Regenerative Agriculture Framework for Island Ecosystems Using São Miguel as a Case Study

Mya Hunter

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REGENERATIVE AGRICULTURE FRAMEWORK FOR ISLAND ECOSYSTEMS:

Using São Miguel as a Case Study

Mya Hunter
School of International Training
Portugal: Sustainability and environmental Justice
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Abstract

CONTEXT: Regenerative agriculture is a farming approach that uses soil health as the entry point to contribute to multiple objectives, such as improved nutrient cycling and climate regulation. Farmers can apply different practices to reach these objectives. The objectives and practices, however, are not equally relevant or applicable for farming systems on island ecosystems and the local context.

OBJECTIVES: The main objective of this paper, therefore, is to find out how solutions towards regenerative agriculture can be identified and evaluated as such that they result in meaningful advice for farmers on island ecosystems in order to mitigate the effects of climate change.

METHODS: In this study, a well-established modeling framework to redesign farming systems is applied to three typical but diverse Azorean farming systems. The modeling framework combined the regenerative models of Shrefeefel et al. to create an innovative and equally applicable model for farms on island ecosystems. The modeling framework covered a crop farm on andissoil, a dairy farm on andissoil, and a mixed farm on rocky soil. A multitude of solutions is subsequently composed of combinations of practices for these farming systems, each showing solutions that contributed in varying degrees towards the objectives of regenerative agriculture and climate change mitigation.

Keywords: climate change, regenerative agriculture, biodiversity, soil health, carbon sequestration, island ecosystems
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To Hawai’i- always my passion, forever my purpose.

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1. Introduction

Regenerative agriculture (RA) proposes a solution to mitigate the effects of climate change on islands. In the not-too-distant past, all agriculture was organic, animals were fed on naturally growing grass, and manure was used as fertilizer. What was the norm no more than a century ago is now the exception. Recovering the behavior model in which human beings can feed themselves while respecting the natural process of regeneration needs to be coupled with innovation. The current agriculture system provides people globally with an abundance of food services, and has improved food security for the most vulnerable groups. The production, processing, and distribution of food is the world’s largest economic activity.

However, this success comes at a considerable cost: today the global food system causes one third of terrestrial acidification and is responsible for most of the global eutrophication of surface waters (Poore & Nemecek, 2018). As stated in the recent Intergovernmental Panel on climate change report, agriculture accounts for 70% of global freshwater use and a third of global greenhouse gas emissions (IPCC, 2). According to the United Nations Food and Agriculture Organization, the agriculture industry is one of the largest emitters of CO₂ and is associated with 80% of global deforestation (UN, FAO 3). Nevertheless, agricultural systems hold vast potential for reducing global greenhouse gas emissions, preventing land degradation, protecting terrestrial biodiversity, and mitigating the effects of climate change.

The systems most vulnerable to these effects of climate change and variability include island ecosystems. Findings emphasize that most urban and rural reef and high islands have undergone increasing exposure and vulnerability, as a result of environmental conditions causing major changes in settlement, demographic patterns, lifestyles, economies, and natural resource availability (Duvat, 2017). Apart from these modern threats, islands are, and often have been, regarded as particularly vulnerable to climate change. The existence of anthropogenic-driven path-dependency has created unsustainable systems of yield, input, and production in the agriculture sector (Grelet, 2021). Due to problems such as limited natural resources, social fragmentation, and economic disadvantages on the global market, islands are vulnerable to environmental stresses in the form of sea level rise, drought, flood, erratic weather patterns, and temperature changes (IPCC, 2019). The inextricable link between agriculture, global warming, and island ecosystems lay open risks as well as opportunities to develop methods and practices that utilize this link advantageously (Levin, 2022).

In order to mitigate climate change effects on island ecosystems, this paper proposes RA to put forward sustainable food systems. RA is a nature-based solution that aims to transition agriculture from being a primary source of environmental degradation to a primary source of regeneration of modified ecosystems (Gosnell, et al., 2019). This practice is an ecosystem-based approach to farming that aims to improve farmer resilience, yield, and quality by improving soil health, enhancing biodiversity, and reducing the impact of synthetic inputs (Giller, et al., 2021). Carried out in a regenerative way, agricultural production could also improve the livelihoods of farm workers, preserve biological integrity, and mitigate the effects of climate change on island ecosystems (Lal, 2020).

The wide variety of sustainable farming approaches that aim to limit detrimental environmental impacts are
gaining both public and academic attention. The urgency to transition towards a regenerative food system is increasingly recognized in European agreements such as the Common Agricultural Policy (European Commission, 2019a), the Biodiversity Strategy (European Commission, 2021), and the European Green Deal (European Commission, 2019b). Farmers using these innovative methods have proven that while agriculture has damaging impacts on the environment, the process holds dual potential for well-regulated and efficient management of agricultural land that possesses conceivable positive outcomes for environmental and ecosystem services (Siddi, 2020).

RA frameworks exist for specific countries, as well as tailor-made modeling frameworks for regenerative practices made for farm models. Although insightful, there are a number of caveats on which these frameworks fall short in delivering the same applicability to farms taking place on island ecosystems (Soloviev & Landua, 2022). To accumulate information, support examinations, and provide stakeholders with the knowledge necessary in a transition towards regenerative agriculture, this paper builds upon the framework of Schreefel et al. (2022) to further explore solutions for contrasting farming systems on islands, in particular, São Miguel Island, in the Azores.

São Miguel was selected as a seemingly case study due to its intensive agricultural landscape and successful regenerative farming practices. São Miguel holds history and potential for this study to be a launching point in applicability to islands alike. Therefore, the hypothesis is that global warming will be the largest indicator in this framework. With the agriculture industry fueling climate change, islands lay the most susceptible to loss and therefore put the biosphere at risk.

This paper proposes RA as a solution, providing the same opportunity of applicability to farmers practicing on islands that existing frameworks give to farms on continents. To meet this goal, a framework can be created that recognizes and enhances applicability for farmers in island ecosystems using current methods that set São Miguel apart from its continental counterparts. Firstly, data gathered on São Miguel will be clustered into indicators outlining the differences between island and continental regenerative farming practices. Secondly, a comparative analysis between understandings, needs, and implementations of RA will be evaluated. Finally, using the bases of previous regenerative frameworks, a new model can be proposed. The two goals of this framework will 1- adapt “conventional” agriculture to regenerative agriculture, and 2- choose regenerative practices that will contribute to mitigate climate change effects.

2. Background

2.1 Climate Change in Islands

Earth is undergoing drastic climate change due to increased greenhouse gas emissions. Changes in global climate have occurred several times throughout the Earth’s history, but have stretched over prolonged periods of time, whereas currently, these changes are taking place over the space of a century or less (IPCC). This rapid change, associated with other threats resulting from anthropogenic activity related to production and consumption, are having radical impacts on biodiversity (Ceballos, 2017). The direct alterations of natural habitats are a result of climate change. This forces species to move from their historical range, adapt to new environmental conditions, and find refuge in unaltered microhabitats, or may lead to
species extinction (Ferreira, et al., 2016). Importantly, climate change acts in synergy with other human-induced threats to increase the effects such as land use intensification, or biological invasion, which are all processes resulting from the current agricultural system. With agriculture being the leading cause of climate change, it is appropriate for this paper to source solutions linking from this interconnection (Rhodes, 2012).

In this context, island biodiversity requires specific attention for several reasons. Since they are spatially segregated and have evolved in isolation, insular communities are characterized by extremely high rates of endemism (Myers, et al., 2015). Additionally, islands hold a disproportionate amount of global biological diversity. These small, yet powerful, carriers contain systems, species, knowledge, and people that are paramount and endemic to the biosphere. The preservation of these systems is vital to upholding island integrity within individual ecosystems, and therefore global chains of biological diversity. Although they occur in less than 5% of the Earth’s terrestrial area, island plants and vertebrates have an endemic richness that exceeds mainland species by a factor of 9.5 (Kier, et al., 2009). Island biota are also very prone to extinction: around 80% of past extinctions and a third of threatened terrestrial species are found on islands (Bellard, et al., 2014).

Although climate change impacts island biota in various ways, sea level rise and climate shifts will be of major importance due to their direct association with the availability of suitable habitats for terrestrial organisms (Barlow, et al., 2018). Sea level rise may lead to the submergence of several islands, also increasing coastal erosion and saline water intrusion, impacting natural habitats (Bellard, et al., 2014). This means that elevation, area, and the complexity of shoreline inlets are of major importance regarding vulnerability to sea level rise. Island environments are known to be particularly sensitive to externally induced changes. The main reason for this sensitivity is the fact that many of the adaptation measures, which involve the relocation of resources and activities, cannot happen in the limited areas of most islands. On the other hand, islands are highly dependent on their coastal areas, and these have been identified as one of the major targets of climate change impacts (IPCC WGII TAR, 2001). There are not only environmental risks at stake, but also the relocation, loss, and erasure of culture, traditions, and people groups.

Accompanying climate change is the induced frequency and intensity of extreme weather events (e.g. droughts, storm surges, hurricanes), as well as altered patterns of seasonal and mid-term weather systems. When weather patterns change so do agricultural activities, e.g. harvesting seasons may be moved up or prolonged. This leads to altering effects on market prices and consumption. Shifts in climatic conditions may then promote a cascade of local extinctions of plants, animals, practices, and peoples (Sachdev, et al., 2022). The global narrative of climate change makes clear the inherent risk to island ecosystems, but lacks emphasis on the integral role that they play in a global arena. In spite of the total area and population of islands, they constitute vital assets for the countries they integrate, for many reasons, namely for their unique landscapes, climates, and for their strategic and economic advantages in the use of the ocean (Kueffer & Kinney, 2017). Continents and therefore the systems established on them such as agricultural, economic, and social have much at stake with islands being at such inherent risk. With the economic and strategic advantages that mainland territories
reap from islands, the lack of initiative to ensure their value is significant.

2.2 Regenerative Agriculture in Islands: Critical Points

Regenerative agriculture focuses on the biology of the soil and reducing levels of artificial chemicals through increased use of composting, and more sustainable methods of land management. Healthy soil is vital, not only because it is the foundation of RA, but because the process can stabilize food systems on island ecosystems (Gordon, 2021). On island ecosystems, RA has the potential to improve the quality of agricultural products and people’s livelihoods. Variables on land, like soil and water, can combat the climate effects of drought, erosion, flooding, temperature fluctuation, and even diseases. With conventional agricultural practices, sterilizing soils and depleting nutrient levels, RA acts as a climate change mitigation tool to areas most vulnerable to its effects (Gosnell, et al., 2019). RA creates fortified food systems and crops that are more likely to withstand genetic mutations or diseases that monoculture crops can succumb to. Through securing food practices, livelihoods and the accompanying cultural practices are also secured.

The defining and endemic properties of islands are not limited to flora and fauna but holistically encompasses ecological and biological systems. Agricultural practices are defined by actions that belong to stewards of the land. RA does not solely focus on the land, but also, on the people it impacts. The risk posed to islands at present threatens entire knowledge and cultural systems that would face displacement, loss, and reform. Additionally, RA on islands elevates island integrity through internal sourcing and consumption. Relying on external sourcing for food processes leaves island communities vulnerable and dependent on outer acquisition (Tershy, et al., 2015). By strengthening agricultural practices internally, the dependency on second parties lessons. Strengthening land ties, advancing practices to younger generations, and coupling innovation with culture creates an overarching goal of structure. The applicability of RA to island ecosystems is non-invasive. It is easier to transition farms on islands because of the scale. Most large monocropping producers inhabit spaces on mainlands where land use expands horizontally on soil that has been stripped of nutrients for years. Islands offer smaller scalability compared to their continental counterparts, which makes the transition or initiation of the integration of regenerative practices less disruptive and most impactful (Sayner, 2022).

2.3 Case Study: São Miguel, The Azores

2.3.1 Characterization

The Azores archipelago, which is of volcanic origin, is localized in the North Atlantic ridge, between the latitudes of 36° 45’N and 39° 43’N and the longitudes of 24° 45’W and 31° 17’W. The archipelago is divided into nine islands and several islets which are clustered into three groups: the western group (made up of two islands: Flores and Corvo), the central group (with five islands: Faial, Pico, São Jorge, Graciosa and Terceira) and the eastern group (comprising the islands of São Miguel and Santa Maria and the Formigas islets, which are classified as a nature reserve). The largest islands are São Miguel (759 km²), Pico (446 km²), and Terceira (403 km²) (Santos et al., 2004). The Portuguese archipelago has temperate climates characterized by mild, wet temperatures year round. The distribution of rain is highly controlled by topography, with very wet
high ground and drier coastal areas. In fact, one of the main processes responsible for the production of precipitation in these islands is the ascent of moist air over the island's terrain.

The Azores sits at a unique position on earth between a trifecta of tectonic plates of the North American, Euro-Asiatic and African triple joint. The geographic isolation of the islands and their volcanic terrain give rise to a wide variety of biotopes, ecosystems and landscapes. The archipelago is home to endemic species of arthropods, birds, and diverse habitats much like other oceanic islands. These ecosystems and species alike play critical roles in the model of the biosphere. UNESCO has listed three of the islands in the archipelago as Biosphere Reserves: Corvo, Flores and Graciosa. 16% of the terrestrial territory is under forms of natural protection status, which makes the Azores one of the European regions with the greatest percentage of classified areas in the EU (European Parliament 2015). The Azores belong to the European Network of Geoparks whose aim is to protect geodiversity, promote geological heritage and support sustainable economic growth.

Image 1.
Map of Azores archipelago with focus on São Miguel

The most populated island, São Miguel, supports over half of the region's population and will be the island selected for the case study. In congruence with other island ecosystems, São Miguel’s microclimates exist near bodies of water that cool the local atmosphere. The Gulf Stream maintains sea temperatures average of 16°C to 25°C, creating a tropical marine climate with humid forests and shrublands. Regular rainfall throughout the year varies between drier summer seasons and wetter winter seasons. The soil and climatic conditions of the Azores allows for a wide range of agricultural produce. The variation in farming methods amongst different regions of the island, allowing variant crop production (Santos et al., 2004).

The Usable Agricultural Area (UAA) covers 120,400 Ha, which is equivalent to just over half of the entire territory. 88% of the UAA is made up of permanent grassland and pasture that is appropriate for extensive livestock farming. 10% of the UAA is arable land used overwhelmingly to cultivate green maize to feed livestock. Scarcely 2% of the UAA is occupied by my permanent crops. The surface area of Azorean holdings involved in organic farming is modest with just under 620 Ha. (European Parliament,
It is important to note agricultural structures when surveying land availability and usage in order to have a complete understanding of the system. The table below displays key indicators of agricultural structures in the Azores.

**Table 1.**
Key indicators of agricultural structures in the Azores

<table>
<thead>
<tr>
<th>Rural areas</th>
<th>Km²</th>
<th>2,333</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of total territory</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Usable agricultural area (UAA)</td>
<td>Ha</td>
<td>120,412</td>
</tr>
<tr>
<td>% of total territories on the island</td>
<td>51.6%</td>
<td></td>
</tr>
<tr>
<td>Forested area</td>
<td>Ha</td>
<td>72,900</td>
</tr>
<tr>
<td>% of total territory</td>
<td>31.2%</td>
<td></td>
</tr>
<tr>
<td>Agricultural holdings</td>
<td>Number of holdings</td>
<td>13,540</td>
</tr>
<tr>
<td>Average of Ha of UAA (Ha)</td>
<td>8.9</td>
<td></td>
</tr>
<tr>
<td>Average economic size (€)</td>
<td>25,918.3</td>
<td></td>
</tr>
<tr>
<td>Contribution of the agricultural sector to GDP</td>
<td>% agriculture of total GDP of islands</td>
<td>9.6%</td>
</tr>
</tbody>
</table>


The Azores islands have 13,540 farm holdings, with an average physical size of 8.9 Ha. Despite the fact that most of the farm holdings are less than 2 Ha, the average physical size of agricultural land calculated is in the hands of medium sized holdings between 20 to 50 Ha (34.5%). At the two extremes, the smallest holdings (<5 Ha) barely account for 8%, while holdings <50 Ha, which are mostly private or municipally-owned meadows and pasture make up an appreciable part of the productive area (31.7%) (European Parliament, 2015). There is a clear link between the size of UAA according to its geographic location and the number of holdings, which attests to the structural similarity of the islands. São Miguel has the greatest UAA (34%), and also the highest number of holdings (54%) (European Parliament, 2015).

Ultimately, the dependence of the Azores upon its primary sector, agriculture, in socio-economic employment, territorial landscape and natural resources aspects, is very high. In fact, the entirety of the Azores territory can be classified as 'rural' according to the economic and demographic criteria of...
the Organization for Economic Co-Operation and Development (OECD). The archipelago is characterized by a strong focus on farming of crops such as banana, maize, beetroot, and potato, as well as livestock farming of dairy products, meat production and lastly timber production. All of these services require ample amounts of land cover, water, and soil to meet production needs (Aguaplano, 2021). The table below indicates the surface area and yield of principal crops in the archipelago.

Table 2.
Surface area and yield of principal crops

<table>
<thead>
<tr>
<th>1. Annual Crops</th>
<th>Surface Area</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green maize</td>
<td>9,342 Ha</td>
<td>270,775 t.</td>
</tr>
<tr>
<td>Potato</td>
<td>599 Ha</td>
<td>11,142 t.</td>
</tr>
<tr>
<td>Beetroot</td>
<td>354 Ha</td>
<td>13,320 t.</td>
</tr>
<tr>
<td>Corn for grain</td>
<td>238 Ha</td>
<td>446 t.</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>60 Ha</td>
<td>1,176 t</td>
</tr>
<tr>
<td>Azores yam</td>
<td>60 Ha</td>
<td>1,191 t</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Permanent Crops</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wine products</td>
<td>926 Ha</td>
<td>12,913 HI</td>
</tr>
<tr>
<td>Orange</td>
<td>366 Ha</td>
<td>3,754 t</td>
</tr>
<tr>
<td>Banana</td>
<td>291 Ha</td>
<td>5,129 t</td>
</tr>
</tbody>
</table>


The soil in the Azores, and many other islands is volcanic. São Miguel has its geology dominated by three volcanic cores that correspond to the major active trachytic central volcanoes of Sete Cidades, Fogo, and Furnas, linked by rift zones (Amaral, 2006). Observed minimum and maximum temperatures taken at several meteorological stations on these islands reveal that these atmospheric parameters have been increasing steadily during the last quarter of a century, in phase with the observed increase in the average global temperature (Karl, *et al.*, 2000). On São Miguel, the dominant soil associations are between Andosols and combinations of Allophanic
soils and Andean soils, as we can see in Figure 1 (Ricardo, et al., 1977). The predominance of soils of the Andosols type is associated with the volcanic origin of the Azores islands being formed by volcanic ash and other volcanic materials (DRA, 2016). The constitution of its clayey fraction, in which mineral phases of weak structural order appear, such as allophanes, imogolite, opaline silica, and ferrihydrite, confer them distinct properties from other types of mineral soils, namely (DRA, 1999): low apparent density, high porosity, high water retention capacity, irreversible alteration after drying, great phosphate fixing power, the high variable load associated with high values of pH in NaF and low in bases. It should also be noted that the spatial distribution of soil types on the island of São Miguel is a reflection of climate, altitude, origin, and age.

Figure 1.
Spatial distribution of soil types on the island of São Miguel (Ricardo, et al., 1977)

2.3.2 Conventional vs Regenerative Agriculture

Agriculture's most incriminating contribution to climate change is the release of carbon held in the soil, primarily from deforestation and land clearing. This process is euphemistically referred to as “changes in land use” and exposes soil organic carbon to oxygen in the air, converting it to carbon dioxide (Toensmeier, 2016). Land clearing and degradation have resulted in 320 billion tons of emissions; 2.5 trillion tons of carbon are currently held in the top meter of soils around the world, with an additional 560 billion in living aboveground biomass and detritus (Toensmeier, 2016). Together these amount to six times the amount of carbon currently in the atmosphere. Plowing or tillage is a highly destructive practice of soil organic carbon. Most agricultural soils have lost 30 to 40 tons of carbon per hectare, or 25 to 75% of what existed in the soil prior to land clearing. This varies by ecosystem, soil
type, and practice. The practice of mass producing a single crop year after year, or monocropping, has unarguably led to the depletion of nutrient rich soil, causing sterile soil, and forcing new land to be deforested for planting. Maize, soy, and wheat are the three most common crops that are monocropped. Further, the monocropped grain and soy is not for direct human consumption, but to create the feed that goes to livestock. The benefits that monocropping provides are increased efficient harvests, plantings in mass quantities, and compatibility with machinery. There is revenue to be found in this practice, but at an unsustainable cost.

Regenerative agriculture can not only reduce emissions, but actually sequester billions of tons of atmospheric carbon, trapping it in the soil and aboveground biomass. RA takes soil as the entry point, and on agricultural land, many ecosystem services are mediated through the soil. The agency upon soil in RA is not only to produce food, but also biodiversity. While traditional forms of monoculture strip soil of nutrients, reduce organic matter, and cause significant erosion over time, regenerative agriculture aims functions for nutrient cycling, primary productivity, and water purification. This soil multifunctionality is the core of the RA foundation that will enhance not only the environment, but also the social and economic dimensions of sustainable food production (Toensmeier & Herren, 2016). Using soil as a starting point can change what agriculture looks like. Conventional agriculture approaches keep plants and animals separated. On the other hand, RA combines flora and fauna in circular ecosystems to have animals feeding the plants, and plants feeding the animals to produce healthier food at scale.

The five themes or cores of regenerative agriculture are (1) soil health; using methods that increase organic matter and promote soil microbial activity such as no-till (or low-till), cover crops, and composting will improve and rebuild soil health. (2) water management; sustainable forms of farming strive to optimize water management to not only converse water, but contribute to drought resilience (Lankford & Orr, 2021). This can be seen in examples of contour farming, mulching, and using drought tolerant plant species. (3) biodiversity; using a variety of crops and animals in the farming system will promote biodiversity, which in turn will improve ecosystem function and resilience (Cusworth, et al., 2022). (4) crop rotation; crop rotation is a critical practice in regenerative farming because it has direct and immediate effects on the soil. Rotating crops breaks pest and disease cycles, improves soil health, and increases yield. (5) livestock integration; practices like livestock rotation and mob grazing improve soil health and increase crop productivity (Carlisle, 2022, Ali & Talukder, 2008). These principles are what distinguish regenerative from conventional agriculture.

2.4 The Link Between Agriculture, Climate Change and Islands

The interconnectedness between soil quality, climate change, and islands is viewed through a narrow lens. It is widely accepted that healthy soil is required to grow abundant crops, and that the quality of soil and crops is negatively affected by [climate change induced] droughts, floods, and storms. This unidirectional understanding disregards a major element of the dynamic— the impact of healthy soil on climate change through the removal (or sequestering) of carbon dioxide or CO2 from the atmosphere. If the link between agriculture and climate is currently being exploited in a harmful way, that same linkage can be utilized in the reversal of the
system’s effects. Since anthropogenic pathways result in the position agriculture plays in climate change, by altering these actions the hypothesis exists.

The framework that this research compares is a tailor-made ex-ante modeling framework made by Schreefel et. all, which uses models of Soil Navigator; a decision support tool to assess and optimize five soil functions at the field level (Debeljak et al., 2019), and FarmDESIGN; a bioeconomic model to explore and optimize overall farm sustainability (Groot et al., 2012). This study took three types of soil (clay, peat, and sand) from farms located in the Netherlands and used their framework to find solutions to the problems ailing environmental processes. This is a successful framework taking in the soil as the starting point and using field-to-farm level assessment to explore alternative farm configurations and create regenerative scenarios.

3. Methods

3.1 Collection of Data

This paper primarily relies on qualitative data collection and analysis. The qualitative data analysis is primarily information from the European Parliament Policy Department on agricultural and rural development in the Azores, as well as Agricultural Systems by Schreefel. The research additionally focuses on secondary sources, scholarly articles, and reports that accumulate the knowledge and expertise of the current systems of climate change, the agriculture industry, regenerative farming practices, and accumulated into a synthesis of how islands are impacted by all of these factors. Focusing on these reports has provided a holistic learning and understanding of how these systems work individually and in par with one another. This provided theoretical information applying to the hypothesis. For the building of a new and innovative framework, the data was collected using a bottom-up approach.

Qualitative data was collected from farms in São Miguel over a series of three days from November 16, to November 18, 2022. Three farms were visited of varying kinds to properties that focused on crops, animals, or both. In Figure 2 these farms are labeled as ‘crop,’ ‘dairy,’ and ‘mixed’. The farms were dispersed ranging from the north, center, and west sides of the island. This allowed variety across the data collected in temperature, soil type, and access. The same round of questions was posed to all three farmers about their practices.

3.2 Interviews

The questions presented in Figure 2 revolve around five cores of regenerative agriculture; soil health, water management, biodiversity, crop rotation, and livestock integration. The questions provided insightful information on practices related to soil, water management, biodiversity, crop rotation, and livestock integration. Information was also collected on climate change and its perception and viewed effects on each farm. These were general questions used with specific follow-up questions tailored to each farm. The questions guided farmers to expand not only on their own practices, but how they see climate change influencing their practices now, and in the future.
Figure 2.
Summary of indicators assessed at each collection point

- How do you define regenerative agriculture?
- How long has your farm been established (/as regenerative)?
- How many hectares of land are you working on?
- How does the soil impact your methods?
- What kind of water system is used? (how much water is used)
- How do you feel being on an island has affected your practices?
- Is there variation in crop yield seasonally?
- What types of interactions do species have with each other and the ecosystem here?
- Do you have suggestions of what could be done with your land/ practice?

Responses to questions were recorded and clustered into indicators showing similar patterns across all three farms, two farms, and one farm. These clusters are recorded in Table 5. The answers recorded by only one farm are not considered outliers to this study since the sample size is not representative of the entire population. In Figure 2 the data was perceived to strategically guide the framework to the best applicability. Below, Table 4 will go into depth about the results from the questionnaire. Table 6 will follow this up with the suggestions to answers recorded from the last question. After questions were answered data was accumulated and synthesized to show patterns across answers from all three farms as the strongest indicators. The last question in this questionnaire is to serve a later part of this study about finding solutions that farmers see for needs within their own properties.

3.3 Island and Continental Comparative Analysis

The integral differences between island and continental practices surrounding agriculture vary from through planting and business all the way to structure and soil of location. Table 3 displays these differences and variations as advantages and disadvantages. The “indicators” for this table are seen as age, diversification, income, cost, labor and yield. This set of indicators offers an overview of differentiation across a broad spectrum of areas between islands and continents when it comes to agriculture. In Table 3 islands are indicated as (A) and continents as (B). These are not all possible indicators that exist for these integral differences, but rather indicators that are integral for this study. Understanding the differences in these categories between islands and continents is what sets apart the framework this paper creates from previous existing frameworks.
Table 3.
Comparative analysis of continent and island farms

<table>
<thead>
<tr>
<th>Indicator</th>
<th>(A) Island (B) Continent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>(A) Islands tend to be younger than their mainland counterparts</td>
</tr>
</tbody>
</table>
| Biodiversity | (A) Biodiversity benefits from generally lower intensive management practices  
(B) Intensive farming reduce biodiversity of flora and fauna |
| Income    | (A) Farmers on islands are more likely to supplement their income with multiple practices 
(B) Farmers on continents are more likely to obtain more than half of their income from farming |
| Cost      | (A) Input and commodity prices are more expensive to export to and from islands  
(B) Mainland farms can produce high yield quantities in bulk |
| Labor     | (B) The use of machinery reduces the number of workers needed |
| Yield     | (A) Susceptible to weather patterns yield may vary 
(B) Monocropping will produce high yield |

The first indicator of age reveals that islands tend to be younger than their mainland counterparts (Matthews, 2021). While mainland structures have been formed for the latest of billions of years, the oldest island is recorded to have the latest of millions of years since separation from a continental junction. Age is seen as an indicator because it will impact the development from anthropogenic practices to technologies, as well as biotic factors, such as species to soils.

Biodiversity is the second indicator. Islands tend to have lower intensive management practices when it comes to farming, for reasons that include variety in the crop, size of yield, or traditional methods of farming. Large scale farms are more likely to be found on continents, and practice intensive farming, which strips the allotted area of biodiversity through the soil and type of yield- this will alter species interactions with the land. Income is the third indicator, which allows a comparison of an important part of regenerative farming- the sustainability it holds for people's livelihoods. Farmers on islands are more likely to supplement their income with another practice. In the Azores; specifically São Miguel, farming was regularly paired with tourism as a second job. This leads into the next indicator of the cost which will be a determining factor for income. Imports and exports of goods to consumers will cost less to a continental practice that can produce a crop “in bulk.” The second to last indicator is labor. Labor also feeds into cost, which determines income. Specialized machinery can be used to harvest large hectares of monocropping. In a regenerative food farm, machinery of this scale cannot be used. This type of technology needs row cropping and stable slopes. It can replace hands working in fields to harvest and prep soil. The initial
The cost of technology like this is a front cost with lower labor costs in the long run. The final comparative indicator is yield. Intensive farming and monocropping often takes place on mainland farms that have expansive hectares. This allows high quantity yields to be produced of singular crops. A smaller farm on an island ecosystem that may focus on a multitude of crops will have a lower yield of one specific crop that is intensely farmed on the mainland.

4. Results and Discussion

4.1 Table Indicators

The data set below demonstrates various indicators across all three farm platforms. Indicators in Table 4 are seen as farm area (ha), soil type, water collection, and livestock density with subsections of cows, chickens, and sheep. These indicators allow the cores of regenerative agriculture to be put against the practices of the farms from which data was collected. The results for table 4 are either indicated as numerical values, qualitative values, or “X” marking presence instead of absence.

Table 4.
Overview of the farm characteristics of selected case-study farms

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Crop farm</th>
<th>Dairy farm</th>
<th>Mixed farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm area (ha)</td>
<td>8</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td>Soil type</td>
<td>andisoil</td>
<td>andisol</td>
<td>rocky soil, andisol</td>
</tr>
<tr>
<td>Water collection</td>
<td>rain, catch</td>
<td>stream, collection</td>
<td>rain</td>
</tr>
<tr>
<td>Livestock density</td>
<td>-</td>
<td>60</td>
<td>&lt;X</td>
</tr>
<tr>
<td>Cows</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Chickens</td>
<td>-</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Sheep</td>
<td>-</td>
<td>-</td>
<td>X</td>
</tr>
</tbody>
</table>

The first indicator is farm area measured in hectares (ha). There was a range of sizes between the three farms, but overall farms on São Miguel, the Azores, and islands, in general, will not be as expansive as farms on continents (Reis, 2015). Soil type is an important indicator because soil can tell a farmer about nutrients, water retention, and cycling patterns. For example, the andisoil and rocky soil that was found at these farms on the Azores is very porous. This means that water from rain, catch, etc. is filtered through the soil quickly. This is important to know what crops will grow best and under what conditions in various soil types.

The third indicator is water collection. Water collection/management is important on a regenerative farm to make sure that the water is being used sustainably,
and not taken away from another process or being overused (Luo, et al., 2022, Petzold & Ratter, 2015). Both rain frequency and total rainfall are significantly enhanced over larger islands compared to the surrounding ocean (Pörtner, et al., 2022). The crop farm used a mixed methods approach by using the rain, as well as distributing water through a rain catch that collected in a basin at the base of the farm's field. The dairy farm used water through a stream that ran down their property (this is common in many of the farms on São Miguel). However, during the dryer season from July-August the stream will run dry and water must be collected from an outside source (as reported by the owner of the dairy farm). This farm would take a water collecting truck and drive to another location on the island to retrieve water. The mixed farm had a hands off approach when it came to water collection. The owner of this farm emphasized letting nature do most of the work. This farm solely relied on rainfall to water all the crops. The farmer noted that at one point a stream ran through the property that has since dried up in the years he has been facilitating it.

The last indicator for Table 4 is livestock density. This was divided into three subsections designating the type of livestock on each farm. It is important to note these subsection categories are not the only animals that can serve a purpose on a regenerative farm; rather, these three subsection indicators are the animals that were found across the studied farms. The first crop farm was strictly for crops. There were no integrated animals into the ecosystem here, with the intent of serving the regeneration of the property. This is a large “flaw” in the framework of a regenerative farm that will be further addressed below in section 4.3 (Newton, et al., 2020). The dairy farm had both a presence of cows and chickens. The mixed farm had a multitude of animals getting regularly rotated into the fields such as chickens, sheep and rabbits. The mixed farm was the best example of livestock density and ecological interaction. Both the crop farm and the dairy farm have more specialized focuses that narrowed the practices used. The farms that had both animals and plants working in synergies together were more successful in RA outcomes.

4.2 Cluster Data from Figure 1

Table 5 displays the cluster data from the questionnaire. Ten clusters were made into indicators showing across the three farm platforms what was in common between all three, all two, and then only one. There are no outliers in this cluster data because the sample size is not representative to scale. The clusters were formed into farm type, define RA, established, hectares, soil, water system, island impact, crop variation, species interactions, and improvements. Holding these indicators in comparison to the five cores of RA; soil, water, biodiversity, crop rotation, and livestock integration can test the validity of these regenerative structures. The indicator of water systems applies to the core of water structures, the indicator of crop variation applies to crop rotation and biodiversity, the indicator of species interaction applies to biodiversity and livestock integration, and the lastly the indicator of island impacts looks at the RA system as encompassing people, planet. and profit in its framework. Looking at the ten clusters guides the indicators in the final framework and their applicability bridging text and applicability. This is used in the final data assessment.
Table 5.
Cluster data

<table>
<thead>
<tr>
<th></th>
<th>Crop</th>
<th>Dairy</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA definition</td>
<td>P/E</td>
<td>P/E</td>
<td>hands off</td>
</tr>
<tr>
<td>Established</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hectares</td>
<td>8</td>
<td>35</td>
<td>5</td>
</tr>
<tr>
<td>Water system</td>
<td>rain</td>
<td>stream</td>
<td>rain</td>
</tr>
<tr>
<td>Island impact</td>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Crop variation</td>
<td>seasonal</td>
<td>-</td>
<td>seasonal</td>
</tr>
<tr>
<td>Species interaction</td>
<td>-</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Improvements</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Starting with the cluster ‘define RA’ both the crop and dairy farm classified as a mix of people and environment P/E. These two farms were heavily integrated in the management practices that took place. The mixed farm had a hands-off approach which allowed nature to do most of the work. All three farm platforms work across similar, if not the same soil type which is common in the Azores. Furthermore, all three farms reported high impacts of climate severity, and differences compared to mainland farms in the cluster of island impacts. Not only were the farmers noticing severe weather changes such as rainfall, erosion, invasive species, and dry seasons, but also economic impacts in competing with external marketing and consumption processes. From the ‘crop variation’ indicator two out of three of the farms plant and harvest seasonally so that the yield will stay consistent in capacity, but diverse throughout the year. The single farm that does not fall into this cluster is because they have not yet established a circular crop system on their land. The next indicator labeled ‘species interactions’ shows that across all three farm platforms there are different levels of animal integration. This cluster is only referring to intervening species interactions of animals that were introduced to serve a purpose in the farming system. This is not referring to wildlife interactions. All of these clusters inform and assess the status of each of the three farms and how they hold into the forming framework of island RA.

4.3 The Future of Modeling: Increased Complexities

Table 6 is representative of the recommended directions for change that will feed into the overall framework. Each farm was given specific recommendations based on current practices and future climate impacts. These recommendations for change are transformational adaptations that process
change and persistence in transitions to ‘climate-smart’ regenerative agriculture. Climate-smart RA includes practices and transitions that adapt to current and future foreseeable climate impacts on the environment, which affects farming lands.

Table 6.
Recommendations for change suggested by data and literature analysis

<table>
<thead>
<tr>
<th>Recommendations for change</th>
<th>Suggested farming practices</th>
<th>(1) Crop farm</th>
<th>(2) Dairy farm</th>
<th>(3) Mixed farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve nutrient cycling</td>
<td>Rotate chickens into pasture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase livestock/ (poultry) interaction</td>
<td>Introduce chickens</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce invasive species presence</td>
<td>Let calves clear invasive grass</td>
<td></td>
<td>Control fungi virus</td>
<td></td>
</tr>
<tr>
<td>Increase grassland diversity</td>
<td>Introduce species-rich grassland into second field</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improve hectare (ha) usage</td>
<td>Limit crop rows</td>
<td>Scale up capacity over time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduce technology</td>
<td>Track kg per cow</td>
<td></td>
<td>Track produce yield</td>
<td></td>
</tr>
</tbody>
</table>

The first direction of change suggested for the (1) crop farm is to increase livestock/ poultry interaction. The only animal interactions on the farm were from wild rabbits that acted more as pests, eating the crops, or turkeys that infrequently crossed the property. The suggested RA practice would be to introduce chickens in rotation cycles around the beds before and after planting. This would allow the soil to be “prepped” by the chickens by putting nutrients back into the soil and mixing it. Chickens’ behavior of scratching and pecking turns the soils while they eat, and their feces, put nutrients back into the soil. This moves into the second direction of change for farm (1) which is to improve hectare usage. Because this farm chooses to plant in crop rows, the horizontal space is being lost to the spacing between rows and sections of crops. The suggested farm practice is to limit crop rows. Farm (1) worked in both greenhouse and outdoor hectarage. By using crop rows in the greenhouses and then a seasonal food forest with the outside space, land, and yield could
be maximized. A seasonal food forest is a layered forest garden that features a diverse variety of plants that produce when it is in the growing season (Wartman, et al., 2018). For example, some trees in a food forest will be summer-producing, while others are winter. There is never a lack in yield, but rather a transition in the type of crop yield. The space in a food forest is utilized well because all of the plants help each other to grow in a mix of nutrients. The growing not only goes horizontally, but also vertically using layered “canopies.” These low-maintenance, self-sustaining systems have huge potential to be sources of sustainable food and livelihoods while improving hectare usage.

The first direction of change for (2) dairy farm is to improve nutrient cycling by rotating chickens into the pasture. The property had chickens on it, but the animals were kept in a separate section away from the main pastures. While the cows on the farm are rotated, the nutrient cycling on the soil level could be holistically integrated with the other animals on the property (chickens) to help turn over the land. Since farm (2) had many hectares of land it could be beneficial to rotate the chickens into the pasture before the cows. The second direction of change for (2) dairy farm is to reduce invasive species presence. There was an invasive grass species present on this farm that covered the entirety of one of their fields. The invasive grass species is not causing harm to ecological or biological systems, but the grass is not as nutrient dense as the native grass that covers the rest of the fields. Grass nutrients will affect the quality of milk the cows give. The suggested farming practice would be to clear the invasive grass plot by having the juvenile calves that are not yet producing milk take turn in this pasture. The calves will eat the invasive grass and it will not affect the quality of milk since they are not yet producing. The next direction for change is related to the latter; increasing grassland diversity would be introducing species-rich grass into the same field. The fourth direction of change for farm 2 is to improve hectare usage. The size of the land in comparison to the number of cows was disproportionate. The surveyed dairy farm (2) was less than 3 years established so this scale will increase over time as more cows are introduced. The last direction of change is to introduce technology. A suggested practice would be to track kg yield per cow. This way the farmer knows amongst the herd which cows are the largest producers, and which cows may need special attention for health purposes.

The first direction of change for the (3) mixed farm is to reduce invasive species presence. This farm, like many farms across the Azores, is plagued with an invasive fungi presence that destroys the harvests and rots the crops. Since it is a fungus it spreads through spores and is very contagious. The recommendation for this direction would be to use organic and chemical-free methods such as orange sprays on plants as a proactive step before they get plagued. Furthermore, to decrease the spread across the farm area, proper and regular rounds of cleaning up harvest fallout and compost are necessary for containment. Secondly, this farm is recommended to introduce technology. This farm was a live mantle of regenerative practices, which is why it only has one suggested direction for change. Farm 3 supplies consumers with what they grow seasonally and what is available. The suggested farming practice would be to track the production and yield it creates. By doing this farm (3) can have consistent notations to inform their consumers of what they have. Farm (3) was successful in its practices of nutrient cycling, livestock interaction, invasive species presence, grassland diversity, and hectare usage. The main
source for this success was the dynamics between flora fauna, and the forest garden that boosted the integrity and structure of the entire farm.

All three farms have areas of suggested improvement. Depending on what kind of farm (e.g. crop, animal, mixed) one has, the transition to a RA system will look different. In this case study, all three farms are considered as regenerative or are on a path to becoming fully regenerative systems. At the end of the interviews, each farmer was asked about future improvements that they see taking place on their properties. Farm (1) crop farm answered with future hopes to have a pollinator section, build a “shepherds” hut, grow mushrooms, and have an improved rain catch water system. It was noted that their practice was on the newer side and much of these improvements will come with establishing more time on the ground. Farm (2) dairy farm answered with the expanding of their practice, and a barn to provide shelter to their cows. Similar to the last farm, this farm is also newly established and attributes its improvements to being settled in due time. Farm (3) mixed farm answered with the riddance of the fungi plaguing their crops. This farm was not newly established and had been practicing for many generations. All of the self-proclaimed improvements for the farms made by farmers are feasible and attainable goals.

4.4 Climate Mitigation Steps

The single greatest estimated impact of global climate change on the Azores may be the change in annual precipitation distribution, with wetter winters while the other seasons become drier (Santos et al. 2004). This could have a significant impact on the island’s water resources and management of farmlands. The dairy farmer, when interviewed disclosed during the questionnaire that harvesting practices have been shifted to one month later and continue for one month longer than previous years. Although the sample size was small, more nuances of this artype may arise given a more expansive sample. Although irregular weather patterns were the main extraction of climate change in this study it does not mean that it will be the exact same experience on every island. Erosion and sea level rise are other examples of climate effects on islands and even within São Miguel despite the fact that the interviewees did not bring these topics up during the data collection.

Figure 3 below is a complete visual synthesis of the framework constructed from the data collected in this study. It incorporated the cores of regenerative agriculture as interconnected levels, showing relational reliance and interdependence. This cycle is displayed as a close-ended loop to showcase the relationship between agriculture and climate change that was mentioned at the beginning of the paper. Figure 3 takes the basis of that relationship and reverses the effects for positive impact resulting through solutions of change. Both Tables 5 and 6 attributed to the data collection and synthesis of this visual framework. After troubleshooting individualized areas of suggested improvement, coupled with RA core values a framework was created to cater more towards the climate sensitivities that islands experience. This framework cycles through the five cores of RA as levels of tracking advancement to achieve full regeneration on a farm. By following the cycle starting at the center soil, and guiding around the loop systems the end is resulting in climate mitigation on island ecosystems.
Figure 3.
Regenerative agriculture framework for island ecosystems

The outermost ring of Figure 3 shows the reliance that people, planet, and profit play on one another into the system of regenerative agriculture. This care for systems outside of profit are what set RA apart from conventional industrial agriculture. Additionally it is what makes this framework integral for the importance of preserving, and empowering island ecosystems and peoples. Since the basis of all RA starts with the soil, it is displayed as the core of the framework since it can reach across to directly influence any of the other systems. From the first level of soil a farmer can figure out what type of soil(s) they are working with and best address and adapt the next levels of this RA framework to create a more tailored solution on their land. The second level to pass through is L2: water. This level of RA tests and improves water quality and availability in order to reduce water shortages, improve clean water supply.
and have safe water runoff, regulation, and purification. L3: biodiversity encompasses high levels of variety interaction and exchange between flora and fauna. These relationships and exchanges are integral for a successful healthy RA system to function. L4: crop rotation returns nutrients to the soil without synthetic inputs. By rotating seasonal crops the soil is left with nutrients instead of having them be depleted. This will aid farmers in minimizing external inputs, waste and surplus while working with L3 to manage disease control and genetic mutations. L5: livestock integration promotes species diversity in cycling nitrogen to ensure soil protection, weed/pest control, and lastly spreading a farmers financial enterprise out amongst variables. L3, L4, and L5 all directly play into one another in the cycle. L1, L2, L3, and L4 are all under the category of ‘planet’ systems. L4 and L5 are under ‘profit’ systems. Lastly, these RA framework levels lead to the end of the cycle of climate mitigation by reducing the use of greenhouse gas emissions and inverting carbon emissions. This is under the layer ring ‘people.’ This framework can be applied to any farm system to create a tailor made display of suggested courses of actions for farmers on island ecosystems.

5. Conclusion
This study showed that the transition towards regenerative agriculture for islands requires different attention than their continental counterparts. By building upon the modeling framework of Schreefel et al. (2022), specific indicators for regenerative agriculture were made for individuals showing which regenerative objectives and farming practices can contribute to the transition towards regenerative agriculture in contrasting contexts. Furthermore, specific solutions were shown for crop farms, dairy farms, and mixed farms on andisol and rocky soil. However, this improvement can come at a cost to profitability when scaling in comparison with practices of monocropping. Although this paper focuses on all aspects of regenerative agriculture, it will disclose the focus on human impacts, specifically on islands that only touched the surface of the importance that indigenous peoples, traditional practices, and culture hold in this world. While the practices ‘sustainable farming’ promote are important, it does not encompass the deep cultural and relational changes needed to realize collective healing between land and people. RA easily becomes colonizing when going through the available literature. The framework purposely leaves out directions of instructing specific types of actions so that farmers may apply their own traditional practices to their system throughout the framework levels. That is how this RA system will work best. In no way does this framework attempt to erase or devalidate traditional ecological knowledge, but rather reaffirm and empower land ties. Future prospects for this study involve the integration of the framework applied to another island separate from the Azores archipelago to be tested in various scenarios and a larger sample size.

Transitioning to regenerative agriculture involves more than a suite of ‘climate-smart’ mitigation and adaptation practices supported by technical innovation, policy, education, and outreach. Rather, it involves subjective, nonmaterial factors associated with culture, values, ethics, identity, and emotion that operate at individual, household, and community scales and interact with regional, national and global processes. Findings have implications for strategies aimed at facilitating a large-scale transition to climate-smart regenerative agriculture.
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