinois created a long-term temperate multistory agroforestry trial, "Agroforestry for Food," inspired by the original oak savanna and prairie of the Central Illinois landscape [19,42]. This trial is testing the performance of multifunctional woody polyculture configurations to understand their potential as "an alternative option for agriculture in the Midwest" [42].

Another consideration is the wide range of regional differences within regions that also have an extensive range of latitudes (e.g., Europe, United States, India). Complex agroforestry is more common in tropical regions than in temperate regions due to distinctions in seasonality, socioeconomic conditions, cultural influences, and agricultural development histories. Global and regional differences necessitate a flexible framework for considering and measuring regenerative agroforestry systems and the practices that yield such systems.

In addition to their ubiquity, agroforestry systems around the world are recognized for their high biological and natural resources conservation values [43,44] and are increasingly considered an innovative response to today's agricultural challenges including increasing weather extremes, soil and water degradation, and declining biodiversity [45]. A recent USDA Forest Service study [46] with over 50 contributors from around the USA documents the ability of agroforestry systems to "enhance agricultural production; protect soil, air, and water quality; provide wildlife habitat; and allow for diversified income." Recent review papers on agroforestry [47,48] confirm a list of benefits in alignment with regenerative agriculture goals: soil enrichment; water quality enhancement; biodiversity enhancement and conservation; ecosystem services; and carbon sequestration. This alignment suggests that agroforestry systems—when appropriately designed, implemented, and managed—are regenerative in their outcomes.

Agroforestry practices also have the potential to repair degraded and deforested land [49–51] and restore or enhance the multifunctionality of landscapes [52,53]. Agroforestry can significantly improve ecosystem services and enhance biodiversity conservation on degraded agricultural land and deforested areas [54,55]. Agroforestry promises myriad of other significant benefits, including cultural and social [56–58]. For example, regeneration of degraded lands through agroforestry offers the added benefit of producing food within communities and supporting rural economies and subsistence livelihoods [54,59]. While recognizing the importance of the sociocultural benefits, in this paper we focus on the environmental and agroecological benefits of agroforestry as they relate to regenerative agriculture and standardization efforts.

2.1. Regenerative Characteristics of Example Agroforestry Practices

A wide range of agroforestry practices can be integrated into existing agricultural systems. Recognized agroforestry practices include alley cropping, contour hedgerow, forest farming, living fence, multistory cropping, riparian forest buffer, silvoarable systems, silvopasture, and windbreak [15,60,61]. The five most common agroforestry practices implemented in the USA are alley cropping, forest farming, riparian buffers, silvopasture, and windbreaks [47,61], which are briefly described below. For their wide applicability and well-developed knowledge base, we will focus on these five practices and their role and relationship with respect to regenerative agriculture. Our discussion of a regenerative agroforestry standard in Section 5, however, is applicable to all recognized agroforestry systems beyond those explored here.

2.1.1. Alley Cropping

Alley cropping, also known as intercropping and closely related to silvoarable agroforestry, is the practice of planting single or multiple rows of trees with cultivated crops in the "alleys" between the tree rows [16]. There is strong evidence that alley cropping systems can reduce runoff and soil erosion by water, improve nutrient use efficiency, sequester carbon, and increase biodiversity [62,63]. Alley cropping systems can be oriented to increase potential benefits. For example, planting tree rows along the contour of the land can reduce soil erosion [64]. A diverse crop portfolio and the mix of perennial and annual crops also diversifies revenue streams over time, providing short-term and long-term income generation [65]. Alley cropping can also be leveraged to transition from monocultures and/or row crop farms to perennial agricultural systems. Beneficial interactions occur between complementary plant species and plant types when grown together; these interactions can result in yields exceeding those in monoculture or plantation stands [66,67].

2.1.2. Forest Farming

Forest farming is the practice of cultivating high-value, shade-tolerant specialty crops under the protection of a forest managed to provide a favorable microclimate for understory crops such as mushrooms and medicinal herbs [68,69]. A forest farming system is established by selectively thinning an existing woodland or plantation to manage the conditions for understory crops or by adding a new layer to the structure of an existing system [70]. Products produced from forest farming are typically referred to as non-timber forest products (NTFPs), and include four categories of products: food, botanicals, decoratives, and handicrafts. While people have been informally managing forests for NTFPs for generations, forest farming has become popular in North America as "a way for landowners to diversify income opportunities, improve management of forest resources, and increase biological diversity" [71]. In addition to providing valuable ecosystem services, forest farming can help protect forests from clearing for other uses and NTFP populations from being over harvested.

2.1.3. Riparian Buffer

As defined by Gold and Garrett [16], riparian buffers are "strips of permanent vegetation consisting of trees, shrubs, herbs, and grasses that are planted and managed together" adjacent to waterways and water bodies. These planted zones buffer water bodies from potential negative impacts of surrounding cropland or pasture by reducing soil erosion and runoff of sediment and nutrients, stabilizing banks, improving water quality, and increasing biodiversity [72–74]. While riparian systems are typically implemented for their conservation benefits, they can also provide perennial crops and thus another source of revenue for a farmer or rancher [75]. The conservation benefits and crop production potential, combined with utilization of riparian areas that are not considered for production, afford this multifunctional agroforestry practice great potential to meet regenerative goals.

2.1.4. Silvopasture

Silvopasture is an agroforestry practice that "combines trees with forage (pasture) and livestock production" [47]. There are two approaches to the establishment of silvopasture: (1) the planting of tree species on pastureland; or (2) the thinning and management of existing forestland to establish forage crops and accommodate grazing of livestock, sometimes referred to as forest grazing [16,76]. Through either approach, trees and pasture are managed as a single integrated system that is actively used to graze livestock [77]. Converting pasture to silvopasture diversifies a rancher's sources of revenue and can provide the security of mid- to long-term revenue from tree crops, such as fruit, nuts, and/or timber [76]. The trees in silvopasture systems can also shade livestock from direct sunlight, as well as abate winds to provide livestock with limited protection from cold weather [77]. Of the five categories of agroforestry practices, Jose et al. [47] found silvopasture to have the largest potential available area for expansion, suggesting that the adoption of silvopasture practices on existing pasture lands holds great potential as a regenerative system in the USA, while Project Drawdown identified silvopasture in the top 10 potential solutions for reversing carbon emissions [78].

2.1.5. Windbreak

Windbreaks, also known as shelterbelts, are the intentional planting of trees and/or shrubs as barriers to decrease the speed and impact from winds to protect a specific area downwind, thereby creating a different microclimate [79]. Windbreaks can be planted on existing crop or pastureland. On cropland, field windbreaks can reduce wind erosion of soils, improve growth and yield performance, protect plants directly from wind damage, increase the availability of water by reducing evaporation [63,80–82]. On pastureland, windbreaks can help reduce animal stress or even mortality due to extreme heat and cold; visual impacts; and odors [83,84]. By reducing wind speed, windbreaks can control blowing and drifting snow [85]. With appropriate species selection and design, windbreaks can also produce food, fodder, fiber, timber, and pollinator and predatory insect habitat [86] as key secondary products or functions.

3. Relevant Certifications, Standards, and Guidelines

In our review, we analyzed relevant standards, certification programs, guidelines, and associated scientific literature to understand the presence and content informing existing efforts to standardize agroforestry practices and systems. In doing so, we also sought to identify measurable criteria for what constitutes an agroforest.

3.1. Agricultural and Forestry Certifications and Standards

A review of 21 existing agricultural and forestry certification programs and standards provided insights as to their applicability to agroforestry. We studied a subset of 14 U.S. and international certification programs and standards that met the following review criteria: (1) include management of forests, agroforests, or tree farms; (2) include requirements related to biodiversity, soil building, or perennial systems; or (3) claim to be holistic in nature. We identified whether the certification programs and standards:

- Recommend agroforestry as an option to achieve stated goals.
- Require agroforestry practices to achieve stated goals.
- Contain prescriptive criteria as to how agroforestry systems should be implemented, maintained, and measured.

After our initial research and review, we contacted expert agroforestry stakeholders for recommendations of additional certifications/standards to review. To verify our findings, we reached out to representatives of the most relevant certifications/standards (those that "require agroforestry practices", and/or "contain prescriptive agroforestry criteria"), including Bird Friendly Coffee, Rainforest Alliance Sustainable Agriculture Standard, Forest Gardens Products, and PCO Verified Forest Grown.

Table 1 summarizes our findings for each certification program and standard reviewed based on the above-listed criteria. None of the certification programs and standards reviewed explicitly disallow the use of agroforestry practices. Additionally, agroforestry practices can conceivably meet the requirements set forth by all of the certifications and standards reviewed. Seven of the 14 certification programs and standards reviewed explicitly mention agroforestry within their most recently published standards or rules of certification as a recommended practice or system that could meet or exceed their base requirements. Of these, two certifications require agroforestry practices or systems to meet the desired outcomes of their corresponding standards: the Smithsonian Migratory Bird Center's Bird Friendly Coffee and the Rainforest Alliance Sustainable Agriculture Standard. These standards can provide insights into the development of a regenerative agroforestry standard, as will be addressed in Section 5.

Table 1. Agroforestry positions of select certification programs and standards. Review of certification programs and associated standards was conducted March–July 2018 using the most up-to-date available documentation for each program/standard. "Y" refers to "yes"; "N" refers to "no".

Certification/Standard [1] (Standard Owner)	Scope	Recommends Agroforestry	Requires Agroforestry Practices	Contains Prescriptive Agroforestry Criteria
Agricultural Certifications				
Bird-Friendly Coffee (Smithsonian Migratory Bird Center) [87,88]	Int'l	Y	Y	Y
Certified Naturally Grown (Certified Naturally Grown) [89]	U.S.	N	N	N
Demeter Biodynamic® Production Standards (Demeter-International) [90]	Int'l	Y	N	N
Forest Garden Products (International Analog Forestry Network) [91]	Int'l	Y	Y	N
GLOBALG.A.P. (GLOBALG.A.P.) [92]	Int'l	N	N	N
IFOAM Standard (IFOAM-Organics International) [93]	Int'l	N	N	N
PCO Verified Forest Grown (Pennsylvania Certified Organic) [94]	U.S.	Y	Y	N
Regenerative Organic Certification (Regenerative Organic Alliance) [8]	U.S.	Y	N	N
Rainforest Alliance Sustainable Agriculture Standard (Rainforest Alliance) [95]	Int'l	Y	N	Y
USDA Organic (USDA National Organic Program) [96]	U.S.	N	N	N
UTZ Standard (UTZ) [97]	Int'l	Y	N	N
Forest Management Certifications				
American Tree Farm System (American Forest Foundation) [98]	U.S.	N	N	N
Forest Stewardship Council Forest Management Certification (Forest Stewardship Council) [99,100]	Int'l and U.S.	N	N	N
Sustainable Forestry Initiative North American Program (Sustainable Forestry Initiative) [101]	U.S. and Canada	N	N	N

[1] See Section 5 for description of distinction between certification versus standards.

Of the certification programs that require the use of agroforestry practices, only the Smithsonian Migratory Bird Center's Bird Friendly Coffee program contains prescriptive agroforestry criteria within the agricultural production standards that make up the certification program. The 2017 Rainforest Alliance Sustainable Agriculture Standard also offers agroforestry criteria, but while agroforestry practices are recommended, it does not require them to meet the standard. However, this standard does provide criteria and discrete metrics for tree/shrub cover and species diversity for a select list of shade-tolerant crops that must be followed for a given agroforestry system to qualify [102].

Three of the programs profiled at the bottom of Table 1 are forest management standards, none of which recommend, require, or regulate agroforestry practices. All three of them do, however, mention management of NTFPs in their standard, which can be interpreted as the agroforestry practice of forest farming. While NTFPs often include food products, these three standards mention NTFPs in reference to ensuring indigenous peoples' access to forests and to harvesting forest products when evaluating the certification of a given forest management plan. Alternatively, the PCO Verified Forest Grown program certifies forest botanicals from privately owned forests in the Eastern USA grown in "non-timber forest product management systems (e.g., woods-cultivated, woods-grown, virtually wild, wild-simulated) in which intentional husbandry practices are used to produce a non-timber forest product in a forest environment" [94].

In September 2015, the Forest Stewardship Council (FSC) began designing a process by which forest managers that already hold an FSC Forest Management Certification can demonstrate their operation's impact on ecosystem services within FSC-certified forests [103]). Through the FSC Ecosystem Services Procedure, forest managers can produce FSC-verified ecosystem services claims that they can use to access ecosystem services markets. The Procedure suggests general criteria for biological diversity conservation, watershed services, carbon sequestration and storage, and soil conservation that align with four of the goals of regenerative agriculture as defined earlier in the paper, however, no measurable thresholds are provided for the criteria outlined. The Procedure framework could inform the design of an agroforestry standard and certification and may be a promising effort to track through its development.

Another promising effort related to forest management certification is the expansion of the Programme for the Endorsement of Forest Certification's (PEFC) focus to include "Trees outside Forests" through which PEFC is exploring standards for agroforestry [104]. PEFC is an umbrella organization that endorses national forest certification systems. In the USA, for example, PEFC endorses the American Tree Farm System and Sustainable Forestry Initiative certifications, two of the forest management certifications in Table 1 [105].

For cues in developing metrics for a regenerative agroforestry standard, we analyzed the two certifications in Table 1 that include prescriptive criteria for agroforestry systems: the Smithsonian Migratory Bird Center's Bird Friendly Coffee and the Rainforest Alliance Sustainable Agriculture Standard, as summarized in Table 2.

Table 2. Prescriptive agroforestry criteria found in two agricultural and forestry standards.

Criteria Measurement	Smithsonian Migratory Bird Center's Bird Friendly Coffee [87,88]	Rainforest Alliance Sustainable Agriculture Standard [95]
1. Presence of trees, shrubs, and perennials	≥10 woody species (in addition to the predominant shade trees or "backbone" species). At least 10 of these should represent 1% or more of all individuals sampled and be dispersed throughout. Backbone species must be native. [87]	Incorporation of native trees as border plantings and barriers around housing and infrastructure (e.g., live fences, shade trees, and permanent agroforestry systems).
2. Plants per unit area	≥40% tree/shrub cover, measured during dry season after pruning.	Minimum total canopy cover of 20–40%, depending on geographic region.
3. Layers represented in the tree/shrub structure	≥12 m (40 ft) height of the backbone species. Preferably three layers or strata [88]: a. The layer formed by the backbone species and other trees of that size; b. The taller emergent species comprised of native trees of the natural forest; c. Understory made up of shrubs and small trees or plants. The emergent and understory strata each should account for 20% of the total foliage volume present. The remaining 60% of the foliage volume should be the principal canopy. [87]	Not explicitly given.
4. Number of woody perennial (trees, shrubs, palms, etc.) families, genera, species, and varieties	Requirement same as noted in criteria area #1. The total floristic diversity is the sum of all woody and herbaceous species counted in the sampling. [88]	The tree community consists of 5–12 native species per hectare (per 2.5 acres) on average, depending on the shade-tolerant crop being grown.
5. Additional criteria	Leaf litter should be present; no minimum percentage required, which, together with living ground cover, keeps the soil covered [87]. Weeds/herbs/forbs should be present. Living fences and buffer zones along waterways should be present. Should qualify at least for the category "traditional polyculture" (the more diverse category of the polyculture systems). Must have current organic certification by a USDA-accredited certification agency. [88]	The farm must use and expand its use of vegetative ground cover to reduce erosion and improve soil fertility; structure and organic material content, as well as minimize the use of herbicides.

3.2. Resource Conservation Guidelines

In addition to certifications and standards for agriculture and forestry, we analyzed USDA Natural Resources Conservation Service (NRCS) guidelines, formally referred to as "specifications," for each of the five core agroforestry practices (alley cropping, forest farming, riparian buffers, silvopasture, and windbreaks) for addressing natural resource concerns. These specifications vary somewhat from state to state and provide valuable insights into quantifying agroforestry characteristics. We have selected three example specifications that are relevant to regenerative agroforestry and summarized in Table 3. Measurable criteria from the sources summarized in Tables 2 and 3 inform the proposed regenerative agroforestry standard outlined in Section 5.

Table 3. Criteria from select USDA Natural Resources Conservation Service agroforestry practice specifications.

Criteria Measurement	Mixed Agroforest Specification (Pacific Islands Area) [106]	Riparian Forest Buffer (Illinois) [107]	Silvopasture (Kentucky) [108]
1. Presence of trees, shrubs, and perennials	"Mixed Agroforests" are described as small-scale tree and shrub plantings.	Trees and/or shrubs located adjacent to and up-gradient from watercourses or water bodies.	Use trees and forages (shrubs where desired) that are adapted to the climate, soil, and biological conditions of the site and compatible with its planned use and management.
2. Plants per unit area	Tree/shrub counts must be ≥1050/ha (≥425/ac), including ≥62/ha (25/ac) tall stature trees. The balance must be short-stature trees or shrubs. Specific guidelines are given in tabular form for minimum number of species and structural diversity.	The location, layout and density of the buffer should complement natural features, and mimic natural riparian forests. Initial plant densities for trees and shrubs should be based on their potential height, crown characteristics and growth form, in addition to planting objectives.	Tree density at planting should be approximately 500–1000/ha (200–400/acre) for conifers, or 250/ha (100/acre) for black walnut, black locust, or pecan. Throughout the rotation, trees will be thinned in order to maintain understory-overstory balance that accommodates the producer's goals.
3. Layers represented in the tree/shrub structure	High diversity in the planting arrangement of different genera and structure (height) at maturity, and may include tree, shrub, and vine. A minimum of two layers (tall and short stature trees/shrubs) are required.	Manage the dominant tree canopy to maintain maximum vigor of overstory and understory species. Periodic thinning and/or prescribed burning may be necessary to allow adequate light to reach the forest floor to maintain a good cover of grasses and forbs.	Manage trees, forages, and shrubs as needed to provide appropriate light conditions for forages, and shade/shelter conditions for livestock. Pruning needed to achieve the desired canopy type for production of fruits, nuts, and timber.
4. Number of woody perennial (trees, shrubs, palms, etc.) families, genera, species, and varieties	a. 6 woody plant genera or more depending on field size; b. ≤50% that produce non-timber forest products—any number of timber-producing trees are allowed; c. A minimum of 20% as native species (may be timber producing). Limitations: Individual plant genera that produce non-timber forest products may be planted in pure or contiguous clumps not to exceed five trees or 20 shrubs/vines. Different clumps of the same genera shall be separated by the maximum space feasible given overall species selection and land area of a given agroforest.	No single species will make up more than 50% of the total number of species planted. Favor tree and shrub species that have multiple values such as those suited for timber, nuts, fruit, florals, browse, nesting, and aesthetics.	None specified.

4. Approach to Standardization

Certification is a process for verifying compliance with an existing standard [109]. Certification is defined by the International Standards Organization (ISO) as "a procedure by which a third party gives written assurance that a product, process or service is in conformity with certain *standards*" [110]. In addition to standardizing a product, process or service, standards can also act as guidelines [110] and in that sense may serve an educational function.

Many issues around certification diverge from the standard itself (e.g., compliance monitoring). We have chosen to focus on developing an agroforestry standard in this phase, prioritizing the design and content of a standard over the mechanisms of certification, which are important at the later stage of implementation.

4.1. Practices versus Outcomes

The site specificity of agroecosystems [19] and multifunctionality of integrated farming systems [111] present both an opportunity and challenge for setting standards for regenerative agriculture and agroforestry: *Is it possible to reconcile the high potential of site-specific agricultural systems with the standardization necessary to certify them*? The answer to this question is inextricably linked to the debate as to whether standards should be practices-based or outcomes-based (the latter is also known as performance-based). For example, the USDA National Organic Program, IFOAM-Organics International, and other certification programs that are motivated by ensuring compliance to a set of production practices, rely heavily on a practices-based design. While outcomes-based certification may also require certain practices, compliance is based on the results achieved by the practices on a specific farm.

One concern is that a practices-based standard or certification program would stifle a farmer's drive to improve their practices. The Regenerative Organic Certification, for example, was designed with a tiered approach to allow producers "to adjust and adapt their practices over time, and [that] allows for continuous improvement" [8] and supports ongoing innovation [2].

As it relates to the certification of tropical agroforestry systems for biodiversity conservation, Tscharntke et al. [109] summarize the issue: "Because it is predicated mostly on practices and not outcomes, certification itself generally cannot be taken as direct evidence of conservation effectiveness." In order to prove the conservation effectiveness of biodiversity-centric certification schemes, they emphasize the need for monitoring the outcomes of such certification programs. Even for an outcomes-based standard, the effectiveness of the certification is limited by the robustness of the accompanying monitoring of the prescribed standards, in which skilled site inspectors play an important role [112].

Additionally, as highlighted in Section 2, there are global and regional factors that compound the complexity of standardizing agroforestry systems as it relates to their site-specific and multifunctional nature. These differences further emphasize the need for an adaptable baseline regenerative standard that can be applied across regions that are diverse both environmentally and culturally. To the latter point, such an approach may also prove valuable in the development of international strategies for climate change adaptation (e.g., greening of the subarctic, tree losses from/prevention of forest fires, projected pest and disease outbreaks) [113–116].

4.2. Organic as a Baseline Standard

Adherence to organic standards has been adopted as a baseline for some certifications that seek to go "beyond organic" or advance more stringent or production method-specific standards. Three of the 14 certification programs and standards considered in Table 1 either require or build upon an organic standard. In theory this allows producers to incorporate new certifications as an add-on to their existing organic certification, whether it is through the USDA National Organic Program, IFOAM International, or another international or regional third-party organic certifier. While organic as a baseline certification is an important consideration, we view this issue as primarily a question of the mechanics and implementation of a certification program, rather than an issue relating to a standard itself, which is the focus of this paper.

5. A Standard for Regenerative Agroforestry

We suggest that any interest in certifying agroforestry be channeled into the development of a robust standard describing measurable criteria of regenerative agroforestry systems. While there is potential for agroforestry systems to advance regenerative goals, their ability to do so lies in how they are implemented and managed. As such, the development of a single set of regenerative standards for the many diverse agroforestry practices is a challenging exercise. We maintain that meaningful agroforestry standards require some degree of prescriptivism (what to do, rather than only what not to do), while also allowing for virtually unlimited configurations. To this end, we have proposed detailed criteria and corresponding measurements or thresholds for each criterion to guide the development of such an agroforestry standard based upon a synthesis of criteria from existing efforts (Tables 2 and 3).

Because of the complexity of agroforestry systems as compared to monocultures, as well as the wide range of potential applications in various environments and farm sites, we first identify four interrelated characteristics of regenerative agroforests, which can be achieved through a variety of agroforestry practices. By our definition a regenerative agroforestry system should be highly integrated, densely planted, multistoried, and contain multiple species. We propose these characteristics as the core criteria of a regenerative agroforestry standard.

1. **Integration**: The first of these characteristics is the integration of trees, shrubs, and other perennials within the cropping system, which is a fundamental feature of agroforestry, as stated in all agroforestry definitions. Perennials are more resilient to weather extremes and other environmental variations, imparting increased resiliency compared with annual crops [57,117]. There is evidence that with more extensive and deeper root systems, perennials can appreciably decrease erosion compared with annual cropping systems [118]. They also store carbon in their above- and below-ground biomass, which accounts for their potential to sequester carbon.
2. **Density:** The second important characteristic of agroforestry systems is the density of plants growing together in a stacked or multistory configuration. When optimized for a given environment and species mix, higher density plantings confer multiple regenerative benefits. High plant density builds soil by increasing organic matter production, which through leaf drop, root senescence, and pruning/cutting management can be left in place to add organic matter and mulch cover for the soil [59]. High-density plantings can increase soil-holding capacity and decrease erosion [118], also potentially increasing biodiversity within the agroecosystem [119].
3. **Multistory:** The third characteristic is a multistory configuration, which is a result of integrating many species. Multistory agroforests have a higher total light interception than single-layer canopies, and therefore have higher total primary production of biomass (higher photosynthetic conversion) [120,121]. The multistory aboveground structure of agroforests with diverse species composition are paralleled by root systems that occupy various soil depths and together form a network that efficiently captures nutrients before they can be carried away by water [19]. The abundant leaf litter and herbaceous cover of multistory agroforests create capacity to minimize erosion [59]. Various tree/shrub heights create greater habitat for more organisms, increasing biodiversity [119]. Finally, multistory agroforests have been shown to have a high capacity for carbon sequestration, especially in their early years [122,123].
4. **Multiple species:** The fourth characteristic is the inclusion of multiple species and varieties, which is related to plant density and multistory structure. Increased species diversity increases overall biodiversity of the system. Having a large number of species also confers resiliency by ensuring that ecological niches are occupied even after weather extremes and other disturbances [57,124]. Chisholm et al. [125] state, "As species richness increases, productivity and biomass of the system also increase."

Realizing the potential benefits of agroforestry within a certification framework necessitates quantifiable measures for each standard criterion (Figure 2). Of these four characteristics of regenerative agroforests, by definition, only the first is inherent to all agroforests. The other three can be implemented to various degrees, suggesting minimum measures be developed for plant density, number of layers (Figure 2), and plant diversity. We propose measuring the regenerative agroforestry standard criteria as follows:

1. **Integration:** Presence of trees, shrubs, and perennials integrated into a farming system.
2. **Density:** Plants per unit area (horizontal structure).
3. **Multistory:** Strata represented in the layered structure and root systems (vertical structure).
4. **Multiple species:** Number of plant families, genera, species, and varieties over time (temporal succession).

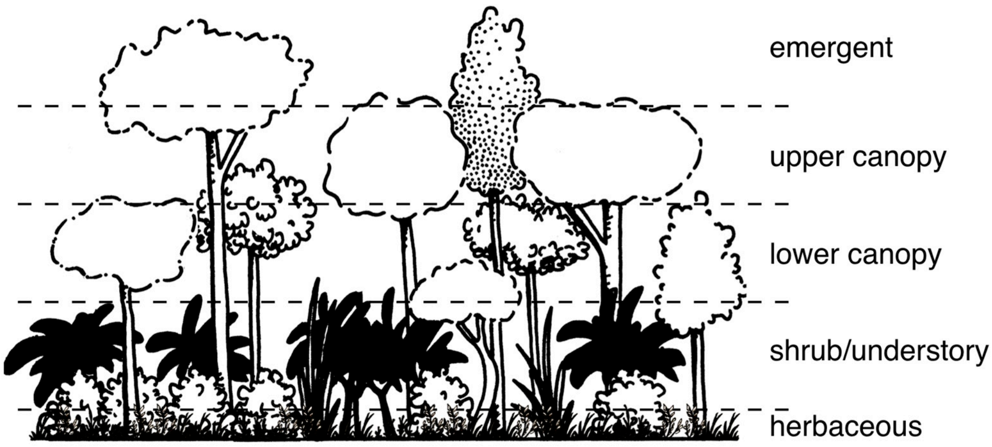

Figure 2. Agroforest structure and descriptive terms used here for the layers.

Table 4 presents the proposed regenerative agroforestry standard, including suggested means of measuring each criterion and thresholds by which to measure adherence to each criterion (as illustrated in Figure 3). The standard as proposed applies to an agroforest itself, rather than the whole farm or other issues related to certification. Tree/shrub cover percentage is given as a minimum based upon the standards and specification recommendations that list specific cover percentages in Tables 2 and 3. As there will be an establishment period for an agroforest, the minimum cover percentage applies after an appropriate transition period, depending on location. Upon reaching a mature phase, cover percentage is the minimum achieved after pruning. The woody perennial density criteria are based upon 500 stems per ha (200/ac), the median of the criteria provided by the standards and criteria we explored. In terms of structural layers, two and three are mentioned as minimum values in the Smithsonian Migratory Bird Center's Bird Friendly Coffee (Table 2), and Mixed Agroforest specification (Table 3), respectively. The threshold for multiple species reflects the median of those specified in Tables 2 and 3. Despite the basis of the criteria threshold numbers in Table 4 in existing certifications and NRCS specifications, the numbers themselves should be seen as initial values to be subject to further evaluation and research.

We have suggested a standard that is outcomes-oriented, rather than recommending or requiring the application of specific agroforestry practices (alley cropping, windbreak, etc.). In other words, in theory, any practice that yields an agroforestry system that meets the standard criteria and corresponding thresholds would meet the proposed standard.

Table 4. Proposed regenerative agroforestry standard.

Standard Criteria	Criteria Measurement	Description of Measure	Criteria Threshold
1. Integration	Presence of trees, shrubs, and other woody perennials.	Annuals have an essential early successional role to play in agroforestry, while the long-term structure of the system emphasizes both woody and herbaceous perennials.	≥40% cover by trees/shrubs, allowing transition time from open field. Individual practices (e.g., windbreak) may require higher cover for acceptable resource conservation functionality.
2. Density	Woody perennials per unit area.	This measure ensures continuous soil cover for erosion control, capture of nutrients, and weed suppression.	≥5 woody perennials per 100 m^2 (1080 ft^2), plus herbaceous cover and mulch.
3. Multistory	Layers occupied in the agroforest structure and root systems.	Based upon five potential vegetation layers (emergent, upper canopy, lower canopy layer or understory, shrub, and herbaceous) occupied per unit area.	≥2 woody perennial layers per 200 m^2 (2160 ft^2), plus the herbaceous layer and mulch.
4. Multiple species	Number of woody perennial (tree, shrub, palm, etc.) families, genera, species, and varieties.	A measure of biodiversity intentionally planted or protected in the agroforest.	≥8 plant families, genera, species, and/or varieties of woody perennials per 100 m^2 (1080 ft^2) present throughout the life of the agroforest. Pure or contiguous clumps not to exceed 3 trees or 10 shrubs/vines of a single species. Different clumps of the same species to be separated by minimum 3 times their maximum canopy diameter.

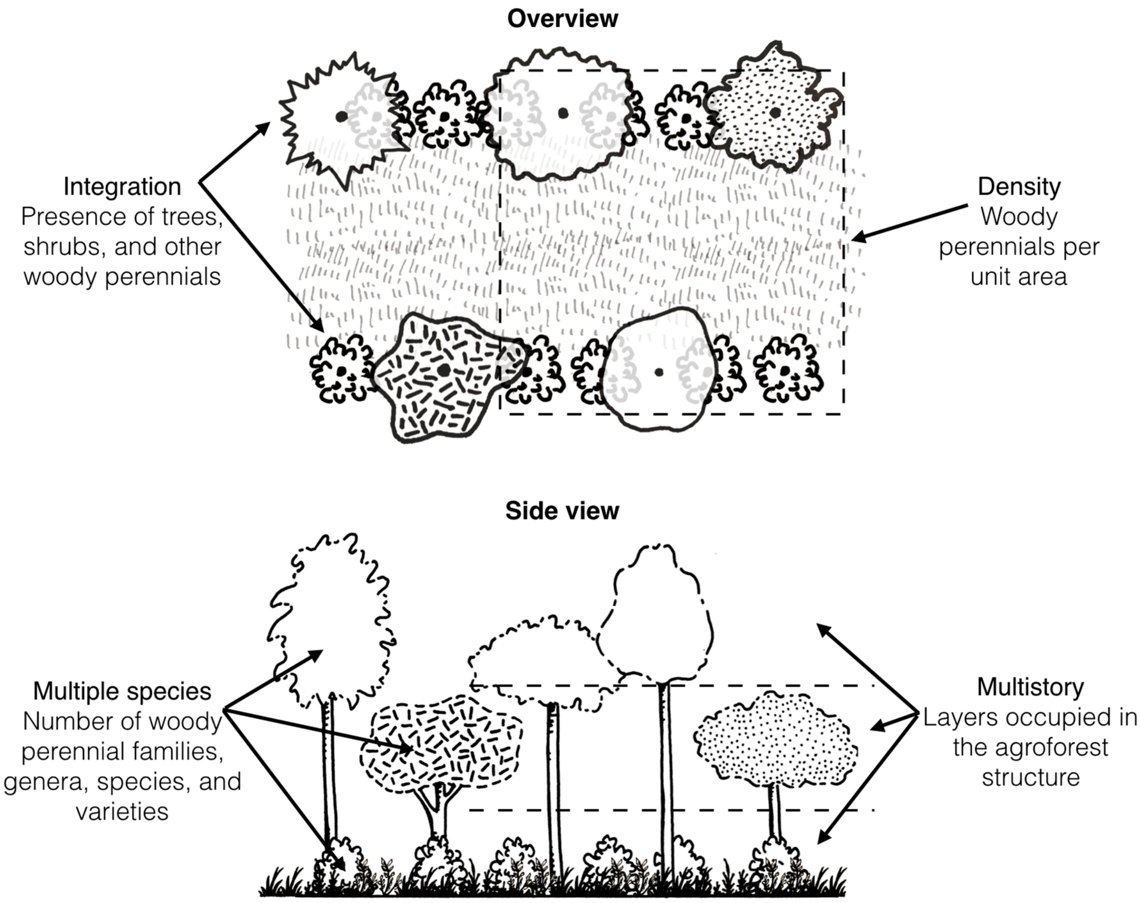

Figure 3. Measurable components of the regenerative agroforestry criteria. Agroforestry systems can be configured in a variety of ways. This generic illustration depicts a system arranged in rows as is commonly done in many agroforestry practices such as alley cropping, windbreaks, and riparian forest buffers.

6. Discussion

The development of a regenerative agroforestry standard alongside current efforts to certify regenerative agriculture offers an opportunity to leverage the common goals and potential strengths of each field/domain. To this end, we have proposed a framework and measurable criteria for a regenerative agroforestry standard with the aim of advancing dialogue around (1) the content of the proposed standard itself; and (2) the role of regenerative agroforestry to advance the goals of regenerative agriculture.

In reviewing existing certification programs and standards we conclude that, while there is demonstrated interest and current efforts to certify agroforestry, there is also a lack of robust standards and measurable criteria available to closely guide agroforestry production, particularly in temperate locations. The sparse inclusion of prescriptive agroforestry criteria in existing certification programs also demonstrates a scarcity of guidance materials that detail quantifiable agroforestry metrics for meeting desired outcomes.

In proposing an agroforestry standard, we have suggested a subtle shift in thinking in order to maximize the regenerative benefits of agroforestry. We recommend orienting the concept of standardization around specific measures generalizable to any agroforestry system rather than requiring the use of specific agroforestry practices, of which there are many promising and site-specific variations. Additionally, we have attempted to create a baseline of quantitative measures for agroforests that translate into the desired outcomes of regenerative agriculture. In order to move beyond this preliminary exploration of a regenerative agroforestry standard, additional research and discussion within the agroforestry and eco-certification community are necessary to refine the thresholds behind each measurable criterion. This further development will likely include discussion within the contexts of individual certification programs, such as the Regenerative Organic Certification, and regional differences such as temperate versus tropical agroforestry systems.

While the implementation of a new standard itself may prove challenging or even infeasible, the exploration of measurable agroforestry criteria may help focus a dialogue on the regenerative outcomes of agroforestry and position agroforestry within the regenerative agriculture narrative. Such an exercise may prove valuable to the regenerative agriculture field itself as it works to codify its broader goals and understand potential intersections with existing efforts or methodologies (in this case, agroforestry).

As compelling as agroforestry is to meet regenerative goals, further exploration is necessary to understand how an agroforestry standard could be implemented through the mechanisms of certification. This includes understanding the barriers to the adoption and promotion of agroforestry, and necessary policy implications related to adoption and promotion; the limitations of eco-certification; and the underlying economic influences that are crucial to the success of market-based certification programs. To this end, the production of breadfruit may offer a promising case study to apply the proposed regenerative agroforestry standards and provide guidelines for the commercial production of breadfruit in agroforestry systems [30]. Additionally, further exploration of the proposed standards should be considered in the context of a changing climate, including examination as to how agroforests can be designed to be both resilient to and mitigate major disturbances (e.g., wildfires, floods, and pest outbreaks).

Lastly, to realize the paper's aim of stimulating dialogue, outreach must be conducted to ensure that stakeholders at all levels are included. Of particular importance is the intentional inclusion of rural stakeholders, such as those represented by the European initiative AGFORWARD [39], and small-scale agroecological farmers, such as those represented by international non-profit organization La Via Campesina [126]. Further development of the proposed standards for regenerative agroforestry systems should be informed by existing models of participatory agricultural research, of which Drinkwater et al. [127] provide numerous examples.

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