Spring 5-18-2024

Assessing the Use of Regenerative Agriculture in California Almonds as Climate Change Resilience

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This Master's Project

Assessing the Use of Regenerative Agriculture in
California Almonds as Climate Change Resilience

by

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Is submitted in partial fulfillment of the requirements for the degree of:

Master of Science
in
Environmental Management

at the

University of San Francisco

Submitted: 5/16/2024

Skyler Seamons Date

Received: 5/16/2024

Simon Scarpetta, Ph.D. Date

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Acknowledgments

I would like to acknowledge my family and friends who have supported me throughout my time completing this project. I would also like to acknowledge all my professors at USF who have shaped my perspective on Environmental Management, which is shown through this project. I would specifically like to thank Professor Simon Scarpetta for being a great advisor to my master's project. I would like to thank those in the regenerative almond industry who allowed me to interview them for providing me with valuable information and insights on this topic. I would also like to thank my fellow MSEM classmates who gave helpful feedback and support. Lastly, I would like to thank anyone who is reading this project. I hope it inspires you to learn about and strive for a more sustainable food system.

Abstract

The agriculture sector is responsible for 10% of the United States' greenhouse gas emissions. In turn, anthropogenic climate change threatens crops. With its Mediterranean climate, California is the country's largest agricultural-producing state. Many California crops are at risk due to increasing temperatures and changed precipitation patterns. This paper investigates regenerative farming techniques as a tool to protect California crops from a changing climate. Almonds are used as a case study to analyze the soil management practices, finances, and policies underlying regenerative agriculture in California. A literature review and comparative analysis are used to compare regenerative and conventional soil management practices and their ecological outcomes. Regenerative soil management practices can have ecological benefits including increased soil health and water retention. Additionally, regenerative soil management practices can have environmental benefits through reduced inputs and carbon sequestration. A literature review and SWOT analysis are used to assess the financial aspects of regenerative almond orchards. Regenerative agriculture can improve the profitability of almond orchards by charging a premium and reducing the costs of inputs. Policies, incentives, grants, and programs can be utilized to make a transition from conventional to regenerative agriculture. There is a need for collaboration amongst farmers, policymakers, and the private sector to encourage and implement the transition to regenerative agriculture in California almonds.

Introduction

There is no doubt of the need for more sustainable food systems. Globally, human food systems account for one-third of anthropogenic greenhouse gas emissions (Crippa et al., 2021). Food systems encompass all aspects of food production, including agriculture, processing, transport, and packaging. However, agriculture by itself is a particularly large contributor to anthropogenic greenhouse gas emissions, accounting for over 10% of annual emissions in the U.S. (Daniels, 2022). Greenhouse gases are emitted through agricultural practices, including methane (CH_4) produced by livestock and carbon dioxide (CO_2) released through land conversion (Bos et al., 2014). Soil management practices emit nitrous oxide (N_2O) and account for over half of the agriculture sector's greenhouse gas emissions (Daniels, 2022). Conventional soil management practices in the U.S. use techniques like tilling, monoculture, and the inputs of pesticides, herbicides, and fertilizers (Le Campion et al., 2023). Current farming techniques are contributing to anthropogenic climate change. In turn, changes in the climate pose a threat to our crops. This creates a feedback loop of our agricultural systems worsening climate change, and climate change negatively affecting our agricultural production.

Because the United States is the second-largest annual producer of greenhouse gases (Daniels, 2022), the 10% component from agriculture is a substantial quantity with respect to total human emissions. Nature-based solutions—a set of practices different from most conventional agriculture—can potentially reduce 40-50% of the United States' agricultural greenhouse gas emissions (Daniels, 2022). Conventional agriculture depends on finite resources, including fossil fuels and pesticides, which contribute to climate change, soil degradation, and loss of biodiversity (Voisin et al., 2023). With a growing population to feed and a changing climate, we must look towards nature-based solutions that can reduce our greenhouse gas emissions and improve the health of the soil. Regenerative agriculture composes a candidate set of nature-based solutions.

Regenerative agriculture is a different practice and philosophy of farming and can provide a viable and sustainable alternative to conventional farming practices. The goal of regenerative agriculture is to improve soil health, biodiversity, ecosystem health, socioeconomic incomes, and climate (Schreefel et al., 2020). Regenerative agriculture has become a widely used term in the past decade (Silva et al., 2022), but it is important to acknowledge the roots of these practices—the techniques entailed in regenerative agriculture have been practiced for millennia by Indigenous peoples and local communities (IPLCs) all over the world (Sands et al., 2024). IPLCs is an internationally used term that refers to communities and members that are self-identified indigenous and communities that maintain intergenerational connections to place and nature through livelihoods, cultural identity, institutions, and ecological knowledge (IPBES).

Regenerative agriculture uses techniques like animal grazing, incorporating compost, and planting cover crops to build and maintain healthy soil (Schreefel et al., 2020). Equally important are the methods that regenerative agriculture does *not* use. Regenerative agriculture does not use conventional methods such as tilling or the input of synthetic fertilizers and pesticides (Schreefel et al., 2020). These practices can improve soil health, in turn making the crops more nutrient-dense and resilient to environmental changes. Regenerative agriculture can also combat anthropogenic climate change because resulting soils capture more carbon than conventional farming soil (White, 2020).

Climate change is impacting our food systems through temperature changes, changes in precipitation patterns, and extreme weather events. These changes alter the growing seasons and affect soil fertility and yield (Xu et al., 2022). With a growing population and more people to feed, we must adapt our food systems to be resilient to a changing climate. Additionally, our current food systems contribute to climate change through their farming techniques. Lastly, current farming techniques can have negative impacts on human health. I am motivated to look into food system solutions that reduce anthropogenic emissions, reduce human health risks, and strengthen our food supply.

Scope

California is the United States' largest agricultural-producing state, growing over 33% of the country's vegetables and 75% of the country's fruits and nuts (CDFA, 2023). California's agricultural industry also factors greatly into the state economy, employing over 420,000 people and generating over $50 billion in annual revenue (Escriva-Bou et al., 2022). California grows many valuable commodities, including grapes, strawberries, and lettuce. However, one crop that is especially valuable to California—100% of the United States almond supply and 80% of the world's almond supply comes from California (CDFA, 2023). Almonds and other crops can grow so well in California due to the Mediterranean climate of the state (Kerr et al., 2018). However, this climate also puts these crops at risk from increasing temperatures and drought, which are being exacerbated by climate change (Kerr et al., 2018). As the climate continues to change, farmers will need to find a sustainable way to protect their crops, and regenerative agriculture might be a key strategy and agricultural philosophy for crop resilience.

Agriculture in California is very sensitive to climate change through temperature changes, precipitation changes, increased intensity/frequency of climate extremes, and water availability (Pathak et al., 2018). Agriculture will be affected by increasing global temperatures, but the impacts will differ between different crops and where they are grown (Kerr et al., 2017). The USDA defines specialty crops as all fruits, nuts, vegetables, and nursery crops (Kerr et al., 2017). In California, specialty crops are responsible for most of the State's agricultural value (Kerr et al., 2017). However, most research that aims to understand the effects of climate change on crop production is based on studies of field crops, such as beans, grains, and oilseeds (Kerr et al., 2017). Kerr et al., 2017 examined the vulnerability of California's top 14 specialty crops, including almonds.

Increasing temperatures can harm perennial crops, including almonds, that are reliant on a certain threshold of chill hours to reach optimum yields (Kerr et al., 2017). According to several studies based on climate models and historically observed temperature-yield relationships, most current perennial specialty crop locations in California will not be suitable for many key crops by the mid-to-late century (Kerr et al., 2017). Almonds have lower chilling requirements than other plants in their genus, *Prunus*, allowing them to remain productive in the Central Valley. (Kerr et al., 2017). However, the loss of winter fog is a significant unknown factor in almonds' susceptibility to climate change (Kerr et al., 2017).

Nine out of ten of the top-ranked California counties for sensitivity to winter temperatures were in the Central Valley (Kerr et al., 2017), where many California almond orchards are located. The highest absolute impacts in both summer and winter were observed in the San Joaquin Valley, the southern half of the Central Valley. When looking at the affected areas (Fig 1), and the locations of almond production (Fig 2), it is evident that California almonds will be impacted by changing temperatures.

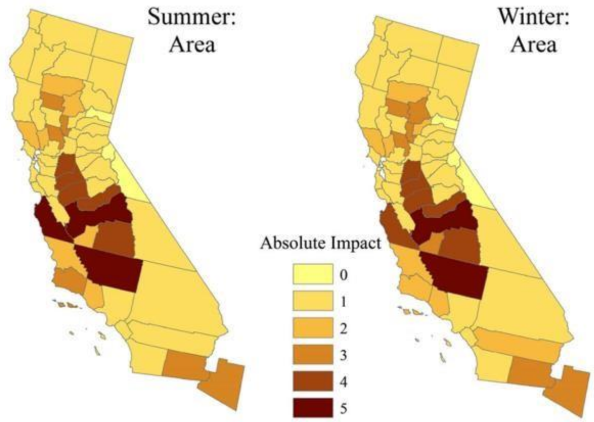

Fig 1. Absolute impact of changing temperatures on specialty crops aggregated at the county level. 1 = low sensitivity, 5 = high sensitivity (Kerr et al., 2017).

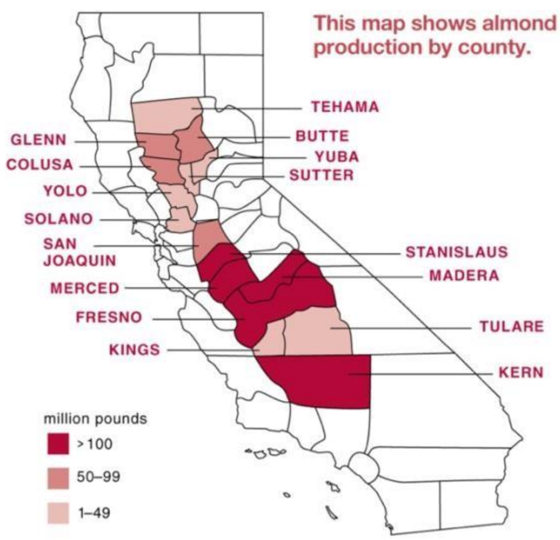

Fig 2. Almond production by county (Almond Board of California, 2013).

Changes in precipitation and availability of water will also affect specialty crops in California. These changes are difficult to predict due to complications of regional modeling, as well as the fact that water availability for California crops is largely dependent on policy and infrastructure (Kerr et al., 2017). Almost 90% of California crops are irrigated, meaning decreases in water availability could have a big impact on crop areas and yields (Pathak et al., 2018) California accounts for over half of specialty crop production in the United States (Kerr et al., 2017). The impacts that climate change can bring to California agriculture will lead to national food security and economic problems (Pathak et al., 2018). To better understand the vulnerability of specialty crops to climate change, additional research on ecological and economic is needed.

Research Questions

The main question this project aims to address is: How can a transition to regenerative agriculture help to protect California almonds from a changing climate? Three sub-questions are used to answer this question. The first sub-question is: What soil management practices are important to increase climate change resilience for California almonds? The second sub-question is: What are the financial costs and benefits of transitioning to regenerative agriculture? The third sub-question is: How can California begin to widely adopt regenerative agriculture farming practices?

I will investigate possibilities to make farming in America more sustainable amidst a changing climate, using almond agriculture in California—the largest almond supply in the world—as a lens to answer these questions. I will address how a transition to regenerative agriculture can help to protect California almonds from a changing climate. I will highlight which farming practices have the largest impact. Which regenerative soil management practices are important for California almonds? To answer this question, I have chosen different soil management practices to focus on based on what my literature review showed to be the most significant. I will evaluate the use of whole orchard recycling, cover crops, and reduced inputs. I will analyze these practices based on three measurement parameters. The measurement parameters I will use are soil health, water infiltration, and yield. variety of outcomes. The outcomes I will look at are water infiltration, soil health, and yield. I will use a comparative analysis method to answer my question.

I will address the financial costs and benefits of transitioning California almond farms to regenerative practices, including production costs, cost of compliance, public and private investment, crop value, profits, ecosystem services, climate change resilience, and input costs. I will use a SWOT analysis to determine the financial costs and benefits of transitioning to regenerative agriculture.

I hypothesize that a transition to regenerative agriculture techniques in California almond orchards can improve revenues while decreasing environmental impact as the climate continues to change. I aim to provide recommendations on transitioning to regenerative agriculture that will provide net ecological and financial benefits for almond farmers in California. More broadly, I will also address how California can begin to widely adopt regenerative farming practices. I will use findings from economic and soil management analyses to determine whether and how regenerative agriculture should be implemented. I will review current policies and programs that interact with regenerative agriculture in California and provide recommendations for future policies and initiatives.

Sub-question 1

What soil management practices are important to improve climate change resilience for California almonds?

Literature Review

<u>Conventional Farming Methods</u>

Tillage

Tilling uses mechanics to prepare soil for agriculture through digging, stirring, or overturning. Tilling is performed to control weeds and pests in the soil and to get it ready for seeding, and is a method in conventional farming that has historically been used due to its short-term benefits and efficiency. Some benefits of tilling soil are aeration, weed/pest prevention, drainage, and providing the ability to mix materials into the soil (Lal, 1991). However, tilling can have serious long-term negative effects on soil health. Tilling can increase the susceptibility of soil to erosion, which decreases water infiltration and increases runoff (Van Oost et al., 2006).

When turning the soil, tilling releases carbon dioxide into the atmosphere that was previously stored in the soil (Mehra et al., 2018). Conventional tilling also disrupts soil organic matter and microorganism abundance and diversity (Simon, 2009). Disturbing microbes in the soil negatively impacts the health of the soil—increased vulnerability to erosion and decreased carbon and nutrient content lead to agriculturally unproductive soil (Srour et al., 2020). When soil becomes less productive, inputs are used to promote crop production.

Inputs

Conventional farming utilizes inputs such as fertilizers, pesticides, and herbicides to maximize crop yield. While these inputs allow for crops to grow optimally for production, they can have long-term impacts on the environment and human health (Tudi et al., 2021). Fertilizers and pesticides contribute to air pollution (Tudi et al., 2021). These inputs also enter water bodies through runoff, harming both humans and other organisms. Groundwater can be contaminated with nitrate from fertilizers, which enters our drinking water and can cause health issues, such as immobilizing hemoglobin in the blood (Sharma and Singhvi, 2017). Fertilizer runoff also impacts bodies of water through nutrient pollution, causing harmful algal blooms and dead zones (Chakraborty, 2017). Synthetic nitrogen and phosphorus fertilizers cause global nutrient imbalances, alter water quality, and contribute to greenhouse gas emissions (Lu and Tian, 2017).

Pesticides use chemical ingredients to kill and control pests and vegetation. These ingredients can be toxic to other organisms and the environment. Once pesticides are applied, they can transfer or degrade, causing them to remain in the environment for a long time (Tudi et al., 2021). In sum, pesticides have negative impacts on the environment, including on water, soil, air, food safety, and non-target organisms (Tudi et al., 2021). The consequences of pesticide use include biodiversity loss, pollution, human health risks, resistance, non-target species harm, and soil degradation.

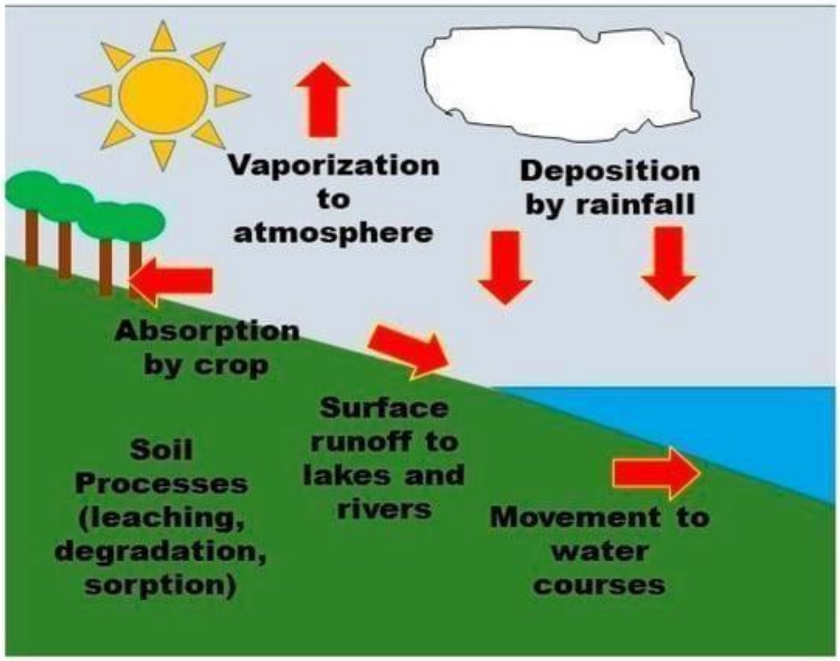

Figure 1. Pesticide behavior in the natural environment (Tudi et al., 2021).

Monoculture

Monoculture is the practice of cultivating only one crop over a large landscape. In this practice, there is no rotation with other crops and the same plant is grown continuously throughout seasons (Salaheen & Biswas, 2019). This practice became widespread in the United States as mechanization expanded with the invention of the steam engine and steel plow in the 19th century (Power & Follett, 1987). While monoculture has many logistical and economic advantages for farmers, it also has serious long-term consequences for the environment and agriculture. Monoculture is a clear danger to biodiversity, food security, and sustainability (Grant, 2007). Monoculture leads to reduced biodiversity by making it difficult for plants, animals, and pollinators to have a supportive habitat. Monoculture also leads to soil degradation and increased input use (Salaheen & Biswas, 2019)..

Conventional farming soil management practices tend to depend on each other. These practices are harmful to the land and particularly to the soil. Conventional farming practices strip life from the soil and lead to a loss of topsoil. Topsoil is the upper layer of the soil that contains the most organic matter, nutrients, and microbial activity in the soil. If current rates of degradation continue, all of the world's topsoil could be gone in 60 years (Leslie, 2015).

Regenerative Agriculture Farming Methods

Compost

Compost uses organic matter as a tool for soil health. Composting decomposes organic solid waste (Diwan et al., 2021). Organic material can be recycled to make natural fertilizer that is healthy for crops. The product is soil with higher biodiversity and microbial biomass (Aguilar-Parades, 2023). Compost fertilizer is advantageous compared to synthetic fertilizers because it allows nutrients to be available in plants for longer (Diwan et al., 2021). While conventional fertilizer supplies crops with nutrients, composting supplies these nutrients for longer periods, while also improving soil structure and health. Compost increases soil biodiversity (Aguilar-Parades, 2023). Soil microorganisms regulate ecosystem services. These ecosystem services include the control of organic matter decomposition, nutrient cycling, pathogen control, pollutant degradation, and greenhouse gas reduction (Aguilar-Parades, 2023). Composting increases soil microorganisms, allowing for the implementation of these ecosystem services.

Cover Crops

Regenerative agriculture implements the use of cover crops, which includes planting plants that are not the primary crop in the area. This is done to improve soil health. Cover crops are used between the primary crop seasons and can be temporary and/or rotated. Cover crops can bring many benefits, such as decreasing erosion, increasing the carbon content of the soil, and reducing nitrogen runoff (Smith, 2008). Cover crops can also help the main crop by reducing weed pressure, improving soil structure and water infiltration, and decreasing water runoff (Hartwig and Ammon, 2002). However, cover crops do use additional water. Cover crops are beneficial when their management is intended for increased infiltration or decreased evaporation. Cover crops can have negative effects if they reduce water availability for the other crop (Unger and Vigil, 1998). Soils with cover crops have higher organic carbon and light fraction contents when treated both with and without fertilizer (Ding et al., 2006). Both organic carbon and light fraction are indicators of healthy and productive soil. Higher soil organic carbon helps control water, temperature, aeration, and structure in the soil organic carbon cycle (Reicosky and Forcella, 1998). Cover crops increase water infiltration and reduce soil erosion in both conventionally tilled and no-tilled agricultural systems (Dabney, 1998). Cover crops can provide available nitrogen through symbiotic fixation, leaving both environmental and economic benefits (Reicosky and Forcella, 1998). Cover crops can be an additional cost but their environmental benefits such as increased soil organic carbon and nitrogen, can allow them to be cost-effective.

Animal Integration

Another aspect of regenerative agriculture is bringing animals into the crops. While integrated crop-livestock systems have been used for thousands of years, most modern North American farmers ceased to use this practice in the past century (Russelle et al., 2007). Livestock are rotated through the crops to graze, which defoliates plants at an even rate, encouraging regrowth after recovery periods (Morris, 2021). The hoof action provided by the animals is important for regenerating soils and providing ecosystem services (Morris, 2021). Soils that have been regeneratively grazed have biodiversity benefits, including greater microbial activity, increased fungal-to-bacteria biomass, and more functional diversity (Morris, 2021). Agricultural systems that incorporate animals can enhance soil fertility, tilth, and carbon sequestration through the utilization of animal manure (Russelle et al., 2007). Animal integration can also help to diversify cropping systems through perennial forage crops, which can bring multiple environmental benefits (Russelle et al., 2007). Adopting integrated crop-livestock systems would not only improve the environmental sustainability but also the profitability of farms (Russelle et al., 2007). Common livestock used for grazing include cattle, sheep, and horses. Regenerative grazing can provide ecosystem services that bring both ecological and economic benefits to farms (Spratt et al., 2021). These ecosystem services include carbon sequestration, nutrient and soil retention, nutrient cycling, habitat and biodiversity, and infiltration and water retention.

Reduced Inputs

No-to-low external inputs are a key characteristic of regenerative agriculture (Voisin et al., 2023). Inputs that are used in conventional agriculture, such as pesticides, herbicides, and synthetic fertilizers, are not used in regenerative agriculture. Instead, regenerative agriculture brings organic matter into the soil through compost (see above). Using food waste as agricultural inputs can utilize nutrient recycling and increase sustainability (Voisin et al., 2023). Additionally, yield volumes of regenerative agriculture are often profitable due to input savings (Voisin et al., 2023).

Table 1 displays the difference in practices between conventional, organic, and regenerative agriculture. Regenerative agriculture differs from organic by using additional practices, rather than just reducing inputs such as pesticides. Organic agriculture does not use harmful inputs like pesticides herbicides, and synthetic fertilizers, but uses other conventional techniques like tilling and monoculture. Typical organic agriculture does not use regenerative practices like compost, animal integration, and cover crops.

Table 1. Typical farming practices of different farming styles.

Farming Practice	**Conventional**	**Organic**	**Regenerative**
Tilling	Yes	Yes	No
Pesticides	Yes	No	No
Synthetic Fertilizer	Yes	No	No
Monoculture	Yes	Yes	No
Compost	No	No	Yes
Animal integration	No	No	Yes
Cover Crops	No	No	Yes

Orchard Recycling

Whole-orchard recycling is a soil management practice specific to almonds and will also be a focal point of my analysis. Whole orchard recycling refers to recycling tree biomass in place before replanting an orchard (Jahanzad et al., 2020). Orchard recycling can improve soil functioning, increase carbon sequestration, and increase irrigation water use efficiency by 20% (Jahanzad et al., 2020). The practice is done by grinding whole orchard trees and incorporating them into the soil. A significant potential benefit of this whole orchard recycling is increasing soil organic carbon (SOC). Maintaining a relatively high SOC has many benefits for soil, such as providing and cycling nutrients, protection from pests and pathogens, water conservation, and reduced soil erosion (Jahanzad et al., 2020). The benefits of SOC increase soil adaptation to harsh climatic conditions (Jahanzad et al., 2020). Additionally, increased SOC sequesters carbon from the atmosphere, which decreases the impact of anthropogenic emissions

California almonds use a perennial cropping system, which typically has low SOC and is particularly susceptible to climate change (Jahanzad et al., 2020). The impacts of climate change that affect California almonds include reduced water availability, increased extreme weather events, and reduced winter chill hours (Jahanzad et al., 2020). A recent study tested the ability of whole-orchard recycling in a productive almond orchard compared to the burn treatment, which uproots and burns the trees and then adds the ashes to the soil, and found that whole-orchard recycling had significant potential to sequester carbon while improving yields and other ecosystem services (Jahanzad et al., 2020). However, the changes took years to accrue and came along with costs.

Nine years after establishment, the almond orchard trees that used whole orchard recycling significantly out-yielded trees that used the burn treatment by 19% (Jahanzad et al., 2020). The increased yield caused increased efficiency of irrigation water use (Jahanzad et al., 2020). The trees using whole orchard recycling also had higher soil organic matter (SOM) and SOC content than the trees that used the burn treatment (Jahanzad et al., 2020). Additionally, the whole orchard recycling trees had significantly higher contents of total nitrogen (23%), manganese (33%), chloride (46%), and sodium (24%) compared to the trees using the burn treatment (Jahanzad et al., 2020). Whole orchard recycling incorporates woody biomass into the soil, which was shown to increase water retention and water infiltration in the soil of the trees using that method (Jahanzad et al., 2020). Microbial biomass carbon was increased by 28% in whole orchard recycling trees compared to burned trees (Jahanzad et al., 2020). The use of whole orchard recycling significantly increased the rates of soil respiration and ultimately increased the soil health index, and soil health improvements were positively correlated with the yield of almonds (Jahanzad et al., 2020).

To address the issue of water shortages, Jahanzad et al. (2020) tested changes in yield resistance and soil health parameters with a reduction in irrigation. Reduced irrigation caused decreased soil moisture in both whole orchard recycling trees and burned trees, but the reduction was greater in the burned trees. Additionally, the whole orchard recycled trees had higher soil water content when exposed to reduced irrigation (Jahanzad et al., 2020). Trees treated with the whole orchard recycling treatment were less water-stressed and better recovered from stress than the trees with the burn treatment (Jahanzad et al., 2020). Ultimately, the study found that whole orchard recycling can improve yields and lessen the impacts of reduced water on tree stress, while sequestering carbon from the atmosphere in the soil (Jahanzad et al., 2020).

Regenerative vs conventional almonds

Fenster et al. (2021) examined and compared soil health, biodiversity, and yield of regenerative and conventional almond systems. The regenerative agriculture practices that were applied included the reduction of synthetic chemicals, incorporation of cover crops, integration of livestock, and use of compost. The soil parameters that were measured include total soil carbon, soil organic matter, total soil nitrogen, total soil phosphorus, calcium, sulfur, and soil health. The measurements of all of these parameters were significantly larger in the regenerative soils compared to the conventional soils (Fenster et al., 2021). Infiltration of water was six times faster in the regenerative soils than in the conventional soils (Fenster et al., 2021). Both microbial and bacterial biomass were significantly greater in the regenerative almond soils (Fenster et al., 2021). The regenerative-grown almonds also led to increased biodiversity, including higher occurrences of invertebrates, earthworms, plant biomass, and larger overall species diversity (Fenster et al., 2021).

Comparative Analysis

I will be synthesizing and comparing the results of multiple studies regarding regenerative agriculture soil management practices. I will be using the studies to compare regenerative and conventional soil management practices and highlight their differences. Based on my literature review, I chose three soil management practices to highlight. I also chose three measurement parameters to use to display the different outcomes in soil management practices. I will use this analysis to draw conclusions about the soil management practices that have significant impacts on California almonds.

To assess the soil management practices for California almonds, I will focus on three different practices and their outcomes. I will measure and compare their outcomes based on various soil measurement parameters. The soil management practices I will investigate are:

- **Orchard recycling**
- **Cover crops**
- **Input reduction**

The measurement parameters I will use are:

- **Soil health (nutrient levels)**
- **Water infiltration**
- **Yield**

Orchard Recycling:

I downloaded the supplemental data from Jahanzad et al. (2020). I created graphs showing the average measurement between the burn and grind treatment for different parameters.

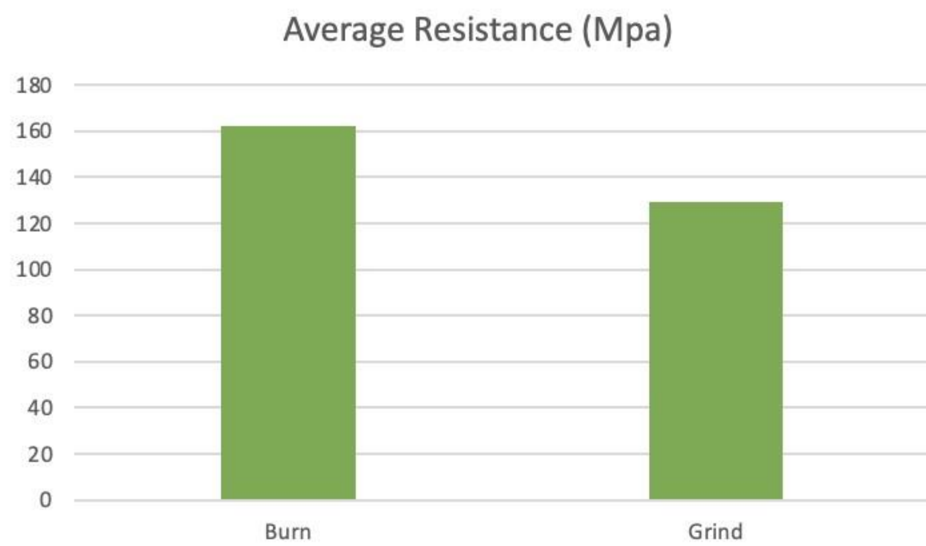

Figure 2. Average resistance (Mpa) in burn and grind treatments showing the soil compaction.

Resistance in the almond orchards was measured using a soil cone penetrometer (Jahanzad et al., 2020). The resistance represents the compaction of topsoil layers. As shown in Figure 2, the grind treatment had lower levels of soil compaction than the burn treatment did. The average level of soil compaction was 162.38 Mpa in the burn treatment vs 129.05 Mpa in the grind treatment. Lower levels of compaction are beneficial because they facilitate water infiltration, root growth, and water and nutrient retention (Jahanzad et al., 2020).

Figure 3. Average bulk density (measured in g/cm^3) of soil in burn and grind treatments showing soil compaction.

Samples of soil cores from both the grind and burn treatments were collected to measure bulk density (Jahanzad et al., 2020). As shown in Figure 3, bulk density of topsoil layers was reduced in the grind treatment, (average of 1.59 g/cm^3–, and slightly higher in the burn treatment (average of 1.64 g/cm^3). Bulk density is also an indicator of soil compaction. Bulk density is the ratio of the dried mass of soil to its total volume (Al-Shammary et al., 2018). Soil compaction has a large effect on agricultural productivity, and is a problem for crops as it reduces water infiltration and drainage (Al-Shammary et al., 2018). Jahanzad et al. (2020) found that bulk density trended negatively with yields. Thus, the lower the bulk density of the soil, the higher the yield of the almonds. Because the grind treatment had lower bulk density than the burn treatment, the grind treatment reduced bulk density and increased yield.

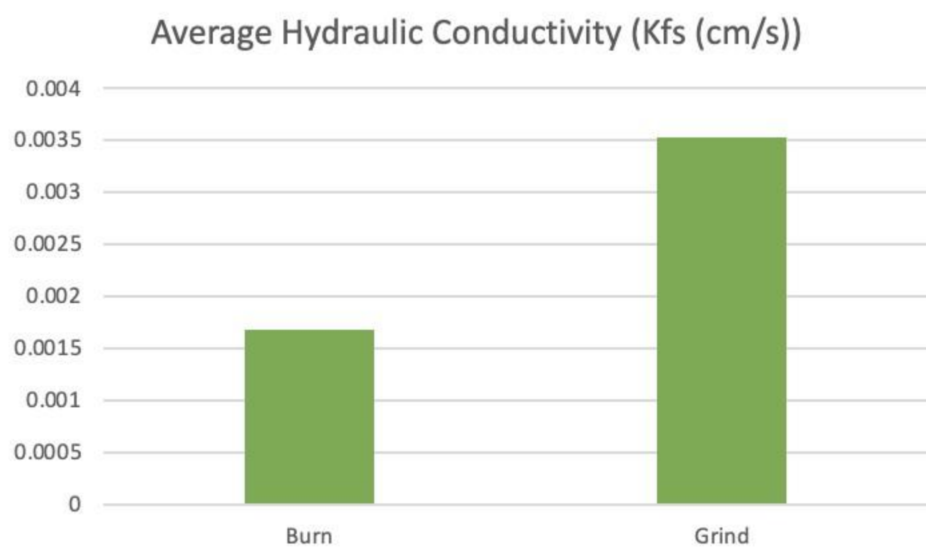

Figure 4. Average soil hydraulic conductivity in burn and grind treatments showing water infiltration.

The hydraulic properties of soil control water fluxes and storage (Jarvis et al., 2013). Soil-saturated hydraulic conductivity was measured to find the infiltration rate (Jahanzad et al., 2020). The hydraulic conductivity of surface soil at saturation is an important measurement because it is responsible for regulating the partitioning of precipitation (Jarvis et al., 2013). The hydraulic conductivity of almond orchards impacts trees and yields resistance to water shortages. This is important because it informs us about how almond orchards will respond to climate change. The average measured hydraulic activity was higher in the grind treatment compared to the burn treatment. As shown in Figure 4, The average hydraulic activity of the almond orchards treated with the grind treatment was 0.003533 Kfs (cm/s). The average hydraulic activity of the almond orchards treated with the burn treatment was 0.001681 Kfs (cms/s), which is less than half of that of the grind-treated orchards. Because hydraulic conductivity is a measurement of water infiltration, this means the grind-treated orchards had higher levels of water infiltration than burn-treated orchards. Soil water infiltration rates were observed to be negatively correlated with soil compaction (Jahanzad et al., 2020). As seen in Figure 2 and Figure 3, soil compaction was reduced in grind treatments. Additionally, infiltration rates were positively correlated with aggregation, as macroaggregate stability was seen to be a crucial element of the water movement in soil (Jahanzad et al., 2020). Increased water infiltration leads to the conservation of water. Water conservation reduces the amount of water farmers need, as it allows the crops to retain more water both from irrigation and precipitation. With better water retention, farmers could reduce irrigation frequency or postpone the start of irrigation (Jahanzad et al., 2020). If almond growers use whole-orchard recycling, they can increase water infiltration, therefore reducing water use.

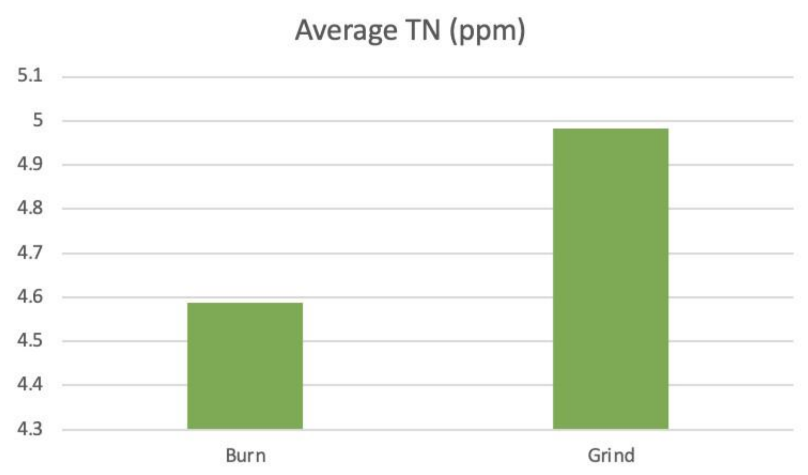

Figure 5. Average total nitrogen (measured in ppm) of burn and grind treatments.

Figure 5 displays that the average measurements of total nitrogen were much higher in the almond orchards treated with the grind treatment, compared to the orchards treated with the burn treatment. The almond orchards treated with the grind treatment had an average of 4.98 ppm, while the almond orchards treated with the burn treatment had an average of 4.59 ppm.

Increases in total nitrogen were strongly positively correlated with total soil carbon (Jahanzad et al., 2020). Orchards that were treated with whole-orchard recycling had higher soil total nitrogen which was correlated to increased microbial carbon cycling (Jahanzad et al., 2020).

Figure 6. Average total carbon (TC) stock (measured in t/ha) of burn and grind treatments at three different depths.

The product of soil carbon concentration, soil sample bulk density, and sampling depth were used to calculate soil carbon stock. Figure 6 shows that the average total carbon stock was higher in the grind treatment compared to the burn treatment at all three depths. The measurements of the burn and grind treatments were 13.72 t/ha vs 21.75 t/ha, 10.76 t/ha vs. 14.49 t/ha, and 4 t/ha vs. 6.97 t/ha at the three depths. The total carbon stock represents the amount of carbon that is stored in the soil. The almond orchards that used whole orchard recycling stored more carbon than those that used the burn treatment. The study measured carbon storage over nine years and found that the practice of whole orchard recycling provided carbon storage services that surpassed the 4 parts per thousand international targets of mitigating anthropogenic atmospheric carbon concentrations (Jahanzad et al., 2020).

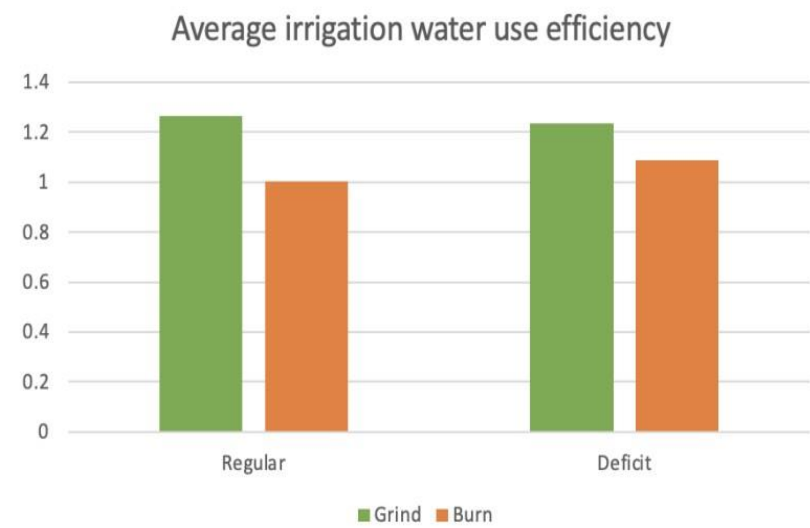

Figure 7. Average irrigation water use efficiency of grind and burn treatments in both regular and deficit water conditions.

To quantify shifts in tree water status and resilience, a deficit irrigation trial was conducted with a control irrigation and a deficit irrigation of reduced 20% (Jahanzad et al., 2020). The results can show us how differently managed almond orchards would respond to water shortages, which is a threat from climate change. Irrigation water use efficiency was calculated using kernel yield divided by the volume of irrigation water (Jahanzad et al., 2020). As shown in Figure 7, the almond orchards that used whole orchard recycling had higher irrigation water use efficiency in both the regular and deficit water conditions compared to the orchards using the burn treatment. Under the regular water conditions, the grind treatment had an average irrigation water use efficiency of 1.27, while the burn treatment had an average of 1.00. Under the deficit water conditions, the grind treatment had an average irrigation water use efficiency of 1.24, while the burn treatment had an average of 1.09. There was a measured 20% increase in irrigation water use efficiency when using whole orchard recycling (Jahanzad et al., 2020). Whole orchard recycling can be used to provide almond orchards with resilience to decreased water supplies.

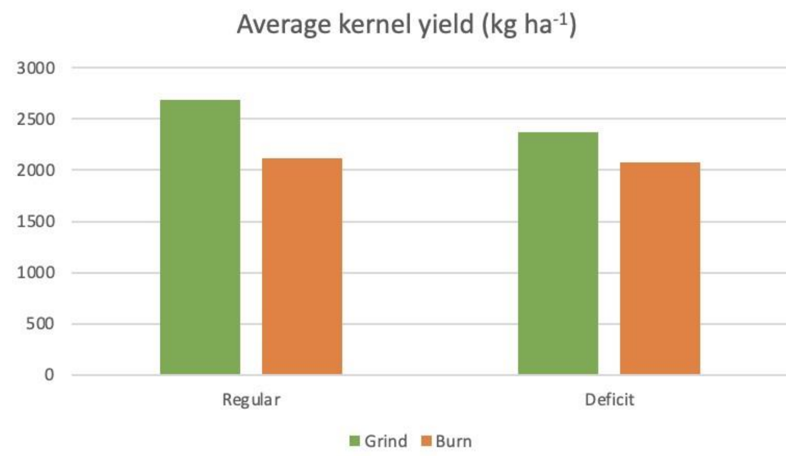

Figure 8. Average kernel yield (measured in ka ha^{-1}) between grind and burn treatments under regular and deficit water conditions.

Average kernel yields were higher in the almond orchards treated with the grind treatment compared to the almond orchards treated with the burn treatment in both regular and deficit water conditions, as shown in Figure 8. In regular water conditions, the whole recycled orchards had an average of 2681.7 ka ha^{-1} compared to that of 2118.2 ka ha^{-1} in the burn treatment. In deficit water conditions, the whole orchard recycled orchards had an average of 2365.5 ka ha^{-1} compared to that of 2072.8 ka ha^{-1} in the burn treatment. These experiments demonstrate that almond orchards that implement whole-orchard recycling can produce larger yields. It also shows that if water supplies were to diminish, which is already occurring due to increasing population and human consumption, orchards using whole-orchard recycling would still produce larger yields. With climate change posing the threat of changed precipitation patterns, resistance to water supply is important for a crop's resilience. Whole orchard recycling not only improves the crop but also the revenue of the farm, because increased yield leads to increased revenue.

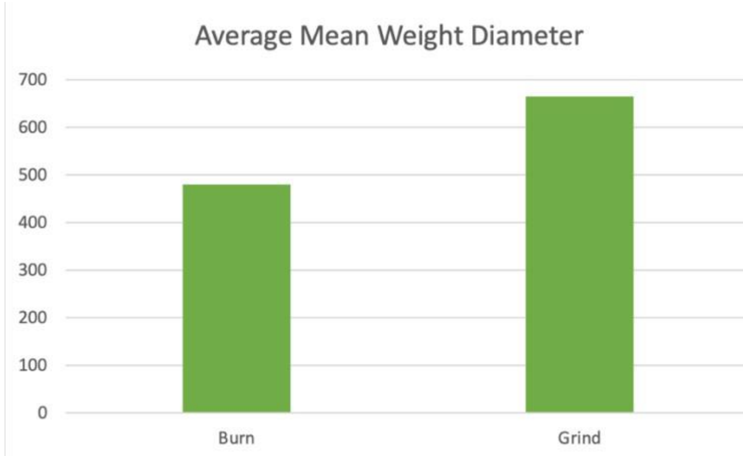

Figure 9. Average mean weight diameter of burn and grind treatments in almond orchards.

The mean weight diameter is a weighted average index of aggregate stability (Jahanzad et al., 2020). Aggregate stability refers to the aggregate's resistance to physical stresses and is an important factor in soil fertility and environmental issues because it determines soil sensitivity to crusting and erosion, germination and rooting, and carbon storage ability (Abiven et al., 2009). With increased resistance to physical stresses, increased aggregate stability will improve a crop's resilience to climate change and the changes it brings. As displayed in Figure 9, the almond orchards treated with the grind treatment had significantly higher measurements of average mean weight diameter than the almond orchards treated with the burn treatment. The average mean weight diameter of the grind-treated orchards was 663.97 µm, compared to that of 480.02 µm in the burn-treated orchards. Increased mean weight diameter in the whole orchard recycling orchards implies higher aggregate stability in those orchards. The orchards implementing whole orchard recycling will have better resistance to physical stresses, therefore having increased resilience to climate change.

Leaf nutrients:

There are 17 elements required for plant growth and development (Yahaya et al., 2023). Of those 17 elements, nine of them are macronutrients that are needed in large amounts. Those macronutrients include nitrogen (N), phosphorus (P), potassium (K), carbon (C), oxygen (O), hydrogen (H) Calcium (Ca) magnesium (Mg), and sulfur (S). The eight other elements are micronutrients that are needed in small amounts. Those micronutrients include zinc (Zn), chlorine (Cl), manganese (Mn), iron (Fe), copper (Cu), boron (B), molybdenum (Mo), and nickel (Ni) (Yahaya et al., 2023). Carbon, hydrogen, and oxygen are acquired through the atmosphere and soil water, while the other 14 elements come from soil minerals, fertilizers (both organic and inorganic), and soil organic matter (Yahaya et al., 2023). The Jahanzad et al., 2020 whole orchard recycling study tested 13 of those 14 leaf nutrients in the grind and burn treatments, with the exception being molybdenum (Mo). Eight of the elements were found in higher amounts in the grind treatment and 5 of the elements were found in higher amounts in the burn treatment.

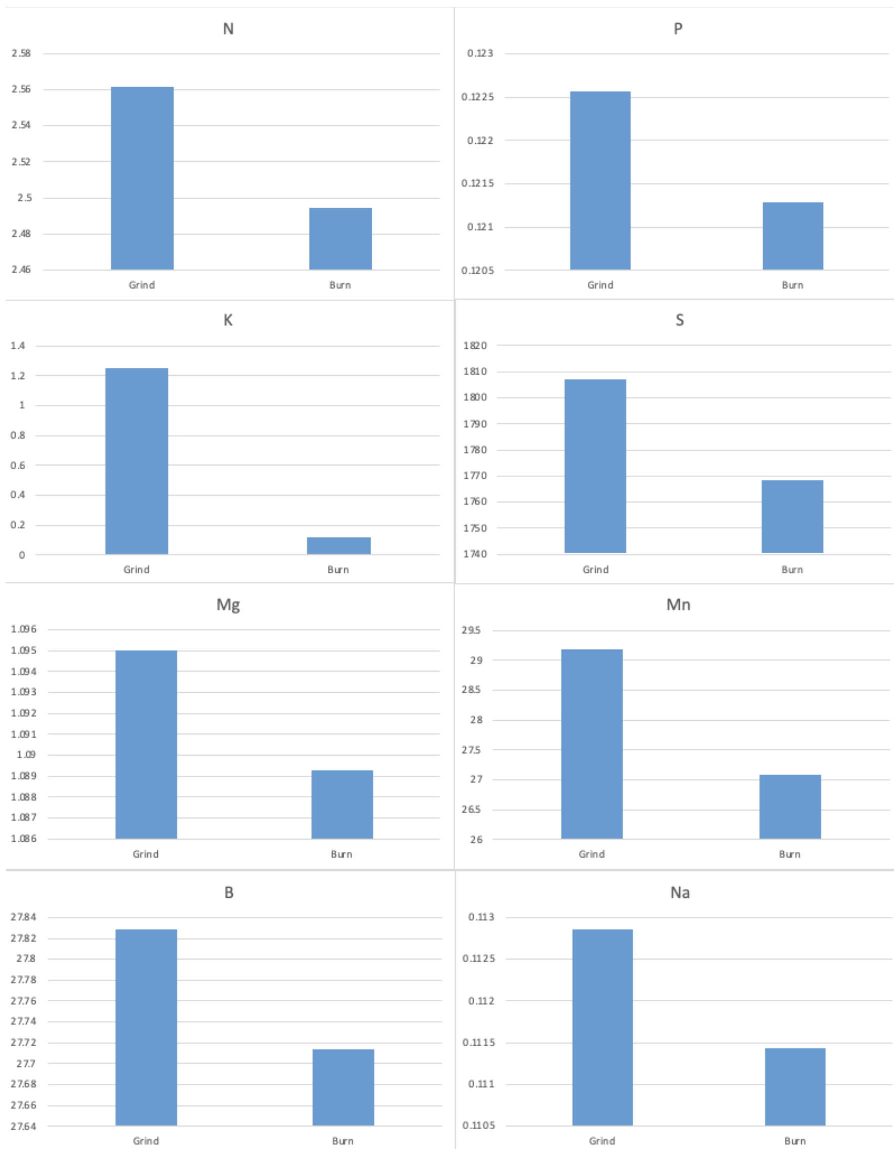

Figure 10. Average nutrient measurements that were higher in grind treatments compared to burn treatments of almond orchards.

Figure 10 displays the nutrients that had larger measurements in the grid-treated orchards. Nutrients that had higher average measurements in the grind-treated almond orchards than in the burn-treated almond orchards include nitrogen, phosphorus, potassium, sulfur, boron, magnesium, manganese, and sodium.

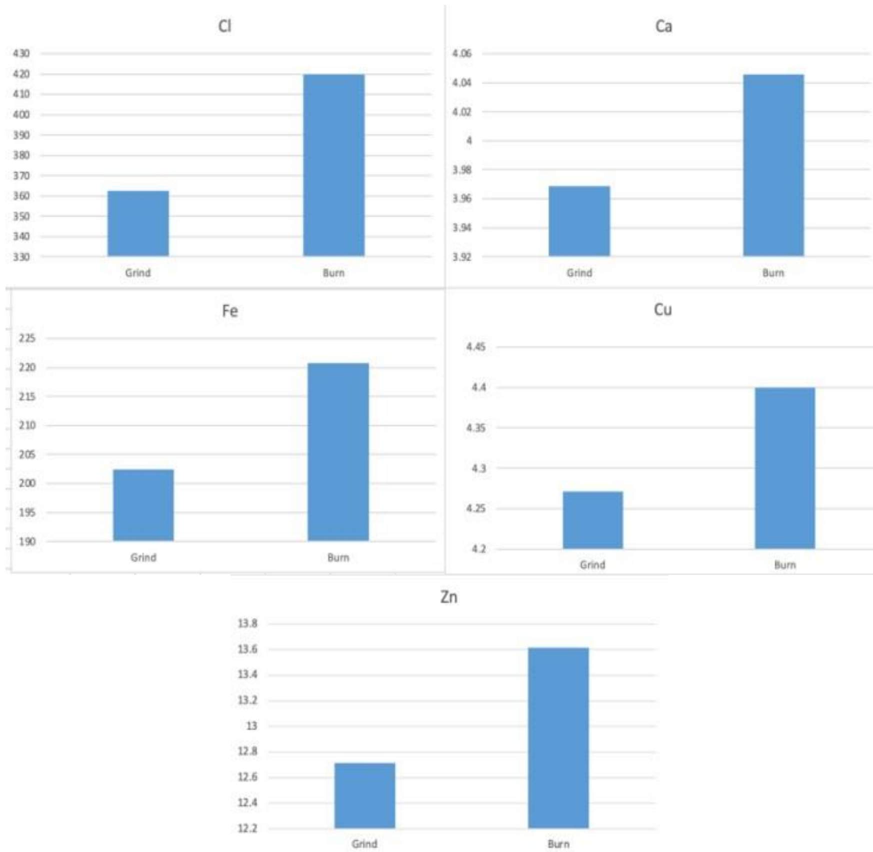

Figure 11. Average nutrient measurements that were higher in burn treatments of almond orchards compared to grind treatments.

Figure 11 displays the nutrients that had higher average measurements in the burn-treated almond orchards than in the grind-treated almond orchards. These nutrients include chlorine, calcium, iron, copper, and zinc. Fertilizers are needed to provide nitrogen, phosphorus, and potassium to soils (Yahaya et al., 2023). Nitrogen is considered the most important nutrient for plants, then phosphorus, then potassium. These three nutrients are used through all stages of plants' life cycles and are referred to as the "building blocks of all living organisms" (Yahaya et al., 2023). Nitrogen, phosphorus, and potassium levels were all higher in the almond orchards that used whole orchard recycling than they were in the almond orchards that used the burn treatment. Sulfur, boron, magnesium, manganese, and sodium were also higher in the whole orchard recycled orchards, showing that those orchards had increased levels of essential nutrients.

However, five nutrients were lower in the whole orchard recycled almond orchards. Chlorine, calcium, iron, copper, and zinc were all found in higher amounts, on average, in the orchards treated with the burn treatment.

Regenerative soil management practices have been shown to have significant effects on the outcomes of almond orchards. While being regenerative means following a set of practices, not every regenerative practice has to be implemented to see results. Fenster et al. (2021) created a scoring system to distinguish regenerative farms based on farm operations and regenerative goals (Fenster et al., 2021). The response variables that they tested were soil carbon and organic matter, soil micronutrients, water infiltration rates, soil microbial communities, plant community structure, invertebrate community structure, pest populations, yields, and profit (Fenster et al., 2021). They found that the regenerative outcomes were strongly correlated with their regenerative farm scoring system (Fenster et al., 2021). This shows that even if every regenerative practice is not implemented, some regenerative practices are better than none for achieving desired outcomes. These desired outcomes benefit the farms ecologically and economically, therefore increasing the farms' resilience to climate change. Figure 12 displays the outcomes on different measurements between the conventional and regenerative almond orchards.

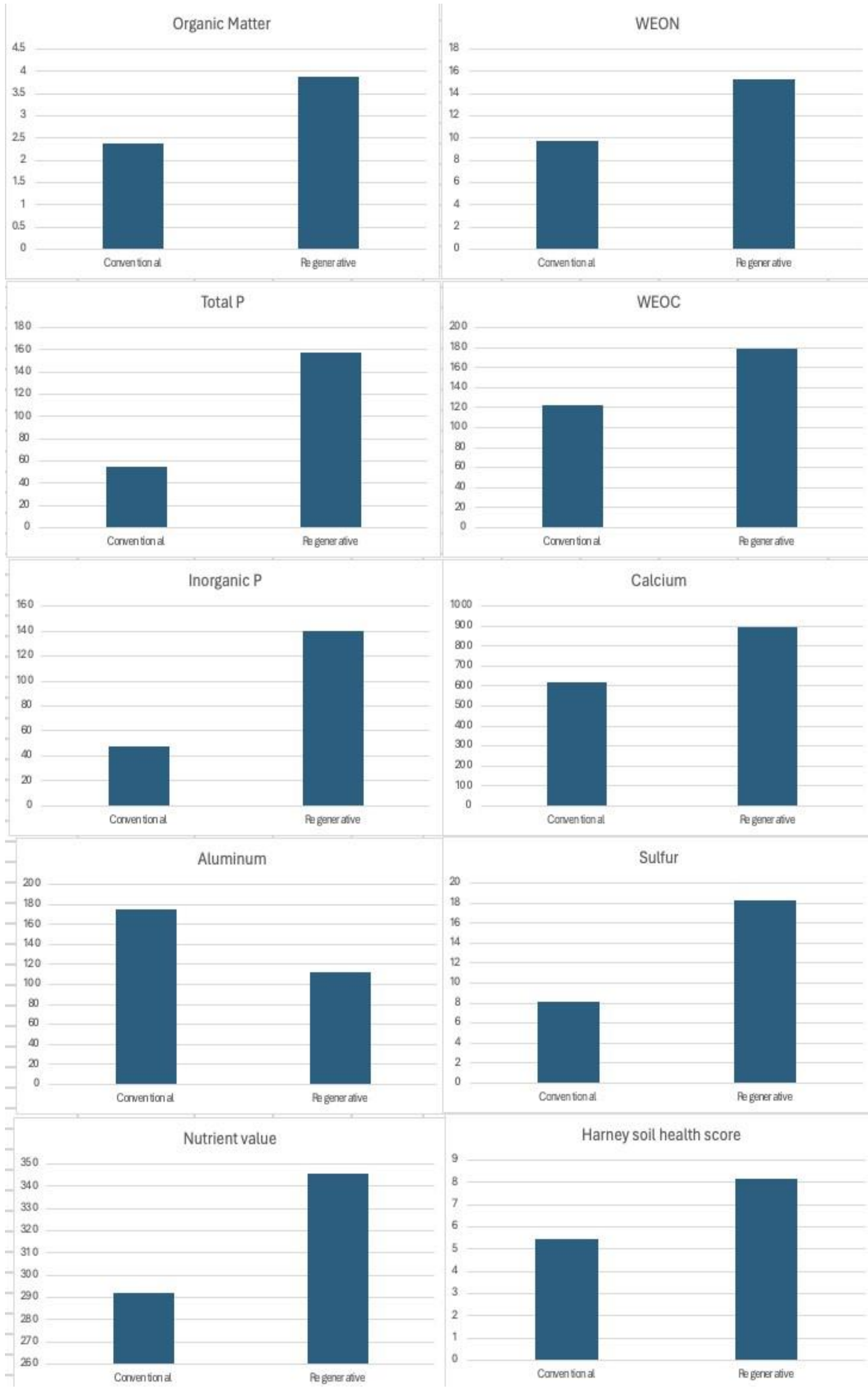

Figure 12. Graphs based on the data from Fenster et al. (2021).

Sub-Question 2

What are the financial costs and benefits of transitioning to regenerative agriculture?

Literature Review

Along with the ecological benefits of regenerative agriculture, these farming techniques have economic benefits as well. The financial benefits are gained from both increased crop revenue and ecosystem services (LaCanne and Lundgren, 2018). Soil erosion and water depletion cost $37 billion in the United States annually and 96% of that cost is from food production (Hawken, 2017).

In addition to ecological outcomes, Fenster et al. (2021) examined yield and profit, comparing regenerative and conventional almond orchards. While there was not a significant difference in yield between the orchards, the regenerative orchards were about twice as profitable as the conventional orchards, as shown in Figure 13 (Fenster et al., 2021).

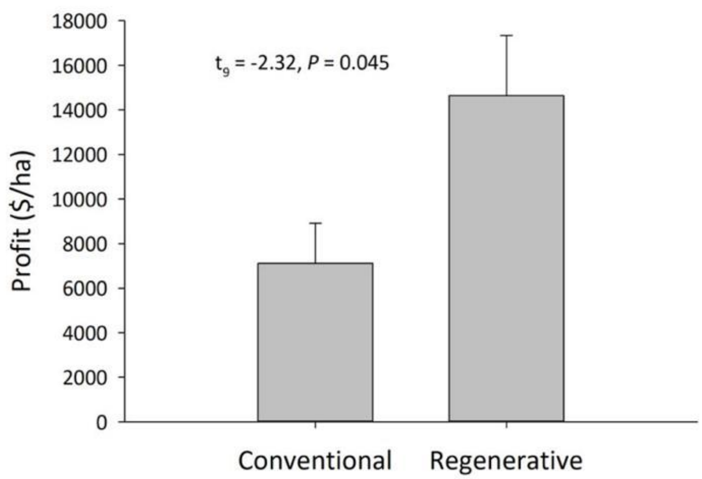

Figure 13. Net profitability of conventional and regenerative almond orchards (Fenster et al., 2021).

The profitability was determined by management practices, costs, and revenues of the regenerative and conventional almond production operations. Operating costs include:

Table 2. Costs associated with agricultural practices.

Costs associated with winter sanitation
Sampling for tree nutrient status and soil salinity, pH, and nutrient levels
Irrigation and frost protection
Fertilizers, insecticides, herbicides, fungicides, disease treatment sprays
Trapping vertebrate pests
Cover crop seeds
Tillage
Mowing
Flamers
Grazers
Harvest
Hourly labor to conduct harvest
Additional revenue streams (co-products such as almond butter)

In the Fenster et al. (2021) study, only regenerative orchards sold value-added products (almond butter), which contributed to their increased profitability. Even when not including the profits from value-added products, regenerative orchards were still almost twice as profitable as conventional orchard, shown in Figure 13. The profitability of the regenerative almond orchards was higher than the conventional orchards, despite their operating costs being higher ($3,402 +/- 425 per ha vs $2,494 +/- 90.32 per ha) (Fenster et al., 2021). Additionally, the gross revenue of the regenerative almond orchards was about 190% of that of the conventional almond orchards in the study ($18,178 +/- 3,033 per ha vs $9,587 +/- 1,851 per ha) (Fenster et al., 2021).

Table 3. Yield, profits, costs, and revenues of conventional and regenerative almond orchards (Fenster et al., 2021).

	Conventional	Regenerative
Yield	1,920 ± 315 kg/ha	1,338 ± 248 kg/ha
Profitability (including value added products)	N/A	$6,093 ± 1,155 per ac
Profitability (not including value added products)	$2,877 ± 733 per ac	$5,299 ± 1,090 per ac
Operating costs	$2,494 ± 90.32 per ha	$3,402 ± 425 per ha
Gross revenue	$9,587 ± 1,851 per ha	$18,178 ± 3,033 per ha

The regenerative almond orchards in this study had a higher gross revenue due to the premium paid for regenerative almonds (Fenster et al., 2021). To supplement the quantitive data that I analyzed from Fenster et al. (2021), I interviewed a local almond butter producer, Sam Richardson, owner of Sam's Adventure Snacks in San Francisco. Sam uses regeneratively grown almonds to maximize the product quality. Sam shared the current economic struggles of conventionally farmed almond orchards. Sam stressed the importance of the opportunity to charge a premium for the product (Richardson, 2024). The regenerative almond orchards studied by Fenster et al. (2021) were all certified organic, meaning they could charge the organic premium in the wholesale market.

A similar study was conducted on cornfields in the Northern Plains of the United States. LaCanne and Lundgen (2018) investigated regenerative and conventional corn production systems. They evaluated the different outcomes of the two farming techniques. While they analyzed ecological factors such as pest management and soil conservation, they also looked at farmer profitability and productivity (LaCanne and Lundgren, 2018). Their results showed that the fields incorporating regenerative practices were 78% more profitable, even though they produced 29% less corn (LaCanne and Lundgren, 2018). The reason for the difference in profitability between the regenerative and conventional systems was the costs of seeds and fertilizers that the conventional farms required, as well as the increased revenue from regenerative products (LaCanne and Lundgren, 2018). As shown in Figure 14, Inputs such as seeds and fertilizers accounted for 32% of the gross income on the conventional cornfields, while these costs only accounted for 12% of the gross income on the regenerative cornfields (LaCanne and Lundgren, 2018). The regenerative cornfields were able to reduce these costs by not tilling, using cover crops, and implementing livestock grazing (LaCanne and Lundgren, 2018). Similar to Fenster et al. (2021), the regenerative systems were able to increase profits with an organic premium.

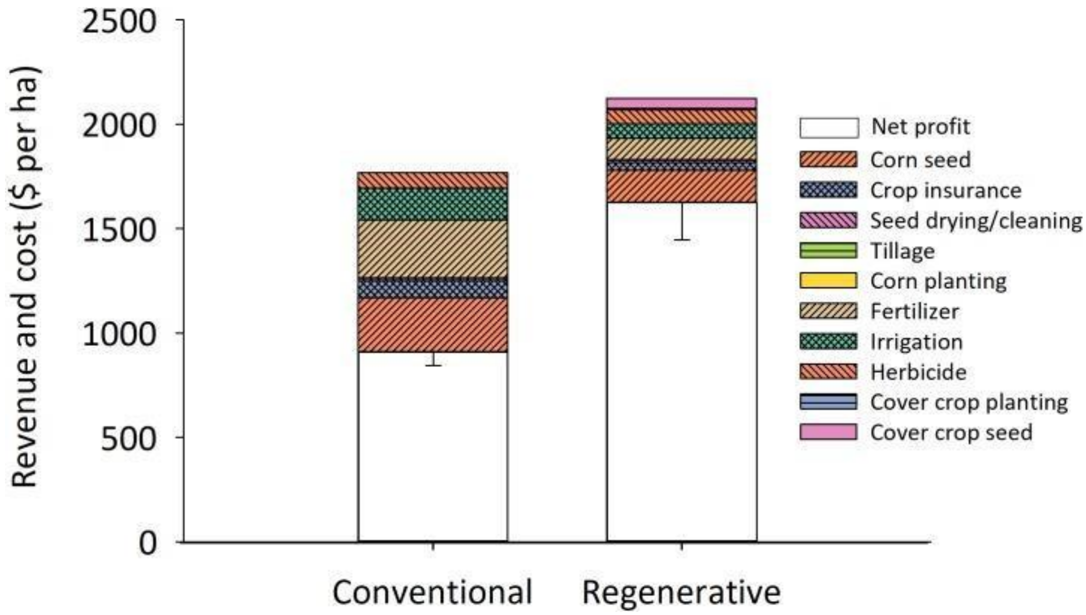

Figure 14. Revenue and costs of conventional vs regenerative corn fields (figure from LaCanne and Lundgren, 2018).

LaCanne and Lundgren (2018) found that the increased financial gain from regenerative systems is dependent on two main factors. They found that regenerative practices supported organic matter and biodiversity in the cornfields, leading to decreased costs for inputs and pest management. Additionally, they found that soil organic matter had a greater positive correlation with farm profitability than yield did (LaCanne and Lundgren, 2018). Regenerative farms had a higher profitability despite their lower yields partly due to marketing techniques and the diversification of income (LaCanne and Lundgren, 2018).

The UC Davis Department of Agricultural and Resource Economics released a study that presents sample costs to establish an almond orchard and produce almonds in the San Joaquin Valley. To establish an almond orchard, the costs are broken down by operations in various categories. Those categories include pre-plant costs, planting costs, cultural costs, harvest costs, operating costs, cash overhead costs, and non-cash overhead costs. Income from production is included to find the net cash costs, the profit above cash costs, the total net cost, the net profit, and ultimately the total accumulated net cost per acre of almond orchard. To produce almonds, total cultural costs, total harvest costs, total operating costs, total cash overhead costs, total cash costs, and total non-cash overhead costs are used to find the total cost per acre of almond orchard. When looking at the operating sample costs to produce almonds, the harvest costs seem to be factors that would remain the same between conventional and regenerative almond orchards. The harvesting costs include the costs of shaking trees, hand poling nuts, sweeping/windrowing/blowing/raking nuts, picking up nuts, and hulling and shelling nuts. These acts would have to be done regardless of whether the orchard was conventional or regenerative. However, the cultural costs section is where we can decipher differences in the costs of producing conventional and regenerative almonds. Within the cultural section, the operations are broken down into categories including pruning, pollination, pests, irrigation, weeds, fertilizer, and winter sanitation. Table 4 breaks down the typical farming costs of conventional agriculture. and Table 5 breaks down the typical farming costs of regenerative agriculture.

Table 4. Costs of conventional agriculture.

Fertilizers
Herbicides
Pesticides
Tilling machines

Table 5. Costs of regenerative agriculture.

Seeds for cover crops
Tools for cover crops
Compost storage
Grazing animals

Conventionally grown almonds are not as profitable as they once were (Richardson, 2024). There was a large boom in almond demand and the almond acreage increased greatly, peaking in 2013 (Nishikawa, 2016). Due to this rise in popularity, many farmers started growing almonds. However, almonds are a relatively expensive crop to produce. Currently, the cost of conventionally grown almonds is not high enough to make them profitable due to the massive surplus in almond supply (Richardson, 2024). Growing regenerative almonds would be a way to increase revenues by changing the value of the crop. Customers might pay more for regeneratively grown almonds, allowing farmers to make a profit after the expenses of growing the almonds.

Since regenerative agriculture is a relatively new idea in industrial-scale agriculture, there is not a huge interest or demand from consumers (Richardson, 2024). In coming years, there is a possibility for a significant growing interest in regenerative agriculture and more consumers could want to buy regeneratively grown products. It takes multiple years to grow and harvest almonds and other specialty crops. It would be ideal to invest in transitioning to regenerative agriculture now so the crops can be ready to harvest and produced by the time the demand for regeneratively grown products is higher (Richardson, 2024). It is important to invest in regenerative agriculture now, to remain profitable down the line.

SWOT Analysis

Based on my literature review on the financial costs and benefits of regenerative agriculture, I will perform a SWOT analysis to highlight the strengths, weaknesses, opportunities, and threats of regenerative agriculture. The strengths represent ways regenerative agriculture is financially superior to conventional agriculture. The weaknesses show how regenerative agriculture may fall short financially compared to conventional agriculture. The opportunities show potential ways regenerative agriculture can be financially beneficial. The threats represent factors that could be detrimental to the financial outcomes of regenerative agriculture.

Table 6. SWOT analysis of the finances of regenerative agriculture.

Strengths	**Weaknesses**
Charging a premium	Costs of making transition
Reduced costs of inputs	Initial decreases in crop yields
Increased ecosystem services	

Opportunities	Threats
Increased interest in regenerative agriculture Resilience to changing climate Diversification of income stream	Lack of current education surrounding regenerative agriculture

Strengths

A financial strength of regenerative agriculture is that regeneratively produced crops can charge a premium for the way they are grown. Regeneratively grown products can be sold for a higher price than conventionally grown products. The premium that is paid for regeneratively grown products is like that of organically grown products. Consumers will pay more for these products due to them being of higher quality and not containing harmful inputs. As discussed in the literature review, the largest financial gain from regenerative agriculture comes from the higher prices that are paid for the products. Almonds can especially use this advantage due to the surplus of conventionally grown almonds. The premium paid for regenerative almonds can bring in significantly greater revenue than that of conventionally grown almonds.

Another financial strength of regenerative agriculture is the reduced costs of inputs. As displayed in the literature review, the biggest financial saving of regenerative agriculture was the reduced cost of inputs such as pesticides, herbicides, and fertilizer. Regenerative farms do not have to spend money on these products, as their other practices provide ecosystem services in place of these inputs' benefits. Not purchasing these inputs allows regenerative farms to save money.

Lastly, regenerative agriculture can provide ecosystem services that would otherwise cost money, making that another financial strength. For example, regenerative agriculture promotes soil health, conserves water, and increases biodiversity. For conventional farms to achieve these benefits, they would need to spend additional money. Table 4 shows conventional farming costs that could be saved with regenerative agriculture.

Weaknesses

A financial weakness of regenerative agriculture is the cost of making the transition from conventional farming practices to regenerative farming practices. Making changes to farming techniques requires an investment. Some costs that come along with the transition to regenerative agriculture include the implementation of cover crops, the animals for grazing, and the necessary equipment for compost. Table 5 displays costs for regenerative agriculture that are not included in the costs of conventional agriculture. Transitioning to regenerative agriculture comes with additional costs in order to implement the new practices. Farms that do not have the extra finances to make these purchases might be held back from making transitions. Fortunately, there are programs, incentives, and grants (discussed in the next section) that can provide aid in this issue.

Another financial weakness is the potential initial decrease in crop yields. As shown through the studies discussed in the literature review, regenerative plots showed similar, if not reduced yield compared to their conventional counterparts. This can be negative for farmers because it could reduce the amount of the crop they have to sell, therefore reducing profits. However, the observed reduced yields did not have a negative effect on the regenerative crops. Even with the reduced yields, regenerative crops outperformed conventional ones in profitability. While initial decreases in yield might cause a period of reduced income, regenerative crops will ultimately be more profitable.

Opportunities

A financial opportunity for regenerative agriculture is the potential increased interest in regenerative agriculture and products. While it is a relatively new term, regenerative agriculture has grown in the past decade (Silva et al., 2022). There is growing interest in what it means and how to buy regenerative products. Sam Richardson, an almond butter producer that I interviewed, suggested that the demand for regeneratively produced products will boom within the next 5-10 years. If almond orchards invest in regenerative agriculture now, their farms will likely be profitable if the demand for regenerative products grows.

Another financial opportunity that regenerative agriculture can provide is increased resiliency to climate change. Regenerative agriculture can improve the nutrient levels, soil health, and water retention of almonds. These ecological improvements can protect the crop from intensified weather, increased temperatures, and drought. If the crop is more resilient to its environment, it reduces the costs of having to fix the potential damage. Comparisons of regenerative to conventional almond orchards found that this style of farming can help to keep farms resilient and profitable amid climate change (Fenster et al., 2021).

Another financial opportunity regenerative agriculture can provide to California almond orchards is the diversification of income stream. Other products, such as almond butter, can be sold and further increase profits. Fenster et al., 2021 showed that regenerative orchards sold specialty items (almond butter), leading to an even larger increase in profitability compared to conventional orchards. Regenerative farms can diversify their income stream by selling additional regenerative products, leading to greater profits.

Threats

A financial threat to regenerative agriculture is the current lack of education surrounding the topic. It is not a super widely known term and consumers might not know what it means. Consumers might not know the benefits of regenerative agriculture and why it is meaningful to support. Even if items are labeled as regenerative, it does not give significant meaning to consumers if they are not educated about what it is. There is a possibility that if consumers understood what regenerative agriculture is, they would be willing to pay more for that product. This gap can be filled by increased education and marketing about regenerative agriculture and its impacts. However, there is a threat that this education does not increase, and consumers are unwilling to pay more for regenerative products.

Sub-question 3

How can California begin to widely adopt regenerative agriculture farming practices?

Literature Review

Policy plays a big role in what farmers can and cannot do with their farms. Multiple policies impact the potential implementation of regenerative agriculture. Additionally, policies can be built upon and created to support the implementation of regenerative agriculture in California crops. Agricultural regulations can be updated to support the goals of regenerative agriculture. This literature review includes overviews of policies, programs, and partnerships that can be used as guidance for implementing regenerative agriculture in California. One California policy that currently impacts California almond farms is the Sustainable Management Act.

Sustainable Groundwater Management Act:

The droughts that California experiences have an impact on California's almond farmers (Nishikawa, 2016). Due to the increased demand for almonds since 2005, California almond farmers began using groundwater to irrigate their farms. This groundwater use was not regulated until California enacted the Sustainable Groundwater Act, which is made up of three groundwater management bills (Nishikawa, 2016). The bills were enacted to manage California's groundwater in a way that will allow it to remain available and sustainable for future generations. The Sustainable Groundwater Act limits the amount of groundwater that California almond farmers can use.

The demand for almonds has grown over 220 percent since 2005 (Nishikawa, 2016). Almonds hit their peak popularity in 2013, and they were not only the top ingredient nut, but also the top overall snack (Nishikawa, 2016). The increase in demand for almonds led to increased almond farming. Because almonds are quite water-intensive, almonds use about 10% of California's water supply (Nishikawa, 2016). Precipitation and surface water were not sufficient to supply this water, so almond farmers started to use groundwater to water their almonds. Due to the slow recharge rate of groundwater, this became an issue (Nishikawa, 2016). Due to increased urban demand, California's agricultural water supply is expected to decrease by about 15% by 2050 (Nishikawa, 2016). This coupled with a growing population that will increase California's water demand by over 10%, will put significant stress on the water supply that is already overburdened (Nishikawa, 2016).

California was the last state to regulate groundwater. In 2014, California signed three groundwater management bills to improve the sustainability of groundwater (Nishikawa, 2016). About 75% of California's available water comes from the northern one-third of the state. However, 80% of California's water demand comes from the southern two-thirds of the state (Nishikawa, 2016). This means the water must be transported from the northern to southern regions. This creates systematic issues during drought years when water gets distributed based on rights. Authorities cut water deliveries to farmers with junior water rights, which can force them out of business (Nishikawa, 2016). Drought causes a fight for water in California.

Drought causes an 80 to 100 percent reduction in surface water allocation to California farmers, which is why they must rely on groundwater, which can supply crops with 50% of their water needs (Nishikawa, 2016). However, California farmers are using groundwater at four to five times the rate at which it can be replenished (Nishikawa, 2016). Increased groundwater pumping for agriculture has caused California groundwater levels to drop over 12 million acre-feet every year since 2011 (Nishikawa, 2016). As drought increases, the use of groundwater will also increase, which also leads to land subsidence (Nishikawa, 2016). If groundwater is properly managed, it can reduce the environmental impacts while bringing benefits to communities (Nishikawa, 2016).

The Sustainable Groundwater Management Act will impact California almond farmers by restricting their groundwater use (Nishikawa, 2016). Due to regenerative agriculture leading to better water retention, regenerative practices can be used as a management technique to reduce water use.

California's Healthy Soils Initiative

The California Department of Food and Agriculture (CDFA) is leading a collaboration of agencies and departments to promote the development of healthy soils. The goal of this initiative is to build "soil organic matter that can increase carbon sequestration and reduce overall greenhouse gas emissions" to combat climate change and soil degradation (CDFA Healthy Soils Action Plan, 2016). There are some challenges with the implementation of this initiative due to California being very large and diverse (Desai, 2021). However, this program is a great example of how soil health can be implemented through state programs.

Many commodities in the U.S. are getting funding from the Climate Smart Commodities grant and other funding opportunities. Here I will highlight available funding opportunities that can support the implementation of regenerative agriculture.

Partnerships for Climate-Smart Commodities:

The U.S. Department of Agriculture (USDA) has an effort called Partnerships for Climate-Smart Commodities that supports farmers while expanding markets for climate-smart commodities (Wagner, 2024). This opportunity is also designed to reduce greenhouse gas emissions and provide benefits to small and underserved agriculture producers. The USDA invested over $3 billion to support 141 projects with this funding (Wagner, 2024). This is an example of how funding can be provided to support agricultural producers. This can be applied and directed towards regenerative agriculture.

NRCS Grants:

The Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture (USDA) has a Conservation Innovation Grants (CIG) program. The CIG program supports the development of new tools, approaches, practices, and technologies to further natural resource conservation on private lands" (NCRS, 2021). NRCS provides technical and financial assistance to farmers. NRCS provides landowners with a conservation planner, technical assistance (including resource assessment, practice design, and resource monitoring), and free consultation (NCRS, 2021). A total of $500,000 was available for the California CIG program in 2023. Grants like this one can be utilized to implement transitions to regenerative agriculture in California.

Another way California can work towards adopting regenerative agriculture farming practices is through increased education about what regenerative agriculture is. Regenerative agriculture is still a relatively new idea and there is a large population of people who are unaware of what it entails. Educational initiatives would be beneficial for teaching people about the benefits of regenerative agriculture. These initiatives can be implemented in schools, communities, and most importantly farming areas. While educating the public is important, it would be especially valuable to provide regenerative agriculture education and training programs to farmers. Many organizations that promote regenerative agriculture have workshops and courses.

In addition to education, more research about regenerative agriculture is needed to promote its benefits. Investments in regenerative agriculture research can be made to better comprehend its outcomes. Regenerative agriculture research in California should be conducted to understand the benefits and potential issues with regenerative agriculture in the Central Valley specifically. Research can be expanded by government agencies such as the United States Department of Agriculture (USDA), California Department of Food and Agriculture (CDFA), and Natural Resources Conservation Service (NRCS). Research can also be expanded through universities. Certain universities are already implementing regenerative agriculture research, such as UC Davis and CSU Chico. CSU Chico has a Center for Regenerative Agriculture and Resilient Systems (CRARS). CRARS and the CSU Chico Colleges of Agriculture and Natural Sciences received a nearly $6 million grant to address climate priorities through a partnership between the University of California and the state of California in 2023.

Financial incentives can be provided to support the adoption of regenerative agriculture in California. Since the initial costs of transitioning to regenerative agriculture can be a financial barrier, subsidies, tax breaks, and grants can be utilized to make this transition easier. Incentives for certain regenerative agriculture practices can be provided, such as cover crops or compost.

Another way to increase the implementation of regenerative agriculture in California is to create a demand for regeneratively farmed products. Increased marketing for sustainable and nutrient-dense food can drive a market for regenerative products. USDA Organic Certified is a certification that comes with a premium. Regenerative Organic Certified is a certification that builds upon organic certifications, while including regenerative principles as well. Premiums can be charged for regenerative products, which will increase the revenues of regenerative farms.

Private Sector Programs:

Private sector programs can help to advance the research and implementation of regenerative practices on a large scale. While public funding options are available and can be further expanded, the private sector is responsible for participating in the transition to regenerative agriculture. Private corporations often have large funds and they decide what they do with it. I will highlight two private sector programs that support regenerative agriculture research and implementation.

KIND Almond Acres Initiative:

KIND Snacks is a food company that makes a variety of products, with almonds being their number one ingredient (KIND, 2023). The KIND Almond Acre Initiative is a three-year pilot project that is testing regenerative agriculture practices in almond acres. The program is in partnership with their almond supplier, ofi, and takes place over 500 acres in California (KIND, 2023). The KIND Almond Acres Initiative is tracking five potential environmental outcomes from the application of six regenerative farming practices. The practices and outcomes that the KIND Almond Acres Initiative is implementing and testing are shown in Table 7. The KIND Almond Acres Initiative works with partners and third parties including ofi, UC Merced, Pollinator Partnership, UC Davis, and California Water and Action Collaborative.

Table 7. KIND Almond Acres Initiative practices and environmental outcomes (KIND, 2023).

Practices:	Environmental Outcomes:
Orchard Recycling	Lowered emissions
Cover Crops	Reduced water use
Compost and Biochar	Healthier soil
Off-ground harvesting	Happier pollinators
Low-carbon fertilizer	Sequestered carbon
Subsurface Irrigation	

The Almond Project:

The Almond Project is another project that brings together multiple stakeholders. This project includes farmers, scientists, brands, technical service providers, processors, and customers to implement and test multiple soil health practices (The Almond Project, 2024). The Almond Project is taking place on almond farms in California and is testing five soil health practices. They are monitoring five outcomes of soil and ecosystem health. Table 8 shows the soil health practices and environmental outcomes that the Almond Project is implementing and testing. The coalition of the Almond Project includes the founding partners: Simple Mills, Daily

Harvest, Capello's, Treehouse California Almonds, White Buffalo Land Trust, Gardiner Family, and Justin's.

Table 8. The Almond Project practices and environmental outcomes (The Almond Project, 2024).

Practices:	Environmental Outcomes
Multi-species cover crops Animal Integration Increased compost application Input reduction	Soil health Water infiltration Carbon sequestration Ecosystem biodiversity Farm-level economics in comparison to baselines

Barriers to Scaling Regenerative Agriculture in California

An issue with scaling regenerative agriculture in California is that the state is large with many different climates and soil types, even within the Central Valley where the bulk of almond agriculture is located. This means that the way different regenerative practices interact with the natural ecosystem in different areas can vary. In some Southern California areas, compost just sits on top of the soil and needs to be integrated with additional turning machinery. In contrast, areas in Northern California break down compost very well due to the additional moisture and cooler temperatures. This makes farming management hard to generalize even within one state.

In California, 90% of almond growers are family-owned and under 100 acres (Birkholz, 2024). However, that number does not reflect the reality that in the past five to ten years, many growers have been consolidated, grouped, or sold their land to larger groups (Birkholz, 2024). One of the reasons for this is the high prices of growing almonds. For example, land and water issues are two very expensive factors in almond farming (Birkholz, 2024).

While regenerative agriculture may seem like a promising solution, there are many barriers to reaching these farming practices. A big barrier to regenerative agriculture in California almonds is regional differences in research and practice. Much of the research on this topic has been done in the northern portion of the state. This could make many farmers hesitant to transition due to the concern that these changes may not be beneficial to their land. For example, one of the reasons that it is hard to apply cover crops in Southern California is the additional water needed for cover crops may be difficult to acquire because of the higher scarcity of water in this part of the state (Birkholz, 2024). Thus, the most viable way for cover crops to germinate and grow is through rain, which is not a consistent water source in the southern growing region of California. Especially with climate change and changing precipitation patterns, this is a concern. This can cause monetary issues for farmers who buy seeds for cover crops that never grow into anything profitable (Birkholz, 2024). However, cover crops can be very beneficial in the northern growing region. This is why it is necessary to have large-scale research done in different regions of the state to show the benefits that can apply in specific areas.

Conclusion

Regenerative soil management practices have various positive outcomes for California almonds, both ecologically and economically. Certain regenerative soil management practices have a more significant impact on California almonds, including whole orchard recycling, the use of cover crops, and reducing inputs. Regenerative soil management practices have ecological benefits to the soil. Regenerative practices can improve the health of the soil with nutrients and increase water retention. By improving the health of the soil, regenerative agriculture practices can help protect California almonds by building resilience to environmental changes. By improving water retention of the soil, regenerative agriculture can help to protect California almonds by requiring less water. These outcomes will be important to protect California almonds from climate change as their water supply can be threatened due to increased temperatures and drought and their environment can change due to increased intensity and frequency of extreme weather.

Regenerative agriculture can improve the profitability of almond orchards. Regenerative products can allow for the charge of a premium, leading to higher profits. Regenerative practices can reduce the costs of inputs. Regenerative practices lead to ecological outcomes, such as increased soil organic matter, which are positively correlated with farm profitability. Regenerative agricultural practices also provide ecosystem services that can reduce costs. Regenerative agriculture can help protect California almonds from a changing climate by allowing them to remain profitable. By improving revenues, almond orchards will be able to continue crop production and income.

Policies, incentives, grants, and programs can be utilized to make a transition from conventional to regenerative agriculture. Public funding should be utilized and expanded to implement regenerative agriculture in California. The private sector should participate in funding research and implementation of regenerative agriculture. There is a need for collaboration amongst farmers, policymakers, and the private sector to encourage and implement the transition to regenerative agriculture in California almonds.

Recommendations

My first recommendation is for California almond farmers to implement regenerative practices, especially cover crops, whole orchard recycling, and input reduction. Through my literature review and analysis, I have found these three soil management practices to be beneficial for California almonds in terms of soil health and water infiltration. I suggest implementing these practices to keep California almonds more resilient to climate change. I recommend implementing some of these practices even if they are not able to implement all of them. Benefits can be gained through regenerative practices even if not transitioning to a fully regenerative farm.

My next recommendation is to charge a premium for regeneratively grown products. Charging a higher price for regeneratively grown crops has been shown to make regenerative farms more profitable than conventional ones. Regeneratively grown almonds can be sold at a higher price than conventionally grown almonds. I suggest regenerative almond farmers charge a premium to ensure the financial stability of their orchards. Growing and charging for regenerative almonds can allow orchards to remain profitable.

I recommend expanding the policies, incentives, grants, and programs surrounding regenerative agriculture in California to support its implementation. I recommend My literature review provides examples of how implementation can be supported. I recommend increased efforts at the state level to expand and develop these ideas. Funding opportunities like Partnerships for Climate-Smart Commodities should be utilized by those looking to transition to regenerative agriculture. The USDA should provide similar funding opportunities to support the transition to regenerative agriculture. Grants like the Conservation Innovation Grants provided by the Natural Resources Conservation Service can be used by farmers who want to implement regenerative agriculture practices. I recommend that there is increased grant funding for this program and programs with similar goals. I recommend more private-sector companies start programs that support the research and implementation of regenerative agriculture.

Another recommendation I give is increased education about what regenerative agriculture is. I recommend implementing education surrounding regenerative agriculture in schools. Garden-based education can have many benefits and is an example of how students can learn about the principles of regenerative agriculture. I recommend increased education about regenerative agriculture techniques, their benefits, and how to implement them for California farmers. I also recommend increased marketing about what regenerative agriculture is. I recommend brands that use regeneratively produced commodities to add information about what regenerative means to their packaging to educate consumers. I recommend the development of increased advertisements that highlight the benefits of regenerative agriculture.

A significant recommendation I have is to increase the amount of research done on regenerative agriculture. Many of the reports I read for the development of this project called for more research on these topics. I specifically recommend more of this research to be conducted on specialty crops in California. I recommend this research to study different regenerative farming methods and their impacts on soil health, water retention, yield, and revenue. I recommend that this research is presented to farmers to encourage a transition. I recommend that regenerative agriculture is implemented in California almond orchards to support their resilience to climate change in the coming years.

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