Impacts of Regenerative Land Management at Jalama Canyon Ranch:

Assessing the Role of Remote Sensing in the Accreditation Process for Regenerative Agriculture Certifications

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Signature Page

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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I. Project Description

White Buffalo Land Trust (WBLT) is a 501(c)3 based in the California Central Coast that practices, promotes, and develops systems of regenerative agriculture for local, regional, and global impact. Through land stewardship, education, field research, and business development, WBLT encourages the next generation of land stewards to manage their land following regenerative principles.

In April 2021, WBLT acquired a 1,000-acre property called Jalama Canyon Ranch (JCR) roughly eight miles northeast of Point Conception in Lompoc, California. This property had been used for ranching operations since the early 1900s. In more recent history, JCR supported an owner-managed cow calf operation and a goat grazing operation. The cattle herd was approximately 100 head, and the goat herd was approximately 120-150 head. The ranch was managed with conventional grazing (CG), meaning that cattle were allowed to graze continuously between five pastures bounded by fencing. Previous owners did not fence off the riparian zones. JCR contains seven habitat types (Figure 1).

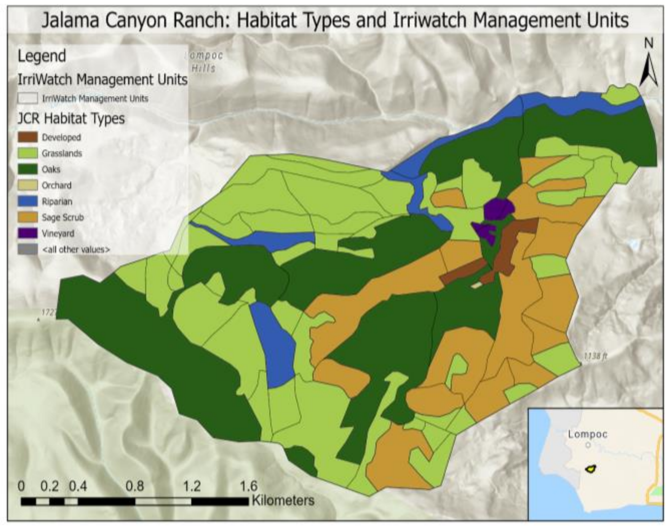

Figure 1. Jalama Canyon Ranch is located eight miles northeast of Point Conception in Santa Barbara, CA. The 1,000-acre property contains seven habitat types: developed, grasslands, oaks, orchard, riparian, sage scrub, and vineyard.

These practices — CG and a lack of riparian protection — have resulted in a succession toward annual grass-dominated systems across JCR. This has reduced ecosystem functioning, decreased biodiversity, eroded soils, lowered forage capacity, and decreased water holding capacity (Mosier et al. 2021). WBLT intends to use this ranch as a research and training center to scientifically quantify the impacts of introduced regenerative practices and communicate their results to increase the adoption of this management style more broadly.

One of the regenerative practices that WBLT introduced is called adaptive multi-paddock (AMP) grazing. AMP grazing is an intensive form of rotational grazing with dense herds of ruminant animals in which a large pasture is divided into smaller paddocks to allow livestock to move from one paddock to the next in rapid succession (Mosier et al. 2021). The goal of AMP grazing is to allow substantial rest periods for forage to regrow, renew carbohydrate stores, and improve productivity and persistence (Smith et al. n.d.). After taking over ownership in April 2021, WBLT first removed the existing herd of cattle and goats to allow the land time to rest. In January 2022, WBLT began rotating their cattle between five pastures under this new regime (Figure 2).

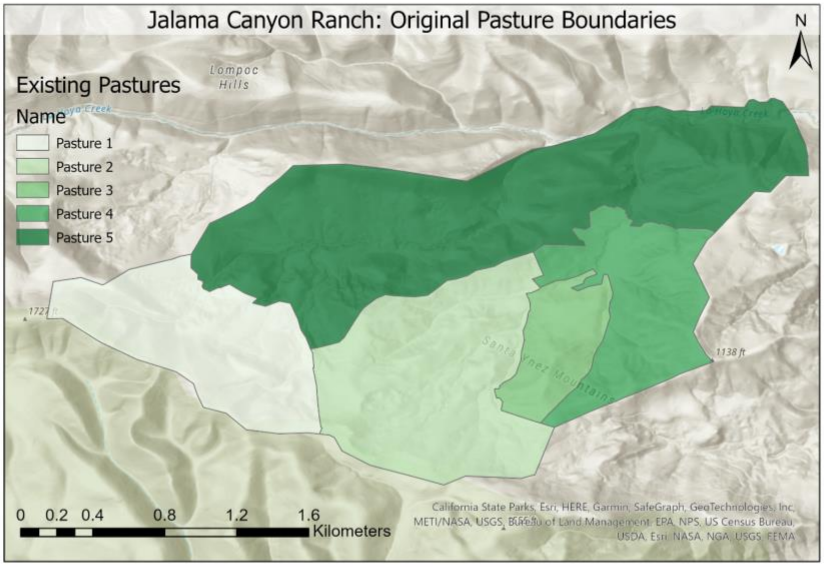

Figure 2. The five pasture boundaries at Jalama Canyon Ranch.

This transition has provided Regeneration Station three opportunities to bring a science-based lens to agriculture and help WBLT quantify its impact. First, we evaluated opportunities to integrate remote sensing data into ecological health monitoring protocols to streamline these data collecting efforts. One constraint for measuring the ecological effects of regenerative agriculture is the cost and time required to conduct rigorous field sampling. By assessing remote sensing methods in this project, we hope to reduce the time and money required to assess the impacts of regenerative management. We used IrriWatch, a digital technology platform already selected by WBLT, to begin quantifying the impacts of AMP grazing on the degraded grasslands. We explain this in greater detail within our Background and Literature Review section below.

Second, we evaluated four certifications for regenerative land practices, previously identified by WBLT as being particularly promising, to determine whether the integration of remote sensing data was feasible. These certifications are Savory Institute's Ecological Outcome Verification, Regen Network's CarbonPlus Certification, Soil Carbon Initiative, and Regenerative Organic Alliance's Regenerative Organic Certification. We created a comprehensive overview of certification requirements to better understand the similarities and differences in their methodologies, costs, and benefits, and to determine whether remote sensing data could streamline the certification process.

Finally, we conducted focus groups with land stewards who were interested in adopting regenerative practices to better understand the priorities and the barriers to adoption. Cost, or perceived cost, can be a common barrier to transition from conventional to regenerative agriculture, and certifications can generate income for land stewards and thereby increase the attractiveness of regenerative practices (Renton and Lafave 2020). However, certifications for regenerative agriculture are relatively new. Understanding barriers to adoption can help WBLT tailor their messaging to address these challenges.

II. Significance

Croplands and grazing lands cover over a third of the earth's livable surface and experience high levels of soil degradation and fertility loss due to poor management (Oldeman 1992, Erpul et al. 2018). This can lead to sediment loss, lower carbon holding capacity, and lower water holding capacity (Batjes 1999, Follett and Kimble 2000). Grasslands are estimated to hold 10-30% of the global soil organic carbon (Schuman et al. 2002), and agriculture significantly impacts, and is impacted by, the water cycle. Conventional irrigated agriculture has disrupted the terrestrial water cycle (Vörösmarty and Sahagian 2000), and the effect of increasing water scarcity on agriculture poses a significant threat to global food security (Mancosu et al. 2015).

Regenerative agriculture can address the twin challenges of freshwater scarcity and atmospheric carbon by sequestering significant amounts of carbon in grassland soils, rebuilding soil health, and increasing soil water retention (Follett and Kimble 2000). Specifically, it is possible to increase soil organic carbon, enhance soil formation, water infiltration, nutrient cycling, biodiversity, and other ecosystem services by adopting alternate ruminant grazing practices (Teague and Kreuter 2020). This project will set up data protocols that use satellite data to assess the impacts of regenerative farming and grazing. Streamlined data collection will also help WBLT qualify for regenerative agriculture accreditation programs and demonstrate the ecological benefits of regenerative management to other stewards in the industry.

Land Acknowledgement

We acknowledge that Jalama Canyon Ranch and UC Santa Barbara sit on unceded lands of the Chumash people, who settled this region more than 9,500 years ago. The Chumash homeland spans from the present-day Malibu to Paso Robles and encompasses the Northern Channel Islands. With more than 150 villages, 6 distinct languages, and over 25,000 inhabitants, the Chumash developed a rich and unique culture, including notable inventions such as the plank canoe and intricate basket weaving. Today, approximately 3,000 people of Chumash heritage continue to reside in Ventura, Santa Barbara, and San Luis Obispo counties.

III. Background and Literature Review

Regenerative Agriculture

While there is no single shared definition of regenerative agriculture (Newton et al. 2020), in general, regenerative agriculture is a systems-based, holistic land management strategy that aims to increase productivity and biodiversity over time. One of the central principles of regenerative agriculture is the enhancement of soil health and functionality. Regenerative practices such as AMP grazing, no-till cultivation, and cover-cropping can improve soil health by increasing carbon sequestration and storage rates.

In this project, we focus on the impact of AMP grazing. The integration of livestock for use in AMP grazing systems has been shown to provide a wide range of ecosystem services: soil stabilization, water infiltration, carbon sequestration, nutrient cycling, biodiversity, and increased economic stability (Teague & Kreuter 2020). This is exemplified in two relevant case studies that compare CG ranches with neighboring AMP ranches in the southeastern US in 2021. On average, AMP grazed ranches averaged 13% more soil C and 9% more soil N compared to neighboring CG ranches (Mosier et al. 2021). In a 1–2-day study in Alberta, Canada, scientists Shrestha et al., compared GHGs fluxes among CG ranches and AMP ranches. Here, AMP soils took up 1.5 times more methane than non-AMP soils, demonstrating that AMP grazing has the potential to sequester carbon more efficiently than CP ranches (Shrestha et al. 2020).

Despite the positive ecological benefits associated with regenerative management, the adoption of such practices has been slow in the industry. One reason for the limited adoption of regenerative agriculture is the labor costs associated with transitioning to this management style. Regenerative agriculture techniques such as no-till seeding, the use of cover crops and rotational grazing can be costly for land stewards during the transition of practices, but has been found to reduce the need for expensive inputs and to stabilize income (Gosnell et al. 2019). WBLT is working to overcome these challenges to increase the adoption of regenerative practices more broadly.

Remote Sensing

Agricultural technology refers to the insights derived from hardware, software and services that can help improve decision making (Goedde et al. 2020). One aspect of agriculture technology includes the use of remote sensing, the science of gathering information about the physical characteristics of an area without physically contacting the area itself. Remote sensing includes the use of various sensors such as those on satellites in space or on aircraft which can detect and measure electromagnetic radiation emitted or reflected by objects on earth.

WBLT has been working to integrate remote sensing into their monitoring protocols for three reasons: (1) to monitor improvements to ecological health accurately and efficiently; (2) to explore how real time climate data might support a better understanding of key hydrologic processes; and (3) to assess innovative sampling techniques to share findings with their community of land stewards and partners.

For this project, we assessed the applicability of data from nine prominent satellite missions, airborne missions, and prebuilt tools that were preselected by our client. The satellite missions were identified by Carmen Blackwood, Deputy Section Manager and Earth Scientist at JPL, as part of a larger partnership between WBLT and JPL. We included the general mission description and the potential to leverage data for JCR monitoring protocols. This information is included in Appendix Table A1.

We presented these findings to WBLT leadership in September 2022. Together, we narrowed the scope of our analysis to one remote sensing software of interest, IrriWatch. IrriWatch uses satellite datasets to inform irrigation processes for farmers. We selected IrriWatch for our analysis because WBLT had already subscribed to this platform prior to our engagement. It made financial sense to allocate

Regeneration Station resources to a project that had been initiated but lacked momentum. We provide a background on IrriWatch in the paragraphs below.

IrriWatch

IrriWatch is intended to help farmers optimize irrigation. IrriWatch is a software package that includes field-level parameters, pixel-level maps, and seasonal graphs for growers. Each field map contains 10 x 10-meter pixel observations from satellites (IrriWatch 2022). IrriWatch uses the Surface Energy Balance Algorithm for Land (SEBAL) to calculate 28 parameters for each field, each day. These parameters can be categorized into four groups: irrigation, crop production, soil health, and climate (IrriWatch 2022). We list SEBAL inputs in Table A2 and IrriWatch parameters in Table A3.

The principal components of the SEBAL model include satellite radiance in the visible, near infrared and thermal spectrum and surface parameters such as surface albedo, vegetation indices, and surface temperature. These components are converted using a land surface parameterization and surface energy balance equations such as net radiation flux density, soil heat flux density, sensible heat flux density, and latent heat flux density (Bastiaanssen et al. 1998).

The literature recognizes that the SEBAL model, the core model of IrriWatch, is largely accurate in estimating evapotranspiration (Bastiaanssen et al. 2005, Verstraeten et al. 2008, Bezerra et al. 2013, Karimi and Bastiaanssen 2014, Jaafar and Ahmad 2020). The model had been applied in 30 countries worldwide (Bastiaanssen et al. 2005). Research studies have gradually been replaced by application studies; in 2020, IrriWatch released a Ground Truth Campaign that validated data in 8 countries (Bastiaanssen et al. 2005).

In California, the IrriWatch model has been validated for the following parameters and crops: actual evapotranspiration (mm) - almonds, wine grapes; soil moisture (cm3/cm3) - almonds; water potential (kPa) - wine grapes; crop yield (kg/ha) - seed cotton, lint cotton, walnuts (IrriWatch 2020). Validation partners performed in situ measurements with soil moisture probes, pressure bombs, lysimeters and eddy covariance flux towers to generate actual evapotranspiration, soil moisture, and water potential values (IrriWatch 2020). To assess crop and pasture yield, partners used yield sensors or weighbridge measurements (IrriWatch 2020). California results demonstrate a 6.3% maximum difference with ground truthing devices. To date, the model has not been specifically validated for grasslands (IrriWatch 2020).

IrriWatch management units are derived from a suite of input layers provided by the land steward. For JCR these included the original pasture boundaries, habitat shapefiles, soil type shapefiles, and whether that parcel will be irrigated or not. These inputs allow the resulting management units to contain unique values for crop type, soil type, and irrigation type. If there are multiple soil types or crop types within a polygon there is a split of the polygon/unit by different soil/crop type. Once they subscribe to IrriWatch, landowners can access their data each day via an online portal (Figure 3). In theory, this technology allows farmers to monitor their fields without the need to be physically present.

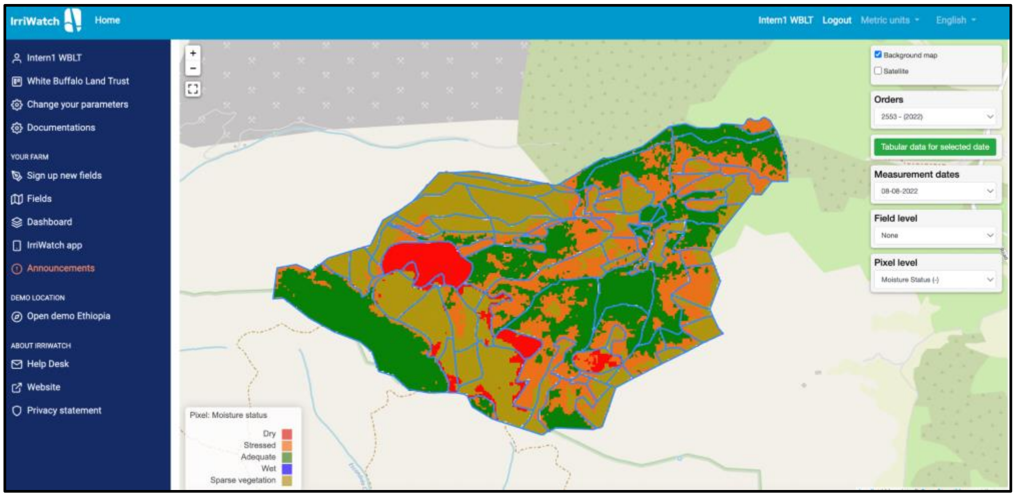

Figure 3. The IrriWatch portal displays an aerial image of Jalama Canyon Ranch. The property is delineated by 79 fields, or management units. Each management unit has 28 parameters that can be accessed each day to make management decisions like when to irrigate.

Two IrriWatch outputs are particularly relevant: evapotranspiration and soil moisture. Changes in evapotranspiration may reflect changes in soil texture, which in turn is related to vegetation shifts that would be expected to result from the new grazing practices implemented on the ranch. According to WBLT, AMP grazing is expected to precipitate a shift from annual grasses to perennial grasses. Perennial grasses tend to have deeper root systems that access more moisture from the soil and increase transpiration relative to annual grasses, thereby increasing evapotranspiration (Kim et al. 2023). Because perennial grasses tend to stay green longer into the dry season, we would also expect a shifting signature in the seasonality of evapotranspiration if grasslands shifted from primarily annuals to primarily perennials.

Soil moisture is relevant because water is the primary environmental variable of concern for WBLT. One of their management goals is to understand which parts of their property hold more water in the soil than others and to determine whether soil moisture increases or changes in seasonality after implementation of AMP grazing. Perennial grasses increase soil carbon, which in turn leads to greater water retention in the soil (Cao et al. 2021). As such, to the extent AMP grazing leads to greater establishment of perennial grasses, we would expect higher levels of soil moisture longer into the dry season after implementation of AMP grazing practices.

Certifications

Certifications and ecolabels are ‘marks’ placed on packaging or marketing materials to help consumers identify products that meet specific performance criteria (U.S. Environmental Protection Agency 2014). Certifications can be single-attribute, where they focus on one aspect of a lifecycle stage in a given social or environmental issue, or they can be multi-attribute, in which they focus on the entire lifecycle of a product or service (U.S. Environmental Protection Agency 2014). Such labels benefit consumers by clarifying producer priorities and product chains and can benefit producers by opening new market opportunities.

Certifications are becoming increasingly popular in the agriculture industry. In 2018, roughly 8% of specialty crops were grown with at least one eco-certification (Gatti et al. 2022). At present, there are more than 190 sustainability certifications for food and forest products in the United States. Of all ecolabels, organic certifications are the most used; they comprise 70% of eco-labeled farmland (Gatti et al. 2022).

Despite the increase in ecolabels, there are still few scientific studies that evaluate the true environmental impacts of eco-labels, particularly for farmed goods (Blackman and Naranjo 2012). One 2012 study compared organic certified coffee farms and conventional coffee farms in Costa Rica and showed a significant reduction in chemical pesticides, fertilizer use, and herbicide application. The only positive practice recorded in this study was the increased adoption of organic fertilizer use (Blackman and Naranjo 2012).

Despite their potential for social impact, certifications benefit some and exclude others. It is often costly for producers to achieve certification because of expensive monitoring practices and/or exorbitant administrative fees. These costs can create an unequal field in which wealthier farms are able to pursue certification, while poorer farms are unable to pay for a product ecolabel even if they are perhaps in compliance with requirements. Certifications can also increase market prices, which prevents low-income consumers from accessing certified goods.

It is important to note that a number of consumers and producers are known to distrust certifications (Wessells et al. 1999, Darnall et al. 2018). This distrust can be attributed to a lack of scientific verification on the benefits of certification and the lack of transparency in the certification process itself (Golden 2010). It behooves certification bodies to ensure their methodology is attainable and scientifically rigorous to address these concerns. It can also be difficult for consumers to navigate the certification market because it is oversaturated.

As more certifications enter the market, it can also be difficult for land stewards to determine which aligns best with their operation. Regenerative certifications claim to go “beyond organic”(Elrick et al. 2022) and require additional monitoring protocols. Regenerative agriculture certifications are either categorized as practice-based, which primarily measures success based on the implementation of management practices, or outcome-based, which measures success based on improvements in a variety of ecological indicators over a period of time. These differences may not be easily discernible to a consumer, but they can significantly influence the environmental impact of a product and the requirements of the landowner. Because most regenerative agriculture certifications are still in development, there is little data available to evaluate the direct financial benefit and/or the extended market opportunities from certification.

There are multiple emerging certifications that land stewards can pursue for regenerative agricultural practices. Each certification has a unique set of requirements that land managers must meet across a range of ecological indicators. Regeneration Station analyzed four separate certifications for regenerative land stewardship that WBLT is actively pursuing: Soil Carbon Initiative Farm Level Commitment Program

(SCI 2022), Savory Ecological Outcome Verification (Savory Institute 2021), Regen Network CarbonPlus Grasslands (Booman et al. 2022), and Regenerative Organic Certification (Regenerative Organic Alliance 2021).

There are a number of other regenerative certifications available or in development including, but not limited to: Regenified (Regenified 2023), Audubon Grasslands (National Audubon Society 2021), Demeter biodynamic certification (Demeter Association, Inc. 2017), Regen1 (Green Brown Blue n.d.), A Greener World: Certified Regenerative (A Greener World 2022), Real Organic Project (Real Organic Standards Board 2022), and Fibershed: Climate Beneficial Fiber (Fibershed 2022).

Certification Summaries

We include a high-level summary of the four certifications to show major differences in their goals, strategies, and survey methodologies below:

Soil Carbon Initiative: Farm-Level Commitment Program

Soil Carbon Initiative (SCI) created the Farm Level Commitment Program as a certification open to any land steward at any point in their journey toward regenerative farming. SCI supports land stewards in the process of creating a specialized "commitment plan" that must be followed to gain certification. SCI allows land stewards to enroll a percentage of their land (e.g., 10%) with the understanding that they will increase that percentage up to 75-100% by the 10th year of enrollment. By providing guidance, land stewards interpret ecological changes on their land using a combination of on-farm and in-lab testing. The measurements are considered tools for learning, rather than a "test" required for achieving certification. As long as the land steward is dedicated to following their commitment plan, sampling and reporting required tests, and increasing the percentage of land enrolled, the land steward will acquire the certification (SCI 2022).

SCI program pillars are:

1.) Minimize soil disturbance
2.) Living roots in the ground year round
3.) Maximize diversity above and below ground
4.) Appropriate integration of livestock
5.) Reduce synthetic inputs
6.) Learning at the systems level to support the SCI community of practice

Savory Institute: Ecological Outcome Verification

The Ecological Outcome Verification (EOV) is a certification geared specifically toward grassland environments, including natural/seeded grasslands, grazed orchards, silvopastoral systems, mixed livestock cropping systems, and forest areas. EOV is an outcome-based certification that assesses whether there are measured improvements through field and soil testing of key indicators, including biodiversity, soil health, and ecosystem function. EOV is based regionally through "Savory Hubs" where there are local advisors to guide and educate land stewards on best practices. These advisors also visit farms to perform the required sampling for certification. EOV allows land stewards to have their verified products sold on their digital platform Land to Market (L2M) for gland stewards to connect to conscientious buyers, brands and retailers seeking regenerative products (Savory Institute 2021).

The EOV program pillars are:

1. Outcome based with measurable land health improvements
2. Contextually relevant to ecoregions
3. Farmer first; educating land stewards through regional savory hubs

Regen Network: CarbonPlus

Regen Network created the CarbonPlus Certification which is geared towards grasslands managed with prescribed grazing methods. CarbonPlus applies a measurement-based soil organic carbon approach to maximize soil organic carbon stocks (SOC) across a landscape with a combination of soil samples and remote sensing data. CarbonPlus also looks more holistically at ecological co-benefits resulting from regenerative grazing practices. Aside from soil organic carbon, overall soil health, animal welfare, and ecosystem health are also measured through multiple indicators (Booman et al. 2022).

Regenerative Organic Alliance: Regenerative Organic Certification

The Regenerative Organic Alliance developed the Regenerative Organic Certification (ROC) that is applicable to farming operations, livestock operations, transportation, slaughter, and certain processing facilities that produce food, fiber, and botanicals. ROC builds off other certifications including USDA Organic (or equivalent), Social Fairness certification (9 options), and an Animal Welfare certification (3 options if this certification is applicable). There are three different levels of certification (bronze, silver, and gold). As land managed under regenerative practices increases and more regenerative techniques are applied, certification level increases (Regenerative Organic Alliance 2021).

The ROC pillars are:

1. Soil health and land management
2. Animal welfare
3. Farmer and worker fairness

Certification Adoption by Farmers

In the United States, organic farming was first coined as a term in the early 1900s and promoted in the decades following the Dust Bowl by stewards like J.I. and Robert Rodale. In 1960, after the publication of *Silent Spring* by Rachel Carson, public attention and education about the negative environmental impacts of insecticides increased dramatically; soon, the organic farming movement progressed into the mainstream food production industry (Adamchak 2022). After the USDA released national standards for organic products in 2000 — creating the official USDA Organic certification — domestic sales of organic food products grew to $20.39 billion in 2008 and $47.9 billion in 2019 (Adamchak 2022). Despite the growing number of domestic organic producers and revenue from the sale of organic food products, the organic movement was slow to start in the United States. After over a century since the initial coining of the organic farming term, there are over 14,000 certified organic farms in the US, but organic sales only account for just over 4% of total food sales (BlueWeave Consulting and Research Pvt Ltd 2022).

The adoption of regenerative agriculture management practices and certifications will likely face a similar slow trajectory. Factors including income, education, behavior, labor, costs, experience, training, extension contracts, and association memberships can all prevent land stewards from adopting new trends (Sapbamrer and Thammachai 2021). Because the USDA has yet to release any formal governmental standards and definitions on regenerative agriculture and the scientific literature is lacking, the adoption of these practices may even be slower than the adoption of USDA organic standards. While there are a number of regenerative certifying bodies that provide land management consulting assistance, there is no governmental financial backing for these practices like there has been for organic farming.

Indicators

Measuring the benefits of regenerative agricultural practices — whether that be to assess changes to ecosystem services or to attain relevant certifications — requires that practitioners select appropriate ecological indicators. In general, there are two approaches used to quantify the impact of regenerative agriculture: process-based indicators (such as the integration of livestock and use of cover crops) and outcome-based indicators (such as carbon sequestration and increased biodiversity) (Newton et al. 2020). Given the volume of process-based and outcome-based indicators, Failing and Gregory (2003) suggest the following guidelines for optimal indicator selection:

1. Indicators should clearly represent the desired end goal and should focus on the desired output not the input.
2. Indicators should be designed with the specific local management context in mind and indicators should be tied to management decisions.
3. Indicators should be given relative weights according to their importance to stakeholders. Weights based on values versus technical judgment should be made clear.

IV. Objectives

Our specific project objectives are as follows:

A. Measure changes in evapotranspiration and soil moisture over time and space in JCR and analyze their correlation with cattle management practices.
B. Develop an indicator matrix and a comprehensive comparison of regenerative agriculture certification criteria in order to assess overlapping ecological indicators across certifications, to evaluate the feasibility of utilizing remote sensing data to measure ecological indicators, to streamline data collection for WBLT, and finally, to help land stewards meet standards.
C. Conduct in-depth focus groups with land stewards to identify challenges associated with the implementation of regenerative management practices and adoption of certifications to inform the development of a targeted certification handout for land stewards.

V. Methods

We accomplished our objectives via the methods below.

A. IrriWatch

Our goal is to develop spatial and temporal outputs for evapotranspiration and soil moisture that will allow WBLT to understand differences across habitat and soil types, pastures, and different grassland fields. Establishing these year-one baselines enables WBLT to begin tracking changes in ecological health, attributing these changes to regenerative management practices, and implementing corrective actions to achieve their desired outcomes.

Data

For each of the 79 management units on JCR (hereafter referred to as "fields"), we downloaded geometry information and daily values for all items in the IrriWatch model from the IrriWatch website. The data spanned slightly more than a year (2021-09-23 to 2022-09-30). We converted units from metric to imperial to standardize units across data sources. We converted cumulative precipitation (which was identical for all fields) to rain events. We also downloaded precipitation data from the County of Santa Barbara rain gauge in Lompoc (County of Santa Barbara Public Works 2023), and obtained precipitation data from seven manually read rain gauges across JCR from WBLT. We are confident that the rain gauge did not overflow for any reading, since the capacity of the gauge is 5.25 inches, the maximum reading was 4.25 inches, and this reading was taken 1 week after the previous reading during a wet and cold December when evaporation was likely low. We used the mean from across the JCR rain gauges because the maximum spread between gauge readings for a single event was 1 inch, and most rain events had a spread of a few tenths of an inch for a single event (see Figure 4 below). The JCR rain gauges were read at the same time for each rain event.

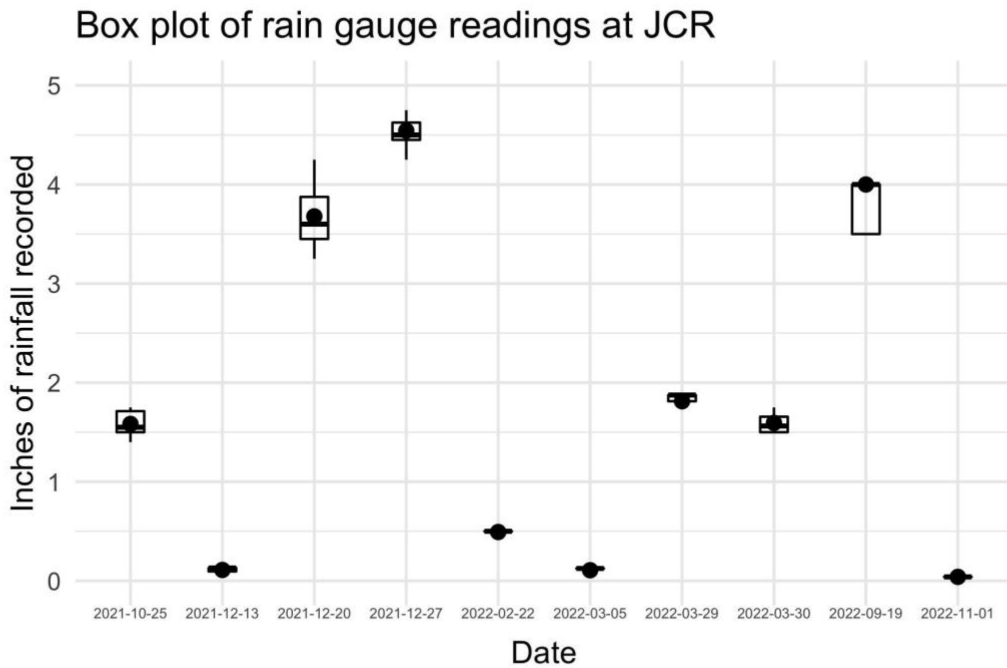

Figure 4. Box plot of rain gauge readings at JCR.

All analyses were conducted in R Statistical Software (version 4.1.2; R Core Team 2021). Primary packages used include tidyverse (Wickham et al. 2019), sf (Pebesma 2018), car (Fox and Weisberg 2019), and effects (Fox and Weisberg 2019).

Ground truthing the IrriWatch Precipitation Data

Precipitation is an important driver of the SEBAL model and affects both evapotranspiration and soil moisture root zone percentage (Kim et al. 2023). We ground-truthed the precipitation data provided by the IrriWatch platform with rain gauge observations from the JCR property and the nearest publicly managed rain gauge in Lompoc to assess the degree to which the precipitation data used in the IrriWatch model matched on-the-ground conditions. We visually compared the timing and magnitude of rain events and cumulative precipitation recorded by the JCR rain gauges, the IrriWatch model, and the Lompoc rain gauge.

Spatiotemporal Patterns in Evapotranspiration and Soil Moisture root zone

Summary Statistics: We used summary statistics to generate and present a comprehensive overview of evapotranspiration and soil moisture root zone distribution across JCR habitat types and soil types. These included mean, median, standard deviation, minimum, and maximum. We also created spatial distribution maps to visualize the distribution of average daily evapotranspiration and soil moisture rootzone levels across the property. We chose to analyze evapotranspiration and soil moisture root zone according to habitat type and soil type because these latter variables are primary inputs to the IrriWatch model and are known in the literature to influence evapotranspiration and soil moisture (Cosby et al. 1984, Rodriguez-Iturbe et al. 1999, Zhang et al. 2001, Razzaghi et al. 2012).

Map Outputs: To assess spatial distribution of mean daily evapotranspiration and soil moisture root zone, we created map outputs visualizing annual mean values on a field-by-field basis. We isolated grassland fields for final map outputs as WBLT is looking to track ecosystem indicator responses based on altered grazing management within the grassland units. Furthermore, we mapped soil type for each of the grassland fields. This allowed us to visually assess whether there were any correlations between grasslands fields with high evapotranspiration/soil moisture root zone values and specific soil types.

Time Series Plots: To assess the temporal distribution of evapotranspiration across natural habitat types, we used time series plots. We included time series plots to assess overall trends over the course of the year, or the period for which we had data. We added a trend line using an automatic smoothing function based on the number of observations and distribution of the data. We selected the generalized additive model (GAM), which fit a flexible and nonlinear function to the data. Finally, we overlaid the trendlines from each natural habitat type into one plot to assess differences in both magnitude and timing of the peaks.

Isolating Variables: We also carried out various data splits to visualize variation in temporal trends based on different factors (habitat type, soil type). We grouped by habitat type and took the mean value for each day to compare trends between habitat types. The vegetation classes of oak, riparian, sage scrub, and grasslands were selected for additional analysis as they are the four prominent habitat types at JCR. We furthered analysis by filtering the data to look exclusively at evapotranspiration in grassland habitat types ($n = 47$). Grasslands were identified as the units of interest because many of the management decisions in 2022 at JCR were carried out in relation to cattle rotation between grassland units. Results visually showing variations in output trends were included. These analyses were done to visually examine if any of these factors (such as soil type) were driving larger trends in evapotranspiration or soil moisture root zone. For the soil moisture root zone, we also visualized the precipitation data overlaid on top of temporal trends to show the response of soil moisture after rain events. We chose an arbitrary cutoff of 1.5 inches as a threshold for visualizing rain events. This threshold was chosen to capture the majority of precipitation while being selective enough to make the graph legible.

Regression Analysis: We created linear regression models to explain the variation in both soil moisture root zone and evapotranspiration. We chose soil type, habitat type, relative humidity, and air temperature as explanatory variables. We chose to add relative humidity and air temperature to our regression analyses because they are primary inputs to the SEBAL model and have a scientifically-established correlation with both soil moisture and evapotranspiration (Mintz and Walker 1993, Zotarelli et al. 2009). Thus, they might be able to explain more of the observed variation in evapotranspiration and soil moisture than soil type and habitat type do alone. Finally, we also included a variable for day that included a unique number for each day in the time series to capture the effects of time on dependent variables. We ran Q-Q plots to assess whether model residuals were normally distributed.

We defined five linear models and compared their Akaike information criterion (AIC) values to determine which model offered the best explanatory power with the fewest number of independent variables. The five linear models were:

- Day only
- Day + habitat type
- Day + soil type
- Day + habitat type + soil type
- Day + habitat type + soil type + relative humidity + air temperature

We then ran an ANOVA test and Tukey's honestly significant difference (HSD) test on the best-AIC model to test the null hypotheses that all variables were not significantly different from each other and all categories within each variable were not significantly different from each other. Finally, we generated effects plots for each independent variable.

Analysis of Seasonality Between Pastures

In order to support grazing management decisions at JCR, we carried out an assessment of the seasonal trends of evapotranspiration and soil moisture by pasture. These pastures, which are divided with fencing, were used by the previous owner before WBLT and WBLT to rotate cattle under the first year of management. The analyses conducted by pasture highlighted differences among pastures that WBLT can use to understand variation across their property and track changes in individual pastures across time.

Using shapefiles provided by the WBLT team, we joined the IrriWatch management units to pasture number. We filtered by grasslands, since cattle will only be grazing on grassland fields, and created a new column to represent seasonality. Using the NOAA-defined meteorological seasons, we identified March, April and May as spring, June, July and August as summer, September, October and November as fall, and December, January, and February as winter. We grouped by pasture and summarized to receive mean daily actual evapotranspiration and daily root zone soil moisture percentage by pasture by season. We then visualized these values using histograms.

Regression Analysis: We created a variable that contained a unique value for each day in the time series. Then we defined two linear models to explain variation in soil moisture and evapotranspiration over time: one that included only day, and the other that included pasture + day. We compared the AIC values of the two models to determine which model was the most parsimonious, i.e., had the most explanatory power with the least number of variables. We checked the Q-Q plots of our best-AIC models to see if the model residuals were normally distributed. We then ran ANOVA and Tukey's HSD tests on the best-AIC models to test the null hypotheses that the variables were not significantly different from each other and that the categories within each variable (i.e., pastures) were all not significantly different from each other. Finally, we plotted the model results using effects plots.

Variation in Evapotranspiration and Soil moisture in Response to Grazing

We conducted a visual analysis of the variation in evapotranspiration and soil moisture among pastures during and following cattle grazing. WBLT's 2022 grazing season began on February 1, 2022, when the ranch received 83 head of cattle. All 83 cattle were rotated into a new pasture according to the following schedule (see below). The date listed is the date on which the cattle entered the new pasture.

- February 2: Pasture 5
- February 17: Pasture 1

- March 7: Pasture 2
- March 29: Pasture 3
- April 13: Pasture 4
- April 20: Pasture 5
- May 2: Pasture 1
- May 12: Pasture 2

We visualized the results by first taking the mean daily actual evapotranspiration and soil moisture root zone percentage for each pasture. We used the pastures as defined in the section Analysis of Seasonality by Pasture above. We then assigned each pasture a value for each day based on whether it was currently grazed by cattle or had been grazed by cattle in the previous two rotations. The shortest rotation was 7 days from April 13-April 20. The longest rotation was 22 days from March 7 to March 29. The difference in rotation lengths means comparison between evapotranspiration and soil moisture responses to cattle grazing among pastures is less standardized than it would be if all rotation lengths were equal and the time duration of the previous two rotations was the same in all cases.

Regression Analysis: We created a variable for day that included a unique value for each day in the time series. We then defined four linear models each to explain the variation in soil moisture and evapotranspiration in our dataset. The independent variables in each model were:

- Day
- Day + pasture
- Day + grazing status
- Day + pasture + grazing status

We compared the AIC values of each model for both soil moisture and evapotranspiration to determine which model was the most parsimonious. We analyzed the Q-Q plots of the best-AIC models to see if the model residuals were normally distributed. We then ran ANOVA and Tukey’s HSD tests on the best-AIC models to test the null hypotheses that all variables were not significantly different from each other and all categories within each variable were not significantly different from each other. Finally, we assessed the relationship of different grazing statuses with soil moisture and evapotranspiration with effects plots.

B. Certification Analysis

Indicators

We compiled a matrix of the ecological indicators required for each of the four regenerative agriculture certifications of interest to WBLT (SCI, CarbonPlus Grasslands, ROC, and EOV).

To do this, we downloaded the four unique accreditation protocols available on each certification website (Regenerative Organic Alliance 2021, Savory Institute 2021, SCI 2022, Booman et al. 2022). We reviewed this documentation and compiled certification requirements into a single spreadsheet. We included the following information for each accreditation protocol where available: ecosystem health categories, ecosystem indicators, metrics, protocols (hereafter referred to as “observations”). We define these observations in Table A4.

We used pivot tables to identify overlapping indicators across these certifications (e.g., the number of certifications that require *water infiltration* in their accreditation process).

Finally, we determined which observations, if any, could be measured via satellite imagery through a literature review of academic and gray sources. These sources were derived from a google scholar search using the terminology used to identify each indicator from the certification documents. Some indicators, such as the *invasive species* indicator required by ROC, could be measured using remote sensing, but according to metric and monitoring protocols, "documentation of operations/management plan or monitoring approach to be used to verify said practices are taking place. Must show control of invasives", they were not included. The indicators included were selected based on feasibility and accessibility, aligning with commonly used remote sensing techniques.

Certification Standards

To enhance our original indicator matrix of ecological indicators and remote sensing opportunities, we expanded our data collection beyond the indicators themselves. We obtained information on additional requirements from the aforementioned accreditation protocols and/or the company websites (Regenerative Organic Alliance 2021, Savory Institute 2021, SCI 2022, Booman et al. 2022). In the event that we had outstanding questions after reviewing the certification requirements (e.g., data was unavailable and/or unclear), we spoke with a representative from the respective certifying body to ensure our data was accurate. Some examples of outstanding questions included:

- Does the land steward need to enroll their entire farm, or can they enroll a portion of their farm and increase the amount over time? Is there a land enrollment increase requirement timeline?
- How many sub samples need to be taken for each soil sample, how are these sub samples mixed and sent to a lab?
- Does the land steward take the soil samples themselves, or does someone affiliated with the certification visit the farm to take samples?
- What is the current cost structure for the certification? If enrollment fees are currently waived, when will they be required again and what is the cost estimate?
- There is contradicting information in the standards and methods; which requirement is correct?

For the Soil Carbon Initiative, we interviewed Taylor Herren, a ranching management consultant who helps land stewards meet certification requirements. We interviewed Molly Taylor, an EOV monitor and EOV certified farmer, for further clarification of the Savory Institute Ecological Outcome Verification certification. At the Regen Network we spoke with Rebecca Harman, the partnership and grants manager, as well as Dr. Gisel Booman, the head of science, for clarifying questions and feedback on deliverables. For the Regenerative Organic Certification, we spoke with Nathaniel Siemens, the ROC auditor, and Bridget Gilmore, the ROC Market coordinator.

We synthesized their feedback into a comprehensive comparison document and identified key components to compare the certifications and further developed these components through internal team discussions, discussions with WBLT, and referencing other certification comparisons to determine areas that could be improved upon (Kiss the Ground 2022, Wolf Tree Ventures 2022).

C. Stakeholder Communications

Focus groups

On Friday, January 13, 2023, Sarah-Anne Rohlfing, Tommy King, and Patrick Pelegri-O'Day conducted hour-long focus groups with the land stewards in attendance at the WBLT 10-day Holistic Management Intensive (HMI) Regenerative Agriculture conference, hosted at JCR via a zoom call. The focus groups were originally scheduled to be held in-person on Monday, March 9th, but due to a heavy rainfall event, it was unsafe to travel to JCR. We rescheduled the focus groups via Zoom; Regeneration Station team members called in remotely and WBLT staff organized participants into groups at JCR. While this allowed us to receive valuable information and feedback, hosting the focus groups over zoom limited our ability to record nonverbal reactions from participants.

Participants at this event were land stewards interested in understanding Savory-accredited regenerative management techniques for ecological, economic, and community health. The 10-day conference included training modules for the foundations of holistic management, holistic financial planning, planned grazing, land planning, and ecological monitoring. Participants were split into two groups: the experienced land stewards and the beginner land stewards. Beginner land stewards were those who had one year or less of land management experience, while the advanced land stewards were those with more than one year of land management experience. This split was designed to maximize discussion from individuals with similar experiences in agriculture. The beginner group consisted of nine new landowners and managers with diverse backgrounds interested in regenerative stewardship, with minimal experience. Many of the individuals in the beginner group were raised around ranches and have had exposure to agriculture systems and are currently beginning their own operations for the first time. The experienced land stewards group consisted of eight commercial ranchers, private landowners, viniculture specialists, biodynamic experts, and regenerative ranching coaches. This group encompassed a wide range of experiences from lifelong Montana ranchers, corporate ranchers for beef companies, specialty wine growers, and permaculture specialists. The majority of attendees were from western states such as California, Oregon, Washington, as well as Montana.

The goal of the hour-long session was to accomplish four objectives, to: better understand the motivations behind pursuing regenerative agriculture, better understand the barriers to adoption of regenerative agriculture, better understand the farm-level challenges of managing regeneratively, and receive feedback about the regenerative certifications pamphlet. The Regeneration Station team hypothesized that the main challenges of pursuing regenerative management would be labor availability, input costs, and the economic unknowns associated with obtaining regenerative certifications.

To best present these questions in an unbiased manner, we prepared questions in accordance with the Institutional Review Board's Human Subject Research process (Appendix A5) and incorporated feedback from Carrie Kappel and Sarah Anderson to ensure proper focus group design, framing, facilitation, group selection, and document review. Questions were designed to garner the best responses to understand the biggest challenges and barriers to adoption for both regenerative management and certification adoption. Each question was designed to be open-ended so as to ensure that each attendee could provide relevant feedback and insights into their unique challenges and barriers to regenerative management.

At each group, a question was asked, and each member of the focus group had an opportunity to share their perspective. Notetakers were present from the Regeneration Station team to ensure oral responses and inter-group dynamics and interactions were accurately recorded. Questions covered such topics as: main motivations behind pursuing regenerative agriculture, biggest challenges in regenerative management, biggest barriers to entry for regenerative management, biggest challenges behind certification adoption, and feedback on certifications comparison pamphlet content/design.

Certification Comparison Handout

We synthesized the information gathered through the review of certifications into a simplified handout, with the goal of providing a high-level comparison across the four certifications to parties interested in pursuing certification. The handout is a tri-fold document that provides a high-level overview of each of the four certifications to assist land managers in identifying which certification is best for them. The information is targeted to land stewards with an interest in regenerative ranching or those already ranching with regenerative methods who may be seeking third-party certification. We developed twelve iterations of the handout after receiving feedback from the WBLT and Regeneration Station team members to ensure aesthetic attractiveness and valuable content selection. We then included targeted feedback from current land stewards and prospective land stewards interested in regenerative ranching via focus groups. We sent the finalized handout to the representative contacts from each certifying body for their final opinions and incorporated their feedback.

VI. Results

A. IrriWatch

Ground Truthing IrriWatch Precipitation Data

The pattern of precipitation recorded in IrriWatch closely matches the pattern of precipitation recorded at the Lompoc rain gauge (Figure 5). However, some IrriWatch storm magnitudes were substantially larger than those in Lompoc, leading to an approximately 7-inch difference in water year total. The JCR rain gauge was not measured often enough to record small rain events, but major events recorded correspond to the events recorded at the Lompoc gauge and by IrriWatch. JCR recorded smaller storm magnitudes in December 2021 than IrriWatch did, but larger magnitudes in spring and fall of 2022.

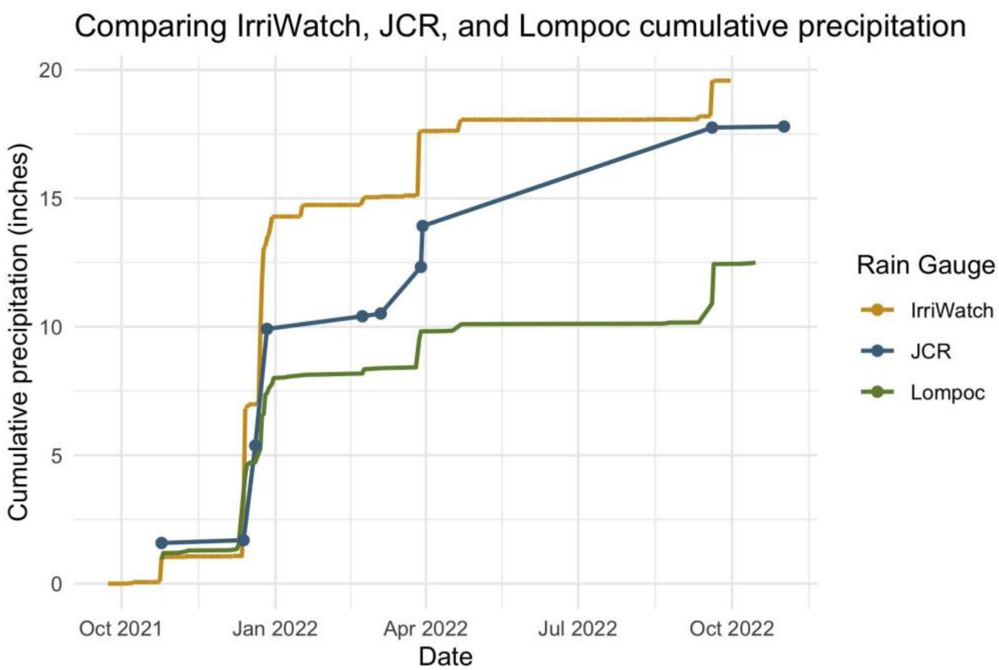

Figure 5. Comparison of cumulative precipitation among IrriWatch estimates and rain gauges from JCR and Lompoc.

Spatiotemporal Patterns in Evapotranspiration and Soil Moisture root zone

Evapotranspiration

Summary Statistics: Spatially, we observed that differences in habitat types result in a slight difference in the distribution of evapotranspiration levels (Table 1) (Figure 6). The highest evapotranspiration rates occur in the riparian oak woodlands (2.20mm) and riparian zones (2.20mm) (Table 1). This is followed by sage scrub habitat, vineyards, grasslands, and orchards. As expected, the region with the lowest evapotranspiration value is the developed area. The distribution of data points is spread over a wide range of values with few observations reaching towards the maximum. This is visually assessed by violin plots that maintain a relatively consistent width across their first, second, and third quartiles (Figure A6). It is important to recognize the difference in observations between each of these habitat types as grasslands have significantly more observations due to the number of grassland fields present across JCR.

Table 1. Daily evapotranspiration (mm) summary statistics across seven JCR habitat types

Habitat	Observations (n)	Mean	SD	Median	Minimum	Maximum
Developed	746	0.69	0.74	0.4	0.0	4.7
Grassland	16785	1.72	1.26	1.5	0.0	6.4
Oak	3357	2.20	1.68	1.8	0.1	8.4
Orchard	373	1.81	1.35	1.4	0.1	6.0

Riparian	1865	1.88	1.73	1.3	0.0	8.7
Sage Scrub	5595	1.51	1.37	1.1	0.0	7.8
Vineyard	746	1.43	1.06	1.2	0.1	6.7

Map Outputs: The areas of two highest evapotranspiration fall in fields categorized by oak and riparian areas (Appendix A7). The westernmost region of the property shows a dramatic contrast between high evapotranspiration from oaks (2.5-3.0 mm) and low evapotranspiration from adjacent grasslands (1.5-2.0 mm). Figure 6 below isolates grasslands fields in order to allow WBLT to visually assess differences across the landscape. The northwest grassland fields have lower mean daily evapotranspiration rates (1.2-1.8mm/day) than regions in the southwest (1.8-2.2mm/day). Three fields in the northeast region of JCR have the highest mean daily evapotranspiration (2.2-2.4mm/day). This map (Figure 6) solely isolates the habitat variable; Figure 7 illustrates each grassland field according to soil type. Looking at the two together, the regions of low mean daily evapotranspiration correlate with grassland fields containing clay soils. Furthermore, the regions with higher mean daily evapotranspiration in the southwest region are dominated by clay loam soils. We include additional statistical analysis on these relationships below.

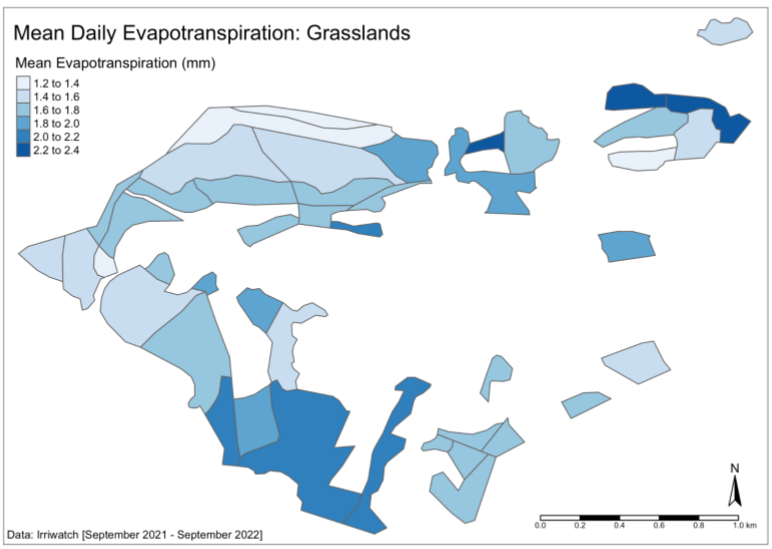

Figure 6. Mean daily evapotranspiration across JCR grassland fields. Each polygon represents an IrriWatch management unit. Light blue regions illustrate a lower mean evapotranspiration, dark blue regions represent a higher mean evapotranspiration.

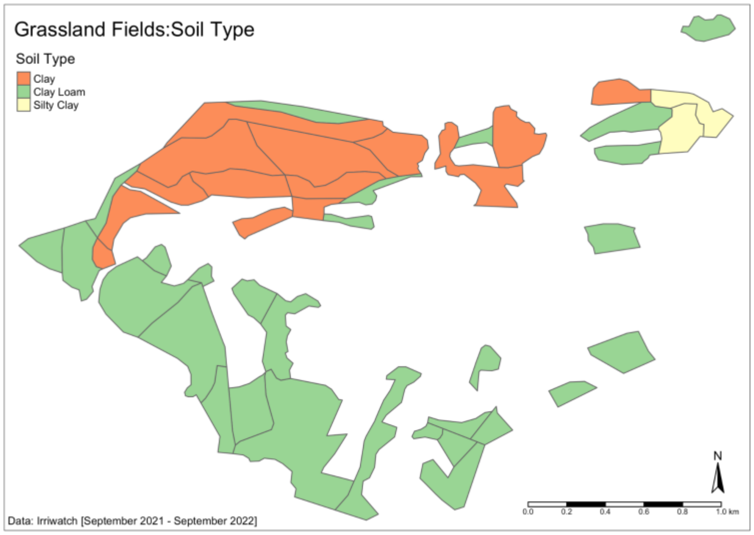

Figure 7. Soil type for each JCR grassland field. Each polygon represents an IrriWatch management unit. Light green regions illustrate clay loam soils, orange represent clay soils, yellow represent silty clay soils.

Time Series Plots: Temporally, we see broadly similar evapotranspiration fluctuations amongst habitat types at JCR (Figure 8)(Figure A8). Minimum evapotranspiration across natural vegetation cover occurs in the winter months (December, January, February). Maximum evapotranspiration occurs between late spring (April, May) and early summer (late June) and begins to decrease in July (Figure 8). Both orchards and grasslands peak slightly earlier in evapotranspiration than other habitat types; that is, they peak in May when the other vegetation classes are peaking in June. Between October and January, there are no habitats which consistently have higher evapotranspiration levels, but between March and May orchards and grasslands have the highest daily evapotranspiration levels, and from May to September oak woodlands have the highest evapotranspiration values.

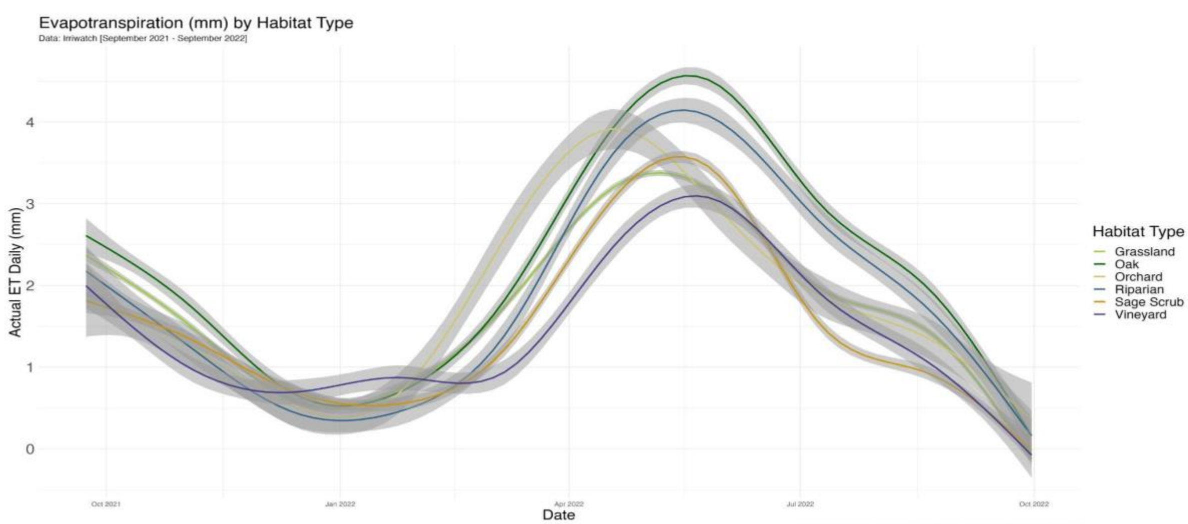

Figure 8. Evapotranspiration (mm) by natural vegetation cover (n = 6). The trend line employed is using a generalized additive model approach to fit a flexible and nonlinear function to the data. The gray bars around the regression line represent the confidence interval of the regression line.

Isolating Variables: In addition to temporal variation, we can break down each habitat type into associated soil types for further analysis (Figure A9). In comparing soil types across evapotranspiration for all fields, we see that sandy loam has higher summer peaks (April through July) than other soil types present. Because of the significant fluctuations in evapotranspiration, we also plotted evapotranspiration trends for each habitat type broken up by soil types, and carried out a specific emphasis on the clay, clay loam and silty clay soils that make up the grasslands in JCR (Figure A10) (Figure A11). Visually, there are similar trends in the overall temporal pattern of grassland evapotranspiration across all soil types, though there is still a fairly wide distribution of values indicating that other factors might explain this variation. Further analysis is carried out below to assess the effect of soil type on evapotranspiration.

Regression Analysis: When comparing the parsimony of four linear models and an intercept-only model by comparing AIC values, we found that the model that included only habitat type and soil type as explanatory had the lowest AIC value (see Table 2 below). We considered including interaction effects but there were insufficient interactions between soil type and habitat type to run this analysis. We conducted Q-Q plots and found that the model residuals were normally distributed.

Table 2. AIC values for evapotranspiration regression models.

Linear Model	**AIC difference from best-performing model**
Intercept Only	2,768.45
Habitat Type + Soil Type + Relative Humidity + Air Temperature	1.79
Habitat Type + Soil Type	0
Habitat Type	125.3
Soil Type	2,640.91

We found that both soil type and habitat type were statistically significant based on the results of an ANOVA test on the regression outputs (the p-value for both variables were $<2.2e-16$). Our Tukey’s test showed that all habitat types were statistically significantly different from each other in their effect on soil moisture except for orchard and grassland, riparian and orchard, and vineyard and sage scrub, which were not significantly different from each other (see Table A12). Among soil types, we found that clay is significantly different from the other three soil types, but they are not significantly different from each other except for silty clay and clay loam (see Table A13).

We ran an effects analysis to visualize the effect of soil type and habitat type on daily ET (Figure 9). Oak is clearly associated with the highest evapotranspiration. Grassland, orchard, and riparian are in the middle, and according to Tukey's test, orchards are not significantly different from either grassland or riparian. Sage scrub and vineyard are associated with the lowest daily evapotranspiration and are not statistically significantly different from each other according to Tukey's test.

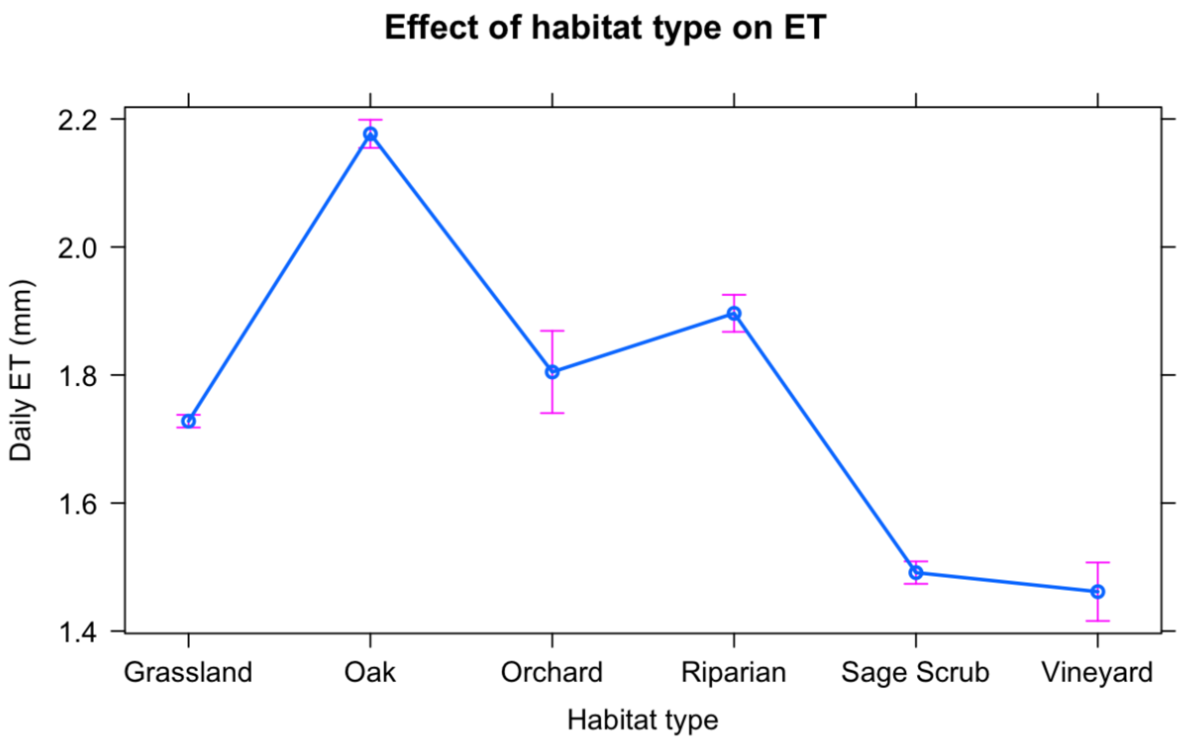

Figure 9. Effects plot of mean ET by habitat type.

Among the soil types, clay is correlated with the lowest evapotranspiration (Figure 10). Sandy loam and silty clay are associated with the highest evapotranspiration values and are not significantly different from each other according to Tukey's test. Clay loam is in between these two groups. According to Tukey's test, clay loam is significantly different from clay and silty clay but not clay loam.

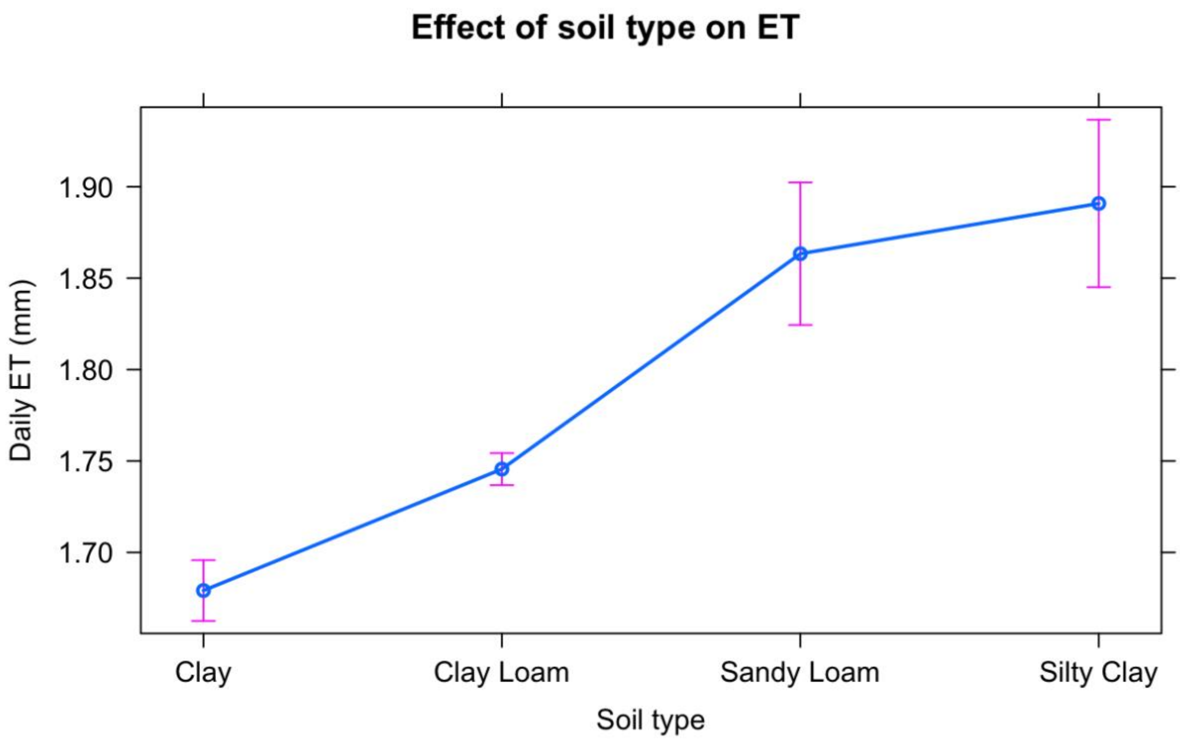

Figure 10. Effects plot of mean ET by soil type.

<u>Soil Moisture Root Zone</u>

Summary Statistics: We observed that differences in habitat types result in subtle differences in the mean and distribution of evapotranspiration levels (Table 3). The difference between the highest mean value for soil moisture root zone in grassland fields only differs 0.05 cm3/cm3 from the lowest mean value for soil moisture root zone in developed or sage scrub fields (Table 3). The distribution of observations is more concentrated in the vineyard and developed fields, illustrated by a small standard deviation (0.03) (Table 3) and visualized by a higher density of observations near the mean value in the violin plots (Figure A14). We analyze spatial and temporal fluctuations in soil moisture across vegetation types and soil types below.

Table 3. Soil moisture root zone summary statistics across seven JCR habitat types.

Habitat Type	Observations (#)	Mean	SD	Median	Minimum	Maximum
Developed	746	0.15	0.03	0.14	0.13	0.30
Grassland	16785	0.20	0.06	0.19	0.09	0.46
Oak	3357	0.17	0.05	0.04	0.04	0.35
Orchard	373	0.17	0.05	0.12	0.12	0.36
Riparian	1865	0.19	0.04	0.13	0.13	0.35

Sage Scrub	5595	0.15	0.05	0.04	0.04	0.35
Vineyard	746	0.17	0.03	0.13	0.13	0.31

Map Outputs: A map of mean soil moisture root zone can be found in Figure A15 which illustrates a fairly distinct spatial pattern. Regions of high soil moisture (0.20-0.25 cm3/cm3) are found in the southwest regions of JCR and much of the rest of the JCR falls into the moderate category (0.15-0.20cm3/cm3). These results can also be visualized in Figure 11 below which isolates solely grasslands fields. When analyzing mean soil moisture in relation to soil type, the southwest regions which have higher soil moisture correlate with grassland fields having clay loam soils (Figure 8). We carry out additional analysis below to partition based on other variables such as soil type.

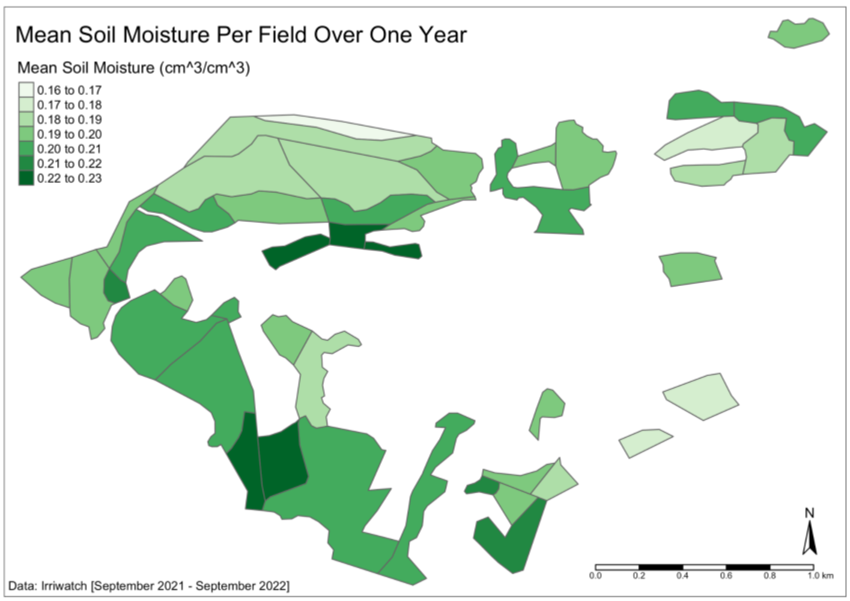

Figure 11. Daily mean soil moisture (cm3/cm3) for grassland fields within the JCR property. Each polygon represents an IrriWatch management unit. Light green regions illustrate a lower mean soil moisture, dark green regions represent a higher mean soil moisture.

Time Series Plots: Like evapotranspiration, we see similar temporal fluctuations in soil moisture root zone amongst habitat types at JCR. Soil moisture root zone spikes in December and across the months of April and May (Figure 12) (Figure A16). While the initial spike in soil moisture root zone for grasslands falls in line with the other habitat types, soil moisture root zone spikes ahead of other habitat types during the spring. Among habitat types, sage scrub consistently has lower soil moisture than the other habitat types (Figure 13) (Table 2). Between January and April, grasslands have the highest soil moisture of the habitat types. Grasslands are neither significantly nor consistently higher in soil moisture than other habitat types at other times of the year.

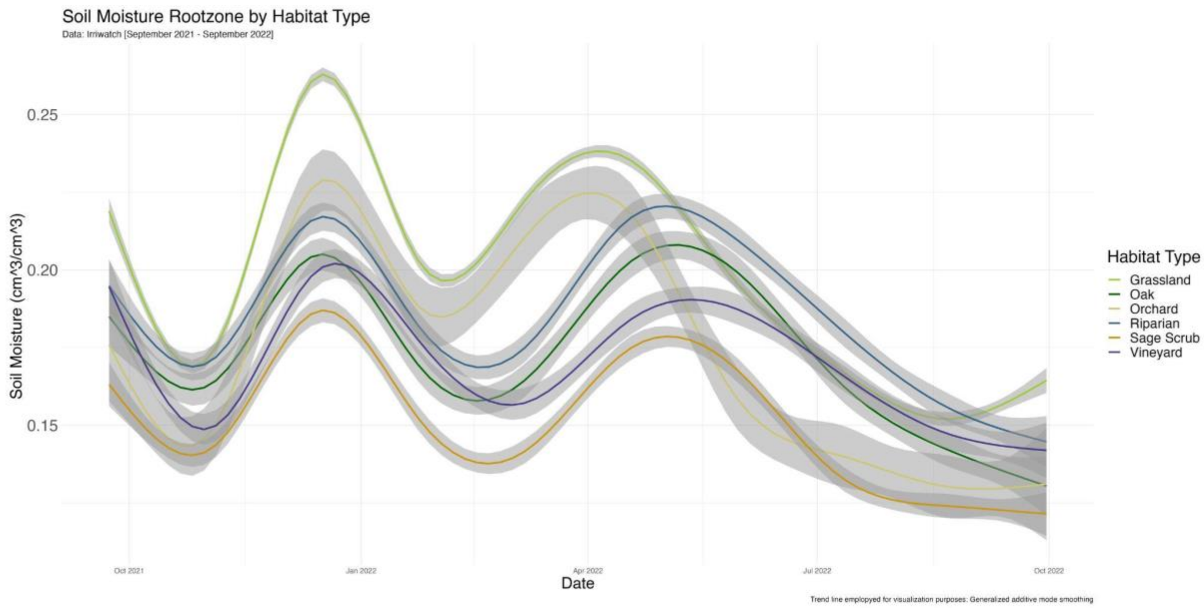

Figure 12. Soil moisture root zone (cm3/cm3) by natural vegetation cover (n = 6). The trend line employed is using a generalized additive model approach to fit a flexible and nonlinear function to the data. The gray bars around the regression line represent the confidence interval of the regression line.

Isolating Variables: In addition to this temporal variation, we also see spatial variation across fields as represented by different habitat types and soil types. Due to the overlapping nature of this data, we took the average of each habitat type to show the change over time and response to rain events. To simplify visualization, we focus on the four prominent habitat types at JCR: oaks, riparian, sage scrub, and grasslands. Grasslands appear to have larger increases in soil moisture after precipitation events than other habitat types. The line graphs below show clear spikes in soil moisture following precipitation events over 1.5 inches (Figure A13).

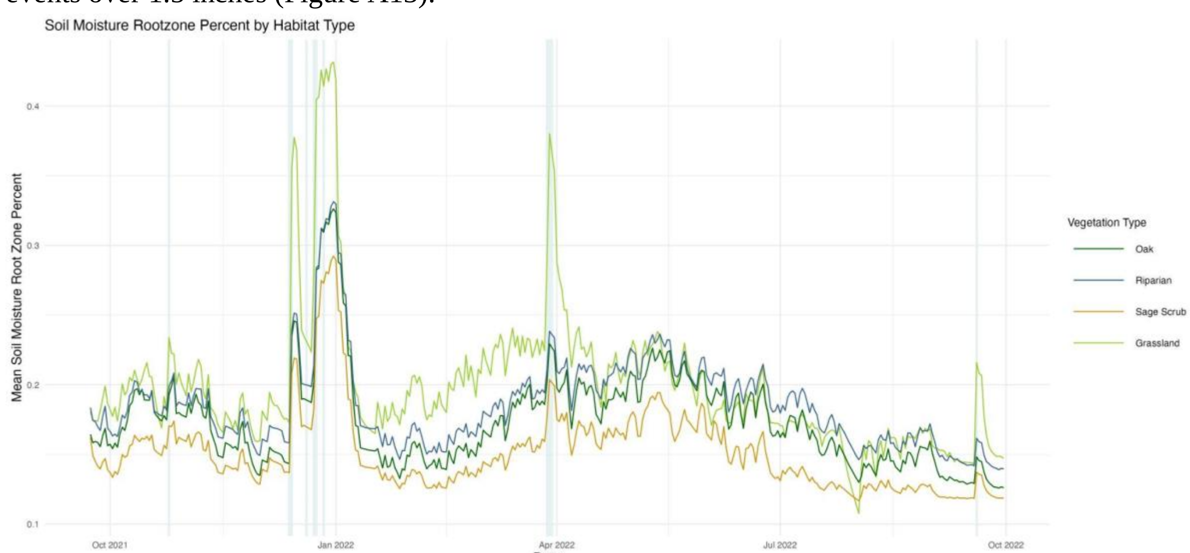

Figure 13. Soil moisture root zone percentage by vegetation cover across time. The vertical bars indicate rain events over 1.5" in magnitude.

Among soil types, sandy loam fields have significantly lower mean soil moisture than the other soil types at all times of the year (Figure 14).

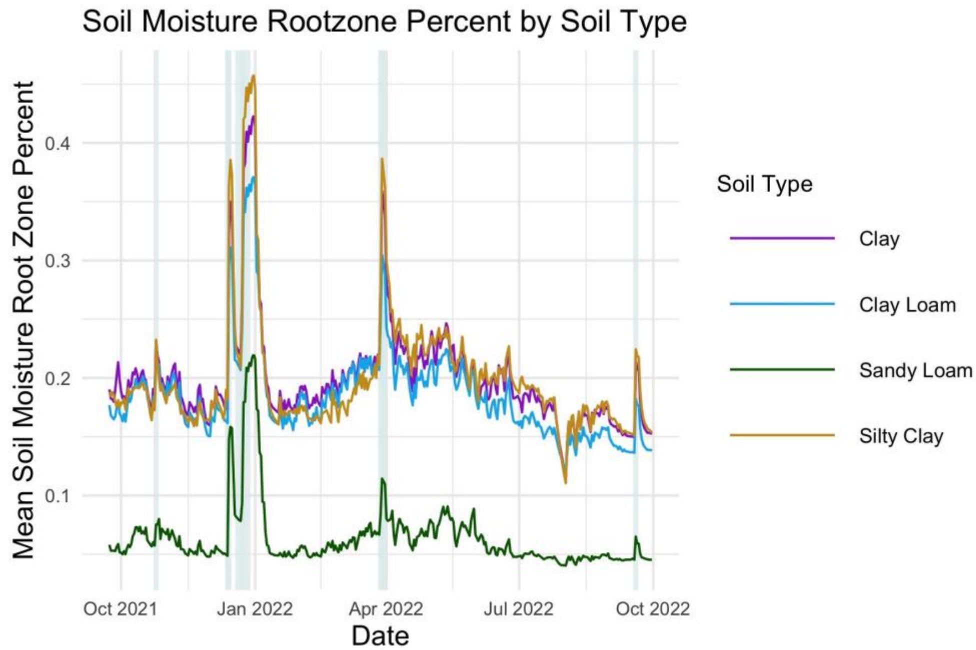

Figure 14. Soil moisture root zone percentage by soil type across time. The vertical bars indicate rain events over 1.5” in magnitude.

Regression Analysis: When comparing the parsimony of four linear models and an intercept-only model using AIC values, we found that the model that included only habitat type and soil type as explanatory had the lowest AIC value (see Table 4 below). We considered including interaction effects, but there were insufficient interactions between soil type and habitat type to run this analysis. We conducted Q-Q plots and found that the model residuals were normally distributed.

Table 4. AIC Values for Soil Moisture Linear Models

Linear Model	AIC difference from best-performing model
Intercept Only	24,696.1
Habitat Type + Soil Type + Relative Humidity + Air Temperature	2
Habitat Type + Soil Type	0
Habitat Type	15,591.3
Soil Type	6,447

Overall, we found that both soil type and habitat type were statistically significant based on the results of an ANOVA test on the regression outputs (p-value <2.2e-16). Our Tukey’s test demonstrated that all habitat types were statistically significantly different from each other in their effect on soil moisture, except for oak, vineyard, and orchard, which were not significantly different from each other (Table A17). Among soil types, we found that sandy loam was significantly different from clay, silty clay, and clay loam, but these latter three soil types were not significantly different from each other (Table A18).

We also ran an effects analysis to visualize the effect of soil type and habitat type on soil moisture root zone percent. Among the habitat types that were significantly different from each other, grassland is clearly associated with the highest soil moisture, oak/orchard is in the middle with riparian, and sage scrub is correlated with the lowest levels of soil moisture (Figure 15). Vineyard is also correlated with low soil moisture but was not found to have a statistically significant difference from oak and orchard in the Tukey's test.

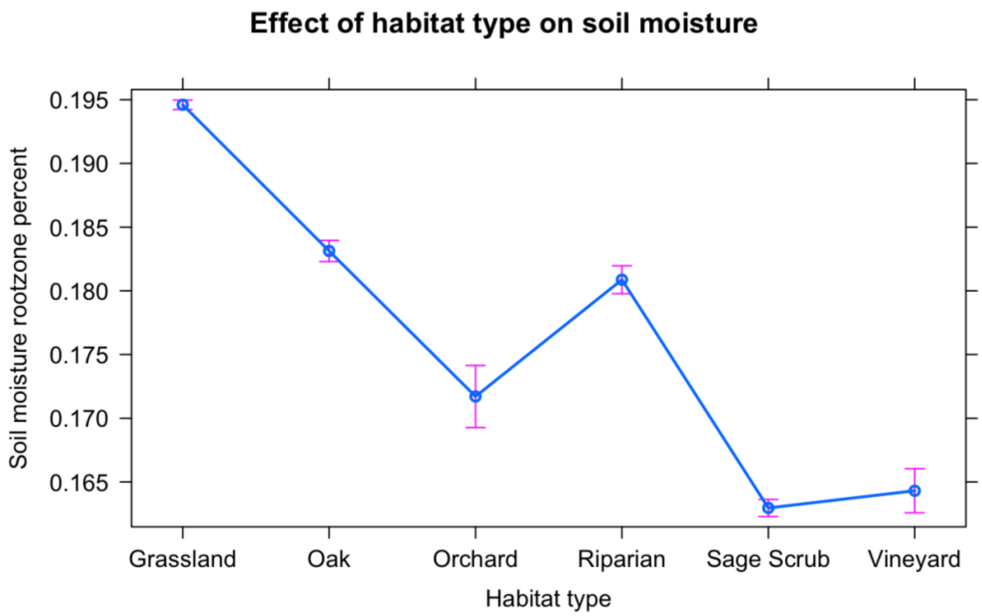

Figure 15. Effects plot of mean soil moisture by habitat type.

Among the soil types, sandy loam is correlated with substantially lower soil moisture than the other three soil types—approximately 8% vs. 19% (Figure 16). The three Clay soil types were not significantly different from each other as seen in both the effects plot and the Tukey's test.

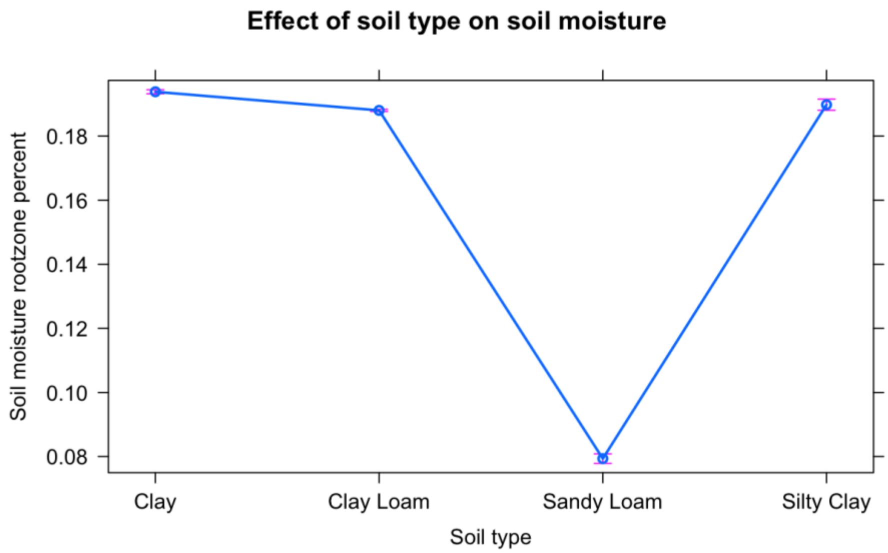

Figure 16. Effects plot of mean soil moisture by soil type.

Differences in Evapotranspiration and Soil Moisture across Pastures

Based on our analysis, no pasture consistently had the highest or lowest soil moisture or evapotranspiration across the meteorological four seasons (Figure 17, Figure 18, Table 5, Table 6). However, except in summer when soil moisture was uniformly low, Pasture 4 had the lowest soil moisture and Pastures 1 and 2 had the highest soil moisture across the seasons.

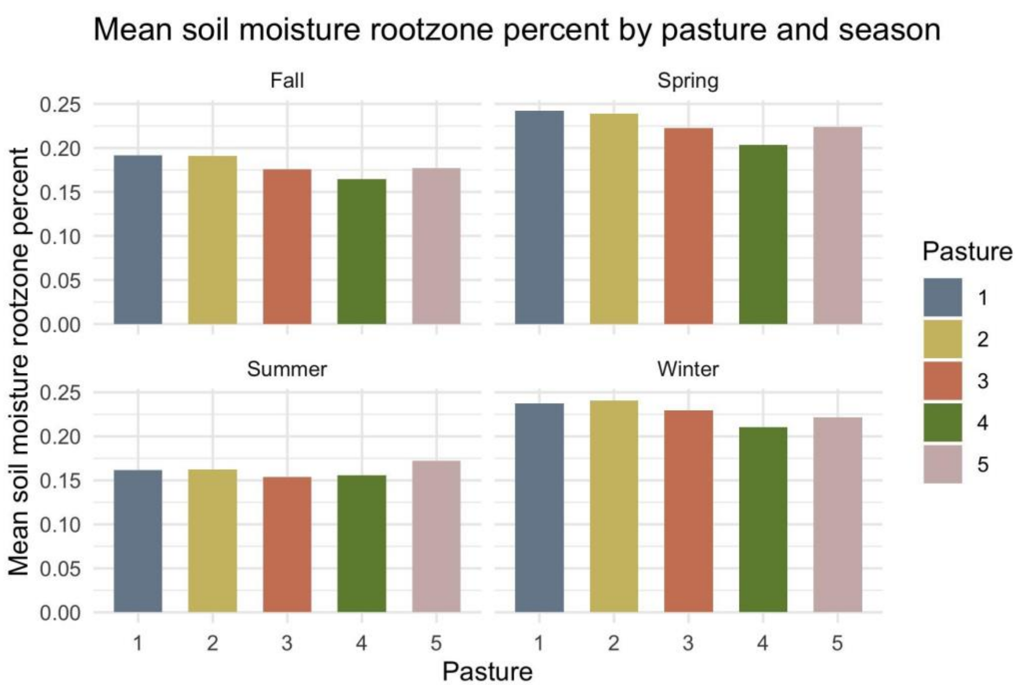

Figure 17. Mean daily soil moisture root zone percentage by pasture and season (cm3/cm3).

Table 5. Mean daily soil moisture root zone percentage by pasture and season (cm3/cm3).

Pasture	Winter	Spring	Summer	Fall
#1	0.237	0.242	0.161	0.191
#2	0.241	0.239	0.162	0.190
#3	0.230	0.223	0.154	0.176
#4	0.210	0.204	0.156	0.164
#5	0.222	0.224	0.172	0.177

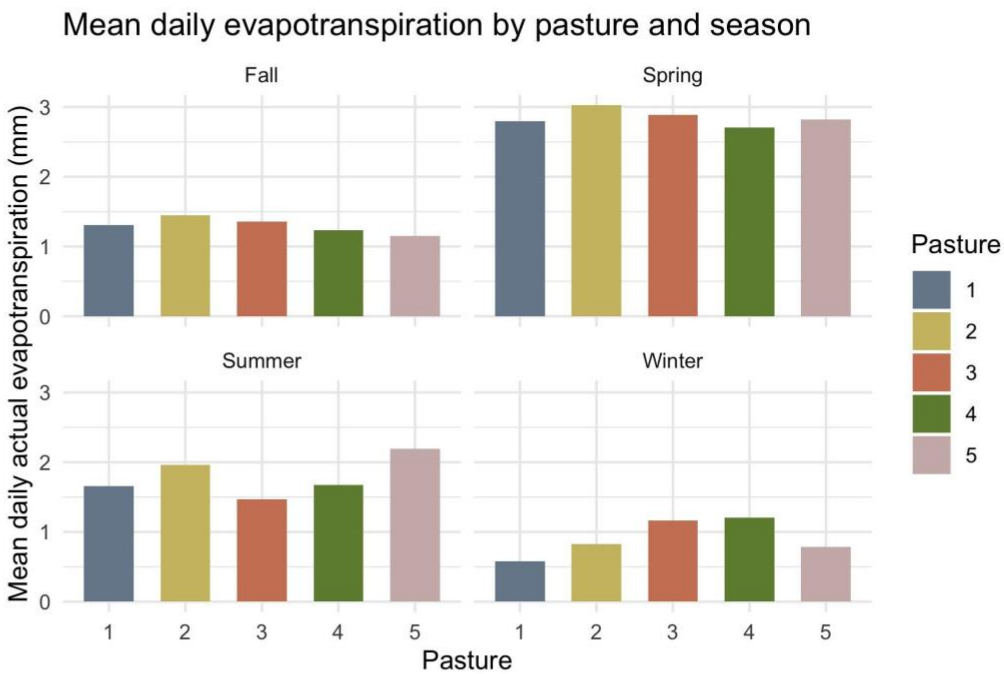

Figure 18. Mean daily actual evapotranspiration by pasture and season (mm).

Table 6. Mean daily actual evapotranspiration by pasture and season (mm).

Pasture	Winter	Spring	Summer	Fall
#1	0.581	2.792	1.655	1.304
#2	0.827	3.022	1.961	1.447
#3	1.162	2.884	1.466	1.359
#4	1.208	2.703	1.677	1.233
#5	0.781	2.822	2.193	1.148

Regression Analysis: According to our linear regression analyses, the best-AIC model included a term for pasture for both soil moisture and evapotranspiration (Table 7, Table 8). We used these models for the remainder of our analysis. We conducted Q-Q plots and found that the model residuals were normally distributed.

Table 7. AIC values for pasture soil moisture root zone linear model.

Linear Model	**AIC difference from best-performing model**
Intercept Only	1,151.19
Pasture	0

Table 8. AIC values for pasture evapotranspiration linear model.

Linear Model	**AIC difference from best-performing model**
Intercept Only	108.1
Pasture	0

We found that overall pasture was statistically significant based on the results of an ANOVA test on the regression outputs in the models for both evapotranspiration and soil moisture (the p-value for pasture was $<2.2e-16$). We found that all habitat types were statistically significantly different from each other in their effect on soil moisture with the exception of oak, vineyard, and orchard, which were not significantly different from each other (see Table A17). Among soil types, we found that sandy loam was significantly different from clay, silty clay, and clay loam, but these latter three soil types were not significantly different from each other (see Table A18).

Our Tukey's HSD tests showed that all pastures were statistically significant from each other in their correlation with soil moisture except for pastures 1 and 2 (Table A19). For evapotranspiration, we found that all pastures were statistically significant from each other except pastures 3-4, 3-5, and 4-5 (Table A20).

The effect plots below show that pasture 4 has the lowest mean soil moisture, pastures 1 and 2 have the highest mean soil moisture, and pastures 3 and 5 are in between (Figure 19 and Figure 20). By contrast, pasture 1 has the lowest mean evapotranspiration and pasture 2 has the highest mean evapotranspiration. Pastures 3, 4, and 5 have mean evapotranspiration between these extremes and are not statistically significant from each other according to Tukey's test.

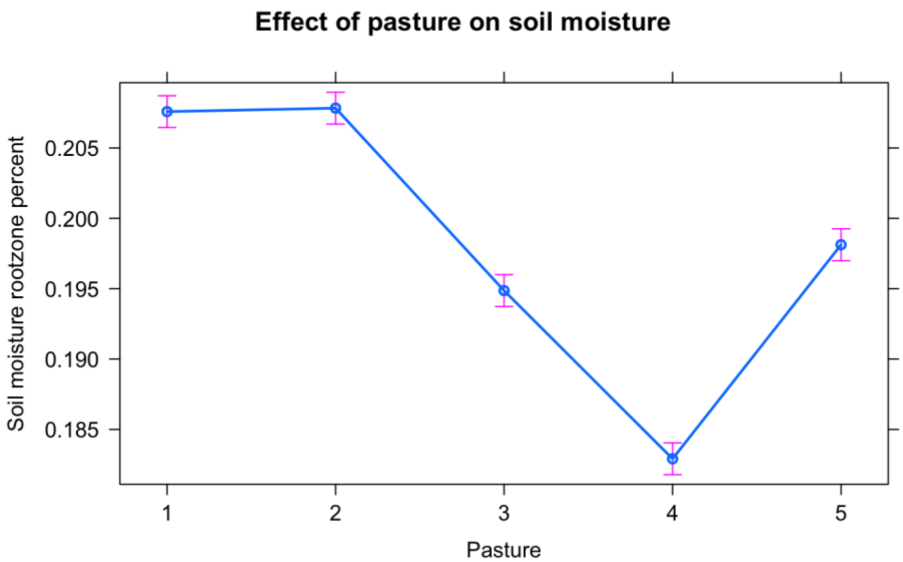

Figure 19. Effect of pasture on soil moisture.

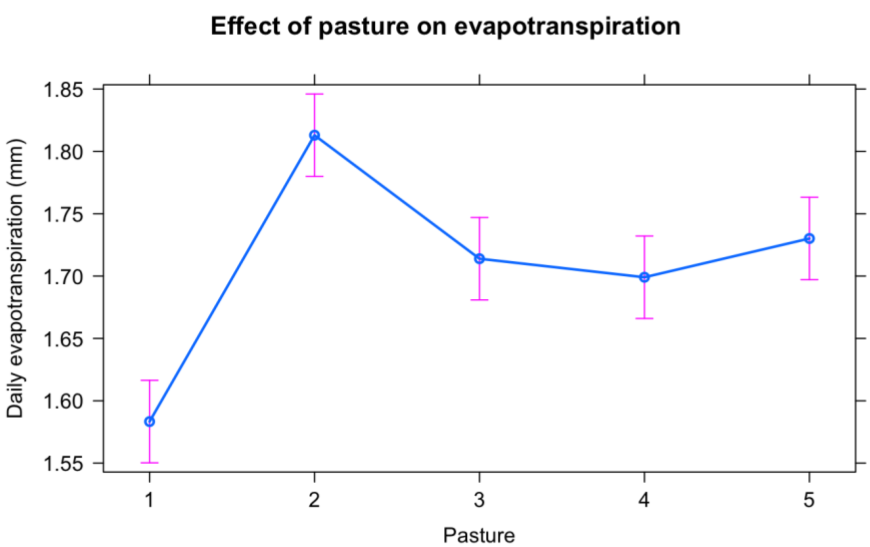

Figure 20. Effect of pasture on evapotranspiration.

Variation in evapotranspiration and soil moisture in response to grazing
The graphs below show the response of mean daily actual evapotranspiration and mean daily root zone soil moisture by pasture to cattle grazing (Figure 21 and Figure 22). There are no clear trends in the data based on a visual analysis.

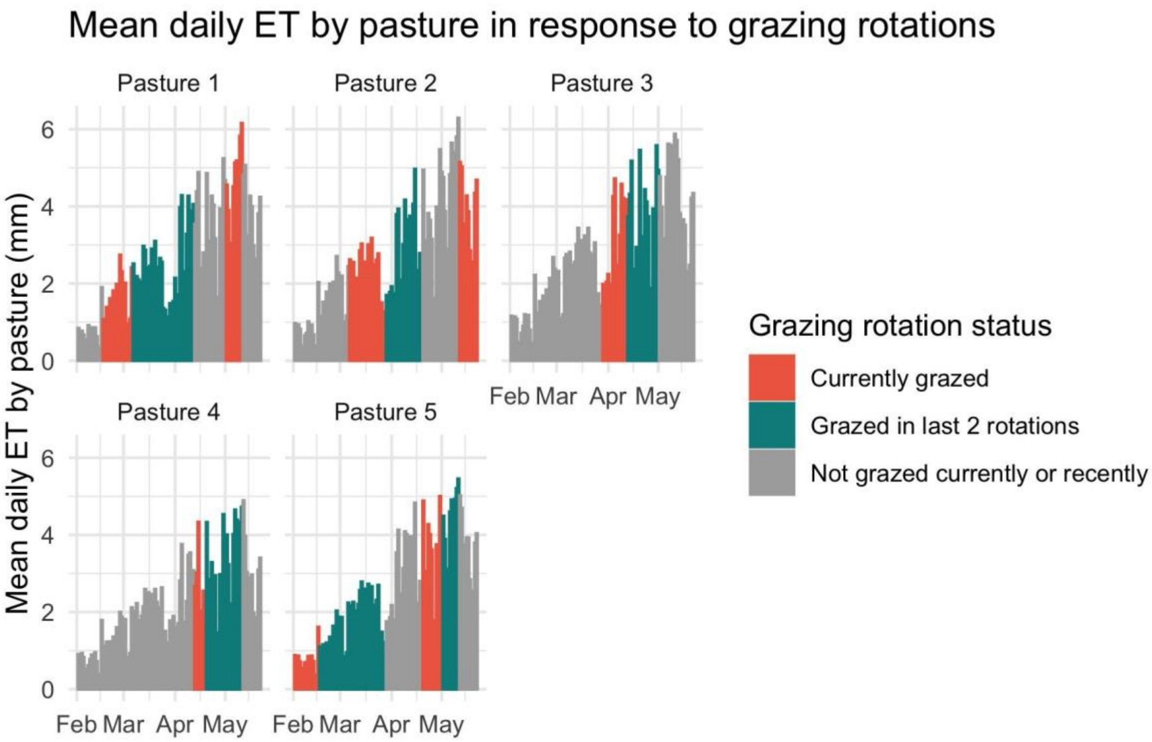

Figure 21. Mean daily actual evapotranspiration (mm) by pasture in response to grazing rotations.

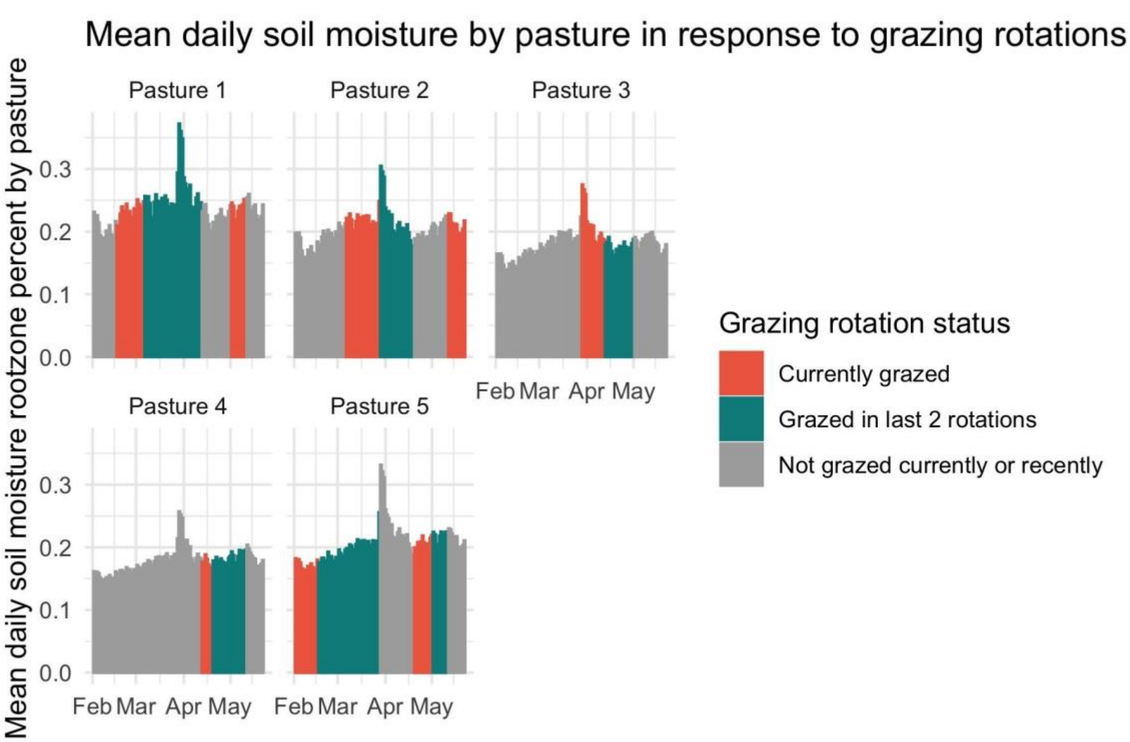

Figure 22. Mean daily soil moisture (cm3/cm3) by pasture in response to grazing rotations.

Regression Analysis: We ran linear regressions on soil moisture and evapotranspiration using grazing status and pasture as explanatory variables and found that the models with lowest AIC values were those that included both grazing status and pasture (Table 9 and Table 10). We also included a variable for "day to capture" temporal differences. We conducted Q-Q plots and found that the model residuals were normally distributed.

Table 9. AIC values for grazing status in the soil moisture root zone linear model.

Linear Model	AIC difference from best-performing model
Intercept Only	1,316.81
Grazing status only	1,273.63
Pasture only	10.76
Grazing status and pasture	0

Table 10. AIC values for grazing status in the evapotranspiration linear model.

Linear Model	AIC difference from best-performing model
Intercept Only	419.88
Grazing status only	392.55
Pasture only	50.65
Grazing status and pasture	0

We ran an ANOVA analysis on the regression models and found that grazing status and pasture were statistically significant in the models for both soil moisture and evapotranspiration. The p-values for pasture were <2.2e-16. The p-values for grazing status were 0.002958 for soil moisture and 4.325e-10 for evapotranspiration.

We then conducted a Tukey's HSD test to determine which categories of grazing status were statistically significant in explaining soil moisture and evapotranspiration. We do not report the significance of pasture because we did so already in a previous section. In the soil moisture model, pastures that were not grazed currently or recently were statistically significant from both pastures that were currently grazed and pastures that had been grazed in the last two grazing rotations (Table 11). However, there was no statistically significant difference between pastures that were currently grazed from pastures that had recently been grazed. In the evapotranspiration model, there was a statistically significant difference between pastures that had been occupied in the last two rotations and pastures that were not grazed currently or recently, but there were not statistically significant differences between the other grazing categories (Table 12).

Table 11. Tukey's HSD results for grazing status and soil moisture.

Pasture Occupancy	**Adjusted P-Value**
Not occupied-Currently occupied	0.0000000
Occupied last 2 rotations-Currently occupied	0.7707733
Occupied last 2 rotations-Not occupied	0.0000000

Table 12. Tukey's HSD results for grazing status and evapotranspiration.

Pasture Occupancy	**Adjusted P-Value**
Not occupied-Currently occupied	0.3396263
Occupied last 2 rotations-Currently occupied	0.6748955
Occupied last 2 rotations-Not occupied	0.0246113

We conducted an effects plot to visualize the effect of grazing status on soil moisture and evapotranspiration. We see that a grazing status of currently being grazed is associated with higher soil moisture than a grazing status of being grazed in the last two grazing rotations or not being grazed recently (Figure 23). According to the Tukey test, currently being grazed is statistically significant from not being grazed recently, but it is not statistically significant from a pasture being grazed in the last two rotations.

We see that a pasture's grazing status of being grazed in the last two grazing rotations is associated with lower evapotranspiration than a grazing status of currently being grazed or not being grazed recently (Figure 24). According to the Tukey's HSD test, a grazing status of being grazed in the last two rotations has a statistically significant difference from not being grazed recently but is not statistically significantly different from currently being grazed.

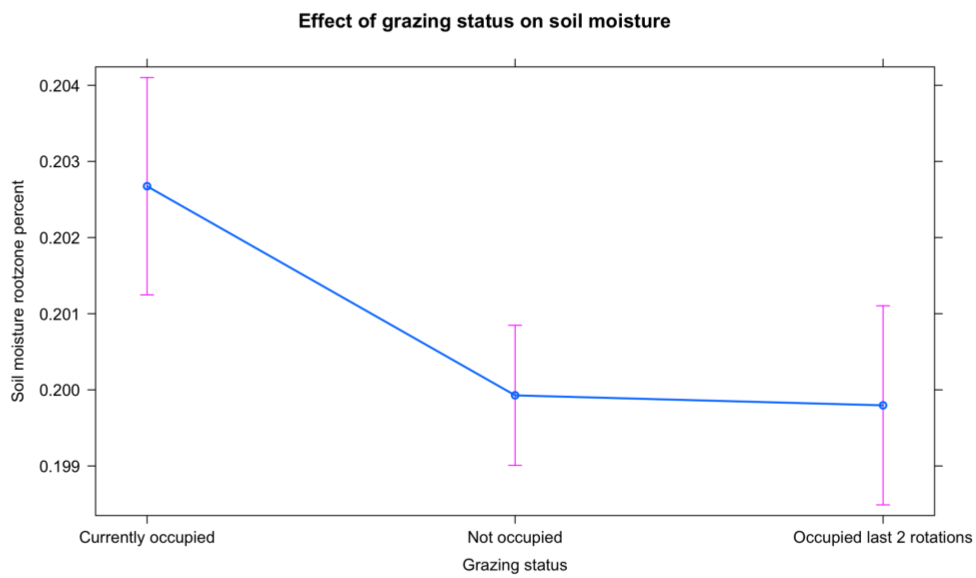

Figure 23. Effect plot of grazing status in soil moisture model.

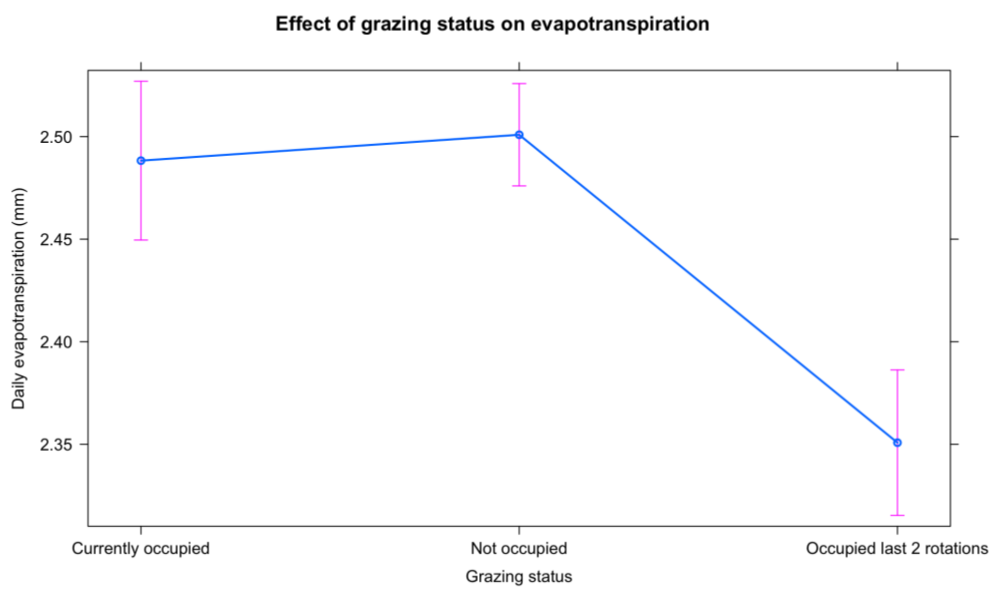

Figure 24. Effect plot of grazing status in evapotranspiration model.

B. Certification Analysis

Each certification required that land stewards report anywhere between 10 and 104 indicators of ecological health. The indicators were grouped into 5 categories: soil health, ecosystem health, general operations and practices, animal welfare, and farmer and worker fairness. These indicators included outcome measures that characterize features such as soil characteristics and biodiversity, process indicators such as using no extractive practices for minerals, as well as equity indicators such as committing to pay workers livable wages. Table 13 shows how many indicators from each certification fall within each category. ROC is the most extensive of the certifications, having the greatest number of indicators in all categories, and with a particular emphasis on social fairness categories: worker fairness and animal welfare. For the “general operations and practices” category, there are 6 indicators in this category for ROC, but the other certifications do have “general operations and practice” requirements. The reason ROC indicators in the “general operations and practices” category were grouped in this way is due to how clear the requirements are written in the standards. The other three certifications are more loosely defined and are made more concrete after enrollment, where the certification bodies work with the land steward to define best practices for their operation.

Table 13. The indicator categories that the 128 indicators are grouped in and how many indicators from each category are required for each certification.

Indicator category	SCI Farm-level Commitment	Regen Network	EOV Savory Institute	ROC
Soil health	10	7	16	24
Ecosystem health	3	3	9	11
General operations and practices	0	0	0	6
Animal welfare	0	1	0	24
Farmer and worker fairness	0	0	0	40

We found little overlap across certifications (Table 14); in fact, land stewards would need to measure a total of 128 indicators in order to attain all four certifications (Table A21, indicator matrix). There are only 18 out of 128 indicators that overlap across more than one of the certifications analyzed (Table 14). There are only 3 of the 18 overlapping indicators required by all 4 certifications: *soil bulk density*, *organic carbon,* and *soil nitrogen*. Table 6 shows that *water infiltration* is the only overlapping indicator that is an in-field test (required by 3 of the 4 certifications), while *synthetic chemicals* and *existing certifications* are documentation that reflect management practices (required by 2 of the 4 certifications).

Table 14. The indicators that are required by more than one certification.

Ecological Indicator	Number of Certifications
Soil Bulk Density (hardness/compaction)	4
Organic Carbon	4
Soil Nitrogen	4
Soil Aggregate Stability	3
Soil Micro/Minor Nutrients	3
Soil Microbial Activity and Community	3
Soil pH	3

Water Infiltration (*in-field test*)	3
Bare Soil Index (BSI)	2
Haney Soil Health Test	2
Living Organisms in Soil	2
Soil Active Carbon	2
Soil Cation Exchange Capacity (CEC)	2
Soil Phosphorus	2
Soil Texture	2
Soil Water Holding Capacity	2
Synthetic Chemicals (*documentation*)	2
Existing Certifications (*documentation*)	2

We also found that there is no overlap between sampling protocols, both in terms of required sampling timelines and sampling parameters. Each certification requires soil sampling at different intervals across varying timespans. For example, while SCI requires annual soil sampling over a 10-year period, Regen Network CarbonPlus requires only 4 samples in the 10-year timeframe. Additionally, there are differences in required sampling parameters, with ROC requiring samples taken at 6 inches depth and EOV requiring samples at 12 inches depth. These differences across certification lead us to conclude that there is little opportunity for ranchers to effectively overlap ecological indicator sampling to pursue more than one certification at a time.

Finally, we identified 18 indicators that might be measured via remote sensing (Table 15). Unfortunately, none of the indicators required by the four certifications we analyzed can be measured via IrriWatch.

Table 15. Indicators included in the indicator matrix that can potentially or certainly be measured via remote sensing according to peer reviewed studies.

Ecological Indicator	Ability to Measure via Remote Sensing
Bare Soil Index (BSI)	Yes
Crop Rotations	Yes
Live Canopy Abundance	Yes
Normalized Difference Vegetation Index (NDVI)	Yes
Production of contextually desirable Functional Groups (FG): Warm season grasses Cool season grasses Forbs and legumes Trees and shrubs	Yes

Vegetation Structure	Yes
Vegetative Cover	Yes
Ground Cover	Yes
Water Erosion	Yes
Rotational Grazing	Potentially
Soil Carbon	Potentially
Litter abundance	Potentially
Wind Erosion	Potentially
Field Farm Assessment of Biodiversity	Potentially
Contextually Desirable Species	Potentially
Contextually Undesirable Species	Potentially
Additional Regenerative Practices: 5 or more practices beyond those listed in USDA NOP (section 2.8) present in operations.	Potentially

The major categories shown in Table 16 and 17 are the areas in which information differs significantly. Table 16 shows all the categories from the comprehensive overview which include the following rows:

- "Enrollment Requirements" discusses the percentage of a farming operation that must be enrolled during initial application as well as the management practices required at the time of application on the enrolled land. It also describes the increase in the percent of land enrolled and how many years this 1st increase must occur within.
- "Land Steward Goal" states at a high level what the certification accomplishes so land stewards have a quick orientation as to which certification does what.
- "Certification Guidelines" describes if a certification is practice-based or outcome-based, where a certification either requires positive trends in the measurements required (*outcome-based*) or measurements are taken to inform the land steward but there are no requirements for positive trends, rather, as long as the land steward is implementing the required practices, they qualify for the certification (*practice-based*). It also describes the overall strategy and goals of each certification.
- "Cost - 2023" shows the enrollment cost and any other recurring costs that could be expected.
- "Benefit" lists the benefits that are included with the certification. There is no information on revenue increases with a certification due to the infancy of the certifications.
- "Soil Tests Done by" states who is responsible for taking the required soil tests.
- "Soil Sampling Protocol" discusses the required samples that must be done. This includes field tests and soil samples, as well as if the number of soil samples is based off acres or not. ROC and EOV both require representative sample areas be chosen for testing throughout the certification process. EOV and ROC representative sample areas do not increase directly with acreage,

whereas Regen Network and SCI sample numbers are directly correlated to the number of acres enrolled.

- "Soil Sample Required" is simply an example of how many soil samples would be required for 100 acres of land enrolled for each certification. Each soil sample must have 3 subsamples taken as described in the methods for the certifications.
- "Timeline" describes the sampling timeline for soil samples and in-field samples. In-field samples are mostly observational with a few exceptions, but the in-field tests take less time to perform and are required more regularly than soil samples.

The comprehensive overview of certifications is compiled in an excel spreadsheet. Table 16 shows the 1st tab of the comprehensive overview excel spreadsheet and lists key differences across certifications, however the comprehensive overview provides further detail showing their required indicators and specifics on measurement methods and timeline.

Table 16. Comprehensive certification overview (Tab 1 of 5) of the 4 certifications on requirements.

Certification Comparison Overview				
Key Components	**SCI Farm-level Commitment**	**Regen Network**	**EOV Savory Institute**	**ROC**
Enrollment Requirements	Land enrolled: Decided by Land steward; must reach 25% by end of year 3; Current management: Ranch does not need to currently use regenerative practices to enroll.	Land enrolled: Decided by land steward, may increase over time; Current management: must be managed with regenerative practices across enrolled land.	Land enrolled: entire ranch; Current management: must be managed with regenerative practices across land.	Land enrolled: 10% (minimum) of operation with annual increase in % enrolled; Current management: organic (or equivalent) & animal welfare certification. Documentation of social fairness required.
Land Steward Goal	Transition land from standard practices to regenerative practices by creating and following a commitment plan.	Earn carbon credits with third party verification. Credits can be sold/traded through Regen Network platform.	Gain third party verification for measurable improvements (in biodiversity, soil health, & ecosystem function) from regenerative practices.	Obtain highest standard third party verified certification that builds off certifications in social fairness, animal welfare, USDA organic or equivalent.
Certification Focus	Practice based: Measure key outcomes from commitment plan practices, such as: reduce soil disturbance, maintain living groundcover, livestock integration, maximize diversity. Key outcomes do not have to be	Outcome based: Measure soil carbon stock increases on land with high resolution satellite imagery & samples; Also, monitor co-benefits in soil health, animal welfare, ecosystem health.	Outcome based: Test for positive trends on the land to gain a regional land health score; this score must continue to improve every year by looking at long term monitoring and short-term monitoring sites.	Practice based: Bring farm beyond organic standard and increase regenerative practices to reach gold level ROC. Practices include reduce soil disturbance, crop rotation, rotational grazing, promote native

	achieved, rather, farmer engages in commitment plan.			biodiversity, etc.
Cost 2023	Enrollment cost: currently waived for founding farmers. Founding farmers are currently providing feedback on the certification process to aid in the development of this certification Soil Lab fees: costs covered and are planned to be covered in the foreseeable future	Enrollment fee: $0 Soil Lab fees: based on # of samples	Enrollment cost: $13,500 Average annual fee: $4,325	Enrollment cost: $600-1750 Annual fee: 0.1% revenue Inspector fee: ~$2,000/yr (this is the cost of having an auditor flown out to farm and for hotel cost) Social fairness fee*: $500-$1000 *If your farm does not yet have a social fairness certification
Benefit	Planning and guidance on transitioning your ranch and creating a commitment plan, dividends per acre, gain connection to product purchasing companies	Earn carbon credits for regenerative practices; provided with a customized online platform to trade and sell credits	Products advertised on Land to Market (purchaser must pay for the land to market verified label); access to coaching & implementation support from regional Savory Hubs.	Receive premium product label, sliding scale provides flexible commitment level, scholarships available, acquiring organic certification streamlines ROC application/audits
Soil Test Done by	Done by Farmer; can be contracted out	Done by Farmer; can be contracted out	Done by EOV monitor; farmer can become an EOV monitor with training	Done by farmer, can be contracted out
Soil Sampling Protocol	Based on number of acres enrolled; in-field tests are also required	Based on number of acres enrolled as well as the soil variability; Regen Network only asks for soil samples (no in-field observational tests)	Standard amount of sampling sites. There are a minimum of 10 short-term monitoring sites for in-field tests and a minimum of 1 long-term monitoring site on a small farm and up to 12 on a large, heterogeneous farm. Long-term monitoring sites require soil sampling.	Standards amount of sampling sites. Typically, 3 sites are chosen to be representative of the farm. 1 site for lowest quality field/block, 1 site for average representative field/block, and 1 for the highest quality field/block. These three locations are used for infield tests and for soil sampling sites.

Soil Samples Required (based on 100 acres)	11 samples	26 samples for low variability land 36 samples for high variability land	1-2 soil samples for each long-term monitoring site	3 samples

Table 17 shows some of the categories that the comprehensive overview is broken down into in our certification comparison handout. The table highlights key areas where information differs between the certifications. Through multiple rounds of feedback from stakeholders, certification representatives, and WBLT, we determined that the key high-level characteristics that need to be presented to land stewards encompass enrollment requirements, certification guidelines, soil and sampling, cost for 2023, and benefits which are listed in Table 8 and areas with major differences are described.

Table 17. Describes the areas that differ significantly between certifications.

Categories on Handout	Major differences
Enrollment Requirements	* Percentages of land required to be enrolled in the program to begin the certification process. * Land percentage increases that are required through a 10-year period. * Current management practices required at time of enrollment (does the land need to be managed regeneratively or not) and the increase of regenerative practices on the land enrolled.
Certification Guidelines	* Practice-based vs. outcome-based as well as the overall goals/practices used for each certification
Soil and Sampling	* The number of samples differ from certifications. In some, the number of samples increases with the number of acres enrolled while in others, samples are less dependent on acreage. For “large” farms, the sample number may increase slightly. This results in far fewer soil samples. * The timeline on soil samples differs greatly between certifications. Some certifications require soil samples every year and others only 3 times in a 10-year period. * Some certifications require both soil and in-field samples (mostly feel and visual tests) while the Regen Network certification only requires soil samples.
Cost - 2023	* Some certifications have enrollment fees waived, or there is a dividend that the land steward receives upon certification, whereas others charge for audits/sampling as well as enrollment fees and percentages of revenue.
Benefits	* Benefits can include labels, support implementing regenerative practices, and carbon credits. Benefits range widely and are an important consideration for land stewards to take terms of tangible benefits. * The main goal of all certifications is to increase land health over time and is a shared goal across all the certifications and is therefore not listed in the comprehensive overview, nor the simplified overview.

C. Stakeholder Communications

Focus Groups

We synthesized the responses of focus group participants into four broad categories: motivations behind pursuing regenerative agriculture, barriers to entry, challenges faced, and financial efficacies of certification (Table 18). The two groups had striking differences in all four areas.

Table 18. Highlighted differences in responses to questions from focus groups from the experienced ranchers and the group new to the regenerative space.

Questions	Experienced Ranchers	New to Regenerative space (not all ranchers)
Motivations behind pursuing regenerative agriculture	● Increase health of land for generational impacts ● Create more nutrient-rich food for personal health	● Care about solutions to climate change; health of the planet
Biggest barriers to entry	● Financial requirements too expensive ● Labor requirements too intense ● Lack of resources to verify efficacy of management practices	● Financial requirements too high ● Revenue increases are unknown, perhaps not worth it ● Most regenerative resources are for larger farms, doesn't make sense for smaller hobby farms
Largest challenges faced	● Convincing neighbors of efficacy ● Work-life balance ● Finding public land to graze ● Combating systemic barriers (viniculture)	● Overcoming costs of entry ● Certification "fatigue" ● Unknown benefits
Financial Efficacies of Certifications	● Suspect of certifications benefiting their own operation ● No market for certified products in rural areas ● Too expensive to justify pursuing	● Suspect of certifications supporting the growth of a movement in the regenerative space ● No data on financial benefits for certifications.
Handout Feedback	● Handout is concise and has good information; a few aesthetic improvements would be good. ● Interested in more resources to gain knowledge on methods.	● Too much information; interested in making the handout more compelling to sell the certifications ● Make them look more appealing to the reader

Experienced Land Stewards:
The main motivations behind pursuing regenerative agriculture for experienced land stewards were focused primarily on the health of their families and their land. Many of the stewards wanted to pursue regenerative agriculture to ensure the health of their land for generational development to give the land to their children. Additionally, they desired to improve their own physical health by growing and eating nutrient-dense, regenerative foods. Lastly, another main motivation was to maintain higher stocking rates and increase biodiversity on their lands.

The biggest barriers to entry for regenerative management for the experienced land stewards aligned with the hypothesized barriers from the Regeneration Station team. First, the financial requirements are too expensive to justify transitioning to regenerative management models. Similarly, labor requirements and equipment upkeep are too intense and costly. On top of the costs associated with the transition to regenerative management, experienced land stewards found that the lack of resources available to verify the efficacy of regenerative management practices make it difficult to assess the potential return on investment. These three factors were the biggest barriers to entry for experienced land stewards interested in regenerative agriculture.

Separate from the barriers to entry, the experienced land stewards provided insights into the biggest challenges in currently managing land regeneratively. The biggest challenge stated, in which all stewards agreed, was convincing their neighbors of the validity of their regenerative practices, and building community in the space. Many of them felt isolated in their regenerative management techniques and wished to have a larger community with which to coordinate. Other management challenges included obtaining land access for grazing, procuring, and maintaining necessary fencing materials for rotational grazing, and maintaining financial stability during transitional years.

Lastly, experienced land stewards provided insights into the biggest barriers to adoption of regenerative certifications. They stated that they are suspicious of whether certifications could benefit their own operations, especially due to the lack of market for certified products in their rural townships. Additionally, the certifications have proven to be too expensive to justify the upfront investment.

Beginner Land Stewards
The main motivations behind pursuing regenerative agriculture for beginner land stewards were broad environmental sustainability goals. They were motivated to pursue regenerative management to mitigate climate change, create more resilient food systems for the health of the planet and reduce input costs.

The biggest barriers to entry for regenerative management for beginner stewards was very similar to experienced land stewards. For them, the financial requirements are too expensive, revenue increases are unknown and thus do not justify the initial investments, and lastly, most regenerative resources are for larger farms and do not make sense for smaller properties.

Lastly, the biggest barriers to adoption for regenerative certifications were 1) suspicions of supporting a “movement”, and 2) the lack of data for financial benefits of certifications. Both reasons kept beginner land stewards from actively pursuing regenerative certifications on their properties. Due to the beginner group being at their very early stages of learning and implementing regenerative practices, they did not discuss challenges faced within the regenerative space.

Feedback on Certification Comparison Handout

The beginner group felt the handout was too wordy and was not a convincing communication tool. They were interested in the handout showing results of regenerative practices to convince land stewards of the benefits of having a certification. The beginner group's priority was to solve environmental problems using regenerative agriculture as a tool, whereas land stewards are interested in protecting and healing their own land. The experienced land stewards thought the handout was concise and gave a good introduction to the certifications. They were also interested in seeing more resources regarding regenerative agriculture practices such as a list of books they could read, references to childcare options, resources for financial assistance for pursuing regenerative agriculture, and the addition of free certifications they could pursue, such as the Audubon Bird-Friendly Land Certification. Other feedback included providing a list of properties that are already certified and improving the descriptions of each certification's benefits to ensure maximum steward understanding. This feedback led to a follow up conversation with WBLT to ensure the handout aligned with their goals. They ensured us this was to be an unbiased tool that does not need to convince land stewards to pursue certifications and the handout includes a link to WBLT's new resource page that has resources to explain regenerative practices. Some suggestions from the focus group had to do with simple aesthetics which were addressed for the final handout. On the comprehensive overview excel sheet, we made sure to include links to the certification standards as well as any material from the certifications on methodology for sampling. Due to limited time for this project, we were unable to include a list of organizations and farms/ranches that have obtained these certifications on the comprehensive overview.

This feedback was valuable to ensure that the certification comparison handout is the best available steward-facing tool to inform land stewards of these 4 regenerative certifications. In order to maintain an objective and unbiased stake in this adoption of regenerative management and certifications, the Regeneration Station team has maintained its goal of providing the best available information without the inclusion of our personal goals for regenerative stewardship. This is simply a tool that land stewards interested in regenerative management can utilize to assess whether pursuing certifications is economically and environmentally feasible for their properties.

Certification Comparison Handout

Within each characteristic we identified and briefly summarized key differences between the certifications (Figure 25). This pamphlet is a simplified version of the comprehensive overview and will help land stewards understand the basics and requirements of regenerative agriculture certifications.

	Enrollment Requirements	Certification Guidelines	Soil Sampling & Monitoring	Cost - 2023	Benefits
Farm-Level Commitment Program	**Land enrolled:** Achieve 25% by end of year 3; 75% by end of year 10 **Current management:** Regenerative practices not required to enroll	**Practice-based:** Measure key ecological outcomes determined by commitment plan via adaptive management	**Farmer takes samples based on acreage;** Soil and in-field tests done annually	**Enrollment cost:** currently waived **Soil Lab fees:** costs covered	Planning & guidance, dividends/acre, access to product purchasing companies
Ecological Outcome Verification	**Land enrolled:** Entire ranch **Current management:** No requirements for farming practices, but must farm to measure improvements to land health	**Outcome-based:** Regional land health score determined by positive trends. Must improve annually	**EOV monitor takes samples;** 10+ short-term annual monitoring sites; 1-2 long-term sites (tested every 5 years)	**Enrollment cost:** $13,625* **Average annual fee:** $4,325 **year 1 total costs*	Products advertised on Land to Market, access to implementation & coaching support from regional Savory Hubs
CarbonPlus Grasslands	**Land enrolled:** Decided by land steward, may increase over time **Current management:** Must be managed with or plan to use regenerative practices	**Outcome-based:** Measure increases of soil carbon stocks; monitor co-benefits of soil health, animal welfare, ecosystem health	**Farmer takes samples based on acreage and soil variability;** 3+ soil sample periods over 10 years; No in-field monitoring	**Enrollment fee:** $0 **Soil Lab fees:** based on # of samples	Earn carbon credits for regenerative practices; provided with a customized online platform to trade & sell credits
Regenerative Organic Certified	**Land enrolled:** 10% of operation with annual increase to 50% by year 5 (bronze) **Current management:** Organic certified (or equivalent) & animal welfare certification; social fairness documentation & audit	**Practice-based:** Increase number of regenerative practices and acres enrolled anually to reach gold standard	**Farmer takes samples;** 3 sites: soil tested every 3 years, in-field monitoring annually	**Enrollment cost:** $600-$1,750 **Annual fee:** 0.1% revenue **Inpector fee:** ~$2,000/yr **Social fairness fee*:** $500-$1,000 **if no social fairness cert.*	Receive premium product label, sliding scale provides flexibile commitment level, scholarships available, aquiring organic certification streamlines ROC application/audits

Figure 25. The table developed for the interior of the handout comparing and highlighting major differences between the certifications that would be informative for land stewards. The front cover, 1st page, and back of the pamphlet can be seen in appendix Figure A22.

The target audience for the handout is land stewards that have control over management practices or have a high level of input who are interested in regenerative agriculture and may also be interested in pursuing a certification for practices they hope to implement, or for practices they are already using on their land. The handout was created to be as simple as possible to give land stewards a high-level overview of the 4 certifications WBLT is pursuing. By highlighting major differences and overall structure of the certifications, a reader can gain some insight as to which certification could be of interest.

Through the focus groups, we found from the beginner group that they wanted a more compelling handout that would convince the land steward to pursue a certification. This was not the goal, however. The handout was not designed with the intention to "sell" these certifications, but rather, to create an unbiased comparison for the reader to make a decision that best fits their goals, whether that be to pursue a specific certification, or to not pursue a certification at all. In order to ensure readers are in the right frame of mind when looking at the handout, on the front cover, we added the statement, "An Unbiased Introduction for Pursuing Certifications". This statement will hopefully eliminate the potential for land stewards to dismiss the handout as a sales tool.

VII. Discussion and Conclusions

A. IrriWatch

Effect of Habitat Type and Soil Type on Evapotranspiration and Soil Moisture

Based on our regression analysis and effects plots, we determined that both soil type and habitat type were statistically significant in explaining some variation in daily evapotranspiration and soil moisture root zone levels. Oak woodlands had the highest evapotranspiration levels at JCR, while sage scrub and vineyard had the lowest. Variation in daily evapotranspiration between habitat types can likely be attributed to differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover, crop rooting characteristics, and/or differences in management practices (Allen et al. 1998). For soil moisture root zone, grasslands were associated with the highest values, while oak/orchard and riparian were in the middle, followed by sage scrub and vineyard — results that support the initial summary statistics findings.

Based on spatial visual assessment across grassland fields, soil type had some influence on the distribution of average annual soil moisture root zone and evapotranspiration. More specifically, clay loam occupied the same spatial region within JCR as those fields with a high average annual soil moisture and high average evapotranspiration. After we carried out a statistical analysis to test this hypothesis, we found that sandy loam and silty clay were associated with the highest evapotranspiration values. This differed from the initial visual assessment. Furthermore, across soil types, sandy loam is correlated with substantially lower soil moisture than the other three soil types, which are not significantly different from each other. These results suggest that simply analyzing the annual mean value on a field-by-field basis is not sufficient when determining differences.

Effect of Pastures on Evapotranspiration and Soil Moisture

Based on our analysis, we found that pastures do have an effect on soil moisture and evapotranspiration. Most significantly, pasture 4 has lower mean soil moisture than the other pastures on JCR. This may indicate that pasture 4 is not holding soil moisture as effectively as the other pastures. This could be due to a variety of factors including grass type, slope, aspect, elevation, soil structure, and/or watershed. Given soil moisture root zone is an important factor in determining plant growth and development because it affects the availability of water and nutrients to the plant (Kisekka et al. 2022), these results may support the decision to graze fields within this pasture earlier in the grazing season. Pasture 4 may not supply sufficient soil moisture for overall forage health later into the summer.

Furthermore, it is important to look at the correlations between soil moisture and evapotranspiration. Soil moisture rootzone is directly connected to the process of evapotranspiration because it contains moisture available to potentially evaporate. Soil moisture "is one of the prime environmental variables related to land surface climatology, hydrology and ecology" (Verstraeten et al. 2008). It makes intuitive sense that as soil moisture root zone decreases, some of that decrease is accounted for by an increase in evapotranspiration. High values in both categories may indicate a surplus of water. Pasture 2 stands out as a location within JCR that ranks highest for both evapotranspiration and soil moisture root zone. This may indicate that more water is collecting in pasture 2 and therefore there is enough water that evaporates/transpires out, while still maintaining high soil moisture levels. Given small variation between pastures in raw mean daily soil moisture root zone in summer, these results may support the management decision to graze pasture 2 later in the season, as forage quality may remain higher with high water throughout the year.

Effect of Grazing Pattern on Evapotranspiration and Soil Moisture

Based on our results, we were able to determine that a pasture being grazed had a discernible effect on both soil moisture root zone and evapotranspiration. While we saw variation in statistical significance between our three categories (currently grazed, grazed in the last two rotations, not grazed currently or recently) and response variables, this result highlights that a remote sensing model can pick up on landscape changes in response to management. Additional research can be done to further refine these models to pair with in-situ observations for grazing management plans.

It is important to note that other factors which play a role in both evapotranspiration and soil moisture root zone were not evaluated here. These may include topographic features associated with each of the IrriWatch fields (slope, aspect, elevation, wind exposure) and positioning in either the north creek or south creek watershed.

IrriWatch and Certifications

Based on our findings, the parameters measured via IrriWatch cannot, as presently defined, provide information on any of the accreditation indicators for the four regenerative agriculture certifications we studied. Thus, we do not recommend the use of this digital farming technology for the purpose of meeting regenerative agriculture certification requirements. However, our analysis suggests that IrriWatch is useful for gaining a better understanding of ecohydrological patterns and processes, such as soil moisture and evapotranspiration fluctuations across the landscape, and how they respond to management choices like rotating cattle through pastures (as described in paragraphs above). Our results *do* indicate that remote sensing can be used to monitor ecological change in response to management techniques.

Recommendations: How WBLT can use These Analyses in the Future

WBLT can use our code scripts to evaluate trends in evapotranspiration and soil moisture going forward at JCR. Observed changes in evapotranspiration and soil moisture in response to cattle grazing may inform how quickly land managers rotate cattle back onto a given pasture. Reviewing the data after the grazing season may help land stewards identify whether cattle were returned to a pasture sub optimally (i.e., too quickly or too slowly). Furthermore, by incorporating IrriWatch daily metrics with in-field assessments of grazing pressure, there may be the potential to establish correlations or “signals” for when to move cattle from one paddock to the next. A single metric or certain combination of metrics can be used here, such as monitoring for a drastic drop in vegetation cover or large changes in daily evapotranspiration trends.

In the spirit of continuous improvement, WBLT could consider integrating primary rainfall data into the model to assess whether any statistically significant changes occur. Our analysis shows that the IrriWatch data has a similar trend to the Lompoc rain gauge data, but the Lompoc rain gauge data is consistently several inches lower due to less rain recorded at the end of December 2021. IrriWatch developers have confirmed that precipitation data is very localized which makes it very challenging to get accurate data from gridded weather models (i.e., NOAA inputs). By integrating data from WBLT's new weather station into the model, derived variables like evapotranspiration and soil moisture may be more accurate.

The literature supports this claim, "It is unlikely that these accuracies will ever be improved much further in the short-term, because most regional scale hydrological databases (of precipitation, stream flow, weather, etc.) lack sufficient accuracy" (Bastiaanssen et al. 2005). Further papers indicate that for assessing soil moisture content, scale is a key issue in hydrological applications, "ideally the scale for measurement, modeling and processing should be identical or at least similar" (Verstraeten et al. 2008). WBLT should assess whether this analysis is the best use of their time and resources. It is possible for clients who have an accurate and well-maintained automatic weather station to post rainfall and meteorological data via API. This then overwrites the rainfall data they are currently retrieving from NOAA.

Limitations

It is worth noting that the rigor of our analysis was limited by data availability and scope. With only one year of IrriWatch data (September 2021 - September 2022), we were unable to interpret seasonal and annual changes to evapotranspiration and soil moisture on a longer timescale. It is for this reason that we developed R Scripts. These can be used as a tool to track changes in future water years, pending the availability of additional data.

Furthermore, given that the primary model of IrriWatch is a surface energy balance for land, it is likely that the unique groundwater dynamics at Jalama Canyon Ranch influence derived model parameters. We recommend further communication with IrriWatch developers to better understand how groundwater plays a role in the IrriWatch model, if at all.

IrriWatch Conclusions

In conclusion, IrriWatch — and remote sensing techniques more generally — are valuable tools for landscape level observations. Our results are promising in that they demonstrate that remote sensing can be used to track changes in ecological health, and therefore more broadly support holistic management goals. Nevertheless, real-time in-situ observations remain critical, and our project deliverables can serve as a helpful supplement to these observations.

B. Certification Analysis

Regenerative agriculture does not have one formal definition or set of standards, which creates challenges when monitoring ecological improvements. This often leads to farm-specific goals, which are difficult to assess across the broader industry. The organic movement saw greatly increased rates of adoption due to the USDA's formal set of standards initially released in the early 2000s (Adamchak 2022). Comparatively, because regenerative agriculture is loosely defined by a wide range of stakeholders, there has been very little commercial adoption (Newton et al. 2020). Thus far, the monetization of carbon sequestration across domestic farmlands has given the regenerative industry traction (Gosnell et al. 2019). However, due to the lack of scientific backing and corporate fraud at various levels of the carbon market, the regenerative industry has seen several setbacks, further contributing to the hesitations to adoption among land stewards (Sapbamrer and Thammachai 2021).

Through our certification analysis we determined that each of the four certifications require conceptually similar indicators for attainment. However, the specific indicators selected differ across certification and even when the indicators are similar, the process or methodology used to assess adequate attainment of that indicator varies greatly. For example, while each certification uses indicators to assess overall soil health, each certification has differences in the type of soil tests, numbers of samples required, sampling frequency, and soil depth for sampling. As such, we found no synergies that easily allow a land steward to enroll in multiple certifications.

We found that, of the 18 overlapping indicators, there are only 3 that are required by all 4 certifications: soil bulk density, organic carbon, and soil nitrogen. These 3 indicators are important to measure when testing for soil health; Organic carbon content has been used to understand soil quality, fertility, and productivity. To best calculate carbon sequestration, bulk density is needed to reach a specific mass of soil organic carbon in an area (Janzen 2005, Cihacek et al. 2015). Carbon sequestration is an area of growing interest due to high amounts of carbon in the atmosphere and the need to recapture carbon in the soil to mitigate global warming (Powlson et al. 2011). There are many soil carbon and nitrogen interactions where carbon cycling rates are strongly correlated to nitrogen availability (Díaz et al. 1993, Gärdenäs et al. 2011). Carbon to nitrogen ratios are important for understanding the plant-available nitrogen, which is often a limiting nutrient (Berthrong et al. 2009). Additionally, we conducted a literature review to evaluate the potential for using remote sensing technology to measure certain ecological indicators required to attain certifications for regenerative agriculture. We found 9 indicators that are proven to be monitored in this way and determined another 8 indicators that could potentially be monitored via remote sensing. Future projects can build upon our findings by conducting a study of these 17 indicators, located in Table 15, to further inform certification bodies of the potential for using remote sensing for evaluation and accreditation. Additionally, certification bodies should communicate with remote sensing practitioners to collaborate on effective, reliable methods for tracking specific indicators via geospatial technology. This has the potential to increase access to certification for land stewards that would have difficulty conducting soil and in-field testing. As farming practices, certifications, and technology continue to evolve and improve, these communities should collaborate to have the highest compatibility as possible to encourage adoption of better farming practices and monitoring.

C. Stakeholder Communications

Our focus groups provided perspectives and accounts from land stewards about pursuing regenerative land management and certification for regenerative practices. However, it is important to note that all participants were attendees at a conference on regenerative land management, indicating they held a positive opinion towards regenerative land management practices. As such, the opinions shared may not be representative of land stewards more broadly. Additionally, no participant had already achieved certification for one of the four certifications analyzed. Despite the limited sample size of our participants and their shared interest in regenerative agriculture, we determined this to be an appropriate survey population for our work as we hoped to assess land steward opinion regarding the value and challenges of certifications for regenerative agricultural practices rather than assessing opinions on land management themselves. The responses from focus groups have greatly informed our understanding of land stewards' motivations for pursuing regenerative agricultural practices and why they are, or are not, pursuing certification.

Based on our focus groups, we found that the majority of land stewards for small operations were unable to pursue any one of the four certifications evaluated due to the time required for applying, meeting standards, and soil sampling. Another significant barrier to entry was the high cost of enrollment, in addition to the ongoing cost of audits and sampling for ecological indicators. While not a barrier, an additional, significant cause of concern for land stewards was a lack of clear financial benefit from pursuing certification.

After receiving feedback from land stewards interested in the regenerative agriculture movement, there are several key conclusions that are crucial to this project and the broader regenerative agriculture field. First, regenerative certifications have many barriers to entry which compound to decrease steward demand and consequent adoption. Currently, because certifications are in their infancy and the revenue increase on premium prices for certification is unknown, land stewards are unwilling to pay the upfront investment costs. Additionally, the costs and labor associated with obtaining a certification, which often require years of monitoring, are excessive for land stewards currently interested in the space. Our focus groups did not have any participants that had already received or pursued a certification, so we were unable to obtain opinions on why they paid enrollment costs and if it was worth investing to gain certification. Experienced land managers from the focus group were uninterested in the standardization of regenerative practices and receiving credit for these practices, but rather, are pursuing regenerative management for the health of their land and to pass this land onto their children. The beginner group was uninterested in the certifications for similar reasons, but they were more interested in increasing the health of land for the sake of the environmental impact that everyone can benefit from and were worried about the standardization limiting the potential for the regenerative movement.

Based on our findings, we suggest: 1) certification bodies consider who their intended audience is, whether that includes large-scale or small-scale operations, as the barriers are more likely to prevent small-scale operations from attempting certification, and 2) future research be done in partnership with operations that have already received certification to identify what, if any, financial benefit from certification. Given the limitations we experienced, we suggest that WBLT continues to host focus groups with land stewards to 1) increase the sample size and increase the breadth of perspectives informing their policies as they interact with land stewards seeking to adopt regenerative practices, and 2) learn from the experiences of those who have attempted to reach certification.

A transition from traditional agricultural practices to regenerative agriculture is looked to as an opportunity to reduce greenhouse gas emissions while also contributing to ecological resilience. Certifications for regenerative agriculture are one way to increase the adoption of regenerative land management practices. However, our findings show that there are currently a number of barriers that both experienced and new land stewards experience in pursuing certification. In order to combat the slow rate of adoption resulting from land steward fears, we recommend key stakeholders including certification bodies, land stewards, and government agencies like the USDA coordinate with one another to create a more robust set of regenerative standards. The result of this increased collaboration could lead to a more unified approach that would allow testing to be standardized among the certifying bodies. This would be a more attractive option for land stewards, as they would not be overwhelmed with conducting in-field samples for each certification, independently. Standardization across these variables and a greater understanding of the market opportunities could go a long way in encouraging the adoption of regenerative agriculture practices.

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XII. Appendix

Table AI. A Comprehensive List of the Satellite Missions and Tools Regeneration Station Assessed.

Satellite Mission/ Tools	Full Name/Supporting Organizations	Description/Potential Usage
ARVIRIS	Airborne Visible, Infrared Imaging Spectrometer	Airborne Mission for Ecosystem Change
AVIRIS-NG	Airborne Visible, Infrared Imaging Spectrometer - Next Generation	Airborne Mission for Ecosystem Change
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station	Evapotranspiration, evaporative stress index, vegetation health, land surface temp
HyTES	Hyperspectral Thermal Emission Spectrometer	Airborne Mission with hyperspectral imaging for ecosystem change
NISAR	NASA-ISRO Synthetic Aperture Radar	SAR Radar, biomass Measurements, to be launched in 2024
SMAP	Soil Moisture Active Passive	Soil Moisture, Soil carbon, radar (through 2015)
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar	Airborne radar for ecosystem change, PolSAR
Rangeland Analysis Platform	Supported by Natural Resources Conservation Service (NRCS) and Bureau of Land Management (BLM).	Online application that provides access to geospatial vegetation data for U.S. rangelands
Rangeland Analysis Platform: Production Explorer	Supported by Natural Resources Conservation Service (NRCS) and Bureau of Land Management (BLM).	The rangeland production dataset produces estimates of total new aboveground rangeland production, partitioned to annual production and perennial biomass
IrriWatch	IrriWatch is a private company in which subscribers pay to have access to their derived data	IrriWatch is a software package that includes field-level parameters, pixel-level maps, and seasonal graphs for growers

Table A2. SEBAL Satellites and Derived and Non-Derived Parameters.

<u>**Satellites Used**</u> ● **Ecostress** → Mounted on ISS revisit time 3 days (During certain periods it comes daily, and then there is a gap of several days) ● **Sentinel-2** (2–5-day revisit time) for optical images. ● **Landsat 8** - (16 day) for optical images ● **Sentinel-3** (daily) thermal infrared images for the mid-morning land surface temperature ● **VIIRS** (NOAA) ● **Numerical Weather Prediction Models (NWPM)** usually predict the atmospheric circulation and the exchanges of water and heat between land and atmosphere every 6 hours with a grid of 25 km x 25 km: weatherstack.com, DarkSky API, NOAA <u>**Satellite Radiances Used**</u> ● Visible, Near Infrared, Thermal Infrared
<u>**Parameters**</u> **Non-derived parameters:** (Measured and restricted to satellite measurements) ● (i) land surface temperature, ● (ii) surface albedo, ● (iii) NDVI, ● (iv) solar radiation or irradiance, ● (v) terrain slope and ● (vi) terrain elevation. <u>**Derived Parameters (From SEBAL)**</u> ● Evapotranspiration ● Dry Matter Production. ● Nitrogen is derived from Red Edge reflectance ● Soil carbon accumulation is derived from crop residues and a simple model for humification.
<u>**Additional Parameter Details**</u> Surface Parameters ● Surface Albedo, Vegetation Index, Surface Temperature Surface Energy Balance ● Net Radiation Flux Density, Soil Heat Flux Density, Sensible Heat Flux Density, Latent Heat Flux Density Moisture Indicator ● Bowen-ratio, evaporation fraction, priestley and taylor coefficient, surface reflectance

Source: A remote sensing surface energy balance algorithm for land (SEBAL)

Table A3. A Comprehensive List of IrriWatch Variables.

IrriWatch Parameter	Unit
Dry Matter Production	kg/ha
Vegetation Cover	%

Actual Evapotranspiration	mm/d
Actual Evapotranspiration Cumulative	mm
Actual Transpiration	mm/d
Applied Water Cumulative	mm
Precipitation	mm
Soil Moisture Rootzone	cm3/cm3
Soil Water Potential Rootzone	Cm or hPa
Advised Water Today	mm/d
Date Next Irrigation	d
Soil Temperature Daily	(10cm) (C)
Max. Air Temperature	K
Air Temperature Daily	C
Relative Humidity Daily	%
Carbon Supply in Soil	kg C/ha/d
Carbon Decomposition in Soil	kg C/ha/d
Net Carbon Supply in Soil	kg/C/ha/d
Net Carbon Supply in Soil Cumulative	kg C/ha
Leaf Nitrogen	%
Leaf Nitrogen Uptake Cumulative	kg/ha
Water Unlimited Dry Matter Production	kg/ha/d
Production Gap Cumulative	kg/ha
Stomatal Conductance	mm/s
Midday Leaf Water Potential	bar
Soil Moisture Holding Capacity	mm/m
Midday Air Cooling	Not provided

Source: IrriWatch

Table A4. Accreditation Protocol Terminology.

Term	Definition	Example
Category (Sub-Index)	One primary component of ecosystem health or vulnerability. Often, reporting frameworks will assign each category or sub-index a score by obtaining and considering several indicators that are relevant to the selected category.	Soil Health
Indicator	Surrogates of underlying ecological functions that maintain [ecosystem] health. In other words, a measurable attribute of an [ecosystem] that is relevant to a component of its health or vulnerability.	Soil Water Holding Capacity
Metric (Attribute)	The characteristics of an indicator that are used to evaluate its condition, generally associated with a number value or unit (Sihler 2005). In other words, metrics are generally the raw data of an indicator, sub-index, or index value.	g H20/ g soil (Soil Water Holding Capacity / Infiltration)
Protocol (Methodology)	A set of rules for a situation or a type of test. Often, a protocol is used in areas where the user can make decisions on their own following loose guidelines that they can base their actions around. An example of social protocol would be "keep your elbows off the table." It does not define where you should put your elbows when eating, it just defines one area where you should not put them.	Cylinder or Ring Infiltrometer Alternative Example (unrelated to above): Slaking Test (soil aggregate stability)
Procedure (Method)	A more rigorous set of rules that a user must follow step by step. If social methods existed, the above example would be much longer--"sit at the chair in front of the table with your feet facing forward, hold a fork with your right hand, resting your wrists on the edge of the table in between bites." Methods are used for more complex activities that require specific steps to be followed in a specific order.	*How to Use a Ring Infiltrometer* 1. Place the inner ring with the cutting edge facing down on the ground. Remove small obstacles such as stones or twigs. When measuring below the ground surface, a profiled pit should be made. 2. Put the driving plate on top of the inner ring. Depending on its diameter the ring… 3. Etc..

Appendix A5. Human Subjects (Exempt Review) IRB Approval Responses

Provide a brief description of the project in lay terms, including the specific study objectives, rationale, and hypotheses

We are proposing this survey as a secondary component of our thesis-equivalent Group Project at the Bren School. While the project at large focuses on regenerative agriculture, this survey will provide us with critical information that will ultimately:

1) Help our client, the White Buffalo Land Trust, understand the needs of ranchers and improve their Holistic Management Intensive conference

2) Improve our understanding of the priorities ranchers have regarding regenerative agriculture

3) provide essential feedback on one of our project deliverables to ensure that we are designing a hand-out that accurately conveys information on certifications for regenerative agriculture to our target population.

Describe your study procedures in detail of how the research will be conducted. Include information about all study procedures (e.g., all interventions/interactions with subjects, data collection procedures) and follow-up procedures. Include the number, duration, and frequency of sessions to be completed with the participants.

Our study consists of three components:

1) A pre-conference survey
2) A post-conference survey
3) An optional focus group hosted during the conference

Both the pre-conference survey and post-conference surveys will be offered digitally via a Google Form. There will be no interaction between researchers and participants prior to completing the pre-conference survey. Participants will have met the researchers before they complete the post-conference survey, but the survey link will be sent out by the White Buffalo Land Trust rather than by the research team and then analyzed by the research team.

Researchers will be on-site during one day of the White Buffalo Land Trust's conference to offer an optional focus group to attendees during their mid-day break. The focus group will last approximately 1 hour and will have between 6-8 attendees per session. Participants will be provided with a brochure developed by our research team to provide feedback on the information and layout of the brochure. The intention of the brochure is to provide land stewards with a simple, accessible way of approaching the complex realm of certifications for regenerative agriculture. We plan to use feedback from land stewards to identify gaps in our brochure, as well as to identify which areas or features are not as useful and can be removed. If time permits, we have developed additional questions to further our understanding of the motivations land stewards have for pursuing regenerative agriculture and to gauge their interest in certifications. At no time will we collect individual information during the focus group process.

Describe your consent process.

Participants will receive the following information prior to being invited to take our digital pre-conference and post-conference reflection survey:

Survey Consent Form

For those participating in survey for the Holistic Management Intensive

Purpose:

You are being asked to participate in a survey jointly hosted by the White Buffalo Land Trust and the Regeneration Station Group Project from the University of California, Santa Barbara. Participation is voluntary.

The purpose of this survey is to better understand what motivated your interest in regenerative agriculture and to evaluate what you have learned at the Holistic Management Intensive. Results will be used to improve the Holistic Management Intensive and to develop documents to help ranchers evaluate certifications for regenerative agriculture. We appreciate your support.

Procedures:

If you choose to participate in our survey, you may continue to the next page to complete it via Google Form. The survey should take less than 10 minutes to complete.

Confidentiality & Privacy:

Survey responses with personal identifying information will be kept private between the White Buffalo Land Trust and the Regeneration Station project. Contact information will be kept confidential and will not be shared in any format.

Some results of this survey may be shared during the Bren School's Master's Project Faculty Reviews and during Master's Project Final Presentations which are open to the public. However, we will maintain an individual's privacy by not disclosing any personal identifying information from survey participants.

Informed consent:

After you complete the survey, you may reach out to the contact provided below to have your response withdrawn from our survey at any time.

Contact Information:

If you have questions about this survey, or our project, you can contact Elijah Baker by phone at (760) 718-8236 or by email at ebaker00@ucsb.edu.

Focus Group Consent Form

For those participating in an optional focus group held during the Holistic Management Intensive

Purpose:

You are being asked to participate in a focus group jointly hosted by the White Buffalo Land Trust and the Regeneration Station Group Project from the University of California, Santa Barbara. Participation is voluntary.

The purpose of this focus group is to receive your feedback on a brochure we are developing as a tool to help land stewards learn about certifications for regenerative agriculture. Your feedback is important and will help us improve the survey for continued use by the White

Buffalo Land Trust. We also hope to learn more about what motivated your interest in regenerative agriculture. Results will be used to improve the brochure, the Holistic Management Intensive, and to develop additional documents to help ranchers evaluate certifications for regenerative agriculture. We appreciate your support.

Procedures:

Focus groups will last less than 1 hour and will consist of 6-8 land stewards at a time. We will review and discuss the draft brochure in a group format. If time permits, we will also ask you a few questions about your experience as a land manager and your interest in regenerative agriculture.

Confidentiality & Privacy:

Everything shared during the focus group will be kept private between the White Buffalo Land Trust and the Regeneration Station project. At no time will we be collecting information that can be used to identify you.

Some results of the focus groups may be shared during the Bren School's Master's Project Faculty Reviews and during Master's Project Final Presentations which are open to the public. However, we will not disclose any personal identifying information from focus group or survey participants.

Informed consent:

You are welcome to request to leave the focus group at any time. You may also reach out to the contact provided below to have your responses withdrawn from our focus group notes at any time.

Contact Information:

If you have questions about this focus group, or our project, you can contact Elijah Baker by phone at (760) 718-8236 or by email at ebaker00@ucsb.edu.

If research will be conducted at an entity other than UCSB, their written permission must be obtained before research begins.

This research will primarily be a survey conducted digitally; both the pre-conference and post-conference surveys will be conducted via a Google Form. Participants will have the option to participate in an in-person focus group, located at the White Buffalo Land Trust. The White Buffalo Land Trust has already consented to hosting a focus group on-site. We can provide written verification of this from the White Buffalo Land Trust when we identify the day(s) during which we will host focus groups on site.

Describe your subject population. How will you locate & recruit/contact them? Where will you get your contact information?

Our subject population are attendees of the White Buffalo land Trust's Holistic Management Intensive conference offered this January. Participants will be offered a pre-conference survey and a post-conference survey. Additionally, attendees will have the option to participate in a focus group while at the conference.

All subjects will have voluntarily reached out to the White Buffalo Land Trust prior to attending this conference. We intend to provide this optional survey as part of the conference registration process. We will offer the optional post-conference survey to attendees on the second-to-last day of the conference, and again one week after the conference has concluded. In total the conference will have approximately 30 attendees, and therefore we are anticipating 30 respondents at most.

Describe how privacy will be protected and confidentiality will be maintained.

We will not make this dataset publicly available. The results of this survey may be shared during Master's Project Faculty Reviews and during Master's Project Final Presentations that are open to the public. However, individual's privacy will be maintained as we will not disclose individual names or contact information from survey participants. Any information or statistics shared will be done in such a way that survey-takers will not be identifiable.

If identifiable data (i.e., information and/or biospecimens) will be collected, include the disposition (for example, if identifiers might be removed or retained, if the data will used and/or shared for future research, stored, archived, etc.) NOTE: Consent form(s) must include the storage and disposition of the data. Upload a copy in the Attachments tab.

Data will be shared with our client, the White Buffalo Land Trust, to inform their Holistic Management Intensive conference. All collected survey data will be stored using Box and therefore will be protected by password and UCSB two-factor authentication.

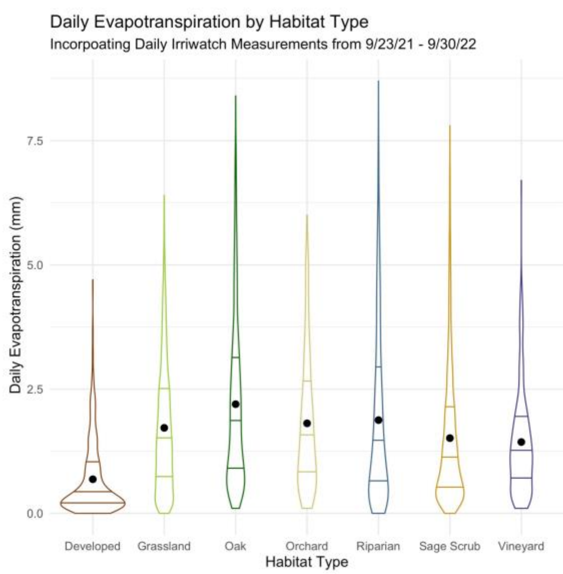

Figure A6. Daily evapotranspiration (mm) distribution across seven JCR habitat types as represented by violin plots. The black point represents the mean value, the horizontal lines represent the first quartile, median, and third quartile.

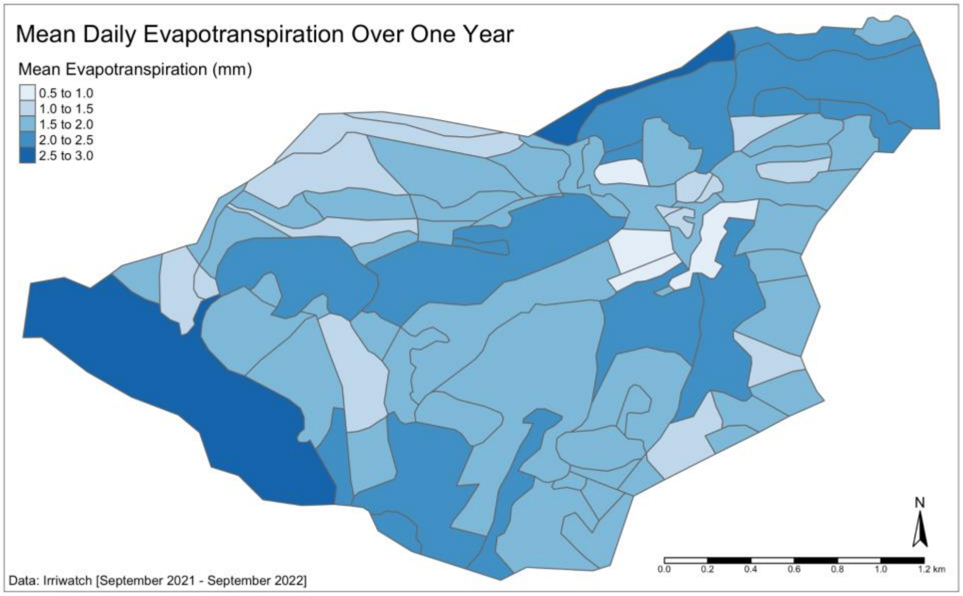

Figure A7. Daily evapotranspiration (mm) across the JCR property. Each polygon represents an IrriWatch management unit. Light blue regions illustrate a lower mean evapotranspiration, green and dark blue regions represent a higher mean evapotranspiration.

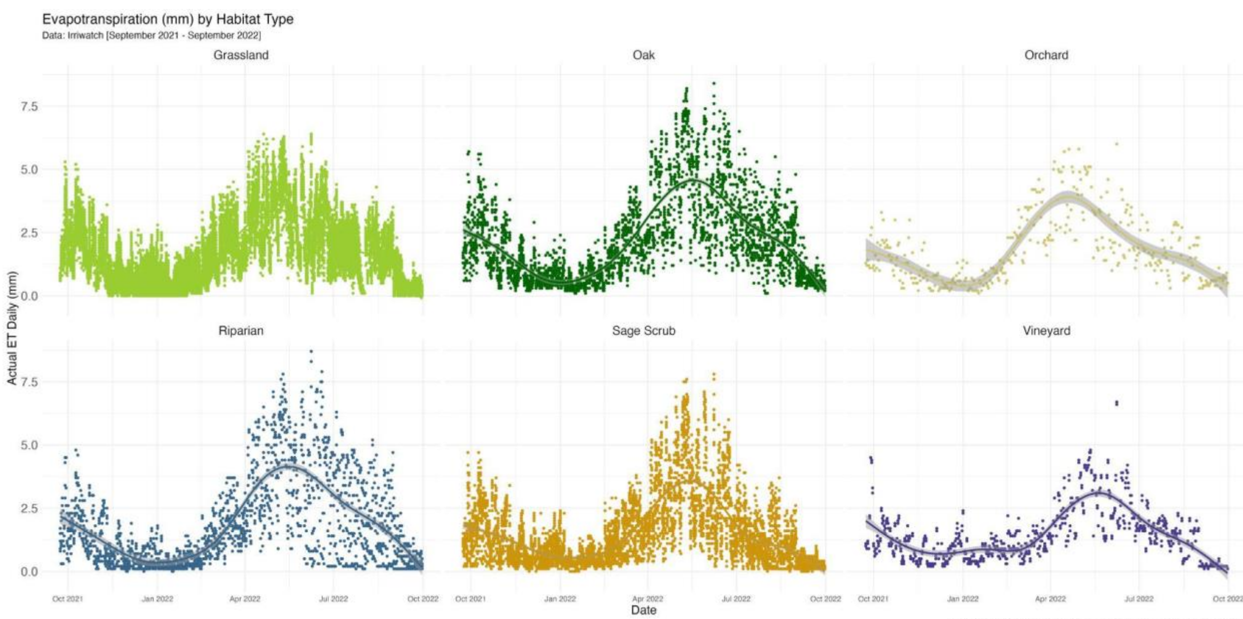

Figure A8. Evapotranspiration (mm) by natural vegetation cover (n = 6). Each dot represents an individual observation. The trend line employed is using a generalized additive model approach to fit a flexible and nonlinear function to the data. The gray bars around the regression line represent the confidence interval of the regression line.

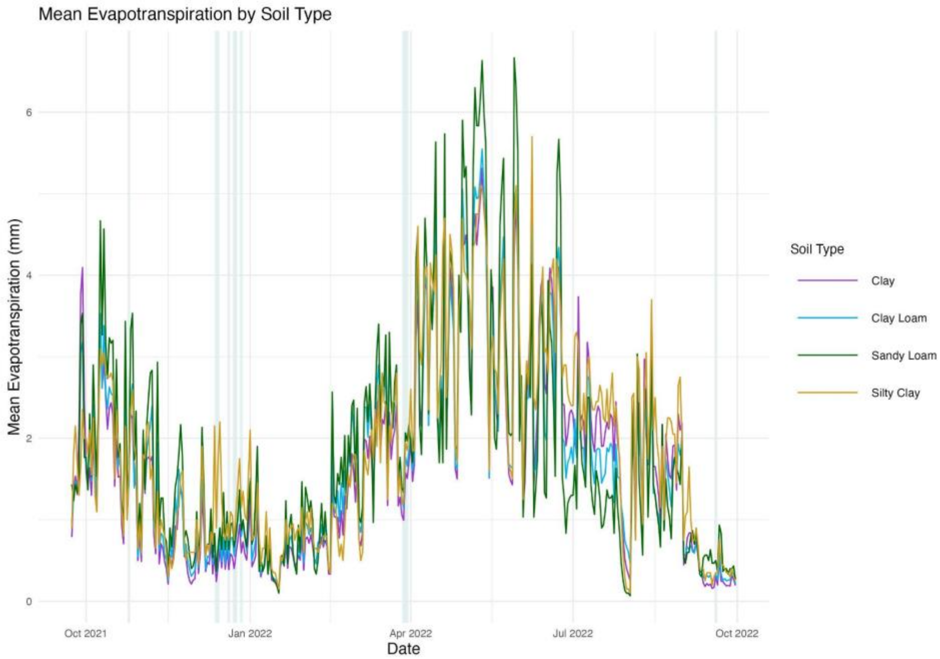

Figure A9. Evapotranspiration (mm) by soil type across time. The vertical bars indicate rain events over 1.5” in magnitude.

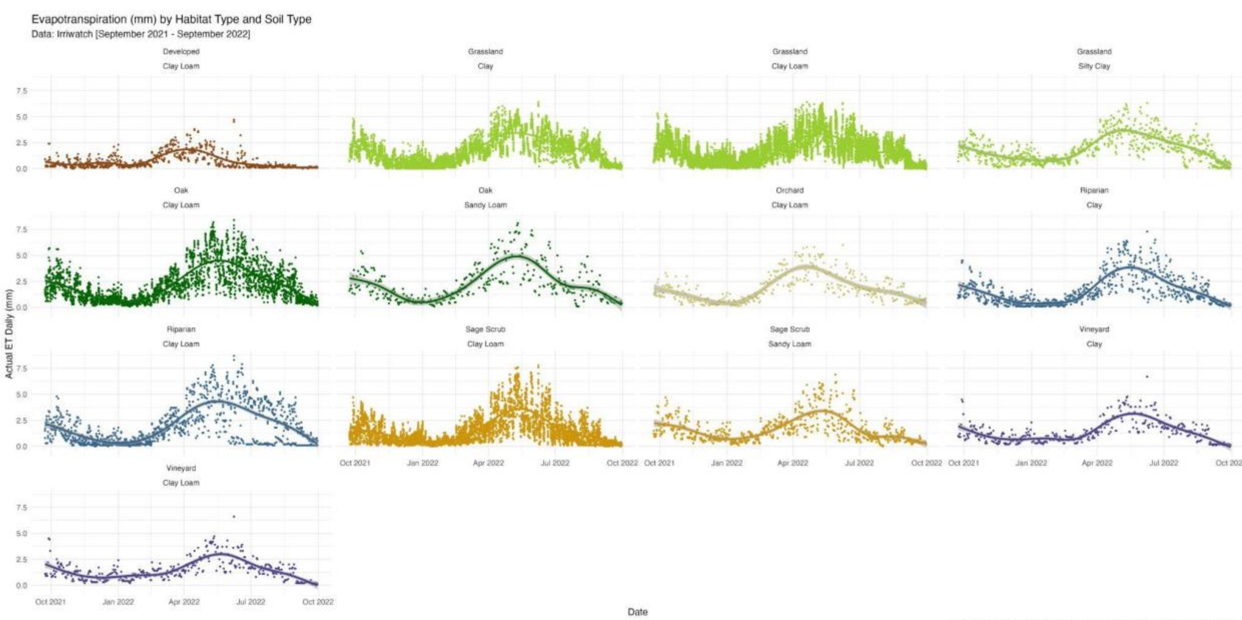

Figure A10: Evapotranspiration by habitat type and soil type. Each dot represents an individual observation. The trend line employed is using a generalized additive model approach to fit a flexible and nonlinear function to the data.

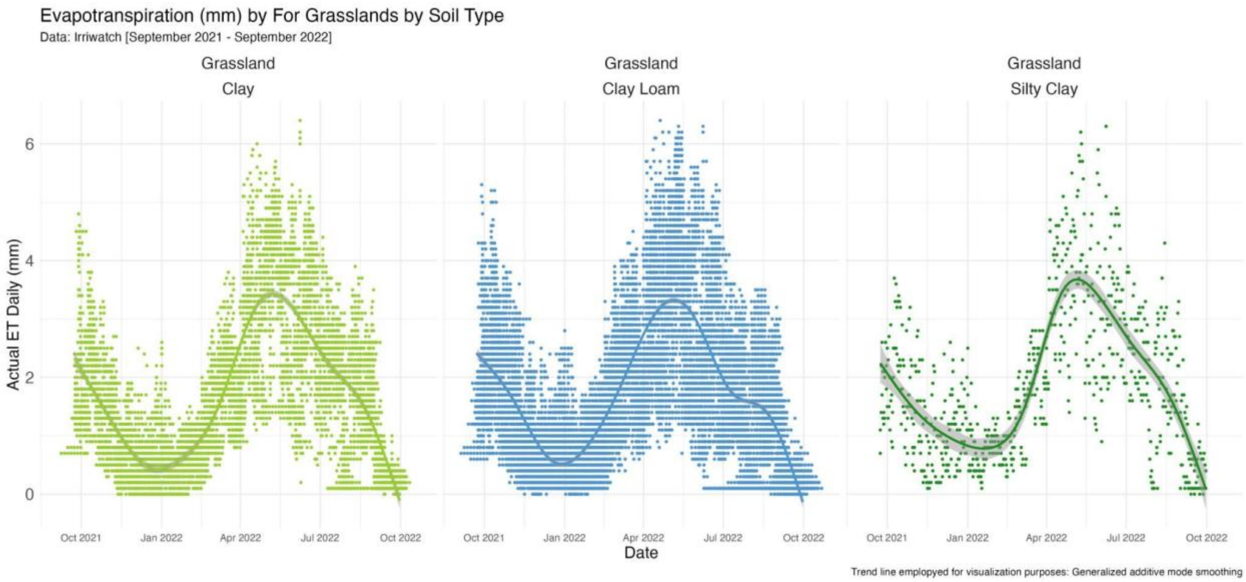

Figure A11. Evapotranspiration within grasslands based on soil type. Each dot represents an individual observation. The trend line employed is using a generalized additive model approach to fit a flexible and nonlinear function to the data.

Table A12. Results of Tukey's HSD test on regression outputs from habitat type explaining variation in evapotranspiration.

Habitat Type	Adjusted P-Value
Oak-Grassland	0.0000000
Orchard-Grassland	0.8014725
Riparian-Grassland	0.0000442
Sage Scrub-Grassland	0.0000000
Vineyard-Grassland	0.0000004
Orchard-Oak	0.0000038
Riparian-Oak	0.0000000
Sage Scrub-Oak	0.0000000
Vineyard-Oak	0.0000000
Riparian-Orchard	0.9605129
Sage Scrub-Orchard	0.0006782
Vineyard-Orchard	0.0002100
Sage Scrub - Riparian	0.0000000

Vineyard-Riparian	0.0000000
Vineyard-Sage Scrub	0.6801576

Table A13. Results of Tukey's HSD test on regression outputs from soil type explaining variation in evaporation.

Soil Type	**Adjusted P-Value**
Clay Loam-Clay	0.0326400
Sandy Loam-Clay	0.0032760
Silty Clay-Clay	0.0004581
Sandy Loam-Clay Loam	0.0855929
Silty Clay-Clay Loam	0.0122862
Silty Clay-Sandy Loam	0.8184273

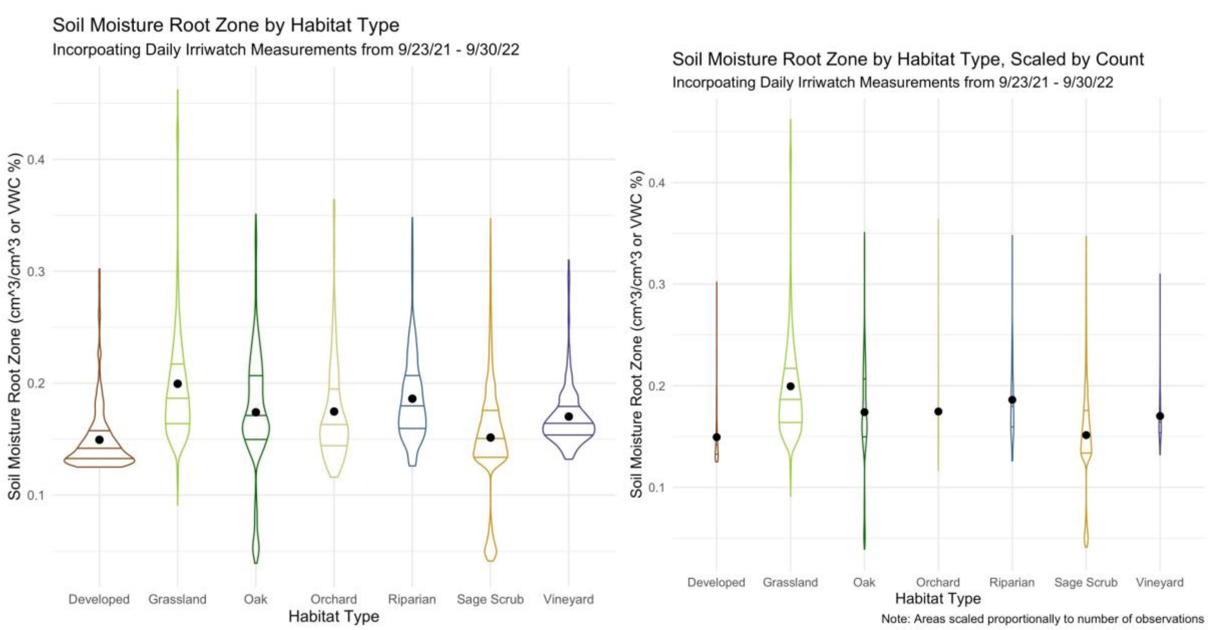

Figure A14. Distribution and density of soil moisture root zone by habitat type. The right plot is scaled by count to represent area proportionally to the raw number of observations included in the distribution. The black point represents the mean value, the horizontal lines represent the first quartile, median, and third quartile.

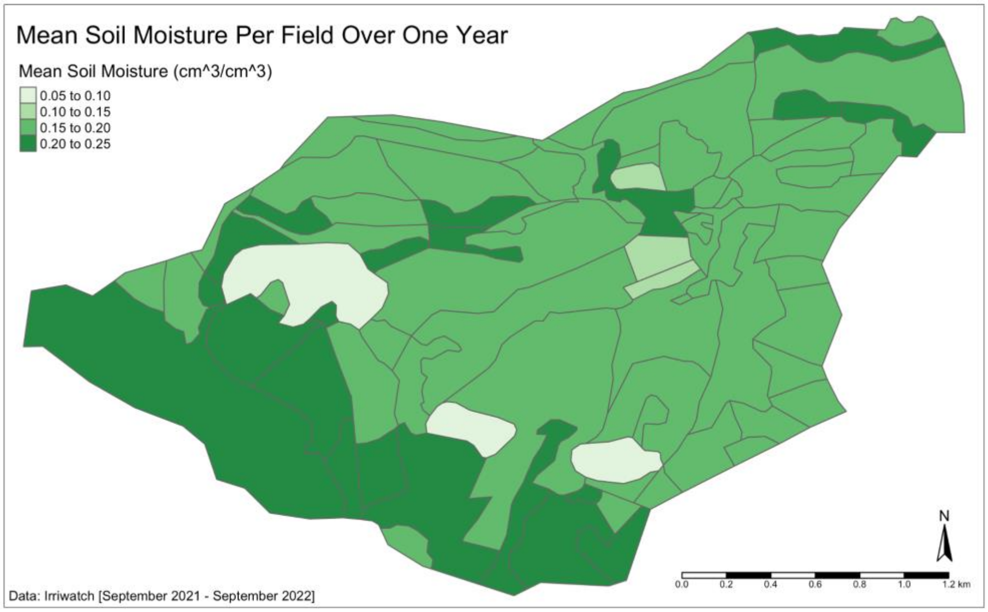

Figure A15. Daily mean soil moisture (cm3/cm3) across the JCR property. Each polygon represents an IrriWatch management unit. Light green regions illustrate a lower mean soil moisture, dark green regions represent a higher mean soil moisture.

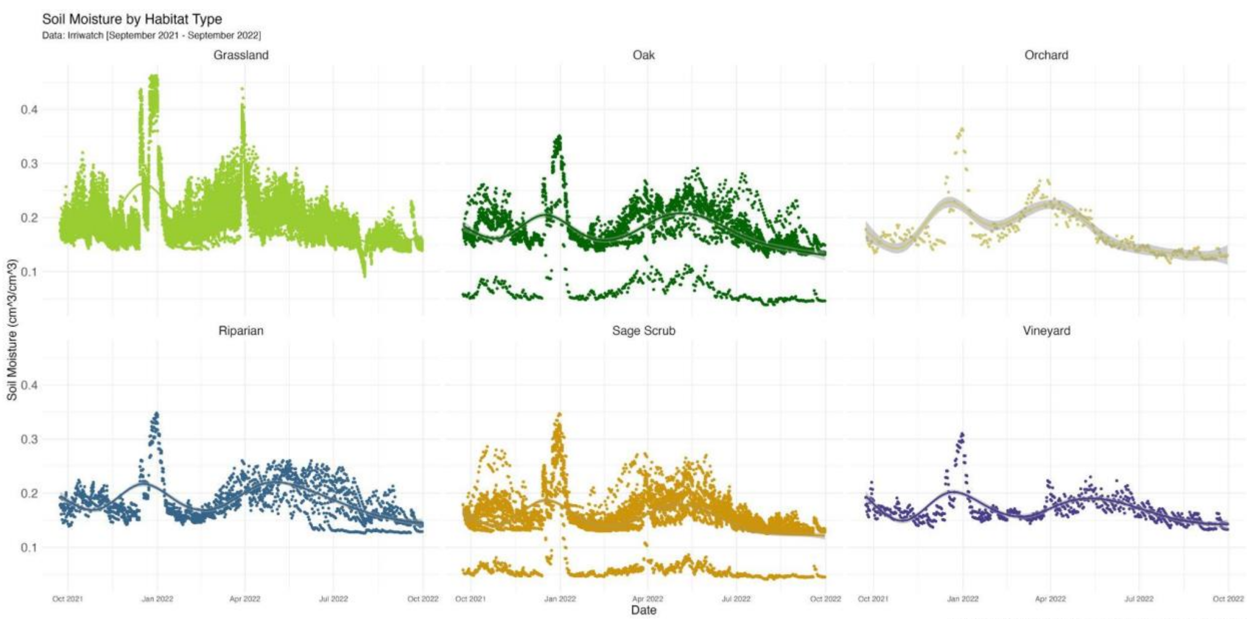

Figure A16. Soil moisture root zone by habitat type. Each dot represents an individual observation. The trend line employed is using a generalized additive model approach to fit a flexible and nonlinear function to the data.

Table A17. Results of Tukey's HSD test on regression outputs from habitat type explaining variation in soil moisture.

Habitat Type	Adjusted P-Value
Oak-Grassland	0.0000000
Orchard-Grassland	0.0000000
Riparian-Grassland	0.0000000
Sage Scrub-Grassland	0.0000000
Vineyard-Grassland	0.0000000
Orchard-Oak	0.9998722
Riparian-Oak	0.0000000
Sage Scrub-Oak	0.0000000
Vineyard-Oak	0.3649093
Riparian-Orchard	0.0003949
Sage Scrub-Orchard	0.0000000
Vineyard-Orchard	0.6863862
Sage Scrub-Riparian	0.0000000
Vineyard-Riparian	0.0000000
Vineyard-Sage Scrub	0.0000000

Table A18. Results of Tukey's HSD test on regression outputs from soil type explaining variation in soil moisture.

Soil Type	Adjusted P-Value
Clay Loam-Clay	0.9929882
Sandy Loam-Clay	0.0000000
Silty Clay-Clay	0.1507294
Sandy Loam-Clay Loam	0.0000000
Silty Clay-Clay Loam	0.0996013
Silty Clay-Sandy Loam	0.0000000

Table A19. Results of Tukey's HSD test measuring pasture differences in relation to soil moisture.

Pasture	Adjusted P-Value
#2-1	0.9981781
#3-1	0.0000000
#4-1	0.0000000
#5-1	0.0000000
#3-2	0.0000000
#4-2	0.0000000
#5-2	0.0000000
#4-3	0.0000000
#5-3	0.0006329
#5-4	0.0000000

Table A20. Results of Tukey's HSD test measuring pasture differences in relation to evapotranspiration.

Pasture	Adjusted P-Value
#2-1	0.0000000
#3-1	0.0000005
#4-1	0.0000132
#5-1	0.0000000
#3-2	0.0003332
#4-2	0.0000192
#5-2	0.0047961
#4-3	0.9712542
#5-3	0.9607360
#5-4	0.6886209

Table A21. The summary table of the 128 indicators measured across all four certifications and the number of certifications that require each indicator be measured.

Ecological Indicator	Number of Certifications
Soil Bulk Density (hardness/compaction)	4
Soil Carbon See "Metric" Column C for specification between certifications	4
Soil Nitrogen	4
Soil Aggregate Stability	3
Soil Micro/Minor Nutrients	3
Soil Microbial Activity and Community	3
Soil pH	3
Water Infiltration	3
Bare Soil Index (BSI)	2
Existing Certifications	2
Haney Soil Health Test	2
Living Organisms in Soil	2
Soil Active Carbon	2
Soil Cation Exchange Capacity (CEC)	2
Soil Phosphorus	2
Soil Texture	2
Soil Water Holding Capacity	2
Synthetic Chemicals	2
Access to Clean Water	1
Additional Regenerative Practices: 5 or more practices beyond those listed in USDA NOP (section 2.8) present in operations.	1
Autoclave-Citrate Extractable (ACE) Protein Test	1
Bargaining	1
Buildings	1
Business License to Operate	1
Buyers	1

Capacity Building	1
Child Labor	1
Commitment to a Living Wage	1
Compliance with all general laws	1
Compost, Manure, Fertilizers: Self sufficiency	1
Computer Models (ex: COMET Farm GHG tool)	1
Concentrated Animal Feeding Operation (CAFO)	1
Confinement	1
Contaminants in Compost, Manure, Fertilizers	1
Contextually Desirable Species	1
Contextually Undesirable Species	1
Contractors	1
Crop Nutrient Demand	1
Crop Rotations	1
Crusting	1
Disciplinary Procedure	1
Discrimination	1
Diversity of Macro Life	1
Dung Decomposition	1
Employer Instituted Unions	1
Employment Contracts & Terms	1
Environment and Shelter	1
Equal Pay	1
Euthanasia	1
Existing Farmer and Worker Fairness Certifications	1
Exits	1
Fair Payments	1
Fair Pricing	1

Family Members	1
Feed for Monogastrics	1
Feed for Ruminants	1
Field Farm Assessment of Biodiversity	1
Forced Feeding	1
Genetically Modified Inputs & Cloning	1
Ground Cover	1
Grower Groups	1
Handling and Management	1
Health	1
Health, Safety, & Potential Hazards	1
Hiring Practices	1
Hours of Work	1
Housing	1
Human Trafficking and Forced Labor	1
Indoor Shelter	1
Interns and Apprentices	1
Invasive Species (plants, animals, insects)	1
Key performance indicators as required per pillar	1
Labor Laws, Legal, & International Conventions Compliance	1
Legal Irrigation Rights	1
Light	1
Litter abundance	1
Litter Decomposition	1
Live Canopy Abundance	1
Malnutrition	1
Manipulated or Manipulative Records	1
Minimal Soil Disturbance (no till-system)	1
Native Flora and Fauna	1

No Harassment or Abuse	1
Normalized Difference Vegetation Index (NDVI)	1
Nutrition and Water	1
Physical Modifications	1
Plant Health	1
Production Obligations	1
Ponding	1
Pre-Slaughter	1
Precarious Employment	1
Privacy	1
Production of contextually desirable Functional Groups (FG): Warm season grasses Cool season grasses Forbs and legumes Trees and shrubs	1
Protection Against Retaliation	1
Protection for Endangered Plants and Animals	1
Quick-acting Fertilizer	1
Reductions of Accidents	1
Respiration	1
Root Growth	1
Rotational Grazing	1
Slaughter and Killing	1
Slaughter Methods	1
Soil Capping	1
Soil Color	1
Soil Compaction	1
Soil Nutrition (nutrition per acre)	1
Soil Smell	1
Soil Water Use	1
Supply Chain Requirements	1

Tillage Action Plan	1
Timely Payment of Wages	1
Training and Personnel	1
Transparent Negotiation	1
Transport Time	1
Transportation	1
Vaccines, Antibiotics, & Growth Hormones	1
Vegetation Structure	1
Vegetative Cover	1
Wages	1
Waste	1
Wastewater	1
Water Conservation and Restoration	1
Water Erosion	1
Work Restrictions for Children and Young Workers	1
Worker Independence & Empowerment	1
Worker Voice	1
USDA Organic	1

1st inside page ***Back page*** ***Front Cover***

Figure A22. The outside of the pamphlet with each page labeled. The Certification Comparison Handout is designed to be printed and folded into a tri fold handout.