Regenerative Agriculture Adoption among Brazilian Soybean Farmers

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Abstract

In the current context of climate change and ecosystem degradation, regenerative agriculture is a farming practice that is gaining attention for its climate mitigation and biodiversity loss reversal potential. However, there is still no global definition for it. Without a global definition, measurements of its adoption vary, as do assessments of the belief that farmers have in the environmental and productivity benefits of regenerative agriculture and the barriers they perceive to adopting it. Furthermore, there are limited offerings of price premiums for the products of farmers who follow such practices. This research assumes that regenerative farming practices entail lower climate and environmental risks compared to traditional farming methods. Therefore, it is important to understand levels of adoption and belief on regenerative agriculture for a transition to regenerative agriculture occur.

To assess the adoption rate of four regenerative practices for soybean farming in Brazil (no tillage, cover cropping, crop-livestock systems, and the use of bio inputs), understand the environmental and productivity beliefs and the main barrier to adoption that farmers face, 22 Brazilian soybean producers were interviewed in a semi-structured format. Respondents answered questions about their adoption rates for the four practices, their perceptions of the environmental and productivity benefits of regenerative farming, the primary barrier to adoption they observe, broader challenges they face with soybean farming, and whether they observe any price premium for adopting regenerative practices.

The results of this research showed that crop-livestock systems and the use of bio inputs were the practices with the least adoption for soybean farming in Brazil, with a 36% and 82% adoption rate, respectively. No tillage and cover cropping were widely adopted (95% and 86% adoption rates). Furthermore, farmers could generally articulate the environmental benefits of regenerative agriculture clearly; however, there was considerable skepticism regarding productivity benefits, especially concerning the effectiveness of bio inputs when neighboring farms do not use them. The main barrier to adoption was operational, while the most common challenge for any form of farming (traditional or regenerative) was identified as climate change. Very few farmers observed a price premium for regenerative soybeans.

This research indicates that there is work to be done on the adoption of crop-livestock systems and bio inputs. However, significant operational challenges exist due to the differing economic profiles of crop-livestock systems compared to crop farming only and the disruptions that bio inputs can cause when their adoption is not widespread among farms in a region (potentially leading to pest concentration in farms using bio inputs only). Future studies could focus on how to overcome the operational barriers of these two practices, and how the market could evolve to recognize the potential price premium that regenerative farming could have over traditional farming practices.

Frontispiece

A Poem on Regenerative Agriculture by Victor Laudisio

What is Regenerative agriculture?

Let me give you a tour.

Imagine a farming practice that helps life endure —

An approach still in its infancy, yet full of allure.

Here's a hint: it can fertilize soils using cow manure.

You might not be accustomed to working the land,

Same as I.

But that doesn't matter; to understand,

We must focus on the land.

The soil—

That's what regenerative agriculture is all about.

Reviving life through the soil that grows the food

You enjoy when you go out.

Out and about,

That's how we designed urban life to be.

But to sustain human life,

We must return to the soil

And regenerate its vitality.

Otherwise, instead of the food we eat,

It might be us who face the heat.

Author's Biographical Sketch

Victor Hazell Laudisio has Brazilian, Italian, British and Uruguayan ancestry. He currently lives in São Paulo, Brazil, working for S&P Global Ratings' (SPGR) Sustainable Finance. He is a primary analyst for Second Party Opinions. He mainly covers extractive industries: agribusiness and mining. Although focused on such sectors, Victor has also analyzed a diversified set of Latin American green, social, sustainable, and sustainability-linked issuers. His thought leadership research revolves around land conservation programs and natural capital accounting and valuation, especially in biodiversity hotspots, such as the Brazilian Amazon. Victor also leads biodiversity-related work streams for the sustainable finance team, having represented SPGR during the Biodiversity COP15 in Montreal (2022) and COP16 in Cali (2024). There, he listened to and participated in external discussions regarding the development and implementation of the Global Biodiversity Framework as well as discussions about the challenges and solutions for nature risk measurement.

Victor joined S&P Global Ratings in 2016 as an intern. He previously worked as an assistant teacher for an international school (Saint Francis College) located in São Paulo. Prior to Sustainable Finance, Victor was an analyst in S&P's corporate credit ratings group where he served as a support analyst for Brazilian national scale credit issuers. Victor majored in Economics from the Insper university in São Paulo, with a focus on behavioral economics. The thesis presented here forms part of his master's degree in Sustainability at Harvard University.

Dedication

I dedicate this thesis first and foremost to my father and mother who encouraged me all along the master's process. I also dedicate this thesis to my grandmother, who always supported my education, and my grandmother who passed away in 2023.

Huge thanks to my manager, who is an inspiration academically and professionally as well as my pod lead for all the support. The same heartful thanks goes to all colleagues from S&P's Sustainable Finance family and Harvard masters' colleagues, especially those who were part of the thesis preparation course during the summer of 2024.

I would also like to thank the A. family for all their support during the first year of my master's, including a family friend, who kindly helped me with my personal statement.

They say that those who have friends, have everything. And this could not be less true with the support that I had from one dear friend throughout my Harvard master's degree. A great soybean farmer and good friend, thanks to him, I was able to begin the network sampling method used conduct this thesis. In the same spirit, I would also like to thank all farmers time when being interviewed. It was fulfilling to go to the Santa Rosa Fenasoja 2024 Fair without knowing anyone, but then many kind souls helped.

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Chapter I

Introduction

Industrial crop farming methods rely on monocultures with significant use of synthetic fertilizers to provide nutrients for plant growth and pesticides for plant health. The overapplication of both, combined with the use of tillage, can lead to soil erosion (Schlatter et al., 2019; Youlton et al., 2016), water contamination (Shen et al., 2021; Youlton et al., 2016; Aparicio et al., 2013) and biodiversity loss (Shi et al., 2024; Pretty et al., 2018). In contrast, regenerative agriculture is an alternative farming practice that is generating attention for the positive effects it has on climate and biodiversity (Jordon et al., 2022). Regenerative agriculture focuses on farming practices that protect soil health to sustain production and ecosystem balance and resilience over an extended period (Khangura et al., 2023). However, there are challenges with defining regenerative agriculture, given the broad principles and outcomes of agriculture.

Defining Regenerative Agriculture

According to a literature review by Newton et al. (2020) of 229 journal articles and 25 practitioner websites, the concept of regenerative agriculture has been around since at least 1982. However, there has been a notable increase in its research from 2015-2019 (the latest year they reviewed).

Regenerative agriculture can be explained through its principles, practices, and benefits (Table 1) (Khangura et al., 2023). For investigating soybean farmers in Brazil, Khangura et al.'s (2023) analysis of the adoption of four main practices of regenerative

Table 1. Regenerative Agriculture (RA) principles, practices, and benefits.

RA Principles	RA practices	RA benefits
Minimize soil disturbance	No/minimum tillage	Improve soil health throughout
Keep soils covered	Stubble retention	Increased soil carbon
Keep living roots in soil year-round	Diverse crop rotations	Improved microbial functions and associated nutrient cycling
Encourage diversity	Multispecies cover crops	Improved soil moisture
Integrate livestock	Intercropping	Improved resilience to pests and diseases
	Composting and use bio stimulants	Nutrient rich food
	Rotational grazing	Reduced greenhouse gas emissions
	Reduce synthetic inputs	

From Khangura et al., 2023

agriculture is useful: no tillage, cover cropping, integrated crop-livestock systems and the use of bio inputs. These four practices are recognized by the Brazil federal government's Renovagro low carbon agriculture program.

The principles of regenerative agriculture stem from the goal of reducing the environmental impact of agriculture. These principles include but are not limited to the encouragement of soil and above-soil biodiversity, soil coverage, and the continuous presence of living roots in the soil (Table 1) (Khangura et al., 2023). Regenerative practices apply these principles and therefore avoid or minimize soil degradation through practices such as cover cropping (planting a new crop after the original one has been harvested to provide the soil with nutrients) and reduced tillage (using less machinery to manipulate the soil) or no tillage, as an alternative to minimize the use of synthetic fertilizers and pesticides (Khangura et al., 2023). By reducing chemical inputs and not turning the soil over, regenerative agriculture can improve the health of the environment (ecosystem) where a farm planting soybean, corn, or other agricultural crops is located (Pretty et al., 2018; Khangura et al., 2023). The health of the environment from regenerative agriculture also stems for a larger amount of soil organic matter and higher nutrient cycling, water infiltration and low erosion risks (Embrapa Integrated Crop Farming Systems, 2021; Croplife, 2024).

Despite the benefit to the environment, transitioning to regenerative agriculture can lead to reduced yields in the initial years (LaCanne & Lundgren, 2018). Reduced yields can occur in the initial years. The recovery of soil structure and nutrient availability of monocrop systems take time (LaCanne & Lundgren, 2018). Additionally, farmers face a learning curve as they adapt to new techniques, which can result in inefficiencies and mistakes that negatively impact yields (Asprooth et al., 2023). The initial increase in pests and weeds, as ecosystems begin to rebalance, along with the experimentation with different crop rotation varieties, can also contribute to lower yields due to nutrient and sunlight competition (Aye & Howeler, 2012). While these challenges may lead to short-term declines, the long-term benefits often include improved resilience to climate change, ecosystem health, and potentially higher yields as soil health and ecosystem balance are restored (Cherubin et al., 2024). Also, in the long-term, the economic loss of the lower yields can be offset by lower expenditures of agricultural inputs once yields stabilize (Khangura et al., 2023). The challenge of transitioning to regenerative agriculture applies directly to soybeans.

Soybean Farming

According to the Brazilian Agricultural Research Corporation, soybean cultivation systems that follow monoculture practices, using scheduled treatments, relying on heavy agrochemicals use, and dependent on regular water availability, are becoming obsolete (Embrapa Soybean, 2023). This is due to stronger weed resistance to herbicides, the emergence of new pests and diseases, reduced affordability and availability of synthetic fertilizers and pesticides, frequent water stress conditions in Brazil, and the demand for more ecological agriculture (Embrapa Soybean, 2023). In Brazil soybean farming expansion has been directly and indirectly linked to deforestation in the Brazilian Amazon (Nepstad et al., 2006; Barona et al., 2010).

To set the stage globally, soybean is the most or second most farmed cropped in agricultural countries such as the United States, Argentina, and Brazil (USDA, 2024). Globally, soybean farming follows a variety of methods and range from small to industrial large-scale farms. Soybean farming has strong economic significance in Brazil and globally given its multiple uses ranging from animal feed, vegetable oil and even biofuels (Embrapa Soybean, 2023). Brazilian soybean exports represented 15% (equivalent to US$166.5 billion) of all (not just agricultural) Brazilian exports in 2023 (Agência Brasil, 2024). This is relevant from the economic perspective given Brazil's fiscal stability dependence on a positive current account balance (S&P Global Ratings, 2023). A positive current account balance occurs when a country's exports of goods and services are greater than its imports, indicating that it is a net lender to the rest of the world (S&P Global Ratings, 2023). This situation can benefit the economy by increasing foreign reserves, strengthening the national currency, and providing capital for domestic investments, which helps promote economic growth and stability. However, there are potential downsides, such as reliance on exports, which can make the economy vulnerable to global market changes, and the risk of trade tensions with other countries due to ongoing surpluses (S&P Global Ratings, 2023). Additionally, focusing too much on exports may lead to underconsumption at home, hindering overall economic growth. Given Brazil's strong domestic consumption market, supported by its large population and consumption habits, and its stable trade relations with main export markets—except for the Mercosur deal with the EU—the positive current account balance can be beneficial for the country's economy (S&P Global Ratings, 2023).

Soybean farming is also relevant from an environmental sustainability perspective as the increase of its economic significance is attached to deforestation and biodiversity loss in the Brazilian Amazon (Barona et al., 2010). The Amazon rainforest is considered ecologically significant biome given its significant reservoir of global biodiversity (Dirzo & Raven, 2003) and a tipping element of the Earth's climate system (Boulton et al., 2022).

Regenerative Soybean Farming in Brazil

Regenerative agriculture adoption for soybean farming in Brazil is nascent. According to Embrapa's Regenerative Agriculture data (2023), around 16 million hectares of Brazil's total agricultural land, or 7%, used agricultural production methods systems (not limited to soybean solely) followed one or more regenerative agricultural principles. The amount ties back to Brazil's federal program for low carbon agriculture (Programa ABC, now named Renovagro), which sets actions that are part of the Brazilian Nationally Determined Contributions (NDC) under the Paris Agreement to reduce greenhouse gas (GHG) emissions from agriculture and land use change. Considering the nascent adoption of regenerative agriculture in Brazil, a better understanding of the barriers that farmers perceive or have faced can help advance its implementation. Does the lack of knowledge of regenerative agriculture practices play a role in the low rate of adoption, or are there other factors, such as financial or cultural drivers, which have a stronger influence on soybean farmers decision on which agricultural method to follow? Additionally, are there any premium payment for regenerative soybean?

Multiple studies show that farmers motivations to adopt sustainable agricultural practices are mostly influenced by economic factors (Arbuckle et al., 2015; Talanow et al., 2021; Tanure et al., 2024). Arbuckle et al. (2015) is based in the U.S., Talanow et al. (2021) in South Africa, and Tanure et al. (2024) in Brazil. These studies were based on semi-structured interviews with farmers, same as this research was. All studies included a component regarding whether farmers believe in the environmental benefits that regenerative practices can provide, including their role in combating climate change.

In addition to economic factors, disseminating technical knowledge about regenerative practices applicable to soybean producers' operations, can help increase the level of adoption (Tanure et al., 2024). Furthermore, understanding farmers willingness to produce regenerative soybean if adequately compensated, can help drive market initiatives to bolster higher production of regenerative soybean, similar to what has been done with organic farming certification (Elrick et al., 2022).

Research Significance and Objectives

This research examined the level of knowledge among a group of Brazilian soybean farmers regarding regenerative agriculture and their level of adoption. Furthermore, it assessed whether these farmers believe there are environmental and productivity benefits associated with regenerative practices. It also assessed whether the main barriers to adoption are economic factors as suggested by other studies (Arbuckle et al., 2015; Talanow et al., 2021; Tanure et al., 2023). The research also examined if the soybean market recognized price premiums for following regenerative practices, as well as the farmers opinions on price premiums for regenerative soybeans.

This research is timely, considering that Brazil's NDC includes a goal of adding five million hectares of cropland that follow regenerative crop farming practices by 2030. Even though certain scholars (Friedrichs & Opp, 2002; Best, 2009) argue that the direct application of rational choice can lead to meaningful insights into environmental behavior, this research outlined the context of regenerative agriculture for soybean farming in Brazil. That is, rather than using an empirical study to explain the adoption of alternative agricultural methods using rational choice theory, this research aimed to describe the current context of regenerative soybean farming in Brazil in a qualitative manner.

The objectives of this research were:

- To measure the level of regenerative agriculture adoption for a group of Brazilian soybean farmers
- To measure the belief of a group of Brazilian soybean farmers that there are environmental and productivity benefits from regenerative practices
- To find the most severe challenges/barriers to implementation of regenerative agricultural practices for Brazilian soybean
- To confirm whether a premium payment for (the ecosystem services generated by) regenerative agricultural practices exists for Brazilian soybean

Background

According to Dall'Agnol (2011), soybean faming in Brazil began when the first seed, brought from the United States, was tested in the state of Bahia in 1882. However, soybeans did not adapt to the low-latitude conditions of Bahia (12ºS). A decade later (1891), new seeds were tested in the state of São Paulo (23ºS), where they had relative success. In 1900, soybean farming succeeded in Rio Grande do Sul (between 28ºS and 34ºS) given that climatic conditions were like the region of import (southern United States). As occurred in the United States during the decades of 1920-1940, the first soybean cultivars introduced in Brazil were studied more for their potential as forage plants than as grain-producing plants for the protein industry (Dall'Agnol, 2011). By the late 1970s, more than 80% of Brazil's soybean production was concentrated in the three states of the southern region (Rio Grande do Sul, Mato Grosso do Sul and São Paulo), although the Cerrado biome in the central region, which was much less urbanized, started to emerge as significant player. Fast forward to 2022, 65% of the production was now concentrated in midwestern states covering the Cerrado biome, with the remaining mostly in the Atlantic Forest biome (Mapbiomas, 2023). Soybean farming accounted for 67% of all cultivated area for annual crops in Brazil by 2023, with the increase associated with the demand for animal feed and human consumption, as well as the technological advancements on field equipment combined with more efficient management practices (Mapbiomas, 2023). With better machinery for soil cultivation, along with seeders replacing manual labor and the use of harvesters, the increase in soybean production in Brazil was successful (Cattelan & Dall'Agnol, 2018). Furthermore, this expansion can also be attributed to the favorable conditions in low latitudes (as Brazil) for cultivating soybean varieties with longer juvenile periods (Destro et al., 2001).

The prevailing soybean faming method in Brazil is commonly referred to as conventional or traditional soybean agriculture (Esteves et al., 2018; Robusti et al., 2020). Traditional soybean farming involves intensive tillage, frequent use of synthetic fertilizers, herbicides, and pesticides, and often relies on monocropping practices. This approach aims to maximize yield and efficiency using high-yield varieties and extensive mechanization. While effective in increasing production, it has led to soil degradation, reduced biodiversity, and environmental concerns (Smith et al., 2014). Table 2 provides a comparison between conventional, organic, and regenerative practices. Organic and regenerative practices have many similarities except for the soil preparation method and the landscape setting (Darolt & Skora Neto, 2002).

Regenerative, organic, and agroecological practices are all under the same agricultural movement of transitioning from traditional farming methods to alternative ones (Food Climate Research Network, n.d). They have similarities in their farming practices (Figure 1) but vary in their ultimate motivations and end goals (Tittonell et al., 2022). For example, all three practices can include the use of cover crops, integrated crop-livestock systems, no or reduced tillage and the maximizing of biological processes. This is motivated by the desire to preserve nature and its biodiversity, and to sequester carbon and ensure soil health (Tittonell et al., 2022). Despite these similarities, regenerative agriculture is not a response to human health or social equity concerns as agroecology principles (Food Climate Research Network, n.d). Instead, the aim is for soil and ecological restoration (Newton et al., 2020; Rhodes, 2017).

Table 2. Conventional versus organic and regenerative practices.

Characteristics	Cultivation Practice: Conventional	Organic	Regenerative
Soil Preparation	Intensive tillage frequency (compared to other crops) under a monocrop	Potential for intensive tillage due to the lack of systemic organic herbicides	No or minimal tillage
Landscape setting	Monocrop	Monocrop	Integrated with livestock and/or forestry plantation and/or crop rotations
Genetically Modified organisms	Yes	No	Yes
Fertilization	Use of highly soluble chemical fertilizers (nitrogen, phosphorus, urea, single superphosphate, potassium chloride	Natural fertilizers - well-composted animal manure and decomposed organic matter	Minimal use of biofertilizers (green manure)
Pest management	Use of synthetic chemical products (insecticides, fungicides, nematicides) as a tool in Integrated Pest Management (IPM)	Preventive measures and integrated control (biological) and organic pesticides. IPM methods including crop rotations, which disrupt pest life cycles and improve soil health; timing of planting, which helps avoid peak pest populations; and cultivar selection, where pest-resistant plant varieties are chosen to reduce pesticide reliance	Preventive measures and integrated control (biological) and promotion of biodiversity
Weed control	Use of herbicides or integrated control (including chemical)	Integrated control (mechanical, cultural, biological) and curative (weeding and mowing)	Integrated control (biological) and curative (weeding and mowing)

	Cultivation Practice		
Characteristics	Conventional	Organic	Regenerative
Possible Environmental Harm	Contamination of water by agrochemicals Biodiversity loss from monoculture	In case of excessive manure use, contamination of water by coliforms, nitrogen and phosphorous	The use of cover cropping and integrated livestock can harm certain other species. That said, the goal of regenerative agriculture is to balance the ecosystem. No tillage, which is a practice used in regenerative agriculture, has been connected to the high use of glyphosate (Clapp, 2021).
Price premium ($ per 60-kilogram bag)	$25	Yes, depending on the jurisdiction.	N/A
Certification	No certification required	Certification widely available across several jurisdictions	Certification in nascent stages

Adapted from Darolt e Skora Neto (2002). Note: Average January to June 2024 price of 60 kilogram of conventional soybean. Extracted from CEPEA-ESALQ database

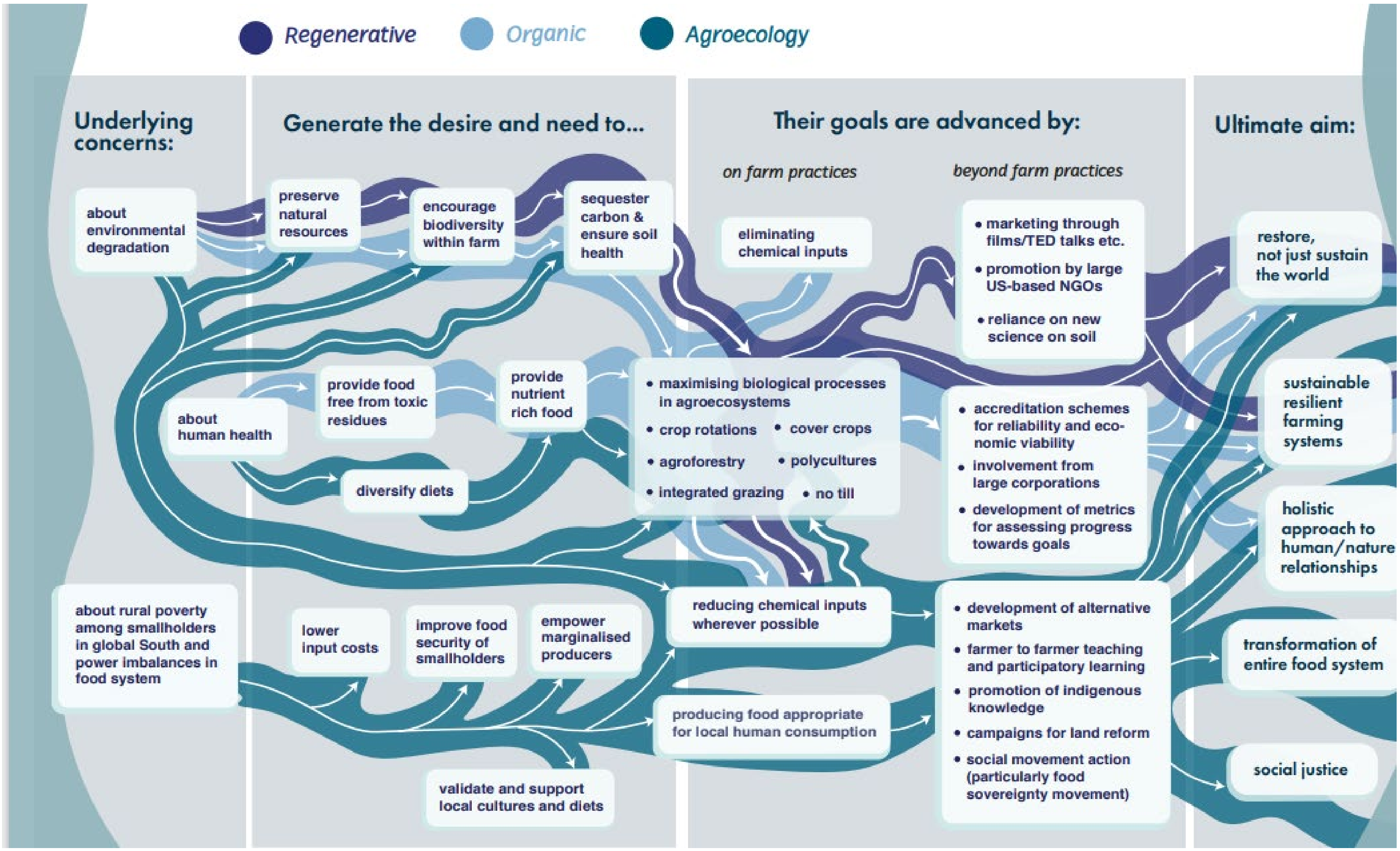

Figure 1. Regenerative, organic and agroecology.

Note. Source: Food Climate Research Network, n.d

In contrast, agroecology brings social justice considerations to the transformation of traditional agriculture (Food Climate Research Network, n.d). Furthermore, regenerative agriculture looks to restore biodiversity and soil health (Tittonell et al., 2022), while organic farming does not have a regenerative aspect. According to the United States Department of Agriculture, organic agriculture is mostly a process-based certification program (USDA, n.d.).

Regenerative Soybean Farming Practices in Brazil

The most practical definition of regenerative soybean farming in Brazil comes from the Brazilian federal government program, “Plano Safra”. Plano Safra is a set of public policies and credit programs for farmers implemented by the Brazilian government to support and promote the country's agricultural sector. This plan is updated annually and aims to provide rural credit, financing, and incentives to farmers, cooperatives, and agribusinesses, with the goal of fostering agricultural production, ensuring food security, and promoting sustainable development. Within many of the policies and credit programs of the Plano Safra lies the Renovagro program. The Program for Financing Sustainable Agricultural Production Systems (RenovAgro, formerly Agriculture Climate Change Mitigation and Adaptation Plan for a Low Carbon Economy [ABC Plan]) aims to transition conventional Brazilian agriculture into regenerative practices, in line with the objectives determined in Brazil's NDC for Agriculture (Brazilian Ministry of Agriculture, n.d.). For a farm to be considered regenerative, Renovagro requires the execution of one or several of the following practices: no or reduced till farming methods, cover cropping, integrated crop-livestock-forests or crop-forests systems and the use of bio-inputs, including biological nitrogen fixation inputs (Brazilian Ministry of Agriculture, n.d.).

Each of these practices is defined below as well as the barriers for its adoption as identified in the literature.

No or Reduced Tillage Farming

No or reduced tillage avoids or minimizes the use of agricultural machinery to turn the soil so that it becomes fertile again after a harvest. Instead of turning the soil and applying synthetic fertilizers and macronutrients for soil productivity, the crop is planted over the residue of previous crops—such as straw or corn stover, with crop rotation and limited or no soil disturbance (Embrapa No Tillage, 2021). It is different than cover cropping, which is the practice of planting another crop before the planting or after harvesting the primary crop. Furthermore, tillage involves seed bed preparation. Seed bed preparation involves the choice of where to place the seed row so that the access to water, heat and nutrients of the crop is adequate (Elevagro, 2022). In no-till soybean farming, seed bed preparation involves the use of slot tillage to create a narrow furrow for seed placement. This method ensures optimal seed depth and good seed-to-soil contact while maintaining soil health and moisture (Elevagro, 2022).

No or reduced tillage can avoid soil erosion as well as above and below ground biodiversity loss from soil degradation (Peixoto et al., 2020). When the soil is broken down from tillage, the organisms that live below ground can lose access to nutrients since tillage can remove the topsoil layer (Jordanova et al., 2011). This in turn reduces the biodiversity below ground (Jordanova et al., 2011). Additionally, microbes can gain access to previously protected organic matter from the tillage breaking apart soil aggregates. This can lead to reductions in total soil organic matter and overall soil health (Embrapa Microorganisms, 2021).

The introduction of no tillage in Brazil occurred in the early 1970s, driven by farmers in the state of Paraná, with the initial goal of reducing drainage and erosion issues (Agro Advance, 2024). No tillage has seen a significant increase since its introduction in Brazilian agriculture in the 1970s. From the 1970-2020, no tillage was adopted for 30 million hectares of farmland in Brazil (Brazilian Federation of No Tillage, 2019). Mckinsey's (2022) survey showed that many Brazilian farmers were aware of the practice (564 farmers spread across the country), and that 80% them were incorporating no till in their operation.

Barriers to adopting no-till or reduced-till practices include farmers' worry over potential loss of yields (Ofstehage & Nehring, 2021). Also, no tillage has been connected to high use of glyphosate (Clapp, 2021) and the compaction of soil (Andrade et al., 2018). The economic sustainability of no-till or reduced tillage practices relies on a long-term approach aimed at gradually increasing productivity. This approach is heavily dependent on access to capital for purchasing inputs and owning machinery (Fuentes-Llanillo et al., 2013).

Cover Cropping (CC)

Cover cropping entails the planting of grasses, legumes, and other species like brassicas before, during, and after the main crop is harvested. The benefits of cover cropping are similar to no or reduced till farming. These are achieving more ground cover (Creamer et al. 1997), reducing wind and water erosion (Sanchez et al., 2004), and avoiding agrochemical runoff (Weinert et al., 2002).

In the southern region of Brazil, knowledge of cover cropping as a regenerative method is widespread (Embrapa Cover Cropping, 2023). Crops preceding corn and soybean cultivation include oats, wheat, and triticale (Embrapa Cover Cropping, 2023). In contrast, in the midwestern region, millet and corn are predominant in soybean cultivation as cover crops (Embrapa Cover Cropping, 2023).

The shortcomings of these systems include the challenges of mechanization for planting and harvesting when intercropping is done, resulting in a higher cost of labor per hectare (Blessing et al., 2021). Furthermore, cover cropping can decease the productivity of the crops if not well managed given the nutrient competition between the crops for growth (Aye and Howeler, 2012) as well as affect soil water content (Raimondi et al., 2023).

Soybean planting in Brazil begins in October (Embrapa Soybean, 2023). The soybeans are then harvested in January or February. Most farmers then plant corn or grass to cover the soil until winter arrives in June. Farmers that follow traditional practices then clear the area by using weed killers and either continue with corn or introduce other crops such as wheat and oats. These crops are grown until October, harvested and then soybeans are planted again (Embrapa Soybean, 2023).

Integrated Crop-Livestock Systems

Integrated crop-livestock systems integrate crop and livestock farming together within the same area. In Brazil it is performed mainly between the harvest of soy and the next planting cycle. After harvesting the soy, farmers plant grass and place cattle in the area where the soy will be harvested in the new harvest year (Brazilian Agricultural Research Corp, n.d.). Crop-livestock systems are still nascent in Brazil, having been introduced by Embrapa in the early 1980s (Embrapa Soybean, 2023). That said, since 2013 integrated systems are nationally recognized low-carbon agriculture production methods (Brazilian National Policy on Integrated Crop-Livestock-Forestry Systems from 2013). In 2020 (latest data available), according to Embrapa's data on integrated systems, around 16 million hectares of agricultural land, or 7% of total agricultural land in Brazil, used these systems. Benefits include a larger amount of soil organic matter and higher nutrient cycling, higher water infiltration, lower humidity losses and lower erosion risk (Embrapa Integrated Crop Farming Systems, 2021).

The environmental benefits are these positive externalities of such systems, but the cost of the transition can negatively affect the willingness of farmers to transition (Opdenbosch & Hansson, 2023). Opdenbosch and Hansson's (2023) study of integrated systems for cattle farmers in Sweden indicated that half of the interviewees were willing to adopt an integrated system at a mean compensation per year per ha of €308. Meanwhile, Davis and Rausser (2020) found that a minimum annual payment of $148 per ha was needed to incentivize silvopasture adoption for livestock producers in Alabama. In the United States a national program pays $75 per acre to fully convert a livestock pasture to a longleaf pine forest (David & Rausser, 2020). All three studies have different ecological and economic structures when compared to Brazilian integrated crop-forestry-livestock systems. That said, they illustrate that integrated systems need economic incentives to be adopted.

Other limitations can relate to size. The adoption of integrated livestock has occurred globally in smaller scale farms, but in Brazil the adoption has also occurred in industrial scale farms (Pereira et al., 2018). That said, the cash flow profile of integrated systems can be significantly different than monocrop systems, which can introduce challenges (dos Reis et al., 2021). Farmers need reliable information around which technologies and activities should be explored in their context as to capture real economic benefits from transitioning to integrated systems (Popp & Rudstrom, 2000).

Use of Bio Inputs

Bio-inputs include bio stimulants, bioregulators, biological control agents, fertilizers and inoculants (for nitrogen fixation). Bio-inputs are substances derived from biological sources—such as plants, animals, or microorganisms—that are used in agriculture and forestry to enhance crop growth, improve soil health, manage pests and diseases, or promote beneficial interactions within the ecosystem. Environmental benefits are concentrated in lower synthetic pesticides runoff risks (Croplife, 2024). The most common used bio-input in Brazil are inoculants, which are especially relevant for soybeans (Embrapa Bio inputs in Soybean Cultivation, 2022).

Inoculants are liquid or powdered bacteria or fungi that are mixed with crop seeds before the planting occurs. In soybean production, *Rhizobia* inoculation is a common practice in Brazil and globally (Embrapa Bio inputs in Soybean Cultivation, 2022). *Rhizobia* are a group of bacteria that form a symbiotic relationship with leguminous plants, including soybeans. A symbiotic relationship means that the soybean plant receives nitrogen fixed from the air by *Rhizobia* within a root nodule. Soybean nodules are small, specialized structures that form on the roots of soybean plants with *Rhizobia* bacteria. These nodules provide a protective environment where the *Rhizobia* live and carry out nitrogen fixation. The bacteria convert atmospheric nitrogen, which plants cannot use directly, into ammonia, a form of nitrogen that the plant can absorb and utilize for growth. This mutually beneficial relationship allows the soybean plant to access a critical nutrient for development, while the bacteria receive carbohydrates and a safe habitat within the nodules (Embrapa Bio inputs in Soybean Cultivation, 2022).

To ensure this symbiotic relationship occurs, farmers will often apply inoculates of *Rhizobia* to their soybean seeds (Embrapa Bio inputs in Soybean Cultivation, 2022). This practice began in the late 1950s in Brazil (FGV, 2022).

In addition to the large-scale use of biological nitrogen fixation, biological control of pests and diseases is also widely used in Brazil (Croplife, 2024). Brazil is a global leader in bio input development with high levels of registered products compared to other regions (Croplife, 2024). According to the Brazilian Ministry of Agriculture, there are 600 products registered or in the final registration phase with the Ministry of Agriculture as of 2023 (Embrapa Bio Inputs, 2023). These products include biofertilizers that improve soil fertility and promote plant growth, bio acaricides which control mites that harm crops, bioinsecticides, bio fungicides, phytotherapeutics and inoculants (Embrapa Bio Inputs, 2023).

Challenges to implementation include in some cases high regulatory barriers for their use and risks (Goulet & Hubert, 2020). Bio inputs also have risks of overapplication and can damage the crop if not used properly (Goulet & Hubert, 2020). For example, overapplication of biofertilizers can disrupt natural soil microbiome, leading to an overdominance of certain microbes and reducing biodiversity. This imbalance may harm long-term soil health and plant resilience (Bhuvanendran et al., 2024). In addition, overapplication of bio inputs such as bio fungicides or bioinsecticides may lead to phytotoxicity, where plants show signs of stress, such as leaf burn, stunted growth, or reduced yields (Laudani, 2022). Finally, another major challenge is the technical specifications for the use of bio-pesticides. For example, farmers must first measure the nutrient levels of the soil before application. This extra step compared to traditional pesticide applications can cause delays and added costs.

Farmers Decision Making Process to Transition to Alternative Practices

An increasing body of literature argues that to achieve profound change in our food systems, the transformation begins with shifts in mindsets before technology, institution, policies, and financial systems embrace the change (Kates et al., 2011). Still, there is a limited knowledge and understanding of how and why transformation of food systems occurs (Klebl et al., 2024). Farmers have diverse individual traits and opinions, and there are several variables to explain adoption decisions. Reimer et al. (2014) showed that agriculture education levels tend to have a positive influence on adoption of alternative farming practices.

Gosnell et al. (2019) studied the transformation of sheep and beef farmers in Australia from traditional to regenerative farming methods. The authors used the concept of zones of friction and traction to understand how such transformation occurs (Figure 2). Friction arises when societal norms influence an individual's decision-making process. Consider an individual who is aware of the environmental impacts of single-use plastic pollution but continues to use such items at social gatherings due to fear of judgment from others if they bring their own alternatives. Conversely, traction facilitates pro-environmental behaviors. For instance, efforts to conserve water during periods of historical drought demonstrate how social acceptance and pressure can foster a shift towards sustainability consciousness. Farmers do not follow a straightforward path when transitioning their practices to regenerative methods (Gosnell et al., 2019).

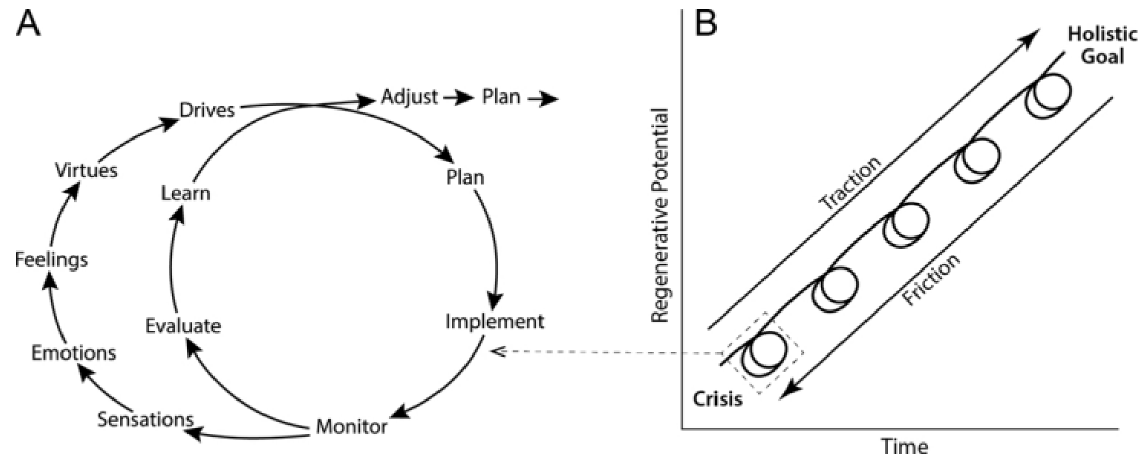

Figure 2. Zones of friction and traction.

Note. Source: Gosnell et al (2019)

After interviewing the Australian farmers, and using the traction-friction concept, Gosnell et al. (2019, p. 11) concluded that:

> transformational adaptation on the farm can be triggered by crisis, epiphany, and exposure to alternative pathways; (2) that decisions to transition to regenerative farming involve important nonmaterial subjective factors associated with feelings, emotions, virtues, drives and motivations; (3) that sustained adoption is influenced by a range of environmental, economic, social/cultural, and personal/psychological factors; and (4) that certain types of traction can support self-amplifying feedback loops that involve ongoing experiential social learning and increasing consciousness which plays out on the landscape and in surrounding communities.

In the Brazilian soybean farming context, pro-environmental behavior tends to come from traction. Tanure et al. (2024) illustrated how, for example, farmers' responses to climate change often stem from regulations and political agendas, which, in turn, increase social acceptance and pressure a shift toward more responses (i.e., influencing the adoption of sustainable agricultural practices).

Despotović et al. (2021) studied how environmental awareness of livestock farmers in Serbia influenced their farming practices. The authors surveyed 382 farmers in the main agricultural area of located in the north of Serbia, breaking down farmer demographics, structural details about their farms, different aspects of farmers' environmental awareness, and the adoption of specific environmentally friendly agricultural practices. These practices included reduced tillage, cultivation of perennial crops, use of cover crops, mulching, biological pest control, and green manure. Environmental knowledge contributed the most to explaining the environmental awareness construct (factor loading = 0.83), whereas biospheric concern contributed the least (factor loading = 0.23). Regarding agricultural practices, environmental awareness was higher among farmers who use biological pest control (+23%), mulching (+17%), and green manure (+9%).

Additionally, Best's (2009) logistic regression analysis of the conversion to organic farming showed that environmental concern has a positive effect on the probability of adopting organic farming practices. Best (2009) also showed that neighbor effects (social recognition or disapproval) can influence farmers attitude towards organic farming, while noting that no causal relationship can be established from the study. This is relevant to Brazilian soybean farmers because social considerations (community norms and fear of judgment) might be a barrier to implementing regenerative practices.

Payment of Ecosystem Services of Regenerative Agriculture

Roberts et al. (2023) showed how regenerative agriculture practices can be costlier than traditional practices if no additional remuneration is provided (e.g., via carbon markets). The authors estimated that over the first six years of the transition from conventional to regenerative farming for barley, potatoes, wheat and other legumes, the latter had higher on farm costs and lower production volumes, thereby lowering profitability. Nevertheless, regenerative practices presented better environmental indicators, especially of soil health.

Merrick (2021) illustrated that payment for ecosystem services systems "range from a purely-market driven approach to ones that operate simply as a public program recognizing a farm's 'environmental excellence' to allow for price premiums on the goods they produce" (Merrick, 2021, p. 6). Merrick argued that the functionality of the system depended on several characteristics: credibility of owner/manager/operator, transparency of entry requirements, whether the system is profit-driven, if the system involves mandatory or voluntary purchasing structure, and the kind of ecosystem services being remunerated.

Wiltshire & Beckage (2022) discussed how regenerative agriculture can bring new revenue streams to farmers via carbon markets. They concluded that, using a price of $20 per ton of carbon dioxide sequestered via the conversion of traditional to regenerative agriculture methods, Vermont farmers that fully adopt regenerative practices could collectively earn $9.8 million over ten years for the carbon sequestered. Assuming that Vermont farmers earn $1 billion per year (University of Arkansas, 2023), the profits from carbon capture would represent a 1% increase in profits. From all regenerative agriculture scenarios analyzed (full, partial, low adoption and types of practices), the afforestation of farmland to non-harvested forests was the scenario estimated to store the most soil carbon over the first ten years after conversion, and continuing to sequester beyond that (Wiltshire & Beckage, 2022). The ten-year mark for remuneration was used given that the stock of organic carbon slows as each carbon pool progressively reaches equilibrium. Furthermore, the quantity of agricultural crops or livestock produced also influences the offset potential. For example, high cattle stocking rates can lead to significant methane emissions from enteric fermentation, which can offset the rising SOC from the transition to regenerative agriculture (Wiltshire & Beckage, 2022).

The 2022-2023 National Cover Crop Survey Report of the United States Department of Agriculture Research Service (USDA's ARS) illustrated how crop farmers would be willing to transition to regenerative agriculture if they were adequately remunerated. The USDA's survey showed that around 78% of cover crop non-users said that incentive payments to adopt cover crops help their adoption (USDA, 2023).

In the Brazilian context, there is a significant amount of farmland available for afforestation. According to Embrapa, as of 2023, 28 million ha of degraded pastureland could be used for afforestation with non-harvested forests (Embrapa Degraded Pastures, 2024).

Price Premium for Ecosystem Services Provided by Brazilian Regenerative Soybean

Five companies from the agricultural value chain—Agrivalle, Bayer, BRF, GAPES, and Produzindo Certo—created a consortium in 2024 aimed at promoting regenerative agricultural practices that support ecosystem resilience. The consortium was created to launch a program called Reg.AI. Soybean farmers participating in the consortium's program received a 2% premium from BRF S.A. over spot prices, when using the following regenerative practices: high-quality no-till farming with cover crops, organic fertilization, and the use of bio pesticides combined with the reduced use of chemical pesticides (Reset, 2025). The consortium is responsible for auditing the farms and ensuring that the regenerative practices were followed so that the premium is paid. The payment is done by BRF S.A., the world's largest poultry processor, headquartered in Brazil. Furthermore, one of these companies (Bayer) is participating in Embrapa's low carbon soy certification program.

Results from Reg.AI are promising. Soil analyses of producers in the Reg.AI program indicated a significant reduction in the application of limestone in 92% of the analyzed areas, potassium in 21%, and phosphorus in 46% (Reset, 2025). The average carbon stock among producers in the Reg.IA was 73 tonnes of CO2 per hectare, evenly distributed across the top 30 centimeters (Reset, 2025). The highest producer recorded 113 tonnes of carbon per ha, while the average for the top 10 producers was 106 tons (Reset, 2025).

These figures demonstrate that productivity exceeded initial projections, as the planted area was 35% smaller, yet production was only 25% below the target (Reset, 2025). The projected necessary planted area was 50,000 ha, but in the first phase, it was only 37,000 ha spread across 38 farms (Reset, 2025). The estimate is that 160,000 tons of soybeans and 300,000 tons of regenerative corn will be harvested, although the soybean volume is below the target of 200,000 tons for the project's first harvest (Reset, 2025).

Embrapa's program is called 'Programa Soja Baixo Carbono' (Low Carbon Soybean Program; PSBC) and has been available for soybean farmers since 2024 (Embrapa PSCB, 2024). The PSBC (Low Carbon Soybean Program) identifies areas eligible to receive a low carbon certification, requiring the adoption regenerative practices. The objective of the PSBC to incentivize the regenerative soybean practices that reduce the greenhouse gas (GHG) emissions intensity of the crop. The SBC estimates that the potential reduction in greenhouse gas emissions can be approximately 30% by adopting sustainable technologies (Embrapa PSBC, 2023). This certification program follows international standards to ensure that soybean producers are implementing regenerative practices that have been proven to reduce greenhouse gas emissions from the field. There is a certification protocol and checklist used in practice for evaluation and granting of the Low Carbon Soybean Certificate by accredited certifiers.

These recent developments, Reg.IA and PSBC, demonstrate that there are incentives in place for Brazil's soybean farmers to increase the adoption of regenerative practices.

Research Questions, Hypotheses and Specific Aims

The main research question examined was: What constraints do Brazilian soybean farmers face in adopting regenerative agricultural practices? There are six sub-questions and associated hypotheses guiding the research:

1. What is the level of knowledge and adoption of certain Brazilian soybean farmers across four regenerative agriculture practices (no tillage, cover cropping, crop-livestock systems and use of bio inputs)?
    - H1: Half or more of the sample of soybean farmers interviewed (>=50%) are knowledgeable and adopt no tillage of farmers interviewed), cover cropping, crop-livestock systems and use of bio inputs.
2. What is the level of knowledge and belief in the environmental benefits of the regenerative practices assessed?

- H2: Half or more of the sample of soybean farmers interviewed are knowledgeable and believe that there are environmental benefits.

3. What is the level of knowledge and belief in the productivity benefits of the regenerative practices assessed?
   - H3: Half or more of the sample of soybean farmers interviewed are fully knowledgeable and believe that there are productivity benefits.
4. What is the main perceived barrier on adoption of regenerative practices?
   - H4: Financial considerations are the number one barrier.
5. What are the main challenges for adopting practices that have a low adoption rate?
   - H5: Operational considerations (weaker yields or technology/machinery availability) are the most common challenge.
6. Have the soybean farmers interviewed seen any form of price premium for regenerative practices?
   - H6: Half or more of the sample of soybean farmers interviewed have seen some form of price premium for regenerative practices.

Specific Aims

To conduct the research and test these hypotheses, I completed the following steps:

1. Developed a questionnaire that defined what the four regenerative agricultural practices meant in the Brazilian soybean farming context.
2. Engaged with Dr. Chase Harrison, Associate Director of the Harvard Program on Survey Research and Preceptor in Survey Methods in the Department of Government,

who provided guidance on the structure of the interview and rubric needed for answering the research questions.

3. Used the literature to generate a rubric to measure the level of familiarity with regenerative practices as well as familiarity and belief in environmental and productivity benefits of the four regenerative practices assessed.
4. Determined the description for the scores for each factor assessed (Familiarity with No Tillage, Cover Cropping, Crop-Livestock Systems, Bio inputs [H1], Familiarity and Belief in Environmental benefits [H2], Familiarity and Belief in Productivity Benefits [H3]) as well as the list of barriers using the literature as a guideline.
5. Conducted pilot interviews to explore potential issues with the questionnaire and refined questionnaire based on farmers' feedback.
6. Surveyed the first five contacts, then applied the network sampling technique (Hancké, 2009), asking the first contacts for other contacts, to finalize the list of interviews.
7. Analyzed the results in accordance with the pre-defined methods after completing the sample 22 soybean farmer interviews.
8. Presented results around the level of regenerative agriculture knowledge and adoption rate, the main barrier chosen and existence of a price premium.
9. Made recommendations to soybean farmers and policymakers that can help soybean regenerative agriculture adoption in Brazil.

Chapter II

Methods

To examine the knowledge, adoption rate, and barriers to regenerative soybean farming in Brazil, as well as beliefs regarding environmental and productivity benefits, a mixed method data-gathering approach was employed. Professor Dr. Chase Harrison (Senior Preceptor at Harvard University's Department of Government at the Faculty of Arts and Sciences and Associate Director of the Program on Survey Research at the Institute for Quantitative Social Science) was consulted, and the network sampling technique was selected. This technique can mimic the variability of a randomized sampling method if the 'seeds' (meaning each person recommended by a previously interviewed farmer) are diverse enough to create the potential variation that a randomized sampling approach would yield.

Farmers Interviews

Due to the challenges of selecting and accessing a randomized sample of Brazilian soybean farmers—no public platform provides farm locations—interviews began with a group of five stakeholders. These stakeholders were soybean farmers in the states of Goiás, Mato Grosso and Mato Grosso do Sul, who were previously interviewed and interacted with as part of the ENVR E-129A Local to Global Agroecology course at the Harvard University Liberal Arts Master's program. The individuals were Brazilian farm administrators, aged 20–29, and operated large-scale (over 1,000 ha), family-owned soybean farms.

These stakeholders were then asked for contacts of other soybean farmers willing to participate in the thesis surveys. This approach is known as the network sampling method. The network sampling method limited the conclusion of this study to a community of farmers thus limiting its generalizability. However, it could be expanded once a randomized sample becomes available. Following Morse (2000), given the relatively narrow scope of the research question and the point-in-time nature of the research, these in-person interviews with the initial five soybean farmers were used to better inform the survey for the remaining participants. The interviews were conducted in Portuguese and utilized open and closed ended questions to inform hypothesis-testing. Additional data collected included gender, age, farm size (ha), location (at the state level) and farmer experience in agriculture (years). The farm size categories used followed Embrapa Soybean (2023) publication: very small (0-10 ha), small (11-50 ha) medium small (51-100 ha), medium (100-500 ha), large (1,001-5,000 ha) and very large (5,001-12,000 ha).

The interviews took place either in person or online via Microsoft Teams. To analyze the interview results, answers were both plotted in Excel and PowerBI to conduct a thematic analysis. A thematic analysis is a qualitative research method used to identify and analyze patterns or themes within a data set, such as interviews, focus groups, or written texts (Hancké, 2009).

Definitions Used for Regenerative Agricultural Practices

The definitions for regenerative agricultural practices for Brazilian soybean farming were extracted from Brazil's federal low carbon agriculture program (Renovagro) (Table 3). Renovagro lists four regenerative agriculture practices – no tillage, cover cropping, crop-livestock systems, and bio-inputs (Table 3).

Table 3. Regenerative agricultural practices definitions.

Practice	Description
No or Reduced Tillage	This practice avoids or minimizes the use of agricultural machinery to turn the soil so that it becomes fertile again after a harvest. Instead of turning the soil and applying synthetic fertilizers and macronutrients for good soil productivity, the crop is planted over the residue of previous crops— with crop rotation and limited or no soil disturbance (CEBDS, 2023).
Cover Cropping	Cover cropping entails the planting of grasses, legumes, and other species like brassicas before, during, and after the main crop is harvested.
Integrated Crop-Livestock	After the soy is harvested, introducing cattle to what used to be the planted area.
Use of Bio inputs	Products of plant, animal, or microbial origin, used in crop farming or planted forests, which interfere in the growth, development, and response mechanisms of pest animals, plants, and microorganisms,

Renovagro is the main source of financing and education for regenerative agriculture in Brazil. U.S. based definitions, such as Gabe Brown's '6-3-4' rules (Regenified, 2024) of regenerative agriculture, were considered out of scope for the purposes of this research.

Assessing the Level of Knowledge of Regenerative Agriculture, and Beliefs About its Environmental and Productivity Benefits

Farmers were provided with the definition of the four regenerative practices relevant to soybean farming (no tillage soybean farming, cover cropping, integrated crop-livestock systems and use of bio-inputs) before the interview. Those definitions were then used to elicit four constructs from soybean farmers when asking them to comment on environmental and productivity benefits and risks.

To examine the level of knowledge (H1) and familiarity with the practice, a 3-point scale was used (Table 4), as suggested by Dr. Harrison. A value of '1' represented the emergent pole of the construct (i.e., the farmer performs the practice) with '3' representing the implicit pole (i.e., the farmer does not know about the practice existence). In this study, one pole corresponded to an enabler (knowing how to do the practice) and the opposite pole to no familiarity. The use of bio inputs was the only practice that had a 4-point scale (Table 5), given that farmers can produce the bio inputs on farm or acquire them. Therefore the '1' emergent pole for use of bio inputs were 'the farmer performs the practice and has the in-house capability to develop it', and '4' represented 'the farmer does not know about the practice existence'.

Table 4. 3-point scale for knowledge of regenerative agriculture practices.

Score	Description
1	The farmer performs the practice
2	The farmer does not perform the practice but knows about its existence
3	The farmer does not know about its existence

Table 5. 4-point scale for knowledge of use of bio-inputs (H1).

Score	Description
1	The farmer performs the practice and has in-house capabilities to develop it (applicable to bio inputs only)
2	The farmer performs the practice
3	The farmer does not perform the practice but knows about its existence
4	The farmer does not know about its existence

A thematic analysis was conducted to illustrate how the characteristics of the surveyed farmers could have influenced the results. To test the relative importance of age, farm size and experience in agriculture, the non-parametric Kruskal-Wallis test determined if there were statistically significant differences between the medians of independent groups (age, farm size and experience in agriculture).

To examine the level of belief in environmental and productivity benefits of regenerative soybean farming practices, a 4-point scale was also used (Table 6 and 7). '1' indicated that the farmer understood the environmental or productivity benefits. For environmental benefits, a '1' indicated that the farmer could describe how the practice can improve soil health, mitigate water overuse, avoid eutrophication, among other. For productivity benefits, a '1' indicated that the farmer could describe the long-term benefits on yields as the ecosystem regains its balance. A '4' indicated that the farmer did not understand the environmental/productivity benefits of the regenerative practice, regardless of whether it was practiced.

Table 6. 4-point scale for familiarity and belief in environmental benefits of regenerative agriculture (H2).

Score	Description
1	The farmer understands the environmental benefits. They can describe well how the practice can improve soil health, mitigate water overuse, avoid eutrophication, and/or provide additional environmental benefits.
2	The farmer can speak to the environmental benefits of the practice but is skeptical about its importance.
3	The farmer can speak about the environmental benefits of the practice but that does not agree that it is an important aspect.
4	The farmer does not understand the environmental benefits of the practice, regardless of whether they practice it or not.

Table 7. 4-point scale for familiarity and belief in productivity benefits of regenerative agriculture (H3).

Score	Description
1	The farmer understands the productivity impact of the practice. They can describe well how the practice can entail lower crop failures in the longer term (i.e. lower doses of biopesticides against multiple chemicals).
2	The farmer can speak to the productivity benefits of the practice but is skeptical about it.
3	The farmer does not agree that the practice has productivity benefits.
4	The farmer does not understand the productivity risks and benefits of the practice, regardless of whether they practice it or not.

Only farmers that scored 1 were deemed as believing in the environmental or productivity benefit of the practice. No checklist was used to specify the minimum number of environmental benefits that needed to be mentioned. A score of 1 could be given to a farmer that was able to identify at least one environmental benefit (soil health) and articulate it without any intervention.

Familiarity and knowledge were used concomitantly throughout the research. Furthermore, familiarity/knowledge and belief were used as distinct yet interconnected concepts in this research. Familiarity referred to the recognition or awareness of something based on prior exposure or experience, without necessarily implying a deep understanding or acceptance. In contrast, belief meant a conviction or acceptance that something is true, often without requiring concrete proof. While familiarity was centered on recognition, belief was focused on the acceptance or conviction regarding the truth of an idea or concept.

Barriers for Regenerative Agriculture Implementation (H4), Challenges (H5) and Price Premium (H6)

For the fourth hypothesis (main adoption barrier), farmers were asked to select one barrier from the five most discussed in the literature (Ofstehage & Nehring, 2021; Aye & Howeler, 2012; Silvestrini et al., 2023; Fuentes-Llanillo et al., 2013; Best, 2009; Blessing et al., 2021; Opdenbosch & Hansson, 2023; Goulet & Hubert, 2020. These barriers were: financial, social pressure (community norms and fear of judgment), regulatory, and operational factors (such as weaker yields).

Also, in this section of the interview, to address the fifth hypothesis (general challenges), an open-ended question was proposed about the challenges they perceive regarding regenerative farming, without providing a pre-defined list of options.

To test hypothesis six (the existence of a price premium for regenerative practices), farmers were not given any information related to existing programs, such as the Reg.IA program discussed in the Background section. Instead, farmers were asked a yes or no question regarding whether they observed price premiums for the four practices discussed. Farmers were then asked about their opinion on whether they see price premiums in any other forms, such as using non-transgenic seeds or organic certification.

Chapter III

Results

Characteristics of the sample of farmers are first presented with descriptive statistics, followed by the results by each hypothesis, including the thematic analysis and the Kruskal-Wallis test conducted for the barriers of adoption.

Descriptive Statistics

Out of the 22 interviewed farmers, there was only one female. In terms of state distribution, the Brazilian states of Rio Grande do Sul (59%), Bahia (14%), Mato Grosso (9%), Mato Grosso do Sul (9%) and São Paulo (5%) were represented in the sample.

The average age of the soybean farmers was 43 years (Figure 3). There was a notable concentration of farmers under 50 (68% of interviewees (Figure 3). There were no farmers aged between 31 and 40. The network sampling started with farmers aged 20 to 30, reaching the oldest farmer, who was 64 years old.

There was a concentration of the survey in farms from 1,000-5,000 ha, considered large farms (Figure 4). The remaining farms were up to 500 ha, with no concentration between small (up to 50 ha) and medium sized farms (50 ha -500 ha). The largest farm measured 12,000 ha, while the smallest was 3 ha. Farm size did not follow a normal distribution and were negatively skewed (Figure 5).

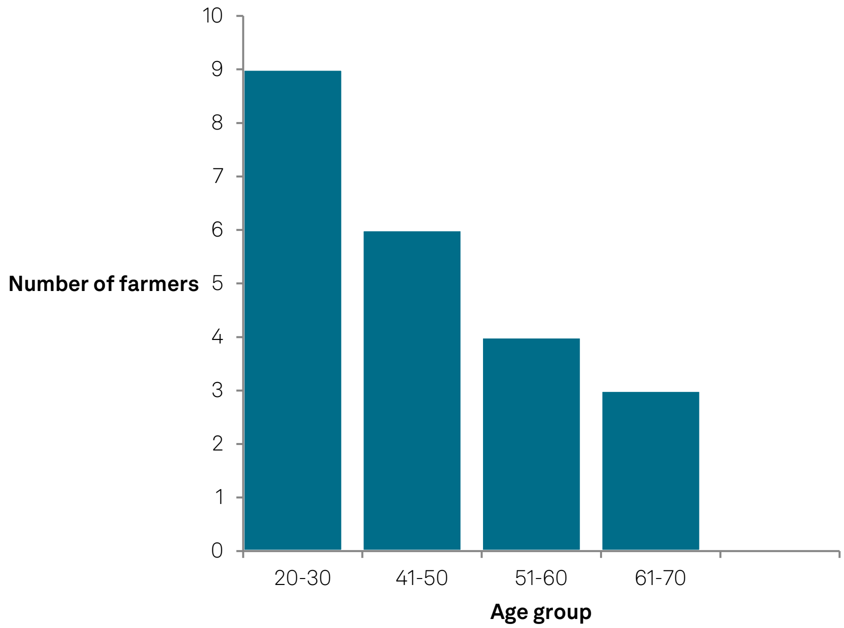

Figure 3. Age distribution of sampled soybean farmers.

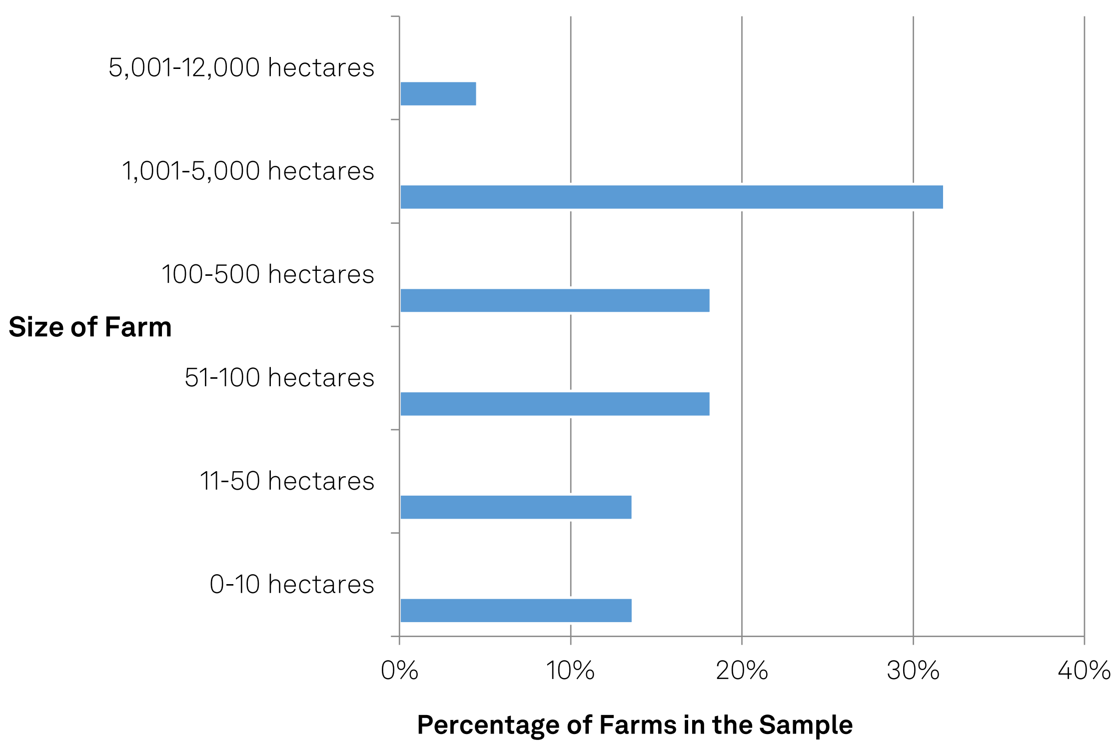

Figure 4. Farm size distribution.

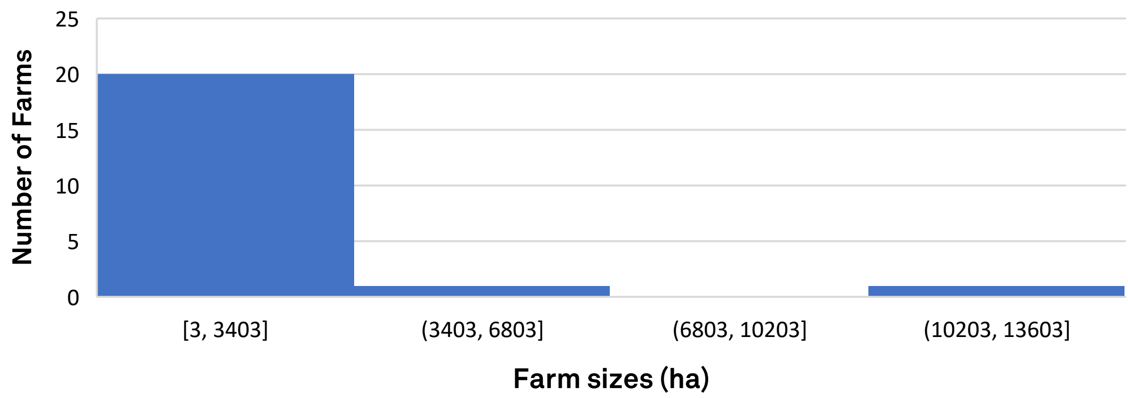

Figure 5. Farm size histogram.

The farmer with the most extensive experience (50 years) was born on the farm and had only completed education up to the 6th grade (Figure 6). Only one farmer held a master's degree, the female farmer. The majority (63%) of the farmers had a university degree, regardless of their years of experience in agriculture.

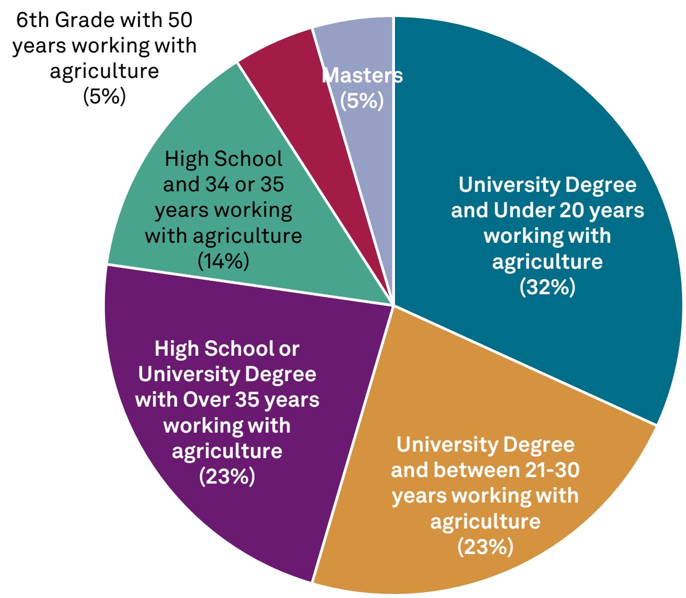

Figure 6. Education and work experience of soybean farmers.

H1: Adoption Rate and Level of Knowledge for Regenerative Practices

Three of four adoption rates exceeded the hypothesized level. Results are broken down by the type of regenerative practice in Table 8.

Table 8. Adoption rate for regenerative practices.

Practice	Hypothesis	Result	Main Barrier for Adoption
No tillage	>= 50% of interviewed farmers	95% (21/22)	Productivity
Cover Cropping	>= 50% of interviewed farmers	86% (19/22)	Productivity
Crop-Livestock Systems	>= 50% of interviewed farmers	36% (8/22)	Financial considerations
Use of Bio inputs	>= 50% of interviewed farmers	82% (18/22), with all 18 of them using inoculants. Only 4 farmers had in-house capability to develop bio inputs on their farms, while 5 went beyond inoculants and utilized biological pest management techniques, such as the use of fungi and parasitic organisms, as well as *Bacillus thuringiensis* to combat pests	Workforce

Thematic Analysis of Regenerative Agricultural Practices Adoption

Table 9 specifies the characteristics of each farmer regarding no tillage adoption. The only farmer that did not perform no tillage had the smallest farm, although had one of the longest experiences in agriculture (40 years).

Table 9. No tillage full results.

	Age	Gender	Education	Agriculture experience (years)	Farm Size (hectares)	State	No Tillage Adoption
Farmer 1	64	Male	University Degree	24	40	Rio Grande do Sul	1
Farmer 2	63	Male	High School	53	68	Rio Grande do Sul	1
Farmer 3	63	Male	High School	53	3000	Rio Grande do Sul	1
Farmer 4	57	Male	University Degree	47	80	Rio Grande do Sul	1
Farmer 5	56	Male	6th grade	50	200	Rio Grande do Sul	1
Farmer 6	55	Male	High School	35	6	Rio Grande do Sul	1
Farmer 7	54	Male	High School	40	3	Rio Grande do Sul	2
Farmer 8	49	Male	High School	35	30	Rio Grande do Sul	1
Farmer 9	48	Male	University Degree	28	12000	Bahia	1
Farmer 10	46	Male	University Degree	30	2500	Bahia	1
Farmer 11	44	Male	High School	34	60	Rio Grande do Sul	1
Farmer 12	43	Male	University Degree	22	10	Rio Grande do Sul	1
Farmer 13	41	Male	University Degree	24	250	Sao Paulo	1
Farmer 14	30	Male	University Degree	10	95	Rio Grande do Sul	1
Farmer 15	30	Male	University Degree	2	2500	Mato Grosso	1
Farmer 16	30	Female	Masters	20	5000	Bahia	1
Farmer 17	29	Male	University Degree	4	350	Goias	1
Farmer 18	29	Male	University Degree	5	2750	Mato Grosso do Sul	1
Farmer 19	27	Male	University Degree	17	130	Rio Grande do Sul	1
Farmer 20	27	Male	University Degree	15	1050	Bahia	1
Farmer 21	26	Male	University Degree	5	1200	Mato Grosso do Sul	1
Farmer 22	22	Male	University Degree	12	15	Rio Grande do Sul	1

1 = Farmer performs the practice. 2 = The farmer does not perform the practice but knows about its existence (highlighted in grey).

Nineteen of the 22 farmers performed cover cropping (Table 10). The three farmers that did not perform cover cropping (2 in last column) varied by age (22, 41 and 57 years old), had either small or mid-sized farms, and university degrees.

Table 10. Cover cropping results.

	Age	Gender	Education	Agriculture experience (years)	Farm Size (hectares)	State	Cover Cropping Adoption
Farmer 1	64	Male	University Degree	24	40	Rio Grande do Sul	1
Farmer 2	63	Male	High School	53	68	Rio Grande do Sul	1
Farmer 3	63	Male	High School	53	3000	Rio Grande do Sul	1
Farmer 4	57	Male	University Degree	47	80	Rio Grande do Sul	2
Farmer 5	56	Male	6th grade	50	200	Rio Grande do Sul	1
Farmer 6	55	Male	High School	35	6	Rio Grande do Sul	1
Farmer 7	54	Male	High School	40	3	Rio Grande do Sul	1
Farmer 8	49	Male	High School	35	30	Rio Grande do Sul	1
Farmer 9	48	Male	University Degree	28	12000	Bahia	1
Farmer 10	46	Male	University Degree	30	2500	Bahia	1
Farmer 11	44	Male	High School	34	60	Rio Grande do Sul	1
Farmer 12	43	Male	University Degree	22	10	Rio Grande do Sul	1
Farmer 13	41	Male	University Degree	24	250	Sao Paulo	2
Farmer 14	30	Male	University Degree	10	95	Rio Grande do Sul	1
Farmer 15	30	Male	University Degree	2	2500	Mato Grosso	1
Farmer 16	30	Female	Masters	20	5000	Bahia	1
Farmer 17	29	Male	University Degree	4	350	Goias	1
Farmer 18	29	Male	University Degree	5	2750	Mato Grosso do Sul	1
Farmer 19	27	Male	University Degree	17	130	Rio Grande do Sul	1
Farmer 20	27	Male	University Degree	15	1050	Bahia	1
Farmer 21	26	Male	University Degree	5	1200	Mato Grosso do Sul	1
Farmer 22	22	Male	University Degree	12	15	Rio Grande do Sul	2

The eighteen farmers that did not have crop-livestock systems (2 in last column) varied across all farmer characteristics (Table 11).

Table 11. Crop-livestock system results.

	Age	Gender	Education	Agriculture experience (years)	Farm Size (hectares)	State	Crop-Livestock Systems Adoption
Farmer 1	64	Male	University Degree	24	40	Rio Grande do Sul	2
Farmer 2	63	Male	High School	53	68	Rio Grande do Sul	2
Farmer 3	63	Male	High School	53	3000	Rio Grande do Sul	2
Farmer 4	57	Male	University Degree	47	80	Rio Grande do Sul	2
Farmer 5	56	Male	6th grade	50	200	Rio Grande do Sul	2
Farmer 6	55	Male	High School	35	6	Rio Grande do Sul	1
Farmer 7	54	Male	High School	40	3	Rio Grande do Sul	1
Farmer 8	49	Male	High School	35	30	Rio Grande do Sul	2
Farmer 9	48	Male	University Degree	28	12000	Bahia	1
Farmer 10	46	Male	University Degree	30	2500	Bahia	2
Farmer 11	44	Male	High School	34	60	Rio Grande do Sul	2
Farmer 12	43	Male	University Degree	22	10	Rio Grande do Sul	2
Farmer 13	41	Male	University Degree	24	250	Sao Paulo	2
Farmer 14	30	Male	University Degree	10	95	Rio Grande do Sul	2
Farmer 15	30	Male	University Degree	2	2500	Mato Grosso	2
Farmer 16	30	Female	Masters	20	5000	Bahia	2
Farmer 17	29	Male	University Degree	4	350	Goiás	1
Farmer 18	29	Male	University Degree	5	2750	Mato Grosso do Sul	2
Farmer 19	27	Male	University Degree	17	130	Rio Grande do Sul	2
Farmer 20	27	Male	University Degree	15	1050	Bahia	2
Farmer 21	26	Male	University Degree	5	1200	Mato Grosso do Sul	1
Farmer 22	22	Male	University Degree	12	15	Rio Grande do Sul	1

Table 12. Use of Bio-inputs results.

	Age	Gender	Education	Agriculture experience (years)	Farm Size (hectares)	State	Crop-Livestock Systems Adoption
Farmer 1	64	Male	University Degree	24	40	Rio Grande do Sul	2
Farmer 2	63	Male	High School	53	68	Rio Grande do Sul	3
Farmer 3	63	Male	High School	53	3000	Rio Grande do Sul	2
Farmer 4	57	Male	University Degree	47	80	Rio Grande do Sul	2
Farmer 5	56	Male	6th grade	50	200	Rio Grande do Sul	2
Farmer 6	55	Male	High School	35	6	Rio Grande do Sul	2
Farmer 7	54	Male	High School	40	3	Rio Grande do Sul	3
Farmer 8	49	Male	High School	35	30	Rio Grande do Sul	2
Farmer 9	48	Male	University Degree	28	12000	Bahia	1
Farmer 10	46	Male	University Degree	30	2500	Bahia	1
Farmer 11	44	Male	High School	34	60	Rio Grande do Sul	2
Farmer 12	43	Male	University Degree	22	10	Rio Grande do Sul	2
Farmer 13	41	Male	University Degree	24	250	Sao Paulo	2
Farmer 14	30	Male	University Degree	10	95	Rio Grande do Sul	2
Farmer 15	30	Male	University Degree	2	2500	Mato Grosso	1
Farmer 16	30	Female	Masters	20	5000	Bahia	1
Farmer 17	29	Male	University Degree	4	350	Goiás	2
Farmer 18	29	Male	University Degree	5	2750	Mato Grosso do Sul	2
Farmer 19	27	Male	University Degree	17	130	Rio Grande do Sul	3
Farmer 20	27	Male	University Degree	15	1050	Bahia	2
Farmer 21	26	Male	University Degree	5	1200	Mato Grosso do Sul	2
Farmer 22	22	Male	University Degree	12	15	Rio Grande do Sul	3

1 = Farmer performs the practice and has in-house capabilities to develop it (applicable to bio inputs only). 2 = The farmer performs the practice. 3. The farmer does not perform the practice but knows about its existence. Dark green coloring to identify the farmer that adopts the practice and has in-house capabilities and Grey to identify the farmer that does not perform the practice.

The farmers that had in-house capabilities to produce bio inputs on farm were large sized in states with advanced technological practices (Bahia and Mato Grosso) (1 in last column of Table 12). The farmers that did not use bio inputs were small farmers that had more than 10 years of agriculture experience.

Kruskal-Wallis Test

Farm size was the only variable that showed a significant difference in median values among the three variables of age, experience in agriculture and farm size:

Test statistic (H) H = (12 / (N * (N + 1))) * SUM(R_j^2 / n_j) - 3 * (N + 1), where

N = 66 observations

For group 1 (age), R_1 (sum of ranks) = 736

For group 2 (experience in agriculture), R_2 (sum of ranks) = 461

For group 3 (farm size), R_3 (sum of ranks) = 1,041

For all groups, n_j = 22

The results showed that, H for group 1 was slightly negative, while for group 2 H was significantly negative (-122). For group 3, farm size, H equaled to 179, indicating a highly significant difference among the groups being compared ($p < .05$).

H2 and H3: Level of Knowledge and Belief in Environmental or Productivity Benefits

Fifty-nine percent of the interviewed farmers (13 of 22) understood the environmental benefits of regenerative practices and could clearly articulate how they contributed to soil health, nutrient cycling, erosion prevention and water retention, among other. The results were in line with the hypothesis that at least 50% of farmers interviewed would be able to do so.

Forty-five percent of the interviewed farmers (10 of 22) understood the productivity benefits of regenerative practices and could describe how they contributed to farm productivity over the long term, lower than the hypothesized value of at least 50%.

H4: Main Perceived Barrier on Adoption and H5: Challenges

Contrary to the hypothesis that economic factors would be the most prominent in the interviews, the primary barrier identified was operational (Figure 7). Many farmers noted that they faced restrictions in crop-livestock integration due to the differing nature of crop and livestock operations. Another operational issue related to bio inputs. Farmers mentioned that if they fully utilized biopesticides while their neighbors did not, they experience more pests as a result. Figure 7 illustrates the main selected barrier of adoption for each farmer while Table 13 shows the percentages of farmers that believed in either environmental or productivity benefits, according to the main barrier selected.

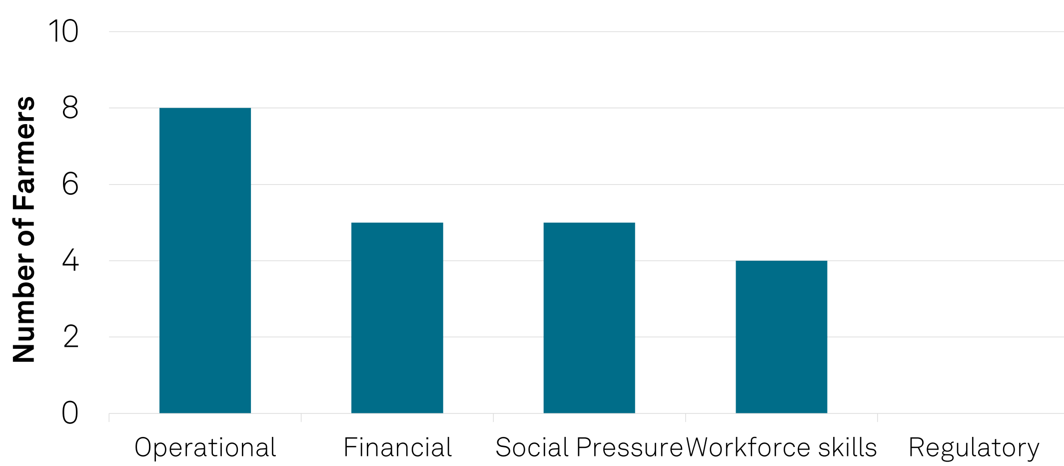

Figure 7. Main perceived barrier of adoption of regenerative practices.

Table 13. Main barrier selected and beliefs of environmental or productivity benefits.

Main Barrier Selected (number of farmers)	Percentage of farmers that understood and could speak about the environmental benefit of regenerative practices	Percentage of farmers that were skeptical or did not agree that there were relevant environmental benefits	Percentage of farmers that understood and could speak about the productivity benefit of regenerative practices	Percentage of farmers that were skeptical or did not agree that there were relevant productivity benefits
Operational, meaning weaker yields (8)	50%	50%	37.5%	62.5%
Financial (5)	75%	25%	60%	40%
Social Pressure, meaning community norms and fear of judgment (5)	80%	20%	60%	40%
Workforce (4)	50%	50%	25%	75%

When asked the open-ended question about the challenges of regenerative agriculture (H5), contrary to the hypothesis that operational issues would be the most frequently mentioned, the term 'climate factors' was the most repeated response among the factors that were mentioned during the interviews (Figure 8). Another commonly cited issue was the guarantee of origin for bio inputs.

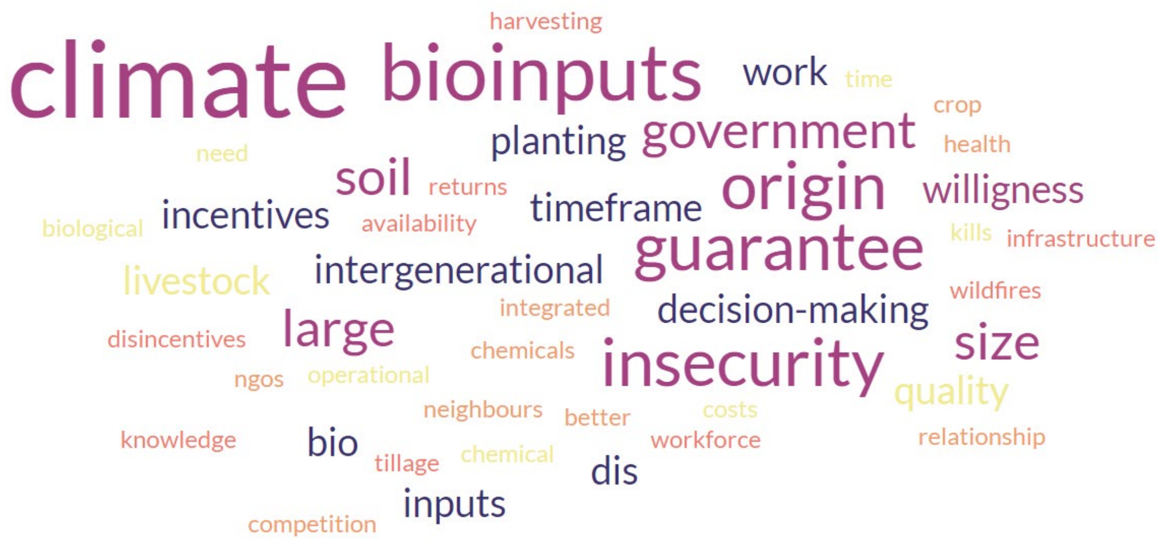

Figure 8. Challenges mentioned.

Note. The more the factor appeared in interviews, the larger the font size.

H6: Price Premium Availability

Only five out of the 22 farmers interviewed indicated the existence of a price premium for adopting regenerative practices (Table 14), far below the hypothesized value that > 50% of the farmers interviewed would have observed one. However, when asked about opinions on price premiums the responses varied, regardless of whether they were related to regenerative practices.

Table 14. Farmers who had observed price premiums.

	Age	Gender	Education	Agriculture experience (years)	Farm Size (hectares)	State	Price Premiums
Farmer 1	64	Male	University Degree	24	40	Rio Grande do Sul	No
Farmer 2	63	Male	High School	53	68	Rio Grande do Sul	No
Farmer 3	63	Male	High School	53	3000	Rio Grande do Sul	Yes
Farmer 4	57	Male	University Degree	47	80	Rio Grande do Sul	No
Farmer 5	56	Male	6th grade	50	200	Rio Grande do Sul	No
Farmer 6	55	Male	High School	35	6	Rio Grande do Sul	Yes
Farmer 7	54	Male	High School	40	3	Rio Grande do Sul	No
Farmer 8	49	Male	High School	35	30	Rio Grande do Sul	No
Farmer 9	48	Male	University Degree	28	12000	Bahia	No
Farmer 10	46	Male	University Degree	30	2500	Bahia	No
Farmer 11	44	Male	High School	34	60	Rio Grande do Sul	No
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Farmer 15	30	Male	University Degree	2	2500	Mato Grosso	No
Farmer 16	30	Female	Masters	20	5000	Bahia	No
Farmer 17	29	Male	University Degree	4	350	Goiás	No
Farmer 18	29	Male	University Degree	5	2750	Mato Grosso do Sul	Yes
Farmer 19	27	Male	University Degree	17	130	Rio Grande do Sul	No
Farmer 20	27	Male	University Degree	15	1050	Bahia	No
Farmer 21	26	Male	University Degree	5	1200	Mato Grosso do Sul	Yes
Farmer 22	22	Male	University Degree	12	15	Rio Grande do Sul	Yes

Dark green coloring to identify the farmer that has seen price premiums

Chapter IV

Discussion

The states that composed the survey (Rio Grande do Sul, Bahia, Mato Grosso, Mato Grosso do Sul and São Paulo) represent 70% of Brazil's soybean planted area (Embrapa, 2024). Rio Grande do Sul is the birthplace of soybeans in Brazil, currently representing 13% of total production (Conab, 2024). The state is known for not using much inoculant, which is reflected in its low productivity of 2,905 kg per hectare in the 23/24 harvest (Conab, 2024). Bahia is the most mechanized production area where regular rainfall favors sowing, germination, vegetative development, and harvesting. It is no coincidence that Bahia has the highest productivity, with the 2023/2024 harvest at 3,780 kg soy per ha, compared to 3,733 kg per ha in Mato Grosso (Conab, 2024). Mato Grosso is the largest soybean farming state of Brazil with 27% of the Brazilian soybean production or 12 million hectares of planted in 2024 (Conab, 2024). Ten percent of the Amazon rainforest is located there (Mapbiomas, 2023). Mempel & Corbera (2021) illustrated how peaks in deforestation of the Brazilian Amazon led to the signing of the Amazon Soy Moratorium (2006) to tackle soybean farming expansion from encroaching on the rainforest. Recent data from Mapbiomas (2023) showed improvement in soybean related deforestation rates, although it remains a risk. Mato Grosso do Sul is a relevant large soybean producing state (8% of total Brazilian soybean production or 4 million hectares of planted area) and Pantanal, the world's largest tropical wetland, is located there (Mapbiomas, 2023).

The states that form database for this research, provide most soybean production, and thereby expand the generalizability of the research. São Paulo has different economic, climatic, and logistical conditions and historically lower productivity, including in the most recent 2023/2024 harvest: 2,800 kg of soy per ha compared to 3,179 kg per ha in Mato Grosso (Conab, 2024). São Paulo represents only 2% of Brazil's total soybean production. Finally, Goiás represents 11% of total soybean production. Goiás is a state with average soybean productivity at 3,480 kilograms of soy per hectare for 2023/2024 (Conab, 2024).

Review of Results in Relation to Hypotheses

There was a notable concentration of larger producers in the sample of interviewed farmers, so this should be borne in mind when inferring the generality of results. The average farm size was 1,424 ha, which contrasts with the Brazilian average soybean farm size, typically in the 30–40-ha range (Embrapa Soybean, 2023). The network sampling method began with larger farms (over 1,000 hectares), which may have skewed the database toward larger operations. Seventy-three percent of the agricultural establishments producing soybeans in Brazil have less than 50 ha, while 70% of the farms in this research exceed 50 ha (Embrapa, 2024).

H1: Farmer Knowledge and Adoption of Regenerative Practices

The knowledge and adoption results for all four practices showed that the farmers from the states of Mato Grosso do Sul and Bahia, which are known for higher productivity, tend to be more knowledgeable and adopt more regenerative practices

Tables 8-12). Rio Grande do Sul tends to be a more conservative state (Legard & Goldfrank, 2021), meaning that the state can face resistance to innovation. Rio Grande do Sul had a lower adoption of bio-inputs compared to other states. During discussions with some farmers from Rio Grande do Sul, some recognized that inoculant use is widespread in Brazil, but that it is not common in their state. The research showed that the farmers with the largest farm size were those who had the in-house capacity to produce bio-inputs on their farms (Table 12 - Farmer 9, 10, 15 and 16). The same was not true for crop-livestock systems, which, despite only a few practicing them, varied in farm size. This contrasts with Pereira et al. (2018), who showed that adoption of these regenerative practices had mostly occurred in industrial scale farms.

The research findings support the claim from the Brazilian Federation of No Tillage (2019) that no-tillage has proven to be a widely adopted in Brazilian soybean farming. Farmers were not reluctant to discuss it, and as the first practice that was discussed, there was little to no skepticism around its benefit and recognition as a successful regenerative practice in soybean farming in Brazil.

The results on the adoption rate of cover cropping were in line with the hypothesis. The type of cover crop was not part of the hypothesis, but Rio Grande do Sul was the state where farmers mentioned the greatest variety in cover crops (wheat, oats, alfalfa, pea). In the other states, it was more common to replant corn in the summer, with a sequenced of soybean (October-January)-corn (January-March)-corn (March-October)-soybean (October-January).

According to Embrapa (2023) and Bolfe et al. (2024), approximately 28 million ha of pastures in Brazil have the potential to be integrated with crop production, particularly since much of the pastureland is degraded. Despite the potential, the results presented in Table 8 indicate that crop-livestock systems are not commonly used. The reasons given by farmers were the differing economics and operational challenges associated with managing cattle and other types of livestock. Bolfe et al.'s (2024) findings support this claim, with a further note that the states of Mato Grosso do Sul, Goiás, Bahia and Mato Grosso, which are represented in this study, present significant potential for expanding crop farming on degraded pastures. That said, this research highlighted that for this potential to be fulfilled, work by both farmers and policymakers is necessary to make it financially and operationally attractive.

Several farmers noted that the lack of bio input usage on neighboring farms negatively impacts their productivity when relying solely on bio inputs. This observation was consistent throughout the interviews. However, Martinazzo et al. (2007) and Santos et al. (2008) highlighted that the application period is crucial for productivity and, consequently, the adoption rate of bio inputs.

H2 and H3: Farmer Beliefs About Environmental and Productivity Benefits

Soybean farmers are knowledgeable and believe there are environmental (H2) and productivity benefits (H2) of regenerative practices. For both H2 and H3, age had an influence in the knowledge and belief of environmental and productivity benefits. The 13 farmers who clearly articulated how regenerative practices promote soil health, among other environmental benefits (Table 6), had an average age of 40, while the nine remaining farmers who were skeptical had an average age of 46. Among the farmers who indicated that productivity benefits existed and could explain what they were (Table 7), the 10 who acknowledged these benefits also had an average age of 40, while the remaining skeptical farmers had an average age of 46. Additionally, the older farmers in the sample were among those who did not have confidence in the environmental or productivity benefits of regenerative agriculture. This aligns with the opinions of some younger farmers, who mentioned that intergenerational perspectives pose a challenge to implement regenerative practices. For example, Farmer 16, 26 years old, from the state of Mato Grosso do Sul, mentioned that “my Father, the second generation to take control of the farm, already had discussions with my Grandfather around innovation and different farming practices compared to the tradition at that time. I face the same situation, with the difference that my Father’s farming methods are now seen as traditional compared to the methods being discussed here".

Regarding the belief of the productivity of cover cropping, Mandro's (2024) study on the use of cover crops (different species of mavuno grass and sorghum) for soybean farming in the state of São Paulo, showed that cover crop techniques did not influence soybean crop productivity. However, they did improve soil fertility (increase in macronutrients necessary for plant growth). The farmers interviewed did not question how cover cropping affected productivity, in line with Mandro’s findings (2024). On the other hand, with bio inputs, many farmers were skeptical about it, which caused many productivity scores to drop to a 2 – 'The farmer can articulate the productivity benefits of the practice but remains skeptical about them.' There was no age concentration among the farmers that scored 2 for productivity benefits. However, farmers that scored 1 generally had higher educational levels, in line with Reimer et al. (2014), indicating that more education could mean less skepticism with the use of bio inputs.

H4: Main Perceived Barrier to Adoption

Many previous authors identified financial as the main barrier of adoption Fuentes-Llanillo et al. (2013); Best (2009); Blessing et al. (2021) and Opdenbosch & Hansson (2023), which informed the hypothesis of this thesis. Meanwhile, for Ofstehage & Nehring (2021), Aye and Howeler (2012), and Silvestrini et al. (2023), operational issues were the main barrier, while for Goulet & Hubert (2020), regulatory was the main one. The results showed that most farmers viewed operational factors (such as weaker yields or the availability of technology and machinery) as the primary barrier (Figure 7). The only barrier listed that was not selected by the interviewed farmers was regulatory. This could be due to the absence of a common definition in Brazilian agricultural regulations regarding what regenerative farming entails.

Farmers who identified operational factors as the main barrier had varied beliefs about environmental benefits (Table 13). Around half of them clearly understood and could explain the environmental benefits of regenerative farming, while the other half were either skeptical or did not agree that there were relevant environmental benefits. This was different from farmers who selected social pressure (community norms and fear of judgment) and financial as the main barrier. Farmers that selected social pressure, all could explain the environmental benefits of regenerative farming, except for one.

The results were mixed for productivity benefits. Every main barrier selected shows a decrease in the belief of productivity benefits compared to environmental. The results indicate that when operational barriers are overcome, the soybean farmer tends to have more confidence on the environmental and productivity benefits of regenerative farming.

None of the farmers who identified operational factors as the barrier saw price premiums for regenerative practices. Those who did mostly selected financial factors as the main barrier. These results indicate that the farmers that selected financial factors might be more in tune with the financials of the farm. Brown (2018) shared his personal experience of how, once more in tune with the financial aspects of farming, profit becomes the objective rather than yield.

H5: Climate Change as the Main Challenge to Adoption

In contrast to the hypothesis that operational considerations would be identified as the main challenge for low adoption of regenerative practices, seven out of the 22 interviewed farmers stated that climate change was their biggest threat. According to several scholars, climate change is one of the main risk factors influencing soybean productivity in Brazil (Justino et al. 2013, do Rio et al. 2016). While this is common given that agriculture is inextricably linked with the climate, many farmers emphasized how they have experienced rising temperatures in their soils or in the atmosphere, and that this has prevented them from exploring different agricultural methods. Climate change can be therefore viewed as an overall challenge for soybean farming, independent of whether through regenerative or traditional methods.

There was no particular trait linking the farmers who mentioned climate as a challenge; they varied in farm size (ranging from 80-1,050 ha), productivity beliefs (some clearly articulated the benefits of regenerative agriculture, while others did not), and were from different states.

H6: Price Premium

The research refuted that more than half of the farmers interviewed had observed a price premium for soy grown by regenerative practices. Only five out of the 22 farmers interviewed knew about any price premium (Table 14). The farmers who have seen a price premium for regenerative practices had an average planted area of 808 ha and were either in Mato Grosso do Sul or Rio Grande do Sul.

When asked about general market conditions and pricing, around half of the farmers interviewed pointed out that non-transgenic seeds generally yield higher sale prices. Others noted that certification, which are becoming common among soybean crushers, can be an expensive process and may not justify the additional income or demand that certified soy can provide. Chen et al. (2024) assessment of the Round Table on Responsible Soy (RTRS) certification on soybean exports showed that, from 2012-2019, higher prices of certified soy reduced RTRS soy market demand.

Similarly to the non-transgenic point, around half of the farmers interviewed in this research pointed out that the absence of a clear definition for regenerative soybean farming limits further development of its pricing. In contrast, organic pricing was the most mentioned feature for the existence of premiums.

Based on the results of this thesis and the discussion above, the next section presents suggestions for soybean farmers, researchers, and policymakers on how to overcome operational barriers and increase the adoption of regenerative soybean agriculture in Brazil.

Research, Policy and Practice Implications

Table 8 illustrates that out of the four regenerative practices assessed—no tillage, cover cropping, crop-livestock systems, and the use of bio inputs—the first two had widespread adoption while the latter two had a more significant adoption gap. Furthermore, the research found that environmental knowledge and belief in regenerative practices are more widespread than a belief that there are productivity benefits. The specific productivity benefit indicated by farmers was that no tillage and cover cropping improve the quality of the soil of the farm. The research also indicated that operational considerations are the main barrier to the widespread adoption of all regenerative practices among the farmers interviewed. The specific operational barriers identified were the absence of farm infrastructure for integrated crop-livestock farming and yield loss from bio input use due to neighboring farms not adopting it. Finally, the research also indicated that price premiums are not reaching many soybean farmers who might be adopting the four regenerative practices assessed here (no tillage, cover cropping, crop-livestock systems, and the use of bio inputs). In the following section, suggestions are addressed to soybean farmers and policymakers, envisioning an increase in regenerative adoption.

Soybean Farmers

To overcome operational barriers, a few (three) interviewees mentioned that an increase in the adoption of crop-livestock systems and the use of bio inputs could benefit from forming partnerships. While they appear to operate within a tight knit community, few partnerships (e.g., equity stakes between farms) exist. Although there is no formal definition of farmer networks (Pape & Prokopy, 2017), many scholars have explored how peer-to-peer learning and replication is an effective way for farmers to increasing the adoption of new practices (Pape & Prokopy 2017; Šūmane et al., 2018). Asprooth et al. (2023) concluded from survey of farmers in the U.S. corn belt that formal networks support the adoption of agricultural practices. Based on the peer-to-peer evidence, their research suggests that shared ownership could help Brazilian soybean farmers overcome operational barriers to regenerative agriculture adoption. More importantly, Leitheiser et al.'s (2022) study of Dutch systems concluded that regenerative adoption can be enhanced by "the use of cooperative resource pooling and municipal resources to access land" (Leitheiser et al., 2022, p. 1). This also suggests that shared ownership, even public private partnerships, could help overcome operational barriers to regenerative agriculture adoption.

Policymakers

For policymakers, considering that operational barriers are the most prominent obstacles to implementation, specific programs for crop-livestock integration or the incentivization of bio inputs may be warranted. No-tillage has proven to be widely adopted in Brazilian soybean farming (Brazilian Federation of No Tillage, 2019). These efforts have been led by a national research enterprise, Embrapa, who pushed it forward via research and development at the farm level. Various programs involving no-tillage have received support from the federal government, such as the Cerrado Zero Tillage initiative, which was backed by the Environmental Ministry through the National Secretariat of Water Resources (Landers, 2001). The "Plano Safra" also reduced crop insurance premiums by 1% for zero-tillage practitioners starting in 1997 (Landers, 2001). Additionally, the ABC Program of the Federal Government includes a special line for no-tillage, where the interest rate is fixed at 5.5% per year (Embrapa ABC Program, 2024) against a variable interest rate above 10% in Brazil currently. Table 15 shows the results that the ABC Program achieved from 2010-2020 (Brazilian Ministry of Agriculture, 2023).

Table 15. ABC program results from the Brazilian Ministry of Agriculture (2023).

	Areas (million hectares)		
Practice	Target	Result	Achievement
Degraded Pastureland Recovery	15	26.8	179%
Crop-Livestock-Forestry Systems	4	10.7	269%
No Tillage	8	14.6	182%
Biological Nitrogen Fixation	5.5	11.	214%
Planted Forests	3	1.88	63%
Animal Waste Treatment	4.4 cubic meters	38.3 cubic meters	871%

In this context, policies aimed at overcoming productivity barriers, such as tax exemptions for soybean farmers who begin developing bio-inputs on their farms, could be a viable solution.

That said, perhaps more important than overcoming operational barriers is addressing the issue of price premiums. As demonstrated, only five out of 22 farmers have experienced a price premium (Table 14). Currently, some state programs reward more sustainable agricultural practices. For example, in the state of Goiás, the Cerrado em Pé program offers an annual payment of R$ 498 per ha to rural property owners who commit to preserving areas of the Cerrado beyond the legally required amounts (Goiás, 2024). Those who commit to restoring at least one field of degraded spring per year receive an even higher payment of R$ 664 per hectare. The funding comes from the State Environmental Fund (Fema), with a maximum payment limit of 100 hectares per property (Goiás, 2024). While these programs might not directly compensate for the regenerative practices evaluated here, they could provide environmental benefits to Brazilian soybean farming as shown by Roberts et al. (2023) and Merrick (2021), although not yet evidenced for Brazil.

Research Limitations

Four main limitations were noted in the research: the sampling methods, the reliance on farmers to share their beliefs, the assumption that regenerative practices are beneficial to the environment and to farm productivity in the long term, and the Kruskal-Wallis (H) statistic.

The network sampling method used in this research did not follow randomized sampling. As a result, the data may not accurately reflect the adoption rate and main perceived barrier that soybean farmers in Brazil face to adopt regenerative practices. Additionally, the total farmers interviewed represent less than 1% of the Brazilian famers—the sample covers 30 thousand hectares of planted soybean compared to 50 million hectares of soybean farms in Brazil.

The definitions used in this research could have influenced the responses given by each farmer. Additionally, depending on how the farmer interview progressed, the farmer might have felt more or less comfortable sharing their opinions on environmental and productivity benefits. Most interviews were conducted in a conversational format to address this issue; however, it was observed that some farmers were not fully comfortable sharing their honest opinions.

This research assumed that regenerative practices are beneficial to the environment and to the crop yields of soybean farms in the long term. While the environmental benefits are well documented in the literature, questions remain regarding how regenerative practices can achieve yields comparable to those of traditional agricultural methods.

Given the small number of observations, a high (H) value found for groups 1 (age), 2 (experience in agriculture) and 3 (farm size) were unusual compared to common Kruskal-Wallis tests. Also, the location of the farm was not added as a variable for the test since the research did not collect such data.

Conclusions

This research attempted to measure the adoption rate of four regenerative agricultural practices (no tillage, cover cropping, crop-livestock systems and use of bio inputs) in Brazilian soybean farming. The main finding was that no tillage, cover cropping and use of bio inputs were widely adopted (over 80% of interviewed farmers practiced it) while crop-livestock systems were less common (36%). The information that crop-livestock systems had the least adoption can support Brazil's goal of increasing integrated crop-livestock systems by 10 million hectares by 2030.

Furthermore, knowledge-sharing about the environmental and productivity benefits of regenerative farming can encourage more widespread adoption of regenerative farming, especially bio inputs, where farmers still have significant concerns regarding the guarantee of origin and usage efficiency.

Overcoming the operational challenges of adding livestock farming infrastructure to soybean farms, and widespread application of bio inputs so that neighboring farm issues do not arise, are necessary for full regenerative practices adoption. An important enabler is cooperation, for example, through partnerships that help alleviate the higher financial costs or yield loss from the conversion to regenerative practices. Farmers with more experience in livestock farming or integrated systems can collaborate with soybean farmers, given that many states have degraded pastures suitable for conversion to cropland as shown in the Brazilian government's ABC program (Table 15; Embrapa ABC Program, 2024).

In conclusion, soybean producers and processors in the states of Rio Grande do Sul, Bahia, Mato Grosso, Mato Grosso do Sul, and São Paulo, along with stakeholders that influence the sector—including local regulators, creditors, and scientific researchers—can strengthen the adoption of regenerative agriculture in Brazil. Legislators can help by implementing federal programs that provide economic or operational incentives for adopting these practices. Creditors can use green loans with potentially lower interest rates to encourage farmers to allocate loan proceeds exclusively toward implementing regenerative practices. Processors can offer price premiums to farmers who adopt regenerative practices. Last but most importantly, producers can transition to regenerative farming with or without the incentives listed above.

A higher adoption rate of regenerative practices for soybean farming in Brazil can support current global movements such as the United Nation's Global Biodiversity Framework and the Paris Agreement to mitigate the significant climate and environmental risks associated with traditional agriculture.

Appendix 1

Interview Guidelines

1. DEMOGRAPHIC DATA

1.1 Gender?

☐ Male

☐ Female

☐ Prefer not to inform

1.2 Age? _____

1.3 Education level?

☐ Elementary school

☐ High school

☐ College or University degree

1.4 Experience in agriculture (years)? _____

1.5 Farm size (ha) and Location? __________

2 Regenerative Soybean Farming

Please read through the definitions and fill out the application rate of the practice for the total soybean planted area of your farm(s).

Practice	**Description**	**Application rate (% compared to total soybean planted area)**
No or Reduced Tillage	This practice avoids or minimizes the use of agricultural machinery to turn the soil so that it becomes fertile again after harvest. The crop is planted over the remains of previous crops. Rotational crops may be introduced to minimize the need for synthetic fertilizers. (CEBDS, 2023).	
Cover Cropping	Cover cropping entails the planting of grasses, legumes, and other species like brassicas before, during, and after the main crop is harvested	
Integrated Crop-Livestock	After the soy is harvested, introducing cattle to what used to be the planted area	
Use of Bio inputs	Products of plant, animal, or microbial origin, used in crop farming or planted forests, which interfere in the growth, development, and response mechanisms of pest animals, plants, and microorganisms,	

Familiarity with the practice

Score	Description
1	The farmer performs the practice and has in-house capabilities to develop it (applicable to bio-inputs only)
2	The farmer performs the practice
3	The farmer does not perform the practice but knows about its existence
4	The farmer does not know about its existence

Environmental Benefits (Familiarity and Belief)

Score	Description
1	The farmer understands the environmental benefits. He can describe well how the practice can improve soil health, mitigate water overuse, avoid eutrophication, among other.
2	The farmer can speak to the environmental benefits of the practice but is skeptical about its importance.
3	The farmer can speak about the environmental benefits of the practice but that does not agree that it is an important aspect
4	The farmer does not understand the environmental benefits of the practice, never mind whether he practices or not

Productivity Risks and Benefits (Familiarity and Belief)

Score	Description
1	The farmer understands the productivity impact of the practice. He can describe well how the practice can entail higher costs (i.e. for biopesticides, specialized machinery), delayed planting, among other
2	The farmer can speak to the productivity benefits of the practice but is skeptical about it.
3	The farmer does not agree that the practice has productivity benefits
4	The farmer does not understand the productivity risks and benefits of the practice, never mind whether he practices or not

3 Challenges

Practice	Please describe the main challenges you had when implementing, or the main productivity challenges	What have been the long-term effects of adopting this practice (both on your farm and the surrounding environment)?	Trade-offs between practices: How does each practice affect the other in your view?

No or Reduced Tillage			
Cover Cropping			
Integrated Crop-Livestock			
Use of Bio-inputs			

4 Barriers for Adoption for Practices

Please select the most prominent barriers for adopting regenerative soybean farming:

- Workforce
- Social pressure (community norms and fear of judgment)
- Financial
- Regulatory
- Operational (weaker yields or technology or machinery availability)

5 Do you see a price premium for regenerative soybean farming?

Appendix 2

Interview Results

Table 16. Full interview results (H1).

	Age	Gender	Education	Experience in agriculture (years)	Farm size (ha)	Brazilian State	Familiarity with No Tillage	Familiarity with Cover Cropping	Familiarity with Integrated Crop-Livestock Systems
Farmer 1	54	Male	High School	40	3	Rio Grande do Sul	2	1	1
Farmer 2	55	Male	High School	35	6	Rio Grande do Sul	1	1	1
Farmer 3	43	Male	University Degree	22	10	Rio Grande do Sul	1	1	3
Farmer 4	22	Male	University Degree	12	15	Rio Grande do Sul	1	2	1
Farmer 5	49	Male	High School	35	30	Rio Grande do Sul	1	1	2
Farmer 6	64	Male	University Degree	24	40	Rio Grande do Sul	1	1	3
Farmer 7	44	Male	High School	34	60	Rio Grande do Sul	1	1	3
Farmer 8	63	Male	High School	53	68	Rio Grande do Sul	1	1	3

Farmer 9	57	Male	University Degree	47	80	Rio Grande do Sul	1	2	3
Farmer 10	30	Male	University Degree	10	95	Rio Grande do Sul	1	1	3
Farmer 11	27	Male	University Degree	17	130	Rio Grande do Sul	1	1	3
Farmer 12	56	Male	6th grade	50	200	Rio Grande do Sul	1	1	3
Farmer 13	41	Male	University Degree	24	250	Sao Paulo	1	2	3
Farmer 14	29	Male	University Degree	4	350	Goias	1	1	1
Farmer 15	27	Male	University Degree	15	1050	Bahia	1	1	3
Farmer 16	26	Male	University Degree	5	1200	Mato Grosso do Sul	1	1	1
Farmer 17	30	Male	University Degree	2	2500	Mato Grosso	1	1	3
Farmer 18	46	Male	University Degree	30	2500	Bahia	1	1	3
Farmer 19	29	Male	University Degree	35	2750	Mato Grosso do Sul	1	1	3
Farmer 20	63	Male	High School	53	3000	Rio Grande do Sul	1	1	3
Farmer 21	30	Female	Masters	20	5000	Bahia	1	1	3
Farmer 22	48	Male	University Degree	28	12000	Bahia	1	1	1

Table 17. Full interview results (H2-H5).

	Familiarity with the use of bioinputs	Familiarity and Belief in Environmental benefits	Familiarity and Belief in Productivity Benefits	Main Barrier for Adoption	Challenges
Farmer 1	3	2	2	Operational	
Farmer 2	2	1	1	Financial	Willingness
Farmer 3	2	1	2	Operational	Intergenerational decision-making
Farmer 4	3	1	1	Social Pressure	Large size
Farmer 5	2	2	1	Financial	Government (Dis)incentives
Farmer 6	2	1	2	Operational	Bio inputs - Guarantee of origin insecurity
Farmer 7	2	1	2	Social Pressure	Operational
Farmer 8	3	3	2	Financial	Willingness
Farmer 9	2	3	2	Operational	Climate
Farmer 10	2	1	1	Social Pressure	Government (Dis)incentives
Farmer 11	3	2	2	Workforce	Climate
Farmer 12	2	1	1	Operational	Climate
Farmer 13	2	2	2	Operational	Climate
Farmer 14	2	1	2	Financial	Bio inputs - Guarantee of origin insecurity
Farmer 15	2	1	2	Workforce	Climate
Farmer 16	2	2	2	Social Pressure	Integrated Crop Livestock -competition between livestock and soil health

Farmer 17	1	1	1	Financial	Relationship with NGOs
Farmer 18	1	1	1	Operational	Large size
Farmer 19	2	1	1	Workforce	Government (Dis)incentives
Farmer 20	2	2	2	Workforce	Planting timeframe
Farmer 21	1	3	1	Operational	Workforce Availability
Farmer 22	1	1	1	Social Pressure	Returns

Table 18. Full interview results (H6).

	Price Premium Exists (Yes or No)	Price Premium Received	Opinion on Price Premiums
Farmer 1	No		
Farmer 2	Yes	No	Organic
Farmer 3	No		Depends on the definition of what regenerative means. Organic isn't a global definition
Farmer 4	Yes	No	Organic premium, but it’s a niche market
Farmer 5	No		Certification systems are challenging
Farmer 6	No		
Farmer 7	No		
Farmer 8	Yes	No	Organic
Farmer 9	No		The producer is only squeezed
Farmer 10	No		Financing
Farmer 11	No		
Farmer 12	No		
Farmer 13	No		
Farmer 14	No		
Farmer 15	No		Only for seeds (transgenic versus non transgenic) latter pays more
Farmer 16	Yes	Yes	Went through all, which took long and had someone responsible for that
Farmer 17	No		
Farmer 18	No		
Farmer 19	Yes	No	Expensive to apply all requirements
Farmer 20	No		
Farmer 21	No		Only talk, no effective price premium
Farmer 22	No		

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