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What soil is worth: A cost-benefit framework analysis of syntropic farming

Aubrey Kettley
SIT Study Abroad

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Aubrey Kettley
University of Puget Sound
School for International Training Portugal: Sustainability and Environmental Justice
ENVI 3500: Independent Study Project

Abstract

Syntropic farming, a type of regenerative agriculture, models its farming system after a forest. This type of farming prioritizes soil health while also providing a varied yield of crops. Because it is a fairly new system globally, little research has been done on the economic impacts of syntropic farming, and therefore the feasibility of scaling up regenerative systems like this. This study aims to analyze the economic feasibility of this system through a literature review and a cost-benefit analysis framework. The results highlight the applicability, environmental advantage and economic feasibility of the system. Based on the presented framework, the short term costs are likely to be outweighed by the long term benefits. A widespread implementation of this system like this could revolutionize modern agriculture, providing varied crops while also repairing harms done to soils by anthropogenic activities.

Introduction

Modern agriculture covers about 40% of Earth's surface (Andrade et al, 2020), while simultaneously depleting soil health, and causing deforestation (Lopes & Romana, 2022). Looking to the future, land is in high demand with increasing populations, need for renewable energies, and the constant need for food (Theismeier & Zander, 2023). Agriculture itself contributes highly to greenhouse gas emissions, water use and biodiversity loss, all of which are critical issues in the face of climate change (Andrade et al, 2020). On top of this, soils are becoming desertified, which is the process of land becoming degraded through human activities and climate variation (UNCCD, 2022), and losing their nutrients and invertebrates (McSweeney, 2019). As shared by a representative from Terra Sintrópica, the issue of soil desertification is becoming more severe, which pushes farmers to look for other solutions, often employing fertilizers, intensifying land use and conventional farming techniques to seek the necessary farm yields. However, these forms of farming ultimately turn good soil into dirt, which lacks the nutrients and minerals necessary for proper farming. Ernst Gotsch, a Swiss geneticist and farmer, has been experimenting for about 40 years with an alternative type of farming: a type of regenerative agriculture called syntropic farming, or successional agroforestry.

Horta da Malhadinha is a syntropic farm with a fruit tree and vegetable focus in Portugal. It is located in Mértola, a semi-arid area that is known for dry, rocky soils, with low organic matter content and high risk of soil desertification (Cortegano et al, 2021). Despite this, after five years of applying syntropic farming principles, the farm there is thriving, partially because of the visible regeneration of the soil. The farm is a part of CARES, or Center for Agroecology and Regeneration for the Semi-Arid Region, an initiative of Terra Sintrópica. CARES seeks to find a process of farming that can be socially and environmentally beneficial, through experimenting, educating, collaborating and research (Terra Sintrópica, n.d.). Terra Sintrópica has other farm-based initiatives such as a nursery, forest gardens for schools, and PREC, which is a space where regeneratively produced goods are sold, as well as a vegan restaurant, in Mértola. This restaurant gets about 80% of their produce from Horta da Malhadinha, which shows the interconnectedness and passion of this group for revitalizing their soil and community. Horta da Malhadinha covers 2.54 hectares (Restor[1], n.d.), and is mostly an experimental farm. They place emphasis on their land as a "living laboratory," focusing on spreading knowledge, innovative practices and community awareness, and hoping to spread their message to promote more regenerative agriculture (Terra Sintrópica, n.d.). In this analysis, CARES, Terra Sintrópica and Horta da Malhadinha will be used interchangeably as the name of the case study.

Before explaining the specifics of a syntropic farming system, it is important to place syntropic farming into the farming sphere. Many differently-named farming systems turn out to be similar, and some concepts overlap with syntropic farming. Agroforestry systems is a main umbrella term, as it is the broadest. The term describes systems that combine agriculture with trees (Mercer et al, 2014). They can also include horticulture, livestock, or both. Regenerative

[1] Restor is a website that reports data on regenerative agriculture sites. The data is self-reported by farms, and the website includes mapping data from Google Maps that shows different indicators like biodiversity.

agriculture is another very broad category of agriculture. This system emphasizes repairing damage done to the soil, sequestering more carbon, and re-establishing a landscape that is good for the soil, while still getting crop yield (Lawton, 2021). Permaculture is a broad and philosophical idea that touches on both agroforestry and regenerative agriculture. While the name comes from "permanent agriculture", originally describing "integrated, evolving system of perennial or self-perpetuating plant and animal species useful to man" (Mollison & Holmgren, 1978), permaculture now includes creating a whole human habitat and emphasizes ethics, using those ethics to make choices about lifestyle (Lawton, 2021). The system encompasses not just farming principles, but also housing, energy, water and more (Noosa Farm Retreat). Syntropic farming has permanent features, but is more specific than permaculture, as it focuses only on farming and it prioritizes soil health (Lawton, 2024). The idea of syntropic farming is that of a "food forest" which has varied sizes and types of plants, specifically pairing plants based on size to promote soil health. In syntropic farming, these different species are grown together, like in a forest, but in lines, like in agriculture. For this analysis, permaculture, agroforestry, syntropic agriculture, regenerative agriculture and food forests will be considered together. Research was done on all five types of systems, and while syntropic farming is the key word used in this analysis, many components of the other four systems are present.

Through in-depth research of the principles of syntropic farming, as well as an examination of case studies and actual farms, this study will propose a set of associated indicators to help price the benefits and costs of the system, especially those that are difficult to cost, such as soil health. The analysis applies observational data from a partner farm to better understand the indicators. The research objective for this analysis is to explore the feasibility of syntropic farming, specifically to assess the economic costs and benefits. This analysis hopes to see the feasibility not just in terms of costs and benefits, but also examine the applicability of this system to different communities.

Tenets and Basics of Syntropic Farming

Syntropic farming is a fairly complex system that has a few main tenets: stratification, succession planting, high biomass production for soil coverage, and pruning (Andrade & Pasini, 2022). Stratification is the idea that different plants in a food forest have different height niches to fill in the system. Figure 1 visually demonstrates the different stratifications, and how the system uses the space for maximum utilization of light, which allows for high amounts of photosynthesis to happen. The intentional use of space allows for more use of solar energy, far more than a monoculture or even a polyculture of the same species (Finch, 2022). It is also important to note that syntropic farming highly values ground cover, and strives for the soil to always be covered, either by a plant, biomass, or by mulch. Usually, the amount of mulch produced varies between 5 and 20 tons of dry matter per hectare (Schulz et al, 1994). Often, there are plants in the system specifically planted for biomass production. Also, the emergent species shown in Figure 1 are intensively pruned to provide biomass to cover the soil and promote more root growth and carbon sequestration from the trees (Agenda Gotsch, 2015). Through these principles, there is high water retention in the soil, and cooling thermodynamic processes (Andrade & Panini, 2022). Because of the level of intentionality in the treatment of the soil, syntropic farms have soil that is microbiologically like the soil of an area that has been naturally regenerating for 10 years (Cezar et al, 2015).

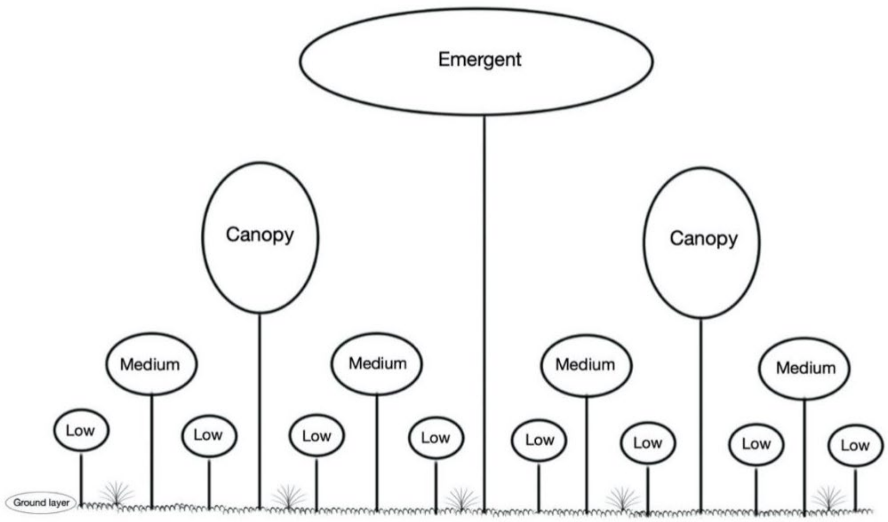

Figure 1. A visual representation of Gotsch's perspective on types of plants in a syntropic farming system (Andrade & Pasini, 2022).

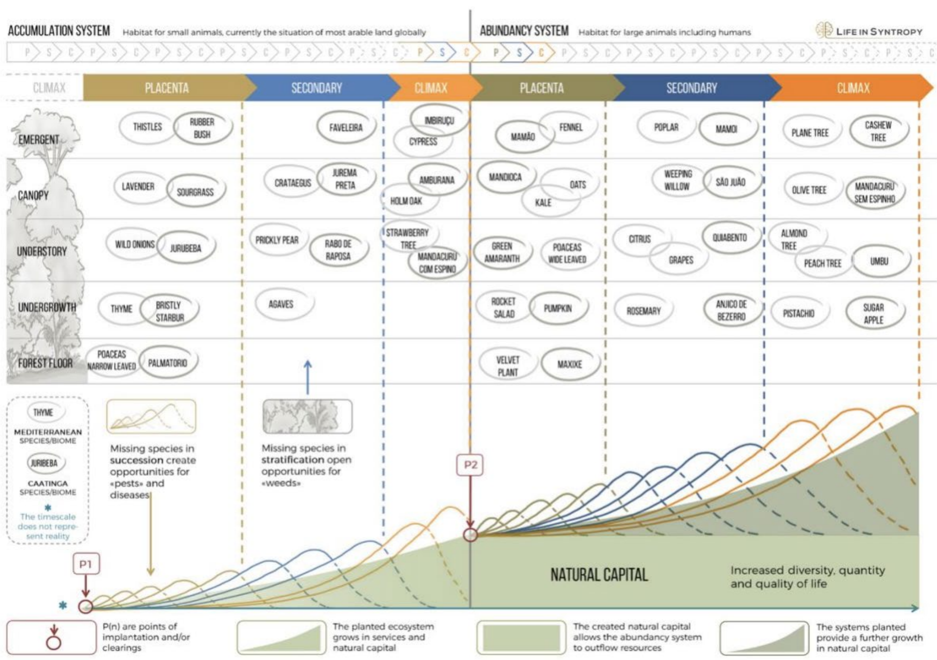

Figure 2. A visual example of the planning for a syntropic farming system. Taken from Andrade & Pasini (2022).

Another aspect of syntropic farming is succession planting. It accounts for two concepts: long-term system planning, and types of plants included in the system. This long-term planning is represented by placenta, secondary and climax plants (Andrade & Pasini, 2022), which allows the system to move from poorer soil to richer soil. Placenta plants are those that have short lifespans and are annual or biannual species. For example, Figure 2 shows thyme, wild onions and lavender as placenta plants in an accumulation system. Secondary plants are trees and shrubs of short to medium lifespan, like Prickly Pear. Climax plants are those with a very long lifespan. An example of this is a cypress tree. Placenta, secondary and climax plants are planted together, and then as the time goes on, the system evolves and changes. Placenta plants will be harvested for profit or consumption, and a new placenta species will be planted, starting the system over again. Syntropic farming encompasses the forethought of which types of plants to include in the system, accounting for nitrogen fixers as well as trees that take longer to grow (Eills, 2021). This change in the types of plants, based on soil health, season and needs of the system is demonstrated by Figure 2. For example, syntropic farming prioritizes reaching abundance systems, which are farming systems that can support big mammals, like humans, while also meeting soil and more intensive plant demands. Figure 2 shows this shift from an accumulation system to an abundance system. Once this shift happens, the placenta, secondary and climax plants change. In an abundance system, the soil can support plants with higher needs, like more necessary minerals or more water.

Considerations for a Syntropic System

Syntropic agriculture aims to both reverse the harm done by conventional agriculture practices and create a sustainable system, not only in terms of amount of output (yields) but also in continuity into the future. Not only does this system allow farmers to have a product to profit from at every stage (Finch, 2022), it also protects soil, encourages biodiversity, and creates a carbon sink (Agenda Gotsch, 2015). Based on the priority given to mulching and additive biomass, water retention in the soil is very high, even higher in some cases than in a regrowth forest (Damant & Villela, n.d.). This means that future irrigation costs are lower, while this system has more resilience against hot summers, especially in drier areas, and thus it contributes to fight desertification. Water retention allows the syntropic system to be applicable to a wider range of areas. Another important ecosystem service associated with soil coverage is soil temperature. Soil temperatures under a syntropic farming system are lower than in monoculture systems (Damant & Villela, n.d.).

Relatedly, syntropic farms require pruning, a practice that is done to add biomass to the soil and allows for another biological process to occur: symbiosis (Agenda Gotsch, 2015). Usually in this system, the trees are pruned every 3-4 months (Schulz et al, 1994). This sends a message to the roots that they need to regrow, and these will gather more nutrients so the tree can grow back. To do this, the tree strengthens ties with its symbiotic partners, the mycorrhizal fungi. Mycorrhizal fungi allow trees to have higher water retention, access greater amounts of soil minerals, and be more immune to disease (Leaf & Limb, n.d.). This leads soil to be more biodiverse, and trees to be healthier, which in turn allows for more growth. Also, this pruning and regrowth cycle creates another benefit: carbon sequestration. By planting a high density of plants together and encouraging excess growth through pruning, the carbon sequestration of these systems is high, turning a syntropic farm into a carbon sink (Agenda Gotsch, 2015).

While this system provides many benefits, it is a long-term investment. The literature cites different numbers for the amount of time required before seeing the results of the system (Portilho et al, 2018; Mercer et al, 2014), ranging between 1.1 months (Andrade et al, n.d.) to 10 years (van Cossel et al, 2020). While the system has profound environmental benefits, it takes some time for these benefits to occur. Due to the system's nature, high levels of technical knowledge are required for success. This includes knowledge on what types of plants to sow together, distances between lines of plants, timing of pruning, among many more things. It is especially difficult because every system is different and there is no “one-size-fits-all” solution. This technical knowledge requirement allows syntropic farming to be a successful and applicable system in many contexts but it nonetheless provides a barrier to entry to syntropic farming. Furthermore, it is a very labor reliant and intensive system. Most of these systems require everything done by hand, as no conventional machine is suited to the diversified work the system needs (Albrecht & Weik, 2021). Also, intentionality and labor intensity are needed throughout, unlike most conventional farming systems where more of the labor is upfront. This ongoing labor intensity is one of the main reasons that adoption of syntropic practices is low (Finch, 2022).

One thing that is evident at first sight of a syntropic farm is the high biodiversity of plants. This is accomplished not just through varying plant sizes, but also by diversity of species. This plant diversity helps the soil, as different plants need different minerals in the soil and have different root systems. In conventional agriculture systems, after a certain number of years, the nutrients needed for a particular monoculture are depleted from the soil and soil compaction tends to arise. In syntropic systems, there are so many types of plants that this depletion is not likely, while the overall root systems cover much larger volumes. Also, in these systems, adding nitrogen fixers is a priority, as these provide nutrients back to the soil (Eills, 2021). Based on soil improvement, with high biomass and mulch, as well as on plant diversity, fertilizers and pesticides are not necessary in a syntropic system like they are in conventional or monoculture systems (Andrade et al, n.d.). Not using chemicals like fertilizers and pesticides supports ecosystems in many ways, including not damaging the mycorrhizal fungi and soil microorganisms that support tree growth, and protecting pollinators. Moreover, the focus on plant diversity supports the inclusion and regeneration of native plants in syntropic systems (Andrade et al, n.d.). Native plants are an important inclusion because they create habitat for native animal species, specifically insects (National Geographic, n.d.). They are also adapted to the area, so they are more drought resistant, can have deeper reaching roots, and can support soil microorganisms better than exotic plants (Ecological Landscape Alliance, n.d.). Furthermore, the inclusion of native plants in a system also allows for faster nutrient cycling (Schulz et al, 1994).

Ernst Gotsch has been developing this method for about 40 years in his farm in Brazil, and this process has spread through South America, but it is very new in Portugal and even in Europe. There are, thus, many case studies that have studied the impact and implementation of syntropic farming in Brazil, but not many studies from Europe, Asia, or North America. Since this is a fairly new concept, case studies test species of plants that are compatible with the system (Portilho et al, 2018), the ecological factors related to the system (Damant & Villela, n.d.), and the timeline of the benefits of the system (von Cossel et al, 2020). A few case studies have shown the benefits of syntropic agriculture over conventional systems (Damant & Villela, n.d.; Andres et al, 2016), and even over organic farming systems (Schneider et al, 2016).

Because of the system's novelty and specificity, most of the literature about syntropic farming is based on case studies, introductory background knowledge, or educational content, such as teaching farmers how to implement it in their own space. While the literature is clear that syntropic farming is highly beneficial in terms of soil health, ecosystem regeneration and food production, there is very little research about the economics behind syntropic farming, and how feasible this system could be for high production models, like providing all the food for a community. There are economic feasibility studies done for some types of agroforestry systems, within which syntropic farming systems belong, but no specific economic study focuses on this type. Because farming is profit-driven, showing that this system is economically feasible could help prove to farmers that it is a good system to implement. This is the gap that this article aims to fill. Even with the high benefits of this type of system, there are higher human capital inputs, like labor, forethought and knowledge, which turn away many interested farmers (Finch, 2022). Therefore, the next section describes the cost-benefit approach as a way to fill this economic gap in the literature.

Methodology

This project includes both a literature review and an economic analysis of syntropic farming. It looks at secondary sources to both inform and validate the aims of the analysis. This study will use a cost-benefit analysis framework (Hanley & Barbier, 2009; FAO, 2018; Mishan & Quah, 2020) to look at the advantages and disadvantages of implementing a syntropic farm instead of using conventional agriculture. The Food and Agriculture Organization of the United Nations provides a format for a cost-benefit analysis for agriculture in the face of climate change (FAO, 2018). They highlight a cost-benefit analysis as a way to understand and provide solutions to a situation with scarce resources, specifically financial resources. An economic analysis of this type looks at the financial, social, environmental, and other costs and benefits that society experiences. However, many of the benefits and costs of a syntropic system are not easily described in monetary terms. While most cost-benefit analyses estimate individuals' willingness to pay for something (Mishan & Quah, 2020), this analysis uses an economic cost-benefit framework to help understand syntropic farming and its related. In this framework, indicators related to syntropic farming are analyzed and considered next to a case study of Horta Da Malhadinha, the CARES farm in Mértola. Information about CARES, and their farm was collected through literature, a visit to the farm, and also an interview with a representative from Terra Sintrópica. Through the interview process, ethical guidelines and procedures were followed including informed consent, respect, and confidentiality. The analysis does not examine actual monetary values, but rather general indicators related to syntropic farming that could be applied to any regenerative farming process, even though farms have different settings and products. Table 1 shows different cost and benefit categories for syntropic farming along economic, environmental and socio-cultural dimensions.

Discussion and Results

Table 1 shows the indicators that would be important to assess a syntropic farm. The table is organized by indicator, starting with "cost" economic indicators. Economic indicators are classified between fixed and variable costs. A fixed cost is one that is independent of the product being sold or made. A variable cost is one that is dependent on the amount of output that is produced. The table also shows the ease of monetarily evaluating the indicator. In a cost-benefit analysis, each indicator would have monetary values associated with them. In this framework, there is not a monetary number, rather an ease of evaluation that is scored from easy to difficult.

Table 1. Costs and Benefits of a Syntropic Farming system.

Cost or Benefit	**Indicator type**	**Indicator name**	**Ease of monetary valuation**	**Considerations**
Cost	Economic (fixed)	Cost of the Land	Easy	Cost of purchasing or renting the land; opportunity cost of using the land for syntropic farming versus alternative applications. It is a fixed cost as it is independent of the product.
Cost	Economic (fixed/variable)	Cost of inputs	Easy	Cost of initial inputs, as well as annual operating costs.
Cost	Economic (fixed/variable)	High Labor Usage	Easy	Syntropic farming can not necessarily be mechanized, and is very labor intensive especially when trees are combined with horticulture.
Cost	Economic (variable)	Lower yields	Easy - Medium	This indicator's value is based on the amount produced and the market price of the product.
Benefit	Economic	Long term investment	Easy	Results of the system are seen far after initial investment. The literature has varying numbers for when the first results of the system are seen, from 6 months (Agenda Gotsch, 2015) to no results seen after a year (Portilho et al, 2018), to predictions of 5-10 years (van Cossel et al, 2020).

Benefit	Economic	Diversifying revenue source	Medium	By having a system with many different species of plant, and different outputs (i.e. fruit, vegetables, nuts, firewood, etc) there is resilience against fluctuations in product markets.
Cost	Socio-Cultural	Knowledge Gap	Difficult	High levels of planning, organization and knowledge needed for the system to be successful (Andrade et al, 2020)
Benefit	Socio-Cultural	Knowledge and Culture	Difficult	Creation of farming communities that share resources and knowledge (ex. Mértola).
Benefit	Social, Environmental	Erosion Control	Medium - Difficult	Syntropic farming lessens the impacts or risk of erosion, and therefore lessens the human risk of the natural disasters that arise with erosion as well.
Benefit	Environmental	Applicability of system	Difficult	Most case studies of this system have been in the tropics (Lawton, 2021), and prime agricultural areas (Brazil, Italy, Australia), although there has been a successful case study from Norway (Finch, 2022).
Benefit	Environmental	Soil Health	Difficult	Case studies report increases in soil health. Part of this price could be determined by the amount saved through not using fertilizers or soil additives.
Benefit	Environmental	Carbon Sequestration	Medium	Intensive pruning of the trees leads to more carbon sequestration (Agenda Gotsch, 2015), and potentially a carbon sink in soils (Selecky et al, 2017).
Benefit	Environmental	Higher biodiversity	Medium - Difficult	Montgomory et al (1999) created a framework for pricing biodiversity in an area. There are also schemes to buy biodiversity credits, which give prices to certain habitats (UK Department of Environment, Food & Rural Affairs, 2024).

Benefit	Environmental	Creation of a microclimate	Difficult	The impacts of syntropic systems can create microclimates, especially at scale, as observed by Ernst Gotsch (Agenda Gotsch, 2015).
Benefit	Environmental	Lower risk of disease and infestation	Easy - Medium	There is the possibility of pricing by using the cost avoided of buying chemical inputs like pesticides, herbicides, fungicides, etc.

Cost of Land

This is an economic fixed value, which is easy to monetarily evaluate. Without land, farming is not possible, and the cost of land is a large investment. Land acquisition looks different across different farms. Horta Da Malhadinha, for example, is a partnership between the landowner and the farmer, where the farmer does not have to pay anything for the land, but the land is regenerating. Oftentimes, farms are on land that was inherited or belongs to a family. In this case, the cost of the land is the opportunity cost of employing syntropic farming versus alternatives, like monoculture or land development. This indicator can also be priced by looking at rental prices at similar or nearby land.

Cost of Inputs

This indicator is a simple sum of inputs. These inputs include initial costs, like prepping the soil manually or by machine, or buying farming tools like machetes or chainsaws for pruning. It also includes this initial prepping of the soil, which is done manually or with machines depending on the compaction of the soil. Some of these initial costs will be economically fixed costs like soil preparation, or installation of irrigation systems, while most others will be economically variable costs, like plants, or mulch. While this indicator is likely higher in the first few years of implementation, it also includes annual or biannual operating costs that will vary with desired output. These longer term costs include planting placenta plants like vegetables that have a short lifespan. Usually, after the soil starts to regenerate, plants can be propagated from seed, but the soil in Mértola continues to have low organic matter and cannot support propagation from seeds. Instead, seedlings are purchased and used for each season. Generally, syntropic farms do not use irrigation, however, CARES does irrigate, and that cost is considered within this indicator. This indicator does not vary with the amount of crop produced, and is incurred habitually in the short term (annually or a few times a year).

High Labor Usage

Syntropic farming is a very labor-intensive farming system. There is harvest many times a year, it has many different crops that have varying needs, and it needs intensive management like pruning and biomass soil cover. Through this, there is high amounts of necessary labor, which accrues high labor costs. This indicator is also an economically fixed or variable cost, depending on the type of product, as there might be a need for more harvesters at a certain time of year. This indicator depends on the type of system, because those that focus on vegetables and fruit trees, like Horta Da Malhadinha do, are more labor intensive, as the different species have different harvesting needs. This indicator also relies on type of topography, as irregular topography needs more specialized machines or higher labor. Also, depending on the size of the farm, there is a more or less likely chance that the system can be mechanized. If the system is mechanized, which syntropic farms rarely are, this can decrease the high labor costs. This indicator is fairly easy to calculate, as it is the number of workers multiplied by their hourly rate, and the average number of hours. For CARES, there is a full time farmer, and two part time workers, as well as occasional volunteers. Depending on the hours of the part time workers, and the wage they receive, this indicator can be easily calculated.

Lower yields

Because a syntropic system has a diversity of crops and included plants, they have lower yield of each particular species. This diversity of plants has positive results for CARES' partners (restaurants and vegetable boxes). This indicator assumes that greater yield is better, because then there is greater profit. However, sometimes lower quantities of a product with higher prices can lead to high profit as well. Therefore, this indicator depends on the market price of each product, and can hence be calculated with the amount produced and those prices. Also, depending on the use of the system, this indicator might not matter. For example, syntropic systems can be used for sustenance farming because of the high diversity of plants. The lower yields are not pertinent in this case, because there are no goods to be bought or sold. However, if syntropic systems are scaled up, this indicator might become more complicated, as they will have higher yield of each species, yet still will have less yield than a monoculture of their size.

Long-Term Investment

This indicator is a reminder that oftentimes the results and benefits of the system are not experienced until much after the initial costs are accrued. These benefits, often environmental, are generally seen in an average of about 5 years after installation of the system (van Cossel et al, 2020; Agenda Gotsch, 2015; Portilho et al, 2018; Terra Sintrópica). While there is a period of paying costs without seeing benefits, the system takes longer to show results of the system, from 1 to 10 years (Terra Sintrópica; van Cossel et al, 2020). The regenerating ability of this system allows for benefits to increase with the amount of time that the system has been implemented. Also, the time to see results depends on the system. Horta Da Malhadinha is a unique case, as their soils are extremely dry and degraded, and their climate is very hot with little precipitation. In this setting, they have seen high amounts of carbon sequestration of their soil, just after 5 years (Oliveira et al, 2021). Also, they have seen improvements in the soil and climate that have been compounding after one year of implementation (Terra Sintrópica, 2024). For example, in the summer, in Mértola it is about 35º but in the farm it is 5º cooler. To calculate long term benefits of the system, the discount rate is necessary for economic analysis.

Diversifying revenue source

This indicator takes account of the economic benefit of the plant diversity of the system, which allows the farmer to have many different revenue sources, rather than just relying on one product. If there was a market decrease in price of a particular product, or a weather phenomena killed a specific plant, the syntropic farmer has many different other plants to gain revenue from. Depending on the system, there can be livestock, and timer production as well, which allows for more diversification of revenue sources. Also, these revenue sources mature at different times. The placenta plants are ready to be sold faster, while other species, like nut trees, take longer to produce revenue sources. Now five years into the building of their syntropic system, Horta Da Malhadinha can produce seasonal products and not produce plants year round. They still have a very diversified system with high numbers of marketable products, but with more time will be able to have more marketable products. Their yield is well formatted to their method of revenue, vegetable boxes, which encourages a variety of products. They deliver about 50 boxes two times a month. Small boxes (4.5 kg) cost €15/box, and large boxes (9 kg) cost €25/box.

Knowledge Gap; Knowledge and Culture

This system, however productive, requires high amounts of technical knowledge, which is a cost, and the community building that is associated with this system is a benefit. In the first place, it is difficult to start a syntropic system because of the knowledge of the distances between rows, species of plants, plant management, and more. On the other hand, the buildup of the necessary knowledge and the interest this new process raises among people who would like to "learn by doing" facilitates the creation of a community. Mértola is a good example, as CARES partners with schools, internship programs, and provides educational demonstrations to those hoping to start their own farm, or integrate syntropic practices. While important, these knowledge and community indicators are very hard to price. This same socio-cultural mindset exists at Olhos D'Água, Ernst Gotsch's farm. Their website frequently posts research about innovative practices (Agenda Gotsch, Andrade & Mhereb, 2019). There is also a cooperation potential for farms across the world to share knowledge on applicable solutions (Albrecht & Wiek, 2021). These indicators are very hard to price, as they have socio-cultural impacts that are hard to quantify.

Erosion Control

While this is an environmental indicator, it is one that has a high impact on people as well. Erosion is both a cause and created by desertification (WWF, n.d.) and poor soil health. Syntropic farming systems have lower erosion than other systems, which improves soil quality and decreases water pollution (WWF, n.d.). Soil erosion is a cause of flooding, desertification, loss of soil, and decreases in the quality of soil, which leads to poor farming conditions. Because of syntropic farming's impact on soil health, there is less risk for humans from the associated natural disasters and environmental issues that arise with erosion. These types of indicators are hard to value, as it is difficult to price an event that does not occur, like the effects of erosion that are avoided through soil regeneration.

Applicability of System

Because of the high technical knowledge and flexibility associated with this system, it is applicable to any zone. While most of the farms using these principles have been in places that are warm and sunny, like Brazil, Italy, Portugal and Australia, there are also case studies from places not as suited to farming, and as disparate as Norway and Mértola. Mértola, in particular, is a very difficult place to farm as soils have low organic content, there is very little rainfall, and the summer temperatures are very hot. Syntropic farming being applicable in this climate is a good sign for the applicability of this system around the world. Because the system allows for flexibility in species, and focuses on pairing species that regenerate the soil, it is widely applicable to many places. However, because of the theoretical nature of this indicator, it is very hard to price in a monetary way.

Soil Health

One of the main benefits of a syntropic system is the emphasis on soil health. Many case studies have shown the increase in organic matter, nutrients and soil health factors (Riolo, 2019; Terra Sintrópica). Syntropic farms have soil that is microbiologically similar to the soil of an area that has been naturally regenerating for 10 years (Cezar et al, 2015). Studies also report rich soil with high amounts of organic matter content (Oliveira et al, 2021), high water-retention and lower temperatures in soil (Damant & Villela, n.d.). This system has success in counteracting desertification, desert conditions, low precipitation, and more, while regenerating and adding nutrients into soil without chemicals. Workers at CARES have noticed differences at the soil level (color, texture and water retention capacity) that emerged after the first year, intensifying over time. This observation is earlier than is detailed in the literature. Also, a study on Horta Da Malhadinha found that the soil has 8.3% clay content, and 14.5% organic content of the soil (Oliveira et al, 2021). It is recommended that clay content is between 20-30% and organic content is around 5% (Londeree, n.d.). Clay content assists in water-retention in the soil, so the small clay content number in CARES' soil demonstrates their soil's less than ideal quality. While this is a very important factor in this system, it is incredibly difficult to price. It could partially be priced by the amount saved by not using fertilizers or soil additives, like nitrogen, phosphorus or potassium, however that does not fully represent the benefits of the indicator.

Carbon Sequestration

Another of very important benefits of this system is the high amount of carbon sequestration that is possible with proper management. The intensive pruning allows for more carbon sequestration than a conventional farming system (Agenda Gotsch, 2015), and can even cause this system to be a carbon sink (Selecky et al, 2017). It was calculated that a syntropic farm accrued a sequestration of 9.8 MG*C*ha^{-1}*$year^{-1}$ in a 6 year old system and 13.5 MG*C*ha^{-1}*$year^{-1}$ in a 34 year old system (Selecky et al, 2017). Also, the planting technique of putting many different plants together allows for more carbon sequestration. This high level of carbon sequestration was observed at Horta Da Malhadinha, where the farm took in ten times the amount of carbon than a conventional farm (Oliveira et al, 2021). While the carbon sequestration itself can be assessed, there is an added layer of choice in how to price that carbon. There is a theoretical social cost of carbon (Griffiths et al, 2012), to real EU ETS prices (European Commission, n.d.; Trading Economics, n.d.) and carbon prices in voluntary markets (Carbon Credits, 2022).

Higher Biodiversity

This indicator is very hard-to-price and a very important factor in this type of system. High biodiversity is both intentionally included in this system, and a byproduct. Farmers include many different species of plants in their system, of varying heights, and scientific families. CARES includes about 23 species of trees, shrubs and aromatic plants, not including seasonal vegetables. These plants create high biodiversity of animal and insect species that come to the farm because of its plant biodiversity. Even though pricing for this indicator is hard to accomplish, there are methods and models that already exist which could be useful in making an applicable framework for pricing biodiversity. For this reason, this indicator is listed as medium - difficult in the ease of valuation column. Montgomory et al (1999) created a framework for pricing biodiversity in an area, specifically birds. This is possible, however, it is difficult to know how many species are truly in the habitat, and also hard to know how this framework could apply to plant species. There are also frameworks for pricing ecosystems that are constructed based on the costs of creating, maintaining and monitoring habitats (UK Department of Environment, Food & Rural Affairs, 2024). This indicator also includes the benefit of the inclusion of native plants in a habitat, which is another reason why it is hard to price, as each species is unequally important to the system.

Creation of a Microclimate

This indicator is yet another environmental factor that is very hard to put in monetary terms. This phenomenon was observed at Olhos D'Água, Ernst Gotsch's farm in Brazil, where, after years of farming syntopically and focusing on ecosystem health, a piece of land that was described as "dry and windy" now experiences the running of 17 streams that had dried up, along with higher levels of rainfall (Agenda Gotsch, 2015; Schulz et al, 1994). This microclimate creation surely has to do with the fact that Gotsch's farm is 480 hectares, and also the time that he has been syntropically farming, which is about 40 years. Horta da Malhadinha, which is only five years old, does not experience many indicators of a microclimate, yet a 5ºC difference in the temperature has been measured during the summer months. This indicator is hard to price, as the impacts vary system to system, and also different climatic factors are valued differently in different places. However, based on the changes in climate that Gotsch observed, which was mostly about water in the system, this could be priced by measuring the amount of rainfall or stream water, and then calculating the cost of irrigating that amount of water. However, this indicator is still listed as difficult to price because the climatic factors change site to site.

Lower risk of disease and infestation

Due to the high amount of biodiversity, and namely the soil coverage, these systems experience lower amounts of disease and bug infestations (Andres et al, 2016). While this is not always the case, as Gasparro (2019) details that a syntropic farm in Brazil uses other methods of disease prevention, most syntropic farms do not use chemical inputs like pesticides or herbicides. By relying on the system to prevent diseases and pests, this indicator is fairly easy to price, as it is the amount saved on not using chemical inputs.

Considerations for this framework

There are many scholars who have studied how to best assess hard-to-price indicators in the environment. Balmford et al (2018) put everything in terms of carbon emissions, specifically the sum of externality generated per unit of production. Hanley & Barbier (2009) say that everything should have a calculated associated marginal social cost/benefit, that is a part of the market price of a good. However, in most environmental cases, there is no market value for the good or service, like soil health. Mendelsohn & Olmstead (2009) mention stated/revealed preferences methods or hedonic models which both include finding a proxy for the natural resource or environmental issue that is being valued, either through travel costs or implicit prices of the inputs. This is also what Pissalingo (2024) and Hanley & Barbier (2009) raise as alternatives to marginal social benefits and costs. In this analysis, putting each indicator through the same pricing method is not necessarily possible, as they are all very different. For this reason, the ease of evaluation was included in Table 1. If there was an idea for how to price an indicator, then it was included in the discussion. The ease of monetary evaluation was determined on how difficult it would be to get data on that particular topic, and then transform the data.

Some of these indicators require a discount rate, specifically carbon sequestration, creation of a microclimate, soil health and long term investments. The discount rate takes the effect of time into account, which is helpful when benefits or costs of an indicator will present in the long term, by finding the equivalent value in the present. Using this tool generally includes using a mathematical equation to convert future values into present values (Prest, 2020).

Another consideration about a cost-benefit analysis is making sure that there is no double counting of costs or benefits. In syntropic farming, so many of the indicators coincide, which could lend to double counting. Double counting is when benefits or costs of a system are evaluated twice, which leads to incorrect results and analysis of data. For this analysis, bundling indicators together to minimize or avoid double counting is important. A projected bundling of the indicators is included below.

Cost of the Land
Cost of inputs

High Labor Usage
Lower yields + Lower risk of disease and infestation
Long term investment
Diversifying revenue source
Knowledge Gap + Knowledge and Culture + Applicability of system
Erosion Control + Soil Health
Carbon Sequestration
Higher biodiversity
Creation of a microclimate

Examination of Case Studies

In order to understand how Horta Da Malhadinha compares to syntropic farms around the world, this analysis examined several case studies of syntropic farming, food forests, agroforestry and economic reviews of these types of farming. Several case studies focus on cocoa production in South America. Cocoa can only be produced in certain tropical places, but is a highly demanded product, which drives farmers to look for different systems that might produce high amounts of cocoa. Mattalia et al (2022), through a scoping review, highlighted the ecological and economic benefits of agroforestry systems, and reported that cocoa trees produced the same or more in agroforestry systems than in monocultures. Two case studies of cocoa production, comparing agroforestry systems against conventional cocoa monoculture, found similar results. Andres et al (2016) demonstrated that productivity under agroforestry systems was either similar or a bit higher compared to monocultures. Schneider et al (2016) wrote that yield difference between monocultures and agroforestry systems was statistically insignificant. However, cocoa yields were 12–46 % higher in agroforestry systems compared to monocultures (Andres et al, 2016), and the cumulative yield of all harvested products was 161% higher in agroforestry systems than monoculture (Schneider et al, 2016). Another case study offered a different perspective on syntropic systems, by comparing conventional cocoa farming, syntropic farming and regrowth forest, specifically on soil water-retention, and soil temperature (Damant and Villela, n.d.). The syntropic agriculture system had 13% higher water retention than a monoculture, and after a few days without rain, performed better than a regrowth forest as well. In terms of soil temperature, regrowth forest had the lowest temperatures, followed by syntropic farming and then monoculture. These case studies show that syntropic farming principles perform at least as well as monocultures, while experiencing much higher water retention, and lower soil temperatures. Gasparro (2019) studied citrus produced in a monoculture, organic farm and a syntropic farm. The authors found that syntropic farms produced good environmental and economic results, showing that large scale successional agroforestry systems are feasible ecologically.

Several case studies also highlighted that there was high interest from farmers wanting to know more about the system, and gain more knowledge about the technical parts of syntropic farming (Andres et al, 2016). A similar type of social benefit was observed by Riolo (2019), who mentioned the community creation that came along with an urban food forest. Horta da

Malhadinha emphasizes this social knowledge effect of syntropic farming, as most of their experimental work is focused on demonstrations, education, and research.

Syntropic farms often take time to realize their full benefits. The literature is not concise on the number of years that it takes to see results of the system. In their study, van Cossel et al (2020) found that the system would likely be fully functional 5-10 years after inception. Riolo (2019) had a similar result to van Cossel et al (2020), as they reported the benefits of the food forest could already be seen after 5 years, specifically in the quality of the soil. Portilho et al (2018) started a syntropic farm and did not see results after a year, which is complementary to the results seen by other authors. Horta da Malhadinha, similarly to Riolo, has seen differences in soil health, and carbon sequestration ability of the soil (Oliveira et al, 2021), starting after the first year.

Albrecht & Weik (2021) provided a sustainability framework that was the inspiration for the framework in this analysis. It focused on fourteen case studies of food forests around the world. They applied a framework of economic, environmental and socio-cultural indicators to these case studies, to give each site a score. In general, food forests often showed high socio-cultural and environmental value, but did not perform as well in the economic indicators. Another study, Mercer et al (2014), found that these systems had low adoption rates despite the economic promise found to be characteristic of agroforestry systems. When environmental benefits were included in the economic benefit framework, agroforestry becomes one of the most profitable land use options, and also had higher production than other options (Theismeier & Zander, 2023). In general, it is highlighted that agroforestry systems are highly dependent on the market prices of the products. Gasparro (2019) did a case study in Brazil that found that operating profit of successional agroforestry systems was higher than both organic and conventional farming systems, while providing high environmental benefits, proving the economic feasibility of these systems in that context.

Another case study calculated the feeding potential of a food forest in Scotland, which is an important gap in research about syntropic farming. Nytofte & Henriksen (2019) found that the average annual yield of the 0.08 ha food forest is 713 kg, corresponding to 415,075 kcal, 9868 g protein, 8394 g fat and 85,627 g carbohydrates. Alternatively, this food forest is able to supply 7 males or 9 females with carbohydrates, 4 males or 5 females with fat, and 3 males or 4 females with protein. While this is not enough food for a community, this is also a fairly small farm at less than one hectare, which opens a research gap about the scaling-up of these systems. Gasparro (2019) argued that large-scale successional agroforestry systems are possible, which would allow the amount of nutritional yield to increase.

Through the indicator table, and the examination of other case studies, it is found that syntropic systems are economically feasible, have high environmental benefits like higher water retention of soil and increased biodiversity, and they also have the possibility to provide enough yield to feed communities. While there was doubt about the applicability of this system (Lawton, 2021), case studies show that it has been implemented in inconvenient farming areas, like Norway (Finch, 2022) and Mértola (Terra Sintrópica). The indicator table analysis provides clues for the low adoption of syntropic farming, because the costs of the system are much easier to price than the benefits, since the costs are mainly economic indicators and the benefits are namely environmental factors. Also, the cost indicators, like cost of inputs, are mostly felt in the short term, while beneficial indicators, like higher biodiversity, generally present in the long term. However, through observation and review of the literature, it seems that these beneficial indicators are highly valuable and outperform the initial costs.

Conclusions

This analysis studied the economic effects of syntropic farming using a literature review and an indicator framework with a case study of Horta da Malhadinha. Through this, it was found that syntropic farming is viable environmentally, economically and nutritionally. Though many costs of this system are incurred in the short term, and the benefits are more easily experienced in the long term, by pricing environmental factors like soil health, or carbon sequestration, this system's benefits can outperform its cost indicators. Because of climate change, and the projected increase in world population (Gasparro, 2019), systems that regenerate soils, prioritize ecosystem health, and provide products useful for humans are essential. Based on the findings of this paper, for syntropic farming, the benefits seem to outweigh the costs, and therefore this system can be economically feasible, although context will be a relevant determinant of profitability.

While this analysis synthesizes much observational and anecdotal data, it is limited by the lack of economic data for many of the cost and benefit categories. Also, since syntropic farming is a fairly new research topic, there are not many case studies or available data. These limitations provide niches for future research. It is recommended that future studies examine the ability of this system to produce food for a community, and the implementation of large-scale syntropic farms. There is a large research gap in the economic feasibility of these systems in terms of economically assessing these systems with data. Also, while there are already a few of these systems in non-tropical places, it would be intriguing to see the implementation of this system in more places around the world. Syntropic farming is a way forward in both food production and environmental health.

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References

About Permaculture | Holmgren Design. (n.d.). Retrieved April 27, 2024, from https://holmgren.com.au/permaculture/about-permaculture/

Agenda Gotsch (Director). (2015). *Life in Syntropy*. Retrieved from https://www.youtube.com/watch?v=gSPNRu4ZPvE

Agenda Gotsch. (n.d.-a). Agenda Gotsch – Ernst Götsch's Syntropic Farming Official Website. Retrieved April 18, 2024, from https://agendagotsch.com/en/

Agenda Gotsch. (n.d.-b). What is Syntropic Farming? – Agenda Gotsch. Retrieved April 15, 2024, from https://agendagotsch.com/en/what-is-syntropic-farming/

Albrecht, S., & Wiek, A. (2021). Food forests: Their services and sustainability. *Journal of Agriculture, Food Systems, and Community Development*, 1–15. https://doi.org/10.5304/jafscd.2021.103.014

Amador, D. B. (2018). BIODIVERSE AGROFORESTRY EXPERIENCES IN BRAZIL: TECHINICAL AND EDUCATIONAL APPROACHES. In *Proceedings of International Biodiversity Congress (IBC 2018)* (Vol. 5, pp. 258–264). Forest Research Institute.

Andrade, D., & Mhereb, M. T. (2019, August 19). Large-scale Syntropic Farming: Results and challenges – Agenda Gotsch. Retrieved April 18, 2024, from https://agendagotsch.com/en/large-scale-syntropic-farming-results-and-challenges/

Andrade, D., Pasini, F., & Scarano, F. R. (2020). Syntropy and innovation in agriculture. *Current Opinion in Environmental Sustainability*, *45*, 20–24. https://doi.org/10.1016/j.cosust.2020.08.003

Andrade, D., & Pasini, Felipe. (2022). *Recarbonizing global soils: A technical manual of recommended sustainable soil management*. FAO. https://doi.org/10.4060/cb6595en

Andres, C., Comoé, H., Beerli, A., Schneider, M., Rist, S., & Jacobi, J. (2016). Cocoa in Monoculture and Dynamic Agroforestry. In E. Lichtfouse (Ed.), *Sustainable Agriculture Reviews: Volume 19* (pp. 121–153). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-26777-7_3

Araújo, J. B. C. N., Souza, A. N., Joaquim, M. S., Mattos, L. M., & Lustosa Junior, I. M. (2020). Use of the activity-based costing methodology (ABC) in the cost analysis of successional agroforestry systems. *Agroforestry Systems*, *94*(1), 71–80. https://doi.org/10.1007/s10457-019-00368-6

Balmford, A., Amano, T., Bartlett, H., Chadwick, D., Collins, A., Edwards, D., … Eisner, R. (2018). The environmental costs and benefits of high-yield farming. *Nature Sustainability*, *1*(9), 477–485. https://doi.org/10.1038/s41893-018-0138-5

Carbon Credits. (2022, February 16). What is the Voluntary Carbon Market? Retrieved April 30, 2024, from Carbon Credits website: https://carboncredits.com/what-is-the-voluntary-carbon-market/

Carlo. (2021, October 11). Why we choose for "process based agriculture", with Rebel Jacob. Retrieved March 25, 2024, from The Green Rebel website: https://www.thegreenrebel.org/post/why-we-choose-for-process-based-agriculture-with-rebel-jacob

Cezar, R. M., Vezzani, F. M., Schwiderke, D. K., Gaiad, S., Brown, G. G., Seoane, C. E. S., & Froufe, L. C. M. (2015). Soil biological properties in multistrata successional agroforestry systems and in natural regeneration. *Agroforestry Systems*, *89*(6), 1035–1047. https://doi.org/10.1007/s10457-015-9833-7

Damant, G., & Villela, F. (n.d.). *CAN AGROFORESTRY IMPROVE SOIL WATER AND TEMPERATURE DYNAMICS IN AGRICULTURE? A CASE STUDY WITH SYNTROPIC FARMING IN BAHIA, BRAZIL*.

Eills, A. (2021). *A Year in Syntropy: Exploring Syntropic Agriculture*.

European Commision. (n.d.). What is the EU ETS? - European Commission. Retrieved April 30, 2024, from https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/what-eu-ets_en

FAO. (2018). *Cost-benefit analysis for climate change adaptation policies and investments in the agriculture sectors*. Food and Agriculture Organization of the United Nations.

Finch, J. (n.d.). *Successional Agroforestry Trip to Denmark, October 2022*.

Gasparro, D. (2019). *From the Atlantic forest to the Mediterranean shrub land: A Farm Performance Assessment and a Functional Design Framework for Large-Scale Successional Agroforestry Systems (SAFS)*.

Geoff Lawton (Director). (2021). *Permaculture Vs Regenerative Agriculture, Syntropic Agriculture & Holistic Management?* Retrieved from https://www.youtube.com/watch?v=yCwoQR9pOsw

Griffiths, C., Kopits, E., Marten, A., Moore, C., Newbold, S., & Wolverton, A. (2012). Chapter 4. The Social Cost of Carbon: Valuing Carbon Reductions in Policy Analysis*. In *Fiscal Policy to Mitigate Climate Change*. International Monetary Fund. Retrieved from https://www.elibrary.imf.org/display/book/9781616353933/ch04.xml

Hanley, N., & Barbier, E. B. (2009). *Pricing Nature: Cost-benefit Analysis and Environmental Policy*. Edward Elgar Publishing.

Leaf & Limb. (n.d.). Mycorrhizal Fungi: The Unsung Heroes of Tree Care. Retrieved April 15, 2024, from Leaf & Limb website: https://www.leaflimb.com/Mycorrhizal-Fungi-Unsung-Heroes-of-Tree-Care/

Leitão, R., & Nogueira, P. (2022). *Successional Agroforestry's central role in a project of rural development and climate change adaptation in Alentejo, Portugal*.

Londeree, N. (n.d.). Garden Good Guys—Soil. *UCANR*.

Lopes, A. A., & Romana, F. A. (2022). Agroforestry: The Future of the Planet through the Operational Teams Management. *American Journal of Industrial and Business Management*, *12*(10), 1591–1606. https://doi.org/10.4236/ajibm.2022.1210087

Mattalia, G., Wezel, A., Costet, P., Jagoret, P., Deheuvels, O., Migliorini, P., & David, C. (2022). Contribution of cacao agroforestry versus mono-cropping systems for enhanced sustainability. A review with a focus on yield. *Agroforestry Systems*, *96*(7), 1077–1089. https://doi.org/10.1007/s10457-022-00765-4

McSweeney, R. (2019, August 6). Explainer: Desertification and the role of climate change. Retrieved April 15, 2024, from https://www.carbonbrief.org/explainer-desertification-and-the-role-of-climate-change/

Mendelsohn, R., & Olmstead, S. (2009). The Economic Valuation of Environmental Amenities and Disamenities: Methods and Applications. *Annual Review of Environment and Resources*, *34*(1), 325–347. https://doi.org/10.1146/annurev-environ-011509-135201

Mercer, D. E., Frey, G. E., & Cubbage, F. W. (2014). Economics of Agroforestry. In *Handbook of Forest Resource Economics*. Routledge. https://doi.org/10.4324/9780203105290.ch13

Mishan, E. J., & Quah, E. (2020). *Cost-Benefit Analysis* (6th ed.). London: Routledge. https://doi.org/10.4324/9781351029780

Montgomery, C. A., Pollak, R. A., Freemark, K., & White, D. (1999). Pricing Biodiversity. *Journal of Environmental Economics and Management*, *38*(1), 1–19. https://doi.org/10.1006/jeem.1999.1073

National Geographic. (2024, April 15). Why you should add native plants to your garden. Retrieved April 15, 2024, from Environment website: https://www.nationalgeographic.com/environment/article/native-plants-garden-lawn-pollinators

Noosa Forest Retreat. (n.d.). What's The Difference Between Syntropic Farming And Permaculture? Retrieved March 25, 2024, from Noosa Forest Retreat: Permaculture Education Centre & Community website: https://noosaforestretreat.com/whats-the-difference-between-syntropic-farming-and-permaculture/

Nytofte, J. L. S., & Henriksen, C. B. (2019). Sustainable food production in a temperate climate – a case study analysis of the nutritional yield in a peri-urban food forest. *Urban Forestry & Urban Greening*, *45*, 126326. https://doi.org/10.1016/j.ufug.2019.04.009

Oliveira, M. Y., Guerrero, C., & Panagopoulos, T. (2021). Resultados de investigação projeto LIFE GEOCARBON. *Universidade Do Algarve*, 5.

Pasini, F. S., Andrade, D. V., & Scarano, F. R. (2021). 41. Syntropic Agriculture. *Food and Agriculture Organization*, *3*.

Pissalingo, P. (2024, March). *Sustainable Tourism*.

Portilho, C., Marasca, I., Oliveira Santos, G., Diniz, R., Lemos, S., & Solino, A. (2018). BIODIVERSITY AGROFORESTRY SYZTEM: SYNTROPIC AGRICULTURE. *Científic - Multidisciplinary Journal*, *5*, 140–144. https://doi.org/10.29247/2358-260X.2018v5i3.p140-144

Prest, B. C. (2020, January 16). Discounting 101. Retrieved April 29, 2024, from Resources for the Future website: https://www.rff.org/publications/explainers/discounting-101/

Restor. (n.d.). Centro de Agroecologia e Regeneração para o Semiárido—Horta da Malhadinha. Retrieved April 18, 2024, from Restor website: https://restor.eco/

Riolo, F. (2019). The social and environmental value of public urban food forests: The case study of the Picasso Food Forest in Parma, Italy. *Urban Forestry & Urban Greening*, *45*, 126225. https://doi.org/10.1016/j.ufug.2018.10.002

Schneider, M., Andres, C., Trujillo, G., Alcon, F., Amurrio, P., Perez, E., … Milz, J. (2017). COCOA AND TOTAL SYSTEM YIELDS OF ORGANIC AND CONVENTIONAL AGROFORESTRY VS. MONOCULTURE SYSTEMS IN A LONG-TERM FIELD TRIAL IN BOLIVIA. *Experimental Agriculture*, *53*(3), 351–374. https://doi.org/10.1017/S0014479716000417

Schulz, B., Becker, B., & Gotsch, E. (1994). Indigenous knowledge in a "modern" sustainable agroforestry system: A case study from eastern Brazil. *Agroforestry Systems*, *25*(1), 59–69. https://doi.org/10.1007/BF00705706

Selecky, T., Bellingrath-Kimura, S. D., Kobata, Y., Yamada, M., Guerrini, I. A., Umemura, H. M., & Dos Santos, D. A. (2017). Changes in Carbon Cycling during Development of Successional Agroforestry. *Agriculture*, *7*(3), 25. https://doi.org/10.3390/agriculture7030025

Terra Sintrópica. (2022, June 13). AGROECOLOGY AND REGENERATION - Synthropic Land. Retrieved April 18, 2024, from https://terrasintropica.com/en/, https://terrasintropica.com/en/

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

Trading Economics. (n.d.). EU Carbon Permits—Price—Chart—Historical Data—News. Retrieved April 30, 2024, from https://tradingeconomics.com/commodity/carbon

UK Department of Environment, Food and Rural Affairs. (2024, February 12). Statutory biodiversity credit prices. Retrieved April 15, 2024, from GOV.UK website: https://www.gov.uk/guidance/statutory-biodiversity-credit-prices

van Cossel, M. von, Ludwig, H., Cichocki, J., Fesani, S., Guenther, R., Thormaehlen, M., … Winkler, B. (2020). Adapting Syntropic Permaculture for Renaturation of a Former Quarry Area in the Temperate Zone. *Agriculture*, *10*(12), 603. https://doi.org/10.3390/agriculture10120603

Why Native Plants Matter. (n.d.). Retrieved April 15, 2024, from Ecological Landscape Alliance website: https://www.ecolandscaping.org/native-plants/

Why Native Plants Matter | Audubon. (n.d.). Retrieved April 15, 2024, from https://www.audubon.org/content/why-native-plants-matter

WWF. (n.d.). What is Erosion? Effects of Soil Erosion and Land Degradation. Retrieved April 15, 2024, from World Wildlife Fund website: https://www.worldwildlife.org/threats/soil-erosion-and-degradation