CARBON FARMING PLAN

RESOURCE CONSERVATION DISTRICT OF GREATER SAN DIEGO COUNTY

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TABLE OF CONTENTS

Table of Contents

I need not emphasize to you the seriousness of the problem and the desirability of our taking effective action, as a Nation and in the several States, to conserve the soil as our basic asset. A Nation that destroys its soils destroys itself.

-Franklin D. Roosevelt, 1937

INTRODUCTION

Introduction

CARBON EMISSIONS

Environmental change is occurring globally at an unprecedented pace in recent years due to human-induced agricultural and industrial activities (fossil fuel burning) and natural influences. In the last four years, atmospheric levels of carbon dioxide (CO_2) quickly surpassed 400 parts per millions (ppm) and are accelerating beyond 410 ppm, the value measured in April 2017 (Kahn, 2017). The emissions of other greenhouse gases (GHG), including methane (CH_4) and nitrous oxide (N_2O), are also skyrocketing (currently above 1835 ppm and 330 ppm, respectively) due to anthropogenic and natural influences. Earth's atmosphere is quickly transforming into a warmer system by 2 °C with acidified sea water with a higher sea level by 30 cm (USGCRP, 2014). Moreover, in combination with mass extinction of marine life, the magnitude and severity of weather events, including floods and droughts, has increased to historic extents. This precipitous climate forecast for Earth suggests significantly greater environmental changes than previously observed. The radical upsurge in carbon emissions from the pedosphere and hydrosphere to the atmosphere demands significant changes in agricultural and industrial activities to mitigate climate changes. Agriculture represents over a third of arable land globally (Kane, 2015), so conservation management strategies could play a significant role in restoring balance to the environment.

CARBON FARMING

Carbon farming engages a suite of agricultural practices that sequesters carbon in soil and vegetation, ultimately reducing atmospheric GHG emissions and storing soil carbon. A building block of life, the cycling of carbon between Earth's major compartments – atmosphere, pedosphere, hydrosphere, lithosphere, and biosphere, results in vital ecological, biogeochemical interactions in air, soil, water, rock, and biota that affect air quality and environmental change (Figure 1). Photosynthesis is a process used by plants to convert light energy to chemical energy by capturing and synthesizing CO_2 with water and nutrients. In the process, light energy produces oxygen (O_2), producing photosynthates, i.e. natural sugars, and chemical energy for plant use:

$$6CO_2 + 6H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6O_2$$

The carbohydrates trapped as photosynthetic sugars can be transferred from plant to soil directly, as plant root exudates, or indirectly. Transmission through plant roots, as decomposers, and/or as deposits on soil surfaces and animals indirectly transfer carbon from plants to soil, where they are protected in stable aggregates. The carbon-based cellulose and lignin components of plants can also be stored as soil organic matter (SOM) to achieve carbon sequestration.

The whole-farm approach to achieve carbon sequestration through agricultural ecosystem management include: cropland management, nutrient management, silvopasture, disturbed land restoration, and riparian restoration (Table 1). Photosynthetic cover crops in farm systems can increase soil carbon storage and limit uncovered soil to which erosion and other disturbances can be significant. Other agricultural practices including no-tillage, composting, and rotating crops, also improve soil health by boosting biological activity, water quality and efficiency, soil structure, and nutrient cycling. Ultimately, carbon farming is an adaptive strategy to build soil and ecosystem health and lower atmospheric CO_2 levels, suggesting that agriculturally-driven sequestration strategies may be a potential solution to restore balance for air quality and climate change.

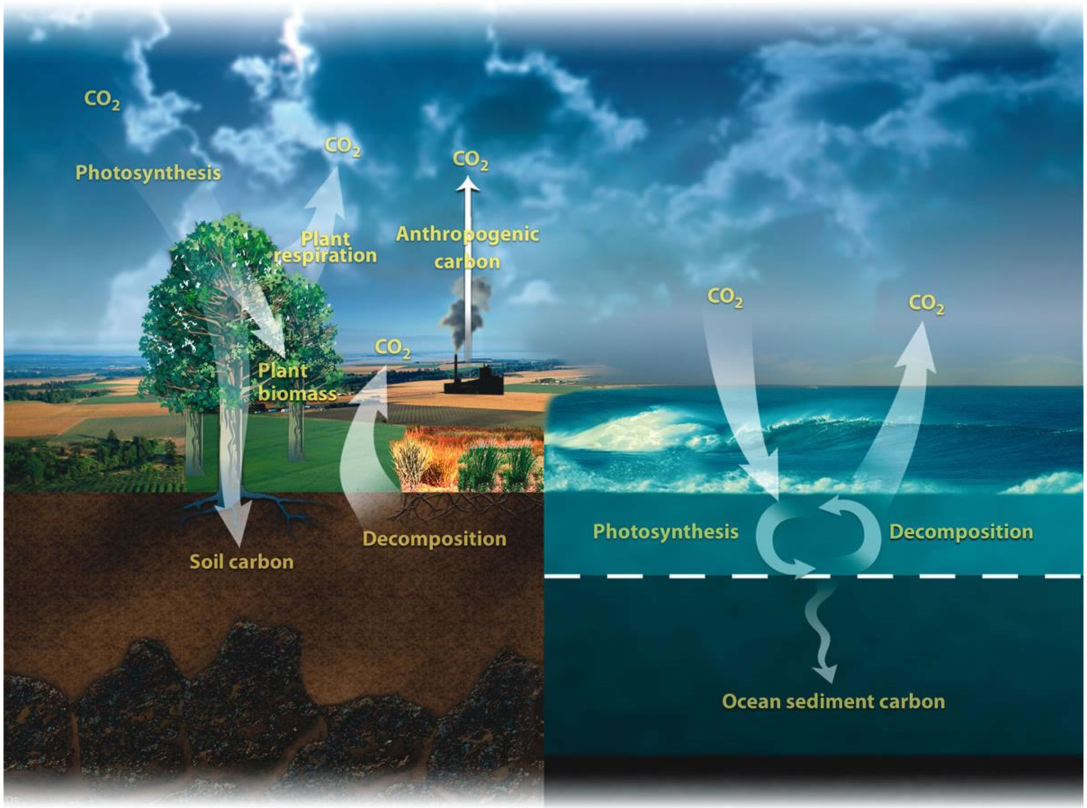

Figure 1. Components of the global carbon cycle (U.S. DOE, 2008).

TABLE 1: CARBON FARMING PRACTICE AND GHG REDUCTIONS

PRACTICE	METRIC TONS CO_2E/ACRE/DECADE
Compost (cropland)	21-46
Cover crop (cropland)	2-9
Nutrient management with cow manure	2-3
Silvopasture	7
Hedgerow planting (crop & grass lands)	80
Disturbed land restoration (vegetative cover)	11
Riparian restoration (woody planting)	10
Riparian forest buffer (crop & grass lands)	18

Reference: Carbon and greenhouse gas evaluation for NRCS conservation practice planning. <www.comet-planner2.com> and <compost-planner.com>.

INTRODUCTION

Carbon sequestration in California soils is a state-recognized method and key pathway toward California's environmental goals. In 2004, the annual emissions in the state were 490 million MT CO_2E, a 14% increase from the 430 million MT CO_2E emissions measured in 1990 (Anders et al., 2006). By 2020, California is required to reduce its GHG emissions below 430 million MT CO_2E, as capped by the passage of AB 32, the California Global Warming Solutions Act of 2006 (Anders et al., 2013). This 15% reduction involves adoption of new regulations in all economic sectors to mitigate climate change risks while improving energy efficiencies, switching to renewable energy, and reducing waste.

Several RCD regions, including Marin, Sonoma, Santa Barbara, and Riverside, have implemented carbon farming. Their efforts have focused on composting, cover crops, grazing, and no-till practices on rangelands, vineyards, and orchards to stimulate plant growth of native grasslands (MCP). These regenerative agricultural methods lead to healthy soils with larger water-holding capacities. Santa Barbara County implemented a carbon farming plan at the 8,000-acre Cachuma Ranch that focused on rangeland and cropland composting, prescribed grazing, riparian restoration, silvopasture, and several other practices. In all, these agricultural methods have the potential to sequester 6.1 to 7.4 thousand metric tons (MT) of carbon dioxide equivalent (CO_2E) per year. Modoc County in northeastern California implemented a plan on the Modoc Ranch to follow similar practices, resulting in the sequestration of 4.1 thousand MT CO_2E annually. These estimates show conservation practices can be utilized to storage soil carbon, therefore allow soils to act as sinks for atmospheric carbon.

AGRICULTURE AND PREDICTORS OF CLIMATE CHANGE IN GREATER SAN DIEGO COUNTY

Agricultural land use in the 1.8 million acres of greater San Diego County (SDC) contributes to 339 thousand acres (18.8%), with 63% represented as farmland and 37% as grazing land (Thompson, 2009). Range land is estimated to represent 61% of agricultural land (206 thousand acres) in SDC (K. Muno, pers. comm.). SDC hosts the largest number of small-scale (<9 acre) farms in the nation, represented by 4270 farms (65% of SDC farms). SDC is also the leading producer of avocados and nursery crops in the nation (San Diego County Farm Bureau, 2017).

In 2006, the annual emissions in SDC were 34 million MT CO_2E, which is an 18% increase from the 29 million MT CO_2E emissions measured in 1990 and may be attribute to population growth by 435 thousand people over the sixteen-year period (Anders et al., 2006). With a population of 2.9 million people in SDC, the carbon footprint is equivalent to 7.1 million cars per year (City of San Diego, 2016). Due to a slight decrease in the 2010 SDC annual emissions to 32 million MT CO_2E, Anders et al. (2013) revised their new projections to 37 million MT CO_2E in 2020. The goal, however, remains to lower annual emissions to 29 million MT CO_2E

Agriculture, forestry, and land use contribute to 1.6% of GHG emissions in San Diego County. However, sequestration of 4 MT per acre per decade on half of California's rangeland area (i.e. 31 million acres) can offset CO_2E by 124 MMT. A single compost application of ¼" over all SDC rangelands could result in the sequestration of 4.1 MMT CO_2E per decade (USDA NRCS, 2017b). An increase in soil organic carbon by 1% on SDC rangelands would sequester 13.3 MMT CO_2E and increase associated water-holding capacities by 16 thousand acre feet. The vision of carbon farming in SDC is to strategically convert farmers to carbon farming practices by developing incentives and reducing barriers to reach environmental and policy goals. Achievable through reductions in transportation and electric sectors, the AB 32 emission reduction targets for carbon polluters are to decrease levels by 33% below projected levels (Anders et al., 2006). Both vehicle (46% of SDC GHG emissions) and energy (25% of SDC GHG emissions) emission standards would both decrease emission by 3 million MT CO_2E by 2020, ultimately contributing to reductions in total GHG emissions in an efficient and affordable manner over time.

OVERARCHING GOALS AND PLANNING PROCESS

A carbon farming plan from the Resource Conservation District (RCD) of Greater San Diego County and a conservation plan from the NRCS are currently in preparation with potential implementation by 2018. The main goal of the RCD carbon farming plan is to identify opportunities and related practices, both currently in use or recommended for implementation, which sequester carbon, improve soil health, and reduce GHG emissions. This carbon plan will contain all elements of a conservation plan, specifically (1) the inventory and analysis of current resource conditions, (2) on-farm carbon sequestration and GHG mitigation potential, and (3) landowner decisions concerning the implementation of a conservation system that will address resource concerns. The plan will also contain target goals (short term (1-2 year) and long term), incentives, challenges, and co-benefits of carbon sequestration. Our focus area for this plan is the full 3000 acres of Montado Farms in southern California; however, the over-arching goals, practices, and potentials for carbon may be applicable to other farms in San Diego County.

Ecological Delineation: Montado Farms

Montado Farms is located along Mesa Grande Road in Santa Ysabel, California 92070. Montado Farms extends roughly from BIA Road 50 (33°8'18.03" N, 116°43'31.62" W) in the west to Crescent Heights Road (33°9'52.77" N, 116°41'32.23" W) in the north to Highway 79 (33°7'35.88" N, 116°40'41,41" W) in the south. The 3107-acre rangeland is equidistant (13.5 miles) from Ramona, CA and Warner Springs, CA, with an area that is one-fourth the size of Encinitas. The farm is co-owned by Kevin Muno, Ryan Cauzza, and Jarrod Cauzza. The Montado Farms is located within the San Dieguito watershed, which extends from Santa Ysabel in the east to Del Mar in the west (Figure 2).

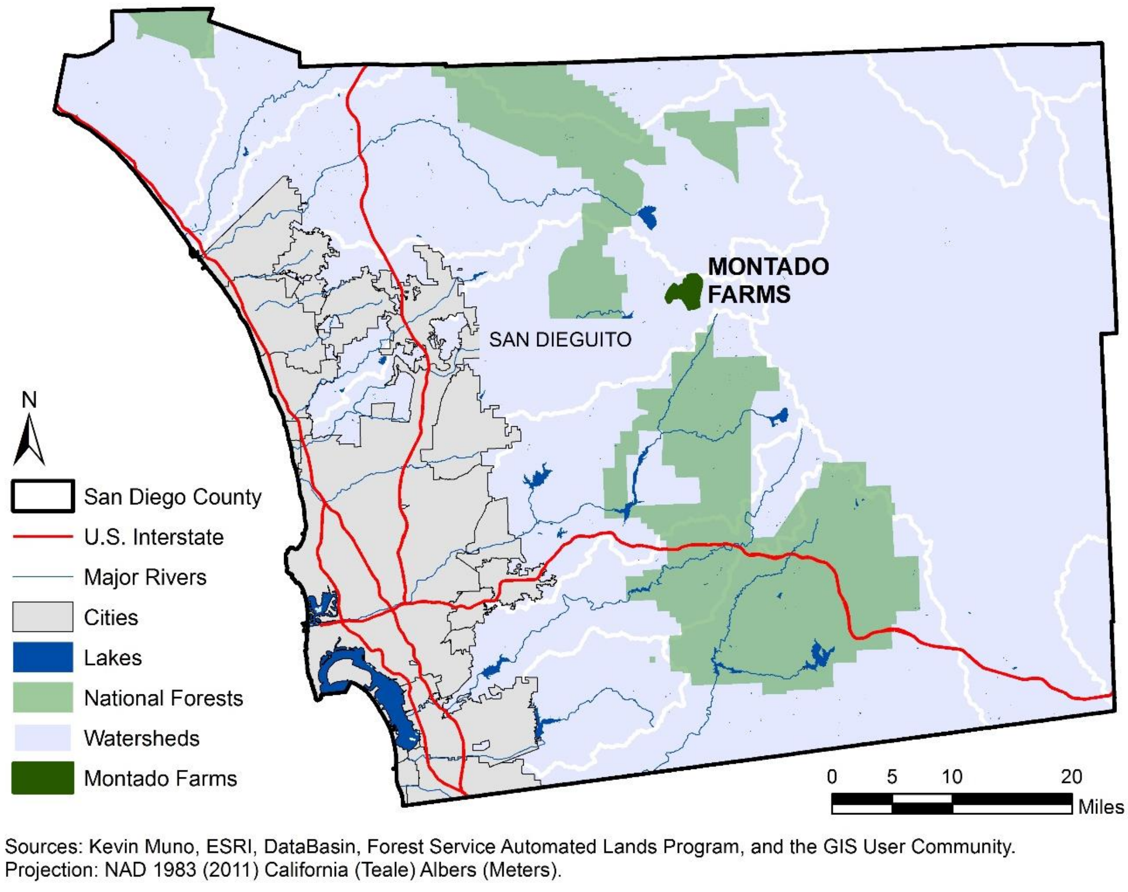

Figure 2. The location of Montado Farms in the San Dieguito watershed within San Diego County.

HISTORICAL USE

Montado Farms was first documented as a Spanish land grant, with grazing of cattle and sheep for almost 200 years (Brennan, 2017). Beginning in 1769, the Spanish managed the land by growing corn, alfalfa, and feed for food and dairy productions. Irrigation was limited to primitive methods. By 1800, cattle, sheep, and horses grazed the land with cattle providing meat and milk there. In the early 1800s, San Diego lands were converted into Mexican land grants and divided for individuals. The Santa Ysabel Valley rangelands were then owned by the Mendenhall family in the late 1860s. The Cauzza Family inherited ownership of the 3000-acre property in the early 1900s after emigrating from Switzerland to work on the dairy that resided there (Beck, 2014). The dairy was closed in 2000 due to its remote location and low profitable yield; the ranch milked only 200 cows, which was a fifth of the loads produced by other nearby dairies (Grimm, 2001).

TOPOGRAPHY AND HYDROLOGY

The elevation of Montado Farms is roughly 3725 feet. The central and southern regions of the land are roughly flat; however, the northern and western regions are hilly (Figure 3). The land receives water from the Santa Ysabel Creek, which runs through the farmland and often floods the land in winter months. The five perennial streams carry water from the north across 1.1-3.0 miles of Montado Farms to Santa Ysabel Creek in the south.

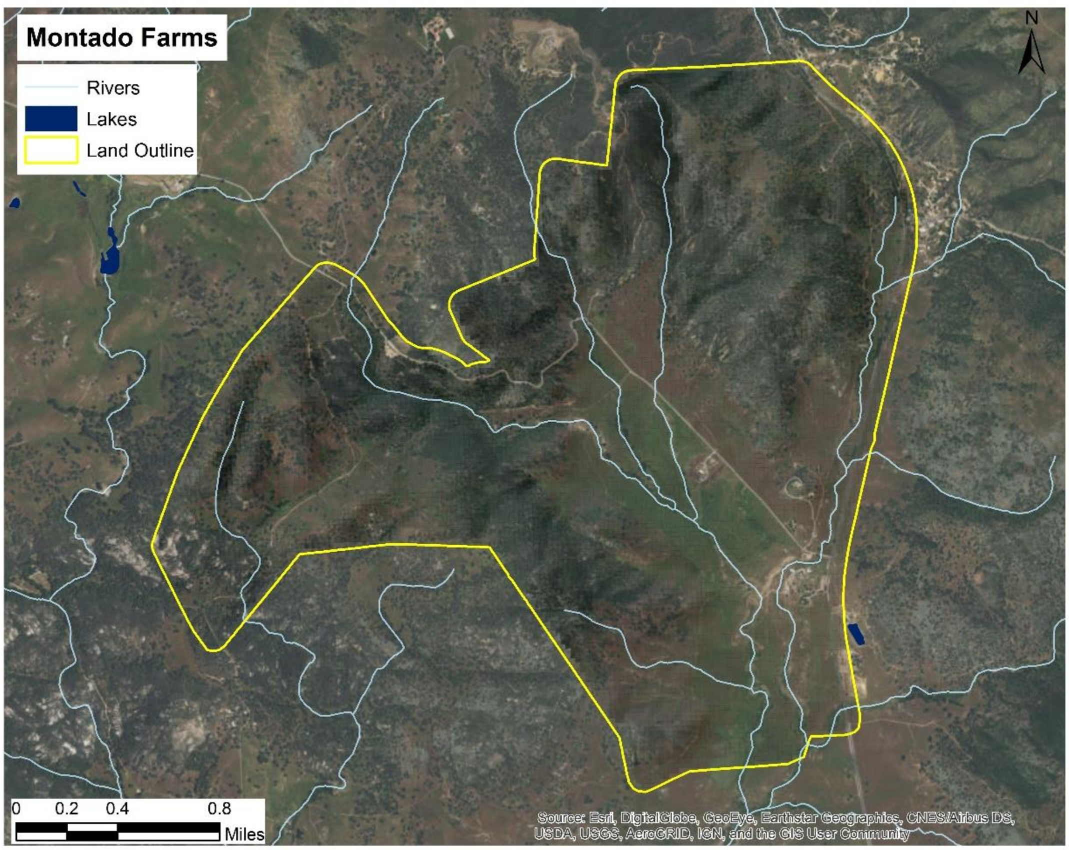

Figure 3. The outline, topography, and rivers of Montado Farms.

ECOLOGICAL DELINEATION: MONTADO FARMS

CLIMATE AND PRECIPITATION

The climate of Montado Farms is Mediterranean with a xeric moisture regime, characterized by warm, dry summers and cool, wet winters. The annual average temperature of this subhumid region ranges from 46-47 °F (8 °C) to 65-77 °F (18-25 °C) (Weatherbase, 2017). Average temperatures range 77-85 °F (1-4 °C) in summer months (May to October) and 46-56 (8-14 °C) in winter months (November to April).

The average annual precipitation is 16 to 30 inches for Santa Ysabel and its equidistant towns (US Climate Data, 2017). The majority (88-90%) of precipitation (averaging 2-5 inches per month) occurs in the winter months between November and April, whereas the dry period averages precipitation is less than 1 inch per month between May and October.

LAND ASSESSMENT

Characteristic of non-irrigated pasture plots, the property has a few springs, wells, and two dams (20 years old) along the tree line and river bed of the Santa Ysabel Creek. The dam is a gravity feed model with outdated infrastructure. Each site dam provides 10,000 gallons each, yet with some seepage loss of water, so there is a major concern for water loss. Access to water by livestock is easy, yet water flow is low in the summer.

The soils are relatively all sandy loams and coarse with low soil organic matter (SOM) (<3%). Gullies are actively eroding; however, this active wind, gully, and interrill erosion does not extend down to the bedrock. The strong, dry Santa Ana winds, which move from inland to coast and down slope, contribute to top soil loss. These winds can also potentially break fencing and other property infrastructure. The farm was not affected by fires in 2004 or 2007; however, a portion of the land may have been damaged by fires in previous decades.

BIODIVERSITY

The oak trees do not show signs of GSOB (gold-spotted oak borer), an invasive beetle native to Arizona oak forests that contributes to significant tree mortalities. GSOB can spread quickly, reducing tall canopies to stumps. A cocoon method is used as a slow drip method for trees. Several of the rare California species were removed by invasive species in the rangelands.

WILDLIFE

There are 400 animal units of medium-sized Angus and Barzona bovine species, the latter is a South African range cattle that is both disease and pest resistant. Both Angus and Barzona are raised as beef cattle. With each drinking 15 gallons per day via a pipeline, this amounts to 6000 gallons per day for livestock. These black and burgundy cows are intensively managed and graze in high density, which equates roughly to small paddocks of 0.5 acres per two-hour increment or 2.5 acres per day. Barzona cattle are easily adaptable and can navigate rough terrain across mountain to desert terrains; they are also valuable calf producers. Similarly, Angus cattle have high fertility rates and use their dark furs to genetically protect their skin from cancers and sunburns.

Southern mule deer also roam the rangeland, while mountain lions are the lone predators for the livestock and deer in recent years. In the last decade, bobcats, coyotes, and deer were also observed along the Santa Ysabel Creek within a 6-mile distance west of Montado Farms.

INFRASTRUCTURE

A dirt path connects the Mesa Grande Road to the farm house. Old fencing surrounds the property.

CURRENT LAND USE PRACTICES

Montado farmers employ mob grazing, a practice in which their 400 cow/calf pairs bunch intensively on half an acre of land for short periods. As a holistic method of grazing, the rangeland is currently grazing 50% more cattle than historically held there. They currently employ cover crop, which is a no-till seeding method using multiple species of cover crops that provide additional forage for livestock and act as an agent for improved soil health. Their crops include corn, squash, and brassica vegetables. A 1-acre plot of the land, located near Mesa Grande Road, has been utilized by NRCS for compost assessment as a field trial.

FUTURE LAND USE PRACTICES AND GOALS

The main interests of Montado Farms are (1) livestock grazing and (2) agrotourism. To achieve these, they will be using conservation practices, specifically agroforestry, multi-species grazing, and silvopasture. The infrastructure for the irrigation system, nutrient feeding, and overall habitat for livestock will also be updated. However, the farmers hope to mimic nature by performing minimal to no tillage, limiting soil exposure, increasing both plant and root numbers with large diversity, and boosting biomass crops to support wildlife populations.

The owners of Montado Farms plan to boost animal units, specifically dairy cows, to supplement a dairy to the ranch. They will also be adding chickens, sheep, goats, and pigs, on the regions of low slope. They will be adding fencing around the riparian regions to develop the management system.

They also intend to boost agricultural tourism, specifically glamping, in the next few years. They intend to create a luxurious experience with glamping tents and a safari atmosphere. The Montado farmers will also be increasing their land by 18 thousand acres by 2018 throughout the San Diego County (Muno, personal communication).

CARBON CAPTURE POTENTIALS

Montado Farms exhibits many unique environmental opportunities for carbon sequestration from the atmosphere and retention in soils that impart soil, water quality, habitat, and economic benefits. A small percentage of Montado Farms exists as riparian and bottomland habitat, which could be restored to riparian buffer zone with vegetative and forest crops. A common conservation practice, riparian buffers capture significant quantities of atmospheric carbon while limiting nutrient runoff and erosion, creating a shaded habitat for biota and aquatic species. In contrast, a significant fraction of Montado Farms is represented as grassland, meadows, and disturbed area, to which silvopasture and mob grazing will increase forage production, cover crop production, and pasture productivity. Renovations to infrastructure, including fencing and water troughs will include the establishment of windbreak and shelterbelts for livestock, leading to decreases in soil erosion, water evaporation, and wildfire hazard. These carbon sequestration projections ultimately offer potentials to enhance water quality, increase soil water-holding capacities, expand agricultural and cover crop production and productivity, and improve livestock and wildlife habitat. Ultimately, these practices seek to build ecosystem health, increase farm resilience to climatic events, and be a part of the climate change solution through carbon farming.

Assessment of Landscape and Soils

ECOLOGICAL SITE CLASSIFICATION

The range of slope for Montado Farms range from 0 (flat) to 34.1 degrees (steep) (Figure 4). Slope class represents the rise or fall of a land surface. Of the full acreage of Montado Farms, 1508.8 acres have flat to low slopes (<10 degrees), and 1197.0 acres have low to moderate slopes (between 10-20 degrees). The remaining minority (12.9%) of the land has a steep slope (>20 degrees).

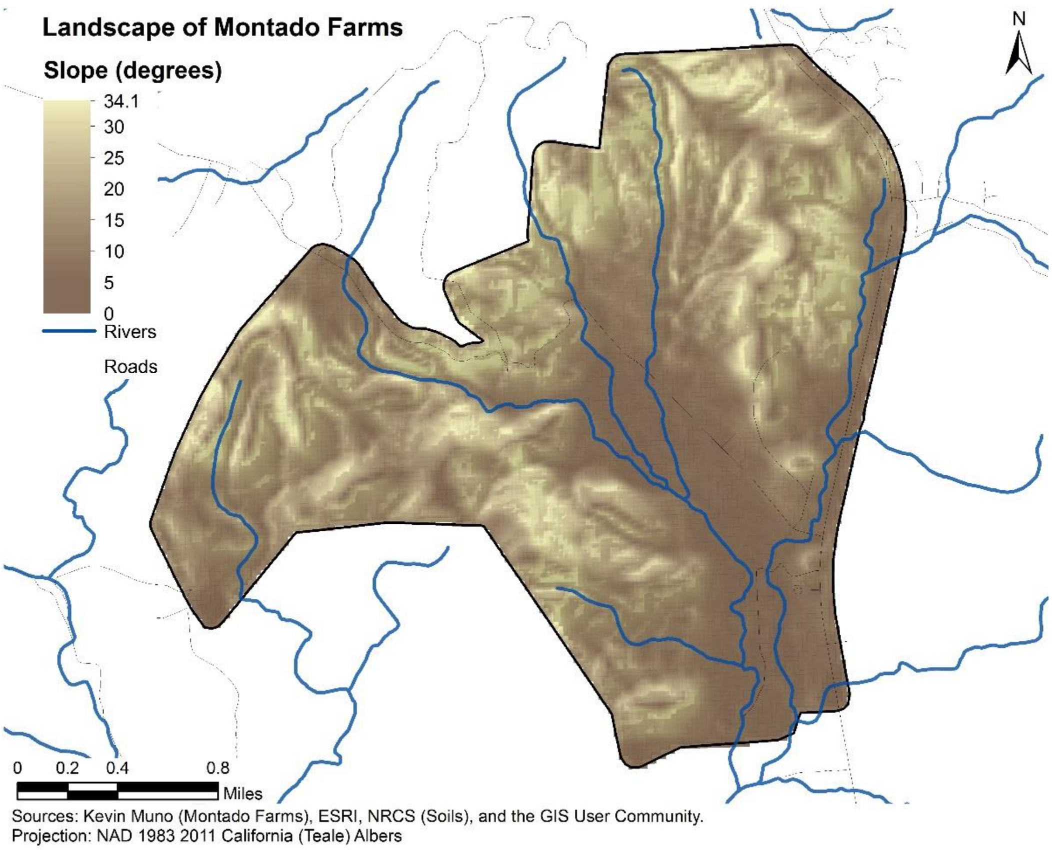

Figure 4. Slope for Montado Farms, with flat slopes in brown and steep slopes in yellow.

For reference, the steepest roads in San Diego County have slopes of 26-28%; the steepest roads in San Francisco, CA have slopes of 29-32%. In agriculture, plant, irrigation, and grazing management can be challenging, depending on the severity and stability of slope. Plant roots reinforce soils and soil aggregates such that soil strength increases and susceptibility to erosion decreases. In contrast, winds force plant and soil movement, leading to added stressors for soils in steeper slope regions. In all, steeper slopes generally contribute to greater rates of water runoff and surface erosion.

Due to its hilly landscape, Montado Farms has a range of aspects (Figure 5). The majority of Montado Farm land has southern-facing slopes (624.5 acres), southeastern-facing slopes (579.3 acres), southwestern-facing slopes (563.5 acres), and eastern-facing slopes (518.4 acres), representing 73.6% of the total acreage. North- and northeastern-facing slopes represent 521.3 acres, while west- and northwestern-facing slopes represent 295.7 acres; in contrast, only 4 acres of the land are flat.

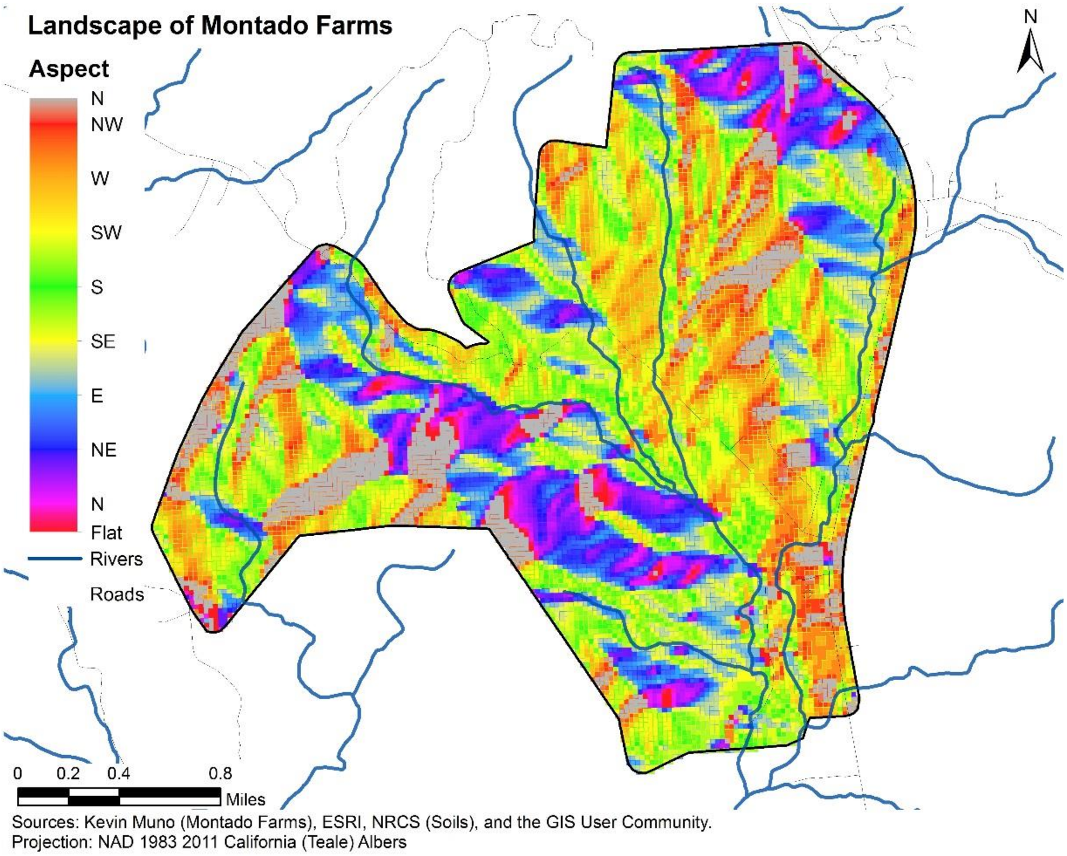

Figure 5. Aspect for Montado Farms, with northern-facing slopes in red and southern-facing slopes in yellow.

Aspect is a landscape feature identifying the compass direction that is faced by a slope. A slope effect is described as the effects of physical and biological features based on the slope and can describe its microclimate and vegetative communities. Generally, a north-facing slope falls to a deeper valley on its northern edge and a shallower valley on its southern edge. These north-facing slopes often receive larger inputs of rainwater, snow, and shade, which is more conducive to plant and forest growth, compared to their south-facing counterparts. South-facing slopes often receive greater inputs of sunlight and winds, therefore indicating that they are warmer and drier than north-facing slopes. The Santa Ana winds originate inland in desert regions, flowing towards sea level in southern California; they are strongest in the fall. West-facing slopes receive greater inputs of sunlight during warmer temperatures than their east-facing counterparts, which receive sunlight during colder temperatures. As a result, west- and south-facing slopes have more evapotranspiration. In terms of vegetation, north- and east-facing slopes are more conducive to forest vegetation, while south- and west-facing slopes are more conducive to grasslands.

SOIL SURVEY

The majority of soils at Montado Farms include the Holland, Crouch, Sheephead, and Reiff series (Table 1). All Montado Farm soils have xeric (i.e. Mediterranean) moisture regimes, representing wet winters and dry summers. The Reiff series and Tujunga sand have thermic soil temperature regimes, ranging 15-22 °C, while the Holland, Crouch, and Sheephead series have mesic soil temperature regimes of 8-15 °C. All soils have a mixed clay mineralogy. The Crouch, Sheephead, Holland, and Reiff series have cation-exchange capacities, as divided by the clay percentage, that are semiactive (0.2-0.4%) to superactive (>0.6%). The descriptions for all soils were obtained from the NRCS site for soil series descriptions and series classifications (NRCS, 2017b).

TABLE 1. SOILS OF MONTADO FARMS

SOIL TYPE	PERCENT SLOPES	SYMBOL	ACRES	PERCENT OF AREA
Holland stony fine sandy loam	5-30	HnE	901.9	29.0
Crouch rocky coarse sandy loam	5-30	CuE	436.7	14.1
Sheephead rocky fine sandy loam	9-30	SpE2	428.8	13.8
Holland fine sandy loam	5-15	HmD	321.7	10.4
Reiff fine sandy loam	0-2	RkA	301.4	9.7
Holland fine sandy loam, deep	2-9	HoC	181.1	5.9
Crouch coarse sandy loam	5-30	CtE	172.0	5.5
Tujunga sand	0-5	TuB	114.6	3.6
Holland fine sandy loam	15-30	HmE	100.7	3.2
Sheephead rocky fine sandy loam	30-65	SpG2	57.2	1.8
Holland stony fine sandy loam	30-60	HnG	51.4	1.7
Riverwash	-	Rm	14.2	0.5
Acid igneous rock land	-	AcG	14.1	0.4
Reiff fine sandy loam	2-5	RkB	11.1	0.4
TOTAL			3107	100

Reference: USDA NRCS soil survey. <www.nrcs.usda.gov>

Acid igneous rock land. Acid igneous rock land soils are rough terrain, characterized by large boulders of granite, quartz, basalt, and other minerals. These soils range in texture from coarse sand to loams and are shallow over decomposed bedrock. Acid igneous rock land has very slow infiltration rates when saturated with water, with very slow rates of water transmission. An acid igneous rock land profile is unweathered bedrock down to 4 inch depths. This soil has severe erodibility due to slope and severe limitations for conversion from brush to grassland. No forage production will be estimated for acid igneous rock land due its infertility.

Crouch series. The Crouch series are fine-loamy Alfisols with grayish-white horizons that are leaning towards Ultisols due to their hilly setting. These soils are moderately deep to deep, well-drained soils derived from weathered granodiorite and micaceous schist. They reside on mountain uplands on slopes of 5 to 75 percent. These moderately coarse-textured soils have moderate rates of water transmission and infiltration when saturated. A Crouch profile ranges from a dark gray-brown surface layer of coarse sandy loams (0-29 in. depths) to a yellowish brown subsoil layer of sandy loams and loams (29-56 in. depths). These soils typically have 4-8 inches of water storage. Soil organic matter (SOM) contents are ~2% at depths of 10 inches and decrease steadily to <1% at depths of 20 inches. Despite fair topsoil, the Crouch series is arable soil with severe erodibility due to structural grades of the surface layers and slight to moderate limitations for conversion from grassland. The predominant vegetation for Crouch soils often include cropland, pastures, and forests.

Taxonomic class: Coarse-loamy, mixed, superactive, mesic Ultic Haploxerolls.

Forage production: Forage production ranges from unfavorable to favorable year values of 2550 to 3825 lbs/acre/year. Forage production in a normal year is 3400 lbs/acre/year.

Holland series. The Holland series are coarse-loamy Mollisols with dark-colored surface layer that are leaning towards Ultisols. These soils consists of moderately deep to deep soils that have slopes of 2 to 75 percent and were formed from deeply weathered quartz diorite or granodiorite. Often consisting of stone and cobble, these moderately fine to fine-textured soils are found in high elevation (1200-5600 feet) regions with subhumid climates. With water-holding capacities of 3-10 inches, they are well-drained with moderate permeability and slow rates of water infiltration and transmission. A Holland profile ranges from a yellowish-brown surface layer of stony to fine sandy loams (0-20 in. depths) to a brown subsoil layer of sandy clay loams and clay loams (20-40 in. depths). SOM contents range 1.5-3% in Holland soils. Erodibility for Holland soils is severe due to the poor structural grade of the surface layers, except for HnG, which has severe issues due to slope. In all, moderate limitations exist for this non-arable series with poor to fair topsoil for the conversion to grassland.

Taxonomic class: Fine-loamy, mixed, semiactive, mesic Ultic Haploxeralfs

Reiff series. The Reiff series is represented as coarse-loamy Entisols with sandy textures that verge towards Mollisols. As the least-developed of the soil orders, they consists of deep, well-drained river deposits that have slopes of 0 to 9 percent and were formed from alluvium deposits. These moderately deep to deep soils have moderate rates of water transmission and infiltration when saturated yet severe erodibility due to the structural grade of the surface soils. A Reiff profile ranges from a grayish brown surface layer of fine sandy loams (0-14 in. depths) to a brown fine sandy loams and loams (14-43 in. depths). SOM contents range from <1% and decrease irregularly with depth. Reiff soil pH ranges from slightly acidic to moderately alkaline. As good topsoil, the Reiff series is an acceptable soil for avocado, flower, and citrus crops and adequate for tomatoes. The water-holding capacity of these soils is 7-10 inches.

Taxonomic class: Coarse-loamy, mixed, superactive, nonacid, thermic Mollic Xerofluvents

Riverwash. Riverwash soils are found in stream channels and consist of sand, gravel, and cobble. These well-drained to excessively drained soils often contain sparse shrubs or lack in vegetation altogether and are rapidly permeable. The slopes of Riverwash soils are 0 to 4 percent and encompass profiles ranging from gravelly coarse sand (0-6 in. depths) to gravelly sand (6-60 in. depths). SOM contents are low, often <0.1% in these soils. Riverwash soils have high rates of water transmission and infiltration when saturated with water, therefore indicating low water-holding capacities. These soils are not arable and have no use for grazing, so no forage production will be estimated for Riverwash soils.

Sheephead series. The Sheephead series consist of loamy Mollisols that verge towards Entisols. They are shallow, well-drained soils formed from deeply weathered micaceous schist and gneiss, residing on slope of 9 to 65 percent. These soils are moderately fine to fine-textured with slow rates of water transmission and infiltration and 2-3 inches of water-holding capacity. A Sheephead profile ranges from a dark grayish-brown surface layer of cobble fine sandy loams (0-8 in. depths) to a pale yellow subsoil layer of micaceous schist and other weathered bedrocks (8-11 in. depths). Erodibility is severe for both, specifically due to the structural grade of the surface soils for SpE2 and for high slope (>30%) for SpG2. SOM contents are ~2% in Sheephead soils. The Sheephead series is generally infertile with poor topsoil and moderate limitations for conversion from brush to grass. The native vegetation is woodland with grassland and shrubs.

Taxonomic class: Loamy, mixed, superactive, mesic, shallow Entic Ultic Haploxerolls

Forage production: Forage production for the Sheephead series ranges from unfavorable to favorable year values of 425 to 1360 lbs/acre/year. Forage production in a normal year is 850 lbs/acre/year.

Tujunga sand. The Tujunga series are sandy Entisols, consisting of deep, excessively drained sandy soils in floodplains. They have low slopes of 0 to 12 percent and were formed in the alluvium from granitic rock. These soils have high rates of water infiltration with low runoff potentials, yet severe erodibility due to the poor texture of the surface layer. A Tujunga profile ranges from a brown sand (0-14 in. depths) to brown loam and fine sands (14-34. depths). SOM contents are <1% in these soils. The soil pH of Tujunga sand ranges from slightly acidic to moderately alkaline and is suitable for grazing and avocado, citrus, and fruit crops due to slight limitations for vegetation conversion to grassland. These soils typically have 3-4 inches of water storage.

Taxonomic class: Mixed, thermic Typic Xeropsamments

Forage production: Forage production for Tujunga sand ranges from unfavorable to favorable year values of 765 to 1870 lbs/acre/year. Forage production in a normal year is 1105 lbs/acre/year.

Each of these soils is displayed below within the 3107 acres of Montado Farms (Figure 6). The Riverwash and Tujunga sandy soils outline regions of water and floodplain; similarly, Reiff soils from nearby river valleys are composed of alluvium.

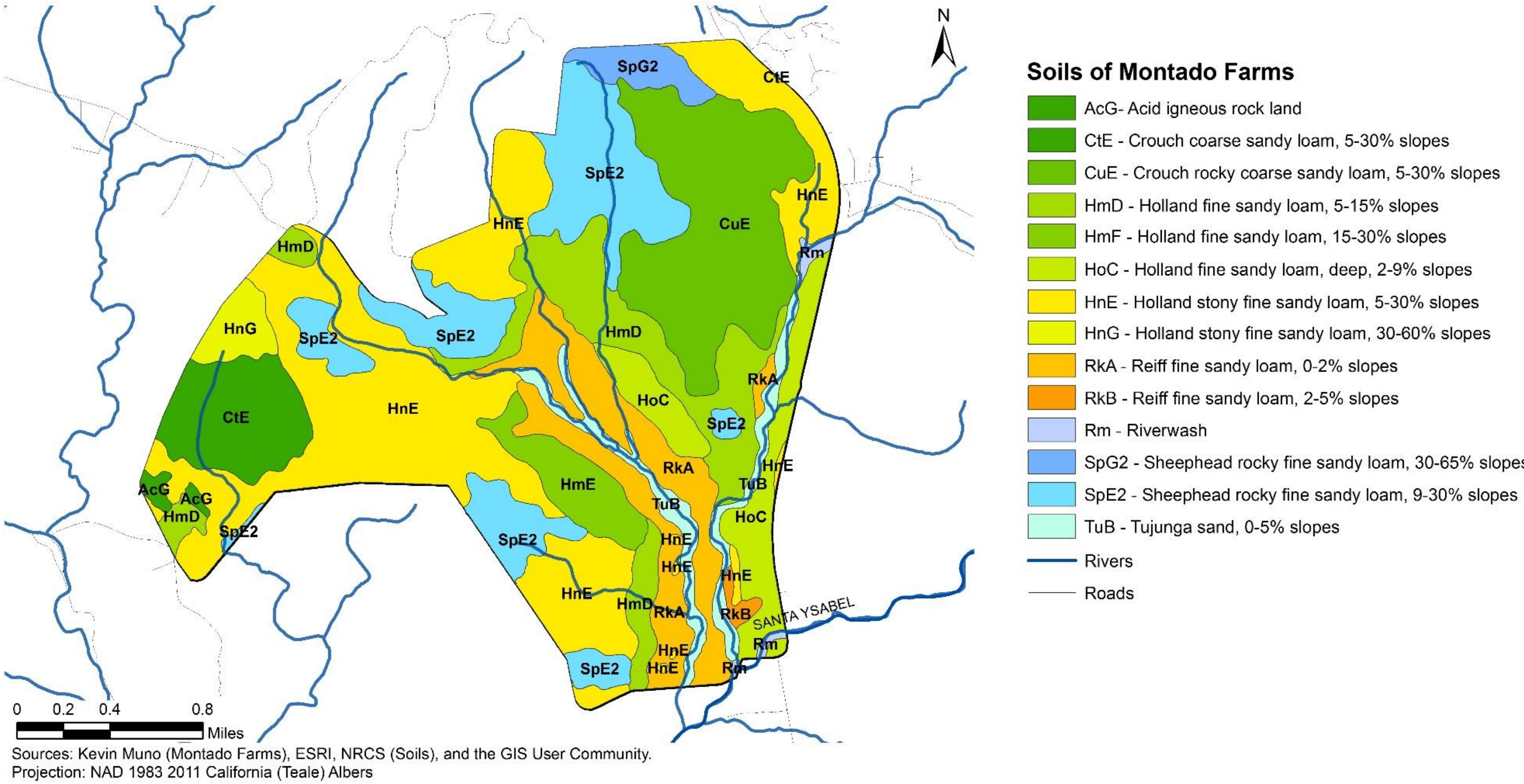

Figure 6. Soils of Montado Farms with outline of creeks and roads through the property.

SOIL HEALTH AND POTENTIAL FOR PLANT GROWTH

Soil health is an integral piece of understanding the functioning of these ecosystems, which facilitates management decisions. An indicator of soil health and soil quality, SOM measures the plant and animal residue resulting from decomposition, biotic cells and tissue, and by-products of soil microorganisms. The three components of SOM include: (1) light fractions of fresh plant exudates which decay in weeks to months, (2) physically-protected mineral particulate aggregates which decay in decades, and (3) chemically-stable organic matter which decay in hundreds to thousands of years. SOM is a major sink of soil carbon and provides additional habitat and food supply for biota. It also exerts many beneficial effects on soil functioning, including improved soil structure, biodiversity, and fertility, water retention, and nutrient cycling. Water content is the fraction of soil water retained at a pressure of 15 bar and is an indicator of the available water capacity or estimated retention in soil.

TABLE 2. SOIL HEALTH, SPECIFICALLY SOIL ORGANIC MATTER (SOM) AND WATER STORAGE

KEY	SOIL TYPE	PERCENT AREA	SOM (%)	WATER CONTENT (%)
AcG	Acid igneous rock land	0.4	NR	NR
CtE	Crouch coarse sandy loam	5.5	2.0	8.2
CuE	Crouch rocky coarse sandy loam	14.1	2.0	8.2
HmD	Holland fine sandy loam	10.4	3.0	8.5
HmE	Holland fine sandy loam	3.2	3.0	8.5
HnE	Holland stony fine sandy loam	29.0	2.3	7.9
HnG	Holland stony fine sandy loam	1.7	1.6	7.9
HoC	Holland fine sandy loam, deep	5.9	3.0	10.5
RkA	Reiff fine sandy loam	9.7	0.6	9.7
RkB	Reiff fine sandy loam	0.4	0.6	9.7
Rm	Riverwash	0.5	0.02	0.3
SpE2	Sheephead rocky fine sandy loam	13.8	2.0	8.3
SpG2	Sheephead rocky fine sandy loam	1.8	2.0	8.3
TuB	Tujunga sand	3.6	0.6	2.7

NR indicates not reported. Reference: USDA NRCS soil survey. <www.nrcs.usda.gov>

At Montado Farms, the Holland series have the highest SOM (Table 2), ranging 1.6-3.0%, followed by the Crouch and Sheephead series (see Supplementary Figure 10 for map). The riverbed soils, Tujunga sand, Riverwash, and Reiff series, have the lowest SOM, ranging 0.02-0.6%. Based on SOM values, vegetation and root exudates more pronounced in Holland, Crouch, and Sheephead soils than their coarser-grained soil counterparts. This difference may be explained by the transport of SOM out of the riverbed environment.

The Holland series also have the highest water contents, ranging 7.9-10.5% (see Supplementary Figure 11 for map). These values are closest to that of the Reiff series (9.7%) and Crouch series (8.2 %). The Tujunga sand and Riverwash soils have the lowest water contents (<3%), indicating that coarser soils generally have lower water contents than their finer-grained counterparts.

Assessment of Grazing and Carrying Capacity

OBJECTIVES AND GOALS

The objectives of the grazing assessment are to determine how the grazing season and forage production of Angus and Barzona cattle can contribute to carbon sequestration in coalition with improvements in soil health, water quality, nutrient cycling, and wildlife habitat in the Montado Farm rangelands. Nutrient cycling will be achieved though natural manure application on the available forage lands to ultimately sequester carbon. The long-term goals of grazing are to enhance habitat and landscape, support the ranching industry, and encourage conservation practices and healthier ecosystems in San Diego County.

Grazing management has visible, achievable results, with increases in vegetation cover, composition, and diversity in a few years. Similarly, without livestock, the population of rare flower species declines dramatically, including that of the Sonoma Spine flower in California (Schohr, 2009). Managed grazing in rangeland ecosystems can improve habitat for livestock and wildlife species, including threatened and endangered species (Schohr, 2009).

RESIDUAL DRY MATTER

Residual dry matter (RDM) represents non-decayed herbaceous plant material remaining in grazing rangelands at the end of the growing season. An RDM assessment determines the effects of forage production, specifically consumption by livestock, species composition, and decomposition, depending on vegetation type and climatic and site conditions. Developed primarily for California annual rangelands, RDM influences vegetation productivity, in which recommended values are 600 lbs/acre in dry annual grasslands, 800 lbs/acre in annual grassland and hardwood rangelands, and 2100 lbs/acre in coastal prairies under low woody cover percentages (0-25%). These recommended standards vary with percent cover of woody vegetation.

CURRENT FORAGE PRODUCTION AND INVENTORY

Montado Farms has 400 cow/calf pairs that graze intensively on about 0.5 acres per two-hour increment. The total annual forage demand of the 1000-lb cows is 4800 Animal Unit Months (AUM). Moreover, the forage demand for an average of 270 calves (i.e. 200-340 calves weighing ~500 pounds each) is 3240 AUM. Since AUY represents the amount of forage needed for an animal unit (AU) grazing for 1 year, this equates to a total forage demand of 38,880 Animal Unit Years (AUY). Of the 3107-acre farm, 39% of the land is estimated for use in forage production annually (Table 3).

TABLE 3. ESTIMATED ANNUAL FORAGE PRODUCTION AND AVAILABLE FORAGE FOR MONTADO FARMS

			FORAGE PRODUCTION (LBS/ACRE/YR)			RESIDUAL DRY MATTER	AVAILABLE FORAGE		
Symbol	SLOPE (%)	ACRES	LOW YEAR	NORMAL YEAR	FAVORABLE YEAR	(RDM) (LBS/ACRE)	LOW YEAR	NORMAL YEAR	FAVORABLE YEAR
CtE	5-30	172.0	2550	3400	3825	600	437,828	584,028	657,128
CuE	5-30	436.7	2550	3400	3825	600	1,112,548	1,483,743	1,669,341
SpE2	9-30	428.8	425	850	1360	600	181,211	363,451	582,139
SpG2	30-65	57.2	425	850	1360	800	23,453	47,763	76,935
TuB	0-5	114.6	765	1105	1870	500	30,369	69,333	157,002

References: USDA NRCS soil survey. <www.nrcs.usda.gov> and UC Division of Agriculture and Natural Resources – Guideline for RDM on Coastal and Foothill Rangelands in California. <http://anrcatalog.ucanr.edu/pdf/8092.pdf>.

These sites include the Crouch, Sheephead, and Tujunga series, in which estimated annual forage production range from 765-2550 lbs/acre/year for low years to 1360-3825 lbs/acre/year for favorable years (NRCS Soil Survey, 2017). Residual dry matter (RDM) levels indicate recommended rates of plant biomass retained at the end of the grazing season and ranged 500 to 800 lbs/acre, with the lowest value recommended for the Tujunga soil. Recommended RDM levels also increase from low to high with decreases from heavy grazing to light grazing and also from dry grasslands to rangelands to coastal prairies (Bartolome et al., 1970). RDM influences the annual forage production and vegetative species composition in following years. The available forage can be estimated by subtracting RDM recommendations from estimated annual forage production. Typically, RDM is set by the manager, based on recommendations from experience and literature.

TABLE 4. ESTIMATED AUM AND AUY FOR MONTADO FARMS

			ANIMAL UNIT MONTHS (AUM)			ANIMAL UNIT YEARS (AUY)		
Symbol	SLOPE (%)	ACRES	LOW YEAR	NORMAL YEAR	FAVORABLE YEAR	LOW YEAR	NORMAL YEAR	FAVORABLE YEAR
CtE	5-30	172.0	486	649	730	5,838	7,787	8,762
CuE	5-30	436.7	1,236	1,649	1,855	14,834	19,783	22,258
SpE2	9-30	428.8	201	404	647	2,416	4,846	7,762
SpG2	30-65	57.2	26	53	85	313	637	1,026
TuB	0-5	114.6	34	77	174	405	924	2,093
TOTAL		**1209.3**	**1,984**	**2,831**	**3,492**	**23,805**	**33,978**	**41,901**

GRAZING STRATEGIES AND MANAGEMENT PLANS

The Holland, Reiff, and Tujunga series of low slopes (<10%), specifically HmD, HoC, RkA, RkB, and TuB, are the only prime regions for farmland. HmD and TuB are farmlands of statewide importance, whereas the other three units are prime if irrigated. Tujunga soil has the lowest recommended RDM, which is indicative of heavier grazing or lower production managements in previous years than the other two series. The SpG2 region (Sheephead rocky fine sandy loam) has the highest slope, which may be less suitable for efficient grazing.

The addition of twenty horses on 10% of the land (310 acres), indicates that their forage demand will be 288 AUM or 3,488 AUY. The total forage demand for the cow/calf pairs and horses would be approximately 42,368 AUY, or 3,530 AUM. The estimated 35 AUY per acre is very low and does not meet the forage demand. This suggests that feed must be also purchased off site. There are no estimates on irrigated forage, or for comparison with rangeland forage.

RESOURCE CONCERNS

Two studies regarding the potential of rangelands as suitable grazing lands showed that slope is a major limiting factor (Guenther et al., 2000; Ariapour et al., 2014). Both studies suggest that an increase in slope results in decreases in water retention times and available forage, and increases in water runoff. These propose that regions with slopes greater than 50 degrees are inadequate for livestock. In contrast, the quantity and quality of water and distance to water did not pose a significant limitation for grazing livestock for this study site but may not be generally true at other ranches.

CARBON BENEFITS OF GRAZING PRACTICES

The carbon capture benefits of planned grazing practices, specifically mob grazing and silvopasture, can result in reductions of atmospheric CO_2 and sequestration in soils and vegetation (Table 5). Using the COMET-Planner assessment for prescribed grazing management on rangelands and combined prescribed grazing and nutrient (i.e. manure-based compost) management practices, estimates of carbon capture are 0.03 and 5.82 Mg/acre/year, respectively. The total carbon capture potentials are 36-967 MT CO_2E annually; moreover, these potentials increase to 544-14,512 MT CO_2E and 1,088-29,023 MT CO_2E over fifteen and thirty years, respectively. These estimates indicate that carbon capture will stabilize or decrease slightly over time as soils reach a new equilibrium under improved management. An analysis of carbon emissions in the California beef production systems showed reductions in carbon dioxide emissions which were potentially within the range of values estimated by COMET-Planner. Stackhouse-Lawson et al. (2012) estimated values of 0.9 Mg/cow-calf pair/year, resulting in carbon capture potentials of 358, 5376, and 10752 MT CO_2E over one, fifteen, and thirty years, respectively. These systems were similar to the irrigated grasslands with sandy loams and varying slopes measured for Montado Farms (Stackhouse-Lawson et al., 2012).

These grazing benefits of added carbon to grazing lands are extensive, reducing the emissions of CO_2 and storing carbon in plants and soils. This conservation practice can decrease soil erosion, runoff, and soil surface evaporation, increase biological activity, and improve nutrient cycling and improve soil quality. It can also increase water infiltration and available water and improve water quality. Vegetation growing conditions and productivity are enhanced through increases in vegetative cover and soil organic matter (SOM), developed root systems, leading to improvements in plant health. Prescribed grazing ultimately has the potential to restore habitat for livestock and wildlife.

ASSESSMENT OF GRAZING AND CARRYING CAPACITY

TABLE 5. CARBON CAPTURE POTENTIALS FOR GRAZING MANAGEMENT AT MONTADO FARMS

		Mg CO_2E estimated from COMET planner: Prescribed grazing management on rangeland			Mg CO_2E estimated from COMET Planner: combined prescribed grazing and nutrient management (dairy and beef manure addition) on rangeland			Mg CO_2E estimated for grazing management from Stackhouse-Lawson et al. (2012)		
		0.03 Mg/acre/year			0.8 Mg/acre/year			0.9 Mg/animal/year†		
Grazing Land	Acres	Annual	15 years	30 years	Annual	15 years	30 years	Annual	15 years	30 years
CtE	172.0	5	77	155	138	2064	4128			
CuE	436.7	13	197	393	349	5240	10481			
SpE2	428.8	13	193	386	343	5146	10291	358	5376	10752
SpG2	57.2	2	26	51	46	686	1373			
TuB	114.6	3	52	103	92	1375	2750			
TOTAL	**1209.3**	**36**	**544**	**1,088**	**967**	**14,512**	**29,023**	**358**	**5,376**	**10,752**

1 Mg (megagram) = 1 metric tonne (MT).

†Values estimated for Angus beef production in California.

References: COMET-Planner, NRCS <comet-planner2.com> and Lewis et al. (2015).

Assessment of Agroforestry

OBJECTIVES AND GOALS

The objectives of the agroforestry assessment are to evaluate how agroforestry, specifically the establishment of trees and other self-sustaining woody vegetation, could contribute to carbon sequestration in plants and soil at Montado Farms. Agroforestry will be achieved through the integration of trees into livestock and crop systems as a sustainable improvement to agriculture. Beneficial across all agricultural systems, agroforestry can incorporate silvopasture, riparian forest buffers, windbreaks, and hedgerow planting, all of which represent the establishment of trees and woody shrubs to achieve carbon sequestration and other long-term environmental benefits. Silvopasture combines tree planting with compatible forage on the same habitat, strengthening livestock production by providing cover and forage. Riparian forest buffers boost trees along rivers and streams, leading to improvements in water quality, enhancements in aquatic species, and protection. Windbreak establishments add trees and shrubs along boundaries perpendicular to the direct of prevailing winds, helping to reduce the wind speed and limit erosion throughout rangeland. Hedgerow planting adds trees simultaneous with crops in widely-spaced rows or along property boundaries; this practice improves crop performance and efficiency and improves the wildlife and pollinator habitat.

Despite slight reductions in the plant community, the addition of agroforestry practices seeks to create a healthier rangeland with both environmental and social benefits. An important goal of agroforestry as a conservation and carbon capture practice includes the enhancement of vegetation to increase cover, root development, and soil organic matter (SOM) to promote better soil health and structure. While also increasing revenue and land efficiency for farmers, agroforestry on rangelands has the ability to contribute to food security and environmental resilience. Silvopasture also improves livestock grazing by improving the overall habitat and forage production.

VEGETATION

The vegetation of the Montado Farms ranges from grasslands and meadows to woodland to riparian habitats (Table 6; Figure 7). The riparian habitat sections roughly outline the streambeds and river ways. Woodlands and grassland represent 51.7% and 27.7% of the Montado Farm area, respectively, while riparian and bottomland habitat represent only 2.3% (Table 6). A small fraction is disturbed and developed area, representing <200 acres of the land.

Engelmann Oak (*Quercus engelmannii*) is a white oak species native to southern California. With a round or elliptical canopy, this vascular tree produces catkin flowers and brown acorn fruits and grows to 10 meters in height. Its deciduous ability in periods of drought make it an ideal tree for San Diego County and for the foothills of Santa Ysabel Valley. Coast Live Oak (*Quercus agrifolia*) is an evergreen Oak native to and thriving in Mediterranean climate regions along California's Pacific Coast. Found on well-drained soils and in floodplains, coast live oak reach 10-25 meters in height, produce catkin and acorn, and have a canopy of 50% cover. Found in riparian regions, Arroyo Willow trees (*Salix lasiolepis*) are winter-deciduous trees that grow to 10 meters in height and are native to California; they are often located with chaparral, mixed forests, and oak woodlands. They have closed canopies of tall, broad leaves.

TABLE 6. VEGETATION OF MONTADO FARMS

VEGETATION TYPE	TYPE	ACRES	PERCENT AREA
Woodland	Open Engelmann Oak	643.1	20.7
(1606 acres; 51.7% of Montado Farms)	Dense Engelmann Oak	587.2	18.9
	Mixed Oak	245.5	7.9
	Engelmann Oak	55.9	1.8
	Dense Coast Live Oak	52.8	1.7
	Coast Live Oak	21.7	0.7
	Non-native woodland	2.2	<0.1
Grassland, vernal pools, meadows, herb communities	Non-native grassland	664.9	21.4
(860 acres; 27.7% of Montado Farms)	Foothill/mountain perennial grassland	133.6	4.3
	Montane meadows	34.2	1.1
	Valley and foothill grassland	28.0	0.9
Scrub and chaparral	Chamise Chaparral and Chaparral	208.2	6.8
(368.9 acres; 11.9% of Montado Farms)	Northern mixed Chaparral	118.1	3.9
	Diegan Coastal Sage Scrub	37.3	1.2
	Montane Buckwheat Scrub	5.3	0.2
Disturbed or developed area	Fields and pastures	167.8	5.3
(197.8 acres; 6.4% of Montado Farms)	Urban and developed regions	31.1	1.0
Riparian and bottomland habitat and vernal pools	Southern Coast Live Oak riparian forest	31.1	1.0
(73.6 acres; 2.3% of Montado Farms)	Southern Riparian Scrub	31.1	1.0
	Southern Arroyo Willow riparian forest	4.7	0.2
	Southern riparian forest	4.0	0.1
	Riparian woodlands	0.6	<0.1
TOTAL		**3107**	**100**

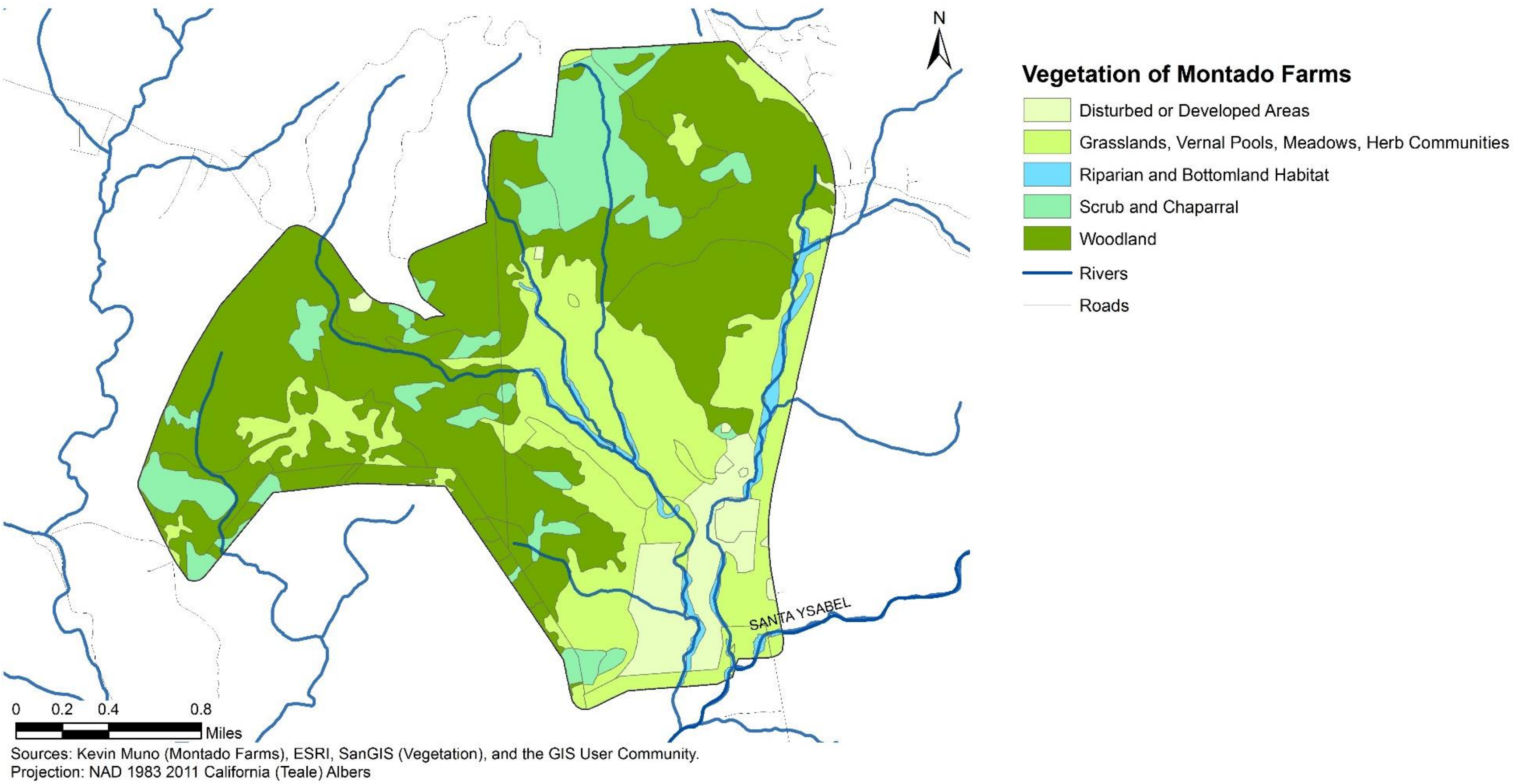

Figure 7. Vegetation on Montado Farms.

Montane meadows support dense perennial herbs found in fine-textured, wet soils. The Montane biome includes grass and shrub lands at high altitude. Valley and foothill grasslands are often located with Northern mixed chaparral and mixed evergreen forests. Native grasslands are comprised of competitive germinators that sprout annually and quickly. Including ryegrass, mustard, and wild oats, these species thrive in Mediterranean subhumid climates where they can germinate in early spring and seed during dry periods; they also support Coastal Sage Scrub and other native grasslands.

The Diegan Coastal Sage and Montane Buckwheat scrubs are low-growing, perennial plant communities that grow in small patches. Diegan Coastal Sage Scrub is dominated by the *Baccharis* species, while Montane Buckwheat represents flat-topped buckwheat at higher elevations in San Diego County (Oberbauer et al., 2008). These native plants were nearly destroyed due to anthropogenic destruction, specifically agriculture and urbanization, yet persist under periods of drought. The Chamise and Northern mixed chaparral belong to coastal biomes in nutrient-poor soils. Chaparral are dense evergreen woody shrubs, covering up to 25% of land in San Diego County. A host for a variety of wildlife, including lizards, butterflies, and birds, chamise chaparral are protected by the San Diego Habitat Conservancy. Both predominant types are drought-tolerant, adaptive to fires, have broad leaves and are found on dry plains in rocky soils with steep slopes.

CARBON BENEFITS OF AGROFORESTRY

The carbon reduction estimates for agroforestry result in considerable carbon capture (Table 7). Of the five conservation practices listed in COMET-Planner for San Diego County and considered in this plan, silvopasture has the lowest emission reduction potential for CO_2E, falling at 0.7 Mg/acre/year. This equates to carbon capture potentials of 226 MT CO_2E or 6,772 MT CO_2E over thirty years over 40% of the grassland regions of the ranch. Windbreak establishment has the second lowest carbon capture potentials, ranging 8.2 Mg/acre/year for 1 row to 4.3 acre/year for 2 rows of woody plants. The installation of these plants along the perimeter of Montado Farms with a twenty foot width of vegetation indicates that a shelterbelt encompasses 27.2 acres of land. The resulting carbon capture potentials for windbreak are 118-223 MT CO_2E annually or 3541-6691 MT CO_2E over thirty years. Riparian forest buffers provide 1.8 Mg/acre/year of CO_2E reduction, equating to 130 MT CO_2E per year over the 73.6-acre riparian region on the rangeland. Hedgerow planting and tree/shrub establishments on 9% and 40% of the full grassland regions can contribute to annual reductions of 622 MT CO_2E and 6,460 MT CO_2E, respectively.

The co-benefits of carbon for vegetation resulting from agroforestry include improvements in plant diversity and food supply, while increasing vegetative matter and reducing temperature. Vegetation adds roots and root penetration through natural regeneration, leading to increases in SOM and improvements in soil structure. Vegetation also protects the soil surface by trapping nutrients and potential metals and reducing direct light/heading, leading to moderations in surface temperature. Infiltration and available water are increased while pesticide runoff, nutrient loss, and erosion are limited. Microbial activity is also increased, supplementing soil quality. Enhancing livestock habitat, agroforestry provides more covered space for grazing, forage, and wind protection.

TABLE 7. CARBON CAPTURE POTENTIALS FOR AGROFORESTRY AT MONTADO FARMS

CONSERVATION PRACTICE	CODE	DESCRIPTION	CO2E (MG/ACRE/YEAR)	ACRES	CO_2E EMISSION REDUCTIONS (MT)		
					Annual	15 years	30 years
Silvopasture	381	Tree/shrub planting on grazed grasslands	0.7	342	226	3,386	6,772
Tree/Shrub Establishment	612	Conversion of grassland to farm woodlot	18.9	342	6,460	96,906	193,811
Windbreak/Shelterbelt Establishment	380	Replace 1 strip of grassland or cropland with 1-2 rows of woody plants	8.2 for 1 row 4.3 for 2 rows	27.2	118-223	1,171-3,346	3,541-6,691
Riparian Forest Buffer	391	Replace a strip of grassland near watercourses or water bodies with woody plants	1.8	73.6	130	1,954	3,908
Hedgerow Planting	422	Replace a strip of grassland with 1 row of woody plants	8.2	75.9	622	9,336	18,671
TOTAL			**42.1**	**860**	**7,662**	**114,927**	**229,854**

1 Mg (megagram) = 1 metric tonne (MT).

Total values are based on 1 row of grassland for windbreak/shelterbelt.

References: COMET-Planner, NRCS <comet-planner2.com>.

CHALLENGES TO AGROFORESTRY

A challenge to agroforestry includes the establishment of trees and crops that can adapt to biological, geochemical, and physical conditions of the rangeland. This speaks to the importance of prioritizing native heliophilic species. These feats may be difficult in drought-stricken landscapes; however, their ability to transform landscapes into thriving agricultural systems is feasible given environmental, collective action, and financial support. Trees and large shrubs may also slow flood water movement and reduce the non-native plant community; however, their addition has shown to have slight to substantial improvements.

Another significant challenge to agroforestry is the introduction of Goldspotted Oak Borer (GSOB), *Agrilus auroguttatus*, which is an invasive pest and wood borer that contributes significantly to the mortality of oak and other native trees. It has been observed extensively in southern California, including in San Diego, Los Angeles, and Orange Counties. GSOB was first discovered in San Diego County in 2004 through infested firewood from its native regions in Arizona (Coleman et al., 2015). GSOB attacks the core of the tree, specifically its water supply and branches, while laying larvae at its base. With dispersal by infested oak woods, the implications of GSOB are severe for the environmental and human safety, affecting a plethora of oak species as a physically-unstable hazard and lead to loss of ecosystem services.

Two physically-identical beetles, called Polyphagous Shot Hole Borer (PSHB) and Kuroshio Shot Hole Borer (KSHB), also contribute to extensive damage to urban, native, and riparian forest systems. These invasive pests have been observed throughout southern California, despite originating in Southeast Asia; they were first discovered in San Diego County in 2012. Similar to GSOB, the beetles carry a pathogen that introduces larvae and Fusarium fungi to the tree core, disrupting water and nutrient storage leading to wilting leaves, branch disease, and tree mortality. In addition to habitat loss for wildlife and decreased property value, tree death ultimately leads to increased water temperature, fire danger, and air pollution and also decreased carbon sequestration. To prevent the spread of oak and hole borer pests, infested wood logs should be removed from the range land when safe and decontaminated by heat treatment, grinding, or debarking methods. These infested trees could, however, be a source of mulch for use on-farm soil management or composting operations, if applicable.

Assessment of Riparian Systems

OBJECTIVES AND GOALS

The objectives of the riparian system assessment are to decrease atmospheric carbon dioxide emissions through the establishment of trees, shrubs, grasses, ferns, and other herbaceous species along the transitional zones between aquatic habitats and upland regions. Conservation practices for riparian and stream systems couple water restoration projects with the re-establishment of vegetation to sequester carbon in woody biomass and in soil. Bank re-stabilization projects along the river corridors often support plant growth due to the large pools of available water. Carbon capture in riverine soils and woody vegetation along stream corridors is often several times greater than in grasslands and mixed woodland regions.

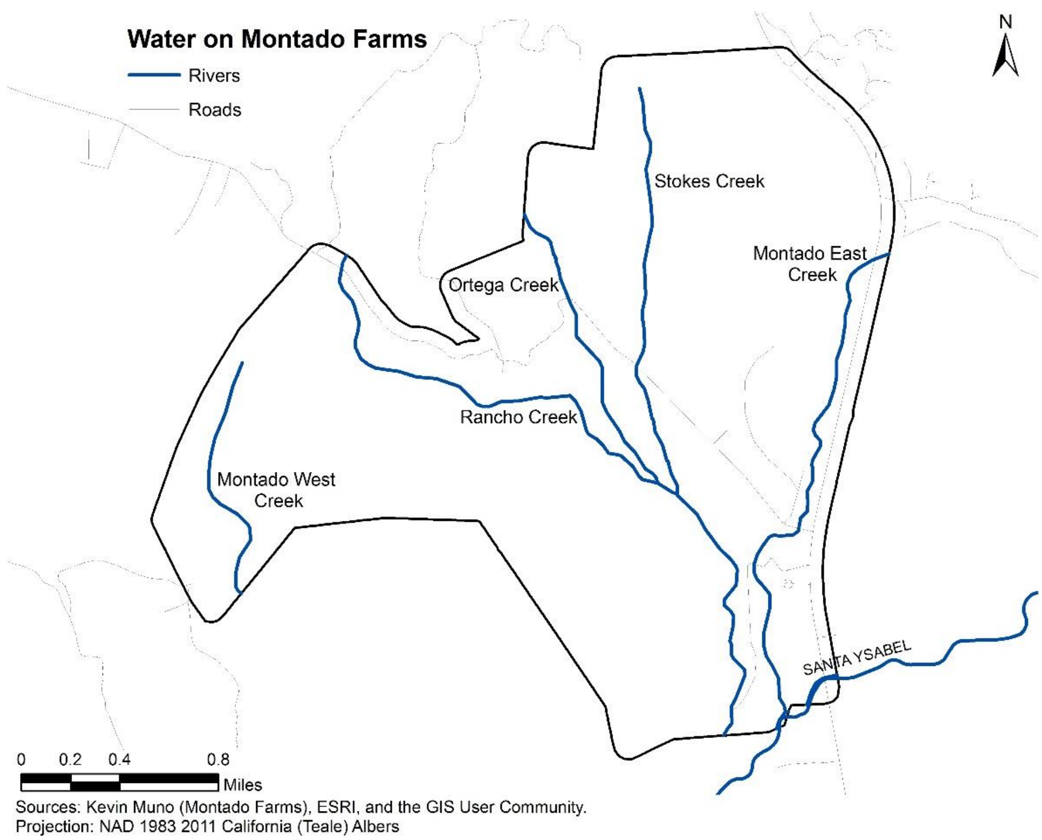

Figure 8. Riparian systems of the Montado Farms, specifically the small perennial tributaries running towards Santa Ysabel Creek.

ASSESSMENT OF RIPARIAN SYSTEMS

RIPARIAN REGIONS

Riparian habitat represents the smallest percentage of the acreage at Montado Farms; however, they can have significant impacts on water storage and increased biotic and plant productivity due to close proximity to water resources (Lewis et al., 2015). Five perennial streams, which have been self-named for this assessment, carry water from the north across the Montado Farms to the perennial Santa Ysabel Creek in the south (Figure 8). The most western and eastern tributaries, Montado West Creek and Montado East Creek, run 1.1 miles and 2.2 miles, respectively, from north to south. The three central tributaries, (from west to east) Rancho Creek, Ortega Creek, and Stokes Creek, traverse 3.0 miles, 1.3 miles, and 1.7 miles, respectively, of the rangeland.

BEAVER RESTORATION

The ranchers at Montado Farms expressed interest in restoring beavers to their riparian systems. Beavers (*Castor canadensis*) are ecosystem engineers due to their high potential to restore landscapes to extensive watersheds. They can also indirectly enable the recovery of fish populations, including salmonid and trout species, through significant habitat improvement. These keystone semiaquatic species once roamed the extensive California network of watersheds and rivers (Hawkes, 2014). Even though beaver were hunted to virtual extinction, their failure to recover throughout their historical range may be attributed to epicycles of erosion, subhumid climate, and little sustenance, leading to significant destruction of their dams and watershed habitats. Despite extreme periods of water shortages and drought, beavers continue to maintain their wetland habitats.

Beavers have been observed in the San Diego River, Sweetwater River, and San Mateo Creek (Lanman et al., 2013), which are 20-55 miles away from Montado Farms. Although beavers are extremely efficient in removing trees from their landscape for use in dam construction, their efforts typically lead to increases in riparian system carbon, as logs are buried in newly-formed wetlands. Within their zone of influence, beavers also indirectly increase soil carbon contents in riparian systems with the recruitment and stimulation of young replacement woody vegetation. Their achievements also include increases in stream flows, groundwater tables, and water availability and significant decreases in pollutants, resulting in significant improvements to water quality and sediment conditions.

CARBON BENEFITS OF RIPARIAN AUGMENTATION

The benefits of riparian augmentation are extensive, resulting in significant carbon capture (Table 8). With estimates of 1, 5.82, and 18.36 Mg/acre/year, the total carbon capture potentials are 115, 670, and 2,115 Mg of carbon dioxide equivalent annually for riparian systems. Over fifteen and thirty years, these potentials could be as high as 1,728-31,726 MT and 3,456-63,452 MT, respectively.

These benefits of added carbon to soil, water, and vegetation are broad, ultimately improving the quality and fertility for both. The addition of carbon to riparian systems boosts biological activity and improves food, cover, and habitat for livestock, wildlife, and aquatic species. In addition to planting new trees and shrubs, vegetation uptakes excess water and nutrients until use and protects soil surfaces and shade. These herbaceous species also increases vegetative matter and improves plant diversity, quality, and quantity. Soil root penetration, infiltration, and soil organic matter (SOM) are increased, while improving soil structure and reducing wind erosion and runoff. These changes also moderate water temperature, decrease water evaporation from soil, and promote positive water quality, leading to optimal conditions for terrestrial carbon storage.

ASSESSMENT OF RIPARIAN SYSTEMS

TABLE 8. CARBON CAPTURE POTENTIALS FOR RIPARIAN SYSTEMS AT MONTADO FARMS

			Mg CO_2E estimated from COMET planner: Riparian restoration			Mg CO_2E estimated from COMET Planner: combined riparian restoration, riparian forest buffer, herbaceous cover, & critical area planting			Mg CO_2E estimated for riparian restoration from Lewis et al. (2015)		
			1 Mg/acre/year			5.82 Mg/acre/year			18.36 Mg/acre/year		
Riparian System	Stream length (miles)	Acres	Annual	15 years	30 years	Annual	15 years	30 years	Annual	15 years	30 years
Santa Ysabel Creek	0.3	3.6	4	54	108	21	314	629	66	991	1983
Montado West	1.1	13.2	13	198	396	77	1,152	2,305	242	3635	7271
Rancho	3.0	36	36	540	1,080	210	3,143	6,286	661	9914	19829
Ortega	1.3	15.6	16	234	468	91	1,362	2,724	286	4296	8592
Stokes	1.7	20.4	20	306	612	119	1,781	3,562	375	5618	11236
Montado East	2.2	26.4	26	396	792	154	2,305	4,609	485	7271	14541
TOTAL CO_2E	**9.6**	**115.2**	**115**	**1,728**	**3,456**	**670**	**10,057**	**20,114**	**2,115**	**31,726**	**63,452**

1 Mg (megagram) = 1 metric tonne (MT).

References: COMET-Planner, NRCS <comet-planner2.com> and Lewis et al. (2015).

Potential Carbon Beneficial Practices

CO-BENEFITS OF CARBON BENEFICIAL PRACTICES

These conservation practices and field operations potentially have substantial effects on air quality, soil erosion, soil quality degradation, water levels, water quality, and plant conditions, as well as fish and wildlife habitat, forage production, and infrastructure energy use and field operations. As established by the Natural Resources Conservation Service (NRCS) (NRCS, 2017a), all estimated benefits of carbon farming to the environment are outlined in Table 9. Carbon beneficial practices have been separated into grazing and crop management, agroforestry, and riparian restoration.

The co-benefits of carbon farming ultimately build regional resilience and sequester carbon. Carbon farming seeks to mitigate and reduce GHG in air and improve air quality. Consequently in soil, these practices increase soil organic matter (SOM) and the percentage of healthy soils, as well as increase water-holding capacity and soil nutrients. The available water-holding capacity increases by 3.7% for every 1% increase in SOM (Hudson, 1994), resulting in the holding capacity of 27.2 thousand gallons of water per acre of soil down to 30 cm depths (NRCS, 2017a). More specifically, a 1% increase in SOM represents 5 tons of organic carbon per acre. An annual increase in SOC by 0.4% globally may halt increases in all GHG emissions, creating more fertile soil that can better cope with climate change effects (Shattuck et al., 2017). SOM also reduces water contamination and fumigant emissions.

Carbon beneficial practices also lead to decreases in overland flow in uncovered soil areas, and limitations on water evaporation and seepage out of the land, while improving water quality and efficiency, increasing water holding capacities and infiltration, and decreasing wildfire hazards. In soil, these practices lead to prevention of top soil loss and erosion by limiting uncovered soil areas, as well increases in SOM, water-holding capacity, and soil nutrients of carbon, nitrogen, and other nutrients. These changes ultimately improve soil health, fertility, and stability, creating significantly healthier soils.

Cover crop has shown to decrease soil and water temperatures, and as a result, reduce evaporation, potentially leading to 4% increases in soil pore water. Plant productivity is increased, leading to higher yields for local food systems and expansions in agricultural and cover crop production. For example, plant productivity has been shown to increase by 40-70% with rangeland composting. Overall, fire, flooding, drought, and farming costs are significantly reduced. For livestock and wildlife, both habitat structure and soil nutrients for food systems are increased, leading to boosts in biological activity. Grazing also minimizes invasive species while increasing plant diversity and densities. The economic benefits of carbon farming include reductions in operating costs of irrigation, fertilizers, pesticides, and livestock, potentially leading to decreases in farm debt. In turn, carbon beneficial practices can potentially lead to improvements in farm efficiency and profitability and decreasing market costs for carbon.

POTENTIAL CARBON BENEFICIAL PRACTICES

TABLE 9. CARBON BENEFICIAL PRACTICES FOR GRAZING AND CROPLAND MANAGEMENT, AGROFORESTRY, AND RIPARIAN SYSTEMS

Grassland Practice	Description	Benefits				
		Soil	Water	Plants	Biota & Wildlife	Air
Fencing	Barriers for animals or people	Reduce soil disturbances by controlling use of area by animals and people	Control access to water	Reduce disturbances and increase protection by controlling use, encourage plant growth and health	Control animal grazing	May reduce emissions of CO_2 due to improved and protected vegetation
Field Border	Establish strips of permanent vegetation at the farm edge or around the field perimeter	Reduce runoff, erosion, and organic matter depletion, root penetration, and SOM, restore soil structure	Increase infiltration, OM, nutrients, and cation exchange capacity (CEC)	Increase water uptake, protect soil surface, trap sediment, increase quality and quantity of vegetation	Provide forage for livestock	Reduce emissions of particulates and CO_2, store C in plants and soils
Firebreak	Establish permanent or temporary strip of bare or vegetated land to retard fires and shade soil	Isolate fire breaks with fuel loading zones	none	Limit vegetation	Interrupt habitat for wildlife	Reduce atmospheric emissions of particulates, ozone precursors, and CO_2 resulting from wildfires
Forage and Biomass Planting	Establish adapted and compatible species suitable for pasture, hay, or biomass	Decrease erosion and runoff	Increase infiltration	Increase vegetative cover, enhance root development and litter accumulation	Enhanced biomass production and biological activity	Reduce emissions of particulates and CO_2, store C in plants and soils
Prescribed Grazing	Manage vegetation harvest with livestock grazing and browsing	Decrease erosion, runoff, and soil surface evaporation, improve nutrient cycling, improve soil quality	Increase water infiltration and available water, decrease risk of pathogen transport, improve water quality	Enhance growing conditions (increase vegetative cover, root system, plant vigor, plant health, and nutrient uptake), speed vegetative recovery	Increase biological activity, restore habitat for wildlife	Reduce emissions of particulates and CO_2, store C in plants and soils

POTENTIAL CARBON BENEFICIAL PRACTICES

TABLE 9 (CONT). CARBON BENEFICIAL PRACTICES FOR GRAZING AND CROPLAND MANAGEMENT, AGROFORESTRY, AND RIPARIAN SYSTEMS

Agroforestry Practice	Description	Benefits				
		Soil	Water	Plants	Biota & Wildlife	Air
Conservation Cover/ Cover Crop	Establish and maintain grasses, legumes, and forbs for seasonal cover	Increase soil cover, organic matter, biomass production, and roots, buffer salts, improve soil structure	Increase infiltration, SOM, and nutrient transport, reduce erosion and runoff	Increase quality and quantity of vegetation, slow noxious plant growth	Increase biological activity, and cover, space and forage production for wildlife	Reduce atmospheric emissions of ozone and CO2, store C in plants and soils, limit wind erosion and dust generation
Critical Area Planting	Establish permanent vegetation on regions with high erosion rates	Decrease erosion and runoff, improve infiltration, increase SOM and root growth	Increase infiltration, SOM, and nutrient transport	Increase quality and quantity of vegetation, uptake excess nutrients, moisture, and salts	Increase food, cover, and space for wildlife	Reduce wind erosion and dust generation, decrease CO_2 emissions, store C in plants and soils
Hedgerow Planting	Establish dense vegetation in linear design	Increase SOM, develop roots, improve soil structure and porosity, reduce runoff and erosion	Reduce runoff of pesticides and nutrients, moderate water temperature	Improve food supply and availability, increase shade	Provide more space, cover, forage, and protection from wind, attracts pollinators	Reduce atmospheric emissions of CO_2, store C in plants and soils
Silvopasture	Establishing trees and shrubs and compatible forage on the same acreage	Increase roots, root penetration, vegetative matter, livestock waste, and SOM, restore soil structure	Increase infiltration, available water, reduce runoff	Provide shade and reduce direct light heating, reduce hazard, uptake heavy metals, intercept airborne pollutants	Provide shelter, food, cover for wildlife	Reduce atmospheric emissions of particulates and CO_2, store C in plants and soils
Tree/Shrub Establishment	Establish woody plants through seed planting, direct seeding, or natural regeneration	Reduce erosion and runoff, increase root development and SOM, restore soil structure	Increase available water	Provide vegetative cover, reduce wind velocities, increase infiltration, uptake excess water and nutrients, moderate water temperature	Increase microbial activity, provide shelter, forage, and cover for wildlife	Reduce atmospheric emissions of CO_2, store C in plants and soils
Windbreak / Shelter Establishment	Establish single or multiple rows of trees or shrubs to limit wind damage	Reduce wind erosion and deposition, increase root penetration and SOM	Increase infiltration, available water	Improve plant diversity, quantity and quality, reduce land temperature, increase water uptake	Improve quantity and quality of feed and forage, cover, and habitat	Reduce emissions of particulates, VOCs, dust, and CO_2, store C in plants and soils

TABLE 9 (CONT). CARBON BENEFICIAL PRACTICES FOR GRAZING AND CROPLAND MANAGEMENT, AGROFORESTRY, AND RIPARIAN SYSTEMS

Riparian System Practice	Description	Benefits				
		Soil	Water	Plants	Biota & Wildlife	Air
Channel Bed Stabilization	Maintain the channel bed elevation, modify sediment transport, and manage water levels in riparian areas	Stabilize channel, prevent erosion and degradation, decrease suspended sediments	Increase water quantities in riparian areas and floodplains, improve water quality	Replace invasive and noxious species with stabilized plants with optimal health and productivity	Provide more food, shelter, and suitable habitat for fish, create deeper pools for foraging	none
Riparian Forest Buffer	Establish trees and shrubs adjacent to and up-gradient from water bodies	Increase root penetration, infiltration, and SOM, promote soil structure	Moderate water temperature, increase infiltration	Increase vegetative matter, uptake excess nutrients, protect soil surface, trap sediments and nutrients, improve plant diversity, quantity, quality of vegetation, provide shade	Improve food, cover, and habitat for wildlife	Reduce atmospheric emissions of CO_2, store C in plants and soils
Riparian Herbaceous Cover	Establish and manage dominant vegetation (grass, ferns) of saturated soils in transitional zone between upland and aquatic habitats	Protect roots, increase SOM and root penetration, reduce wind erosion and runoff	Increase quality and quantity due to decrease water evaporation	Uptake excess water	Improve feed, forage, cover, and habitat for livestock and wildlife	Reduce atmospheric emissions of CO_2, store C in plants and soils
Stream Habitat Improvement and Management	Maintain and improve physical, geochemical, and biological functioning of streams and riparian zones to meet life history requirements for aquatic species	Protect roots, bind soils, limit water and bank erosion, improve bank stability	Improve water quantity and water quality, moderate water temperatures	Provide shade and protection for livestock, aquatic species, and soil	Increase aquatic habitat for fish and other wildlife	Reduce atmospheric emissions of CO_2, store C in plants and soils

POTENTIAL CARBON BENEFICIAL PRACTICES

CARBON CAPTURE QUANTIFICATION

The conservation practices listed in this carbon farming plan for Montado Farms have the potential to sequester up to 189 tonnes of CO_2E per acre per decade, with agroforestry as the most carbon-beneficial practice (Table 10).

TABLE 10. CONSERVATION PRACTICE AND CARBON SEQUESTRATION POTENTIALS

Practice	Code	Conservation Division	CO_2E Potential (tonnes CO_2E/acre/decade)
Channel Bed Stabilization	584	Riparian Restoration	*
Conservation Cover & Cover Crop	327/340	Agroforestry	-0.3 – 4.1
Critical Area Planting	342	Agroforestry	10.5
Fencing	382	Cropland Management	*
Field Border	386	Cropland Management	-0.3
Firebreak	394	Cropland Management	*
Forage and Biomass Planting	512	Cropland Management	2.2
Hedgerow Planting	422	Agroforestry	81.7-82.0
Prescribed Grazing	528	Cropland Management	0.3
Riparian Forest Buffer	391	Riparian Restoration	17.5-17.7
Riparian Herbaceous Cover	390	Riparian Restoration	10.0
Silvopasture	381	Agroforestry	6.6
Stream Habitat Improvement and Management	395	Riparian Restoration	*
Tree/Shrub Establishment	612	Agroforestry	188.6-188.9
Windbreak/Shelter Establishment	380	Agroforestry	0.0

** Supporting practice.*

Reference: COMET-Planner, NRCS <comet-planner2.com>.

Channel bed stabilization, fencing, firebreak, and stream habitat improvement and management are general conservation practices that support carbon sequestration. These practices improve the overall wildlife habitat and management of livestock. Field borders, conservation cover, and cover crop have the potential to increase CO_2E by up to 0.3 per acre per decade; however, the carbon benefits to soil and water suggest that these practices indirectly drive carbon sequestration and improved the quality of air, water, soil, and vegetation.

The combination of carbon-capture potentials from the grazing and carrying capacity, agroforestry, and riparian system assessments for the 3107-acre Montado Farms could potentially results in the sequestration of 9,300 MT CO_2E annually, or 279 thousand MT CO_2E in thirty years. This sequestration could reduce the 2010 CO_2 emission levels to 31.7 million MT CO_2E by 2047 for San Diego County. An extrapolation of these estimates on all San Diego County rangeland potentially results in the sequestration of 617 thousand MT CO_2E annually, which can potentially lower current CO_2 emission levels to 13.5 million MT CO_2E by 2047.

POTENTIAL CARBON BENEFICIAL PRACTICES

CHALLENGES

Financial challenges include mitigating costs for farmers and for measurements and monitoring following plan implementation. Environmental challenges include compost availability and local standards, vectors from organic management, mulch supply, and potential of increased nutrients transporting into watersheds. Policy challenges include regulation harmony for both city and county groups. Moreover, farmers and ranchers will need suitable incentives that drive them toward conservation practices as well as carbon capture and quantification of soil organic matter as an indicator of success.

Carbon Farming Plan

This implementation plan for carbon farming at Montado Farms proposes three pieces: agroforestry augmentations, riparian restoration, and forage growth. This includes a major vegetation overhaul to convert grasslands into thriving forests, whose soils and water can store and retain more carbon, nutrients, and water.

SUMMARY OF PRIORITY CARBON BENEFICIAL PRACTICES

The most carbon-beneficial practice is agroforestry, specifically tree/shrub establishment, which potentially sequesters 189 MT CO_2E per acre per decade. Agroforestry is the dominant conservation practice resulting in potentially significant carbon sequestration on Montado Farms. Hedgerow planting sequesters up to 82 MT CO_2E per acre per decade, followed by riparian forest buffer, which sequesters 18 MT CO_2E per acre per decade (USDA NRCS, 2017a). Cropland and grazing management sequester up to 2.2 MT CO_2E per acre per decade.

TIMELINE FOR IMPLEMENTATION

Short Term (1-3 years)

To achieve riparian restoration and sequestration of carbon in the watersheds, improvements to the land will include stabilization of the channel bed and buffering of the waterways with forests and herbaceous cover. These practices will ultimately improve the stream habitat. In terms of funding, the U.S. Fish & Wildlife Services (FWS) has $25,000 for water-related activities. NRCS and FWS funds can be matched to implement these goals starting in 2018.

To achieve silvopasture, tree seeding and irrigation are large components. Several low-water trees, including native oak species, may be preferable; these would mimic tree/shrub types for high photosynthetic productivity. Until the trees reach above browse height, they will need to be protected from livestock. Other productive crops (corn, vegetables) may be planted in the range. Replanting of resilient and native tree seeds to haste savannah landscape is preferable and will be performed starting in Fall 2017.

To achieve successful grazing, the farmers would like to achieve more grazable forage throughout the year (in 3-4 years). The farmers will also need to update their infrastructure: new fencing and updated trough water systems will be added to improve livestock surroundings and feeding. Fencing will also help to reduce conflict with grazers and increase habitat and passages for deer. There are no plans to add any roads to the farm. The dam infrastructure will be updated to increase water supply for farmers and livestock.

Long Term (>3 years)

To achieve general habitat improvements, western pond turtle, beaver, and barn swallows could be potential wildlife inhabiting the farm lands. The beaver dams could help to raise the water table; the existing habitat is adequate for beaver re-introduction. Willow trees will also be planted as an advantage for the beavers. Pollinators could also be implemented into the farm system. The MSCP (Multiple Species Conservation

Program) could provide support and funding for habitat improvement. These methods may also be applicable to the nearby 5000-acre Santa Ysabel preserves, where conventional grazing occurs.

MONITORING AND RECORDS

The monitoring of soil, water, and vegetation at Montado Farms will include physical, geochemical, and biological tests to assess for quality, composition, and improvements from baseline measurements. The sampling of water, soil, and vegetation from the baseline illustrates changes over time. The components listed for measurement in these compartments are strongly interrelated and each control quality and composition. In soil, we seek to take soil cores down to 20 cm depths with analyses for temperature, texture, bulk density, pH, moisture, water content, infiltration rates, alkalinity, total organic carbon and inorganic carbon content, nitrogen content, heavy metals, and other macro- and micro-nutrient contents. In water, we will measure temperature, pH, hardness, salinity, dissolved organic and inorganic carbon, total dissolved solids (TDS), water quantity (flow rates), and nutrients (nitrate, sulfate, and other major and minor metals). In vegetation, we will measure plant biomass, plant productivity, species composition, residual dry matter, and percent cover. We will also analyze for chlorophyll, or plant vigor, using the normalized difference vegetation index (NDVI). With a ten-year assessment period, these tests will be performed annually for every 100 acres of managed land, equating to roughly 15 sections for the Montado Farm rangelands.

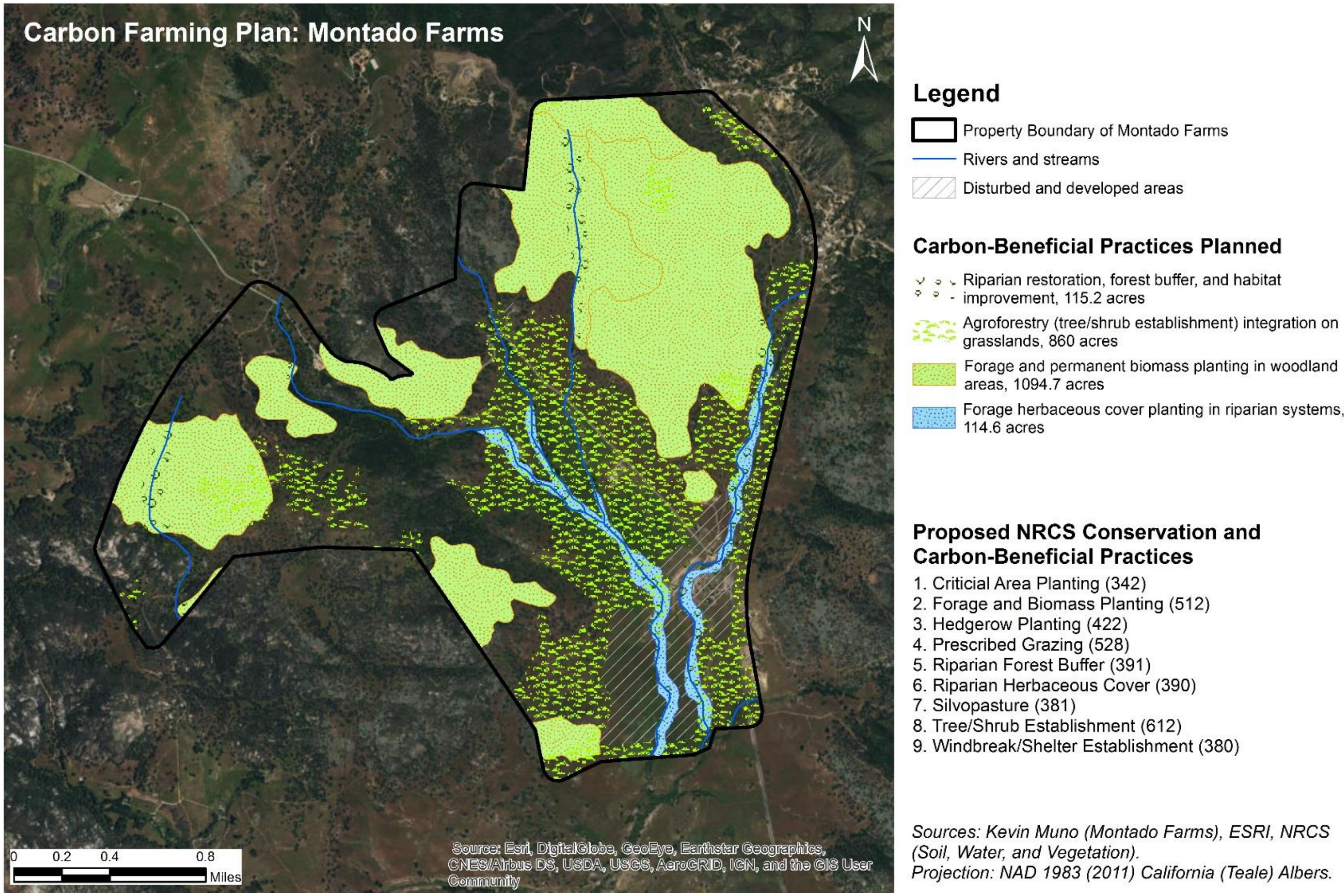

Figure 9. Illustration and descriptions of the proposed carbon-beneficial conservation practices planned for the 3107-acre Montado Farms (Santa Ysabel, CA).

Conclusions

SUMMARY

Carbon farming practices are indispensable methods to sequester pools of carbon terrestrially and limit their emissions to the atmosphere. These carbon sequestration and conservation practices are vital to boost the soil organic carbon pool and provide a plethora of benefits. On-site, soil organic carbon improves soil quality, increases forest productivity, and progresses sustainability and food security, while improving water quality, air quality, and biodiversity, controlling desertification, and limiting disturbances off-site. Each farm and ranch has a suite of unique opportunities for sequestration and greenhouse gas emission reductions, which are evaluated here for Montado Farms (Santa Ysabel, CA). The practices proposed here will be implemented in the next several years. Ultimately, carbon farming plans will be created for agricultural rangelands across San Diego County to effect environmental quality toward AB 32 targets in California.

OUTREACH AND DISSEMINATION

An article on the establishment of carbon farming at Montado Farms was recently published in *The San Diego Union-Tribune* (Brennan, 2017). The planning, implementation, and results of these carbon-beneficial conservation practices will be disseminated widely to the public in San Diego County through this newspaper and others in the Santa Ysabel-Ramona-Julian region. These results will also be publicized via our social media channels, as well as with our conservation partners. We will also look for opportunities to disseminate this work at annual conferences and meetings.

In coalition with the Resource Conservation District of greater San Diego County, carbon farming plans will be created for other farmers and ranchers in San Diego County, to transform their lands into soil carbon hotspots and agricultural rangelands with high efficiencies in energy and productivity. They may read about carbon farming through newspapers and intrigued by several incentives offered in return for long-term terrestrial carbon sequestration practices. It will also be disseminated widely to other resource conservation districts and local groups throughout California and nationally. A class on greenhouse gas emissions and carbon-beneficial practices on agricultural rangelands will be pitched to school curriculum for students across elementary, middle, and high schools.

REFERENCES

References

Anders, S. J. et al., 2006. “San Diego County Greenhouse Gas Inventory: An Analysis of Regional Emissions and Strategies to Achieve AB 32 Targets.” Executive Summary (September 2008). Accessed on 4 May 2017. <http://catcher.sandiego.edu/items/epic/ESPReport1.pdf>.

Anders, S. J. et al., 2013. “San Diego County Updated Greenhouse Gas Inventory: An Analysis of Regional Emissions and Strategies to Achieve AB 32 Targets, Revised and Updated to 2010.” Executive Summary (March 2013). Accessed on 4 May 2017. <http://catcher.sandiego.edu/items/usdlaw/EPIC-GHG-2013.pdf>.

Ariapour, A., et al., 2014. “Assessment of water resource potential for common use of cow and goat by GIS (Case study: Boroujerd Rangeland, Sarab Sefid, Iran).” 7th IGRSM International Remote Sensing & GIS Conference and Exhibition. IOP Conf. Series: Earth and Environmental Science, **20**: 1-7. Accessed on 9 June 2017. <doi:10.1088/1755-1315/20/1/012001>.

Bartolome, J. et al., 1970. “Guidelines for RDM on Coastal and Foothill Rangelands in California.” *Rangeland Monitoring Series*, University of California Division of Agriculture and Natural Resources. Accessed on 25 May 2017. <http://anrcatalog.ucanr.edu/pdf/8092.pdf>.

Beck, D., 2014. “On Memory’s Back Trail: Santa Ysabel, Crossroads of History.” *Ramona Home Journal.* Published on 1 August 2014. Accessed on 15 May 2017. <http://ramonajournal.com/on-memorys-back-trail-santa-ysabel-crossroads-of-history-p6112-265.htm>.

Brennan, D. S., 2017. “‘Carbon farming’ offers new chance for cattle ranch.” *The San Diego Union-Tribute* [San Diego]. Published on 14 May 2017, Sunday edition, Local section: B1-B7. Print. Accessed on 15 May 2017. <http://www.sandiegouniontribune.com/communities/north-county/sd-no-carbon-farming-20170512-story.html>.

Callahan, R., 2011. “Study: No-till farming reduces greenhouse gas.” *The San Diego Union-Tribute* [San Diego]. Published on 5 January 2011. Accessed online on 2 July 2017. http://www.sandiegouniontribune.com/sdut-study-no-till-farming-reduces-greenhouse-gas-2011jan05-story.html

City of San Diego, 2016. “2016 Annual Report: Climate Action Plan.” Accessed on 28 June 2017. <https://www.sandiego.gov/sites/default/files/2016_annual_report_climate_action_plan.pdf>.

Kahn, B., 2017. “We Just Breached the 410 PPM Threshold for CO2.” *Scientific American*, 21 Apr. 2017. Accessed on 12 May 2017. <https://www.scientificamerican.com/article/we-just-breached-the-410-ppm-threshold-for-co2/>.

Kane, D., 2015. “Carbon Sequestration Potential on Agricultural Lands: A Review of Current Science and Available Practices.” In association with the Natural Sustainable Agriculture Coalition and Breakthrough Strategies and Solutions, LLC. Accessed on 4 May 2017. <http://sustainableagriculture.net/wp-content/uploads/2015/12/Soil_C_review_Kane_Dec_4-final-v4.pdf>.

REFERENCES

Grimm, E., 2001. “Moo Twilight: What the Cauzza cowboys do in Santa Ysabel after the demise of dairies.” *San Diego Reader*. Published on 27 September 2001. Accessed on 15 May 2017. <https://www.sandiegoreader.com/news/2001/sep/27/moo-twilight/>.

Guenther, K.S., et al., 2000. “Expected-use GIS maps.” *Rangelands*, **22**(2):18- 20.

Hawkes, A., 2014. “Beavers Used to Be Almost Everywhere in California.” *Bay Nature*, 19 Jun. 2014. Accessed on 24 May 2017. <https://baynature.org/article/beavers-used-to-be-almost-everywhere-in-california/>.

Hudson, B.D. 1994. Soil organic matter and available water capacity. *J. Soil Wat. Con.*, 49(2): 189-194.

Lanman, C. W., et al., 2013. “The historical range of beavers (*Castor canadensis*) in coastal California: an updated review of the evidence.” *California Fish and Game*, **99**(4): 193-221.

Lewis, D.J., M. Lennox, A. O’Geen, J. Creque, V. Eviner, S. Larson, J. Harper, M. Doran, and K.W. Tate. 2015. Creek carbon: Mitigating greenhouse gas emissions through riparian restoration. University of California Cooperative Extension in Marin County. Novato, California. 26 pgs.

Natural Resource Conservation Service (NRCS), 2017a. “Conservation Practices.” United State Department of Agriculture. <https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849>.

NRCS, 2017b. “Web Site for Office Soil Series Descriptions and Series Classification.” United State Department of Agriculture. Accessed on 20 May 2017. <https://soilseries.sc.egov.usda.gov/>.

Niebrugge, L. and J. Creque, 2017. “Carbon Farm Planning.” A collaboration between the Marin Resource Conservation District and Carbon Cycle Institute. Accessed on 10 May 2017. <http://www.cfs.calpoly.edu/pdfs/events/2017%20Carbon%20Farm/Niebrugge_Swanton.pdf>.

Oberbauer, T., M. Kelly, and J. Buegge. 2008. Draft Vegetation Communities of San Diego County. Based on “Preliminary Descriptions of the Terrestrial Natural Communities of California”, Robert F. Holland, Ph.D., October 1986. <http://www.sdcanyonlands.org/pdfs/veg_comm_sdcounty_2008_doc.pdf>.

Ryals, R. and W. L. Silver, 2013. “Effects of organic matter amendments on net primary productivity and greenhouse gas emissions in annual grasslands.” *Ecological Applications*, **23**(1): 46-59.

San Diego County Farm Bureau, 2017. “San Diego County Agriculture Facts.” Accessed on 12 May 2017. <http://www.sdfarmbureau.org/SD-Ag/Ag-Facts.php>.

Schohr, T., 2009. “Grazing for Change, Second Edition. Stories of Ranchers Preserving and Enhancing California’s Grasslands.” Accessed on 12 June 2017. <http://www.carangeland.org/images/Grazing_for_Change_-_Website.pdf>.

REFERENCES

Shattuck, A., et al., 2017. "Healthy Soils, Healthy Communities: Opportunities to Bridge Environmental Justice and Soil Carbon Sequestration, Executive Summary." Oakland, CA: Food First/ Institute for Food and Development Policy in partnership with the Carbon Cycle Institute and Silvestri Strategies.

Stackhouse-Lawson, K. R., et al., 2012. "Carbon footprint and ammonia emissions of California beef production systems." *Journal of Animal Science*, **90**:4641-4655.

Thompson, E., 2009. "Agricultural Land Loss & Conservation." In collaboration between the America Farmland Trust and the California Department Food & Agriculture. Accessed on 1 August 2017. <https://www.cdfa.ca.gov/agvision/docs/Agricultural_Loss_and_Conservation.pdf>.

U.S. Climate Data, 2017. "Climate – Warner Springs – California." Accessed on 11 May 2017. <http://www.usclimatedata.com/climate/warner-springs/california/united-states/usca1729>.

U.S. Climate Data, 2017. "Climate – Ramona – California." Accessed on 11 May 2017. <http://www.usclimatedata.com/climate/ramona/california/united-states/usca0908>.

USDA NRCS, 2017a. "COMET-Planner2." Accessed on 4 May 2017. <http://www.comet-planner2.com**>.**

USDA NRCS, 2017b. "COMPOST-Planner." Accessed on 5 May 2017. <http://www.compost-planner.com**>.**

USDA NRCS, U.S. DOE, 2008. "Carbon Cycling and Biosequestration: Report from the March 2008 Workshop." *DOE/SC-108*, U.S. Department of Energy Office of Science.

USDGCRP, 2014. "Third Climate Assessment." Accessed on 6 May 2017. <http://nca2014.globalchange.gov/report>.

SAMPLE PLANS

Carbon Cycle Institute (CCI), 2015. "Carbon Farm Plan – ABC Ranch." *Marin Carbon Project.* Accessed on 3 May 2017. <http://www.carboncycle.org/carbon-farming/draft-carbon-farm-plan/>.

Creque, J., 2016. "Carbon Farm Plan: Cachuma Ranch." *Carbon Cycle Institute.* Accessed on 3 May 2017.

Creque, J. and Fibershed, 2016. "L-J Ranch: Carbon Farm Plan – Spring 2016." Accessed on 3 May 2017. <http://www.carboncycle.org/wp-content/uploads/2016/12/L-J-Ranch-CFP-2016.pdf>.

Yolo County Resource Conservation District (RCD), 2017. "Carbon Farming Planning for Yolo Land and Cattle – Scope of Work and Budget." Personal communication. Accessed on 3 May 2017.

GIS DATASETS REFERENCES

Muno, K., 2017. "Outline of Montado Farms." Personal communication. Accessed on 15 May 2017.

REFERENCES

SanGIS, 2004. “Rivers.” SanGIS Data Warehouse. San Diego Geographic Information Source - JPA. Accessed on <http://rdw.sandag.org>

SanGIS, 2017a. “National Forests.” USDA Forest Service. Boundaries of the National Forest of Region 5, Pacific Southwest Region. By-product of the Forest Service Automated Lands Program. Accessed on 17 May 2017. <http://rdw.sandag.org/Account/GetFSFile.aspx?dir=Miscellaneous&Name=National_Forests.zip>.

SanGIS, 2017b. “Vegetation in San Diego County.” GIS Data Category: Ecology. Accessed on 2 June 2017. <http://rdw.sandag.org/Account/GetFSFile.aspx?dir=Ecology&Name=ECO_VEGETATION_CN.zip>.

USGS, 2017. “National Hydrography Dataset.” Digital spatial data – surface water features (lakes, ponds, streams, rivers, springs, and wells) in the surface water drainage network. Accessed on 22 May 2017. <https://nhd.usgs.gov/NHD_High_Resolution.html>.

USGS, 2016. “Watersheds.” Polygons of the 10-digit Hydrologic Unit Watersheds in the San Diego Area. Distributed by SanGIS (San Diego, CA). Accessed on 17 May 2017. <http://rdw.sandag.org/Account/GetFSFile.aspx?dir=Ecology&Name=Watersheds.zip>.

USDA NRCS, 2016. “Web Soil Survey (WSS).” Maps of: Soil type, soil organic matter, water content, percent sand, range production (normal year, favorable year, and unfavorable year), farmland classification. Accessed on 4 May 2017. <http://websoilsurvey.sc.egov.usda.gov**>.**

WebGIS, 2009. “San Diego – California – Terrain Data – 1 deg. Digital Elevation Model (DEM).” Warner Springs and Warner Ranch. Accessed on 31 May 2017. <http://www.webgis.com/terr_pages/CA/dem1/sandiego.html>.

Appendices

SUPPORTING DOCUMENTATION

NRCS Web Soil Survey (http://websoilsurvey.sc.egov.usda.gov): Web Soil Survey (WSS) provided spatial reports of soil properties, site suitability assessments, and ecological site assessments, with Montado Farms as our area of interest (AOI). The soil map outlined soil types, and acres and percentages of the AOI, while chemical and physical properties of soil were spatial illustrated for Montado Farms with soil depths ranging 0-20 cm. These include soil organic matter (Figure 10), water content (Figure 11), and percent sand (Figure 12) (see Supplementary Figures). Suitability and ecological site assessments of Montado Farms also provided insight to the rangeland as appropriate farmland, including range production in a normal forage year (Figure 13) and farmland classification (Figure 14).

COMET-Planner2 (http://www.comet-planner2.com) and COMPOST-Planner (http://www.compost-planner.com): COMET-Planner and COMPOST-Planner were utilized extensively in this carbon farming plan to evaluate and estimate the potentials for NRCS conservation practice planning in capturing and sequestering greenhouse gases in plants and soil. The online interactive tools were provided through collaborations between the USDA NRCS, Colorado State University with support from the Marin Carbon Project, the Rathmann Family Foundation, John Wick, and the Jena and Michael King Foundation. The tools provide generalized estimates of greenhouse gas emission reductions in San Diego County based on NRCS conservation practice standards, including cropland management, grazing land, agroforestry, riparian restoration, and compost application.

COMET-Farm (http://cometfarm.nrel.colostate.edu): COMET-Farm is an accounting system of carbon dioxide and greenhouse gases for farms and ranches. This carbon footprint tool applies estimates of cropland, agroforestry, and animal agricultural systems from historic, current, and future management practices to report operational carbon stocks. These interactive farming and ranching options allow agricultural groups to assess how adapting rangeland management and practices will sequester carbon and reduce greenhouse gas emissions. It was created in collaborations between the USDA NRCS and Colorado State University.

SUPPLEMENTARY FIGURES

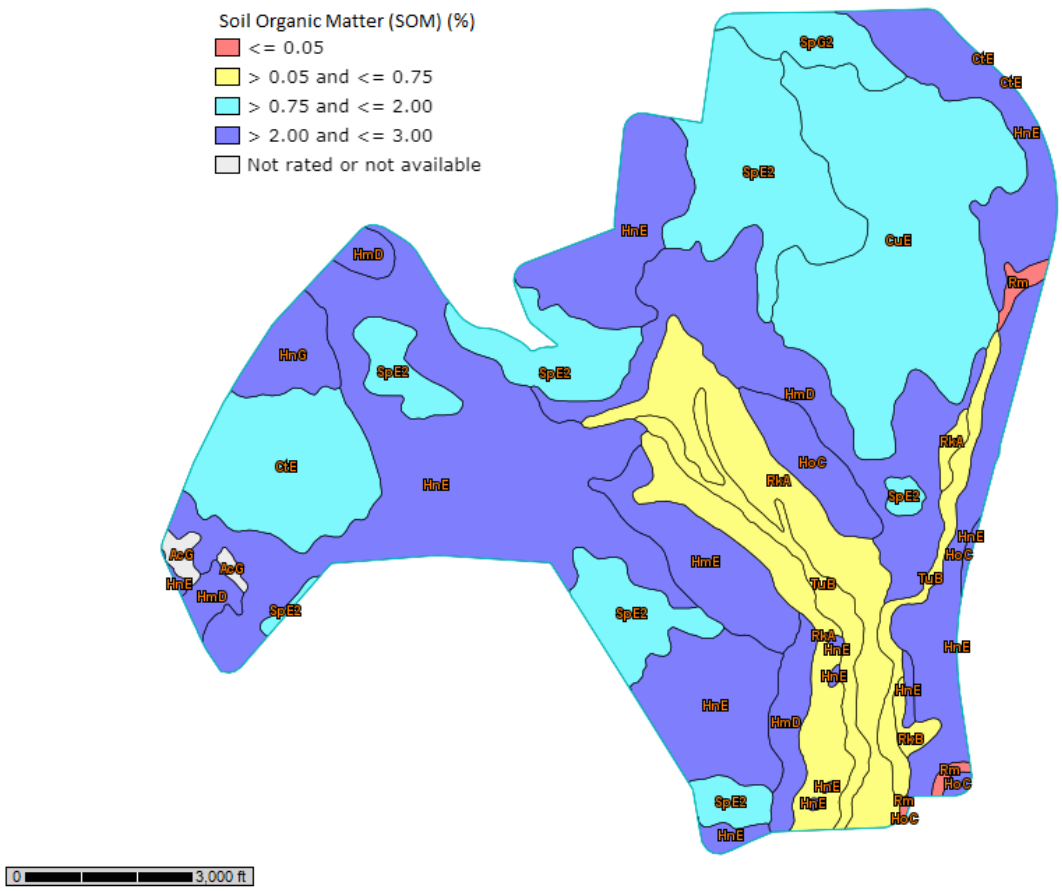

Figure 10. Soil organic matter (SOM) contents for each soil type across Montado Farms (from NRCS Web Soil Survey).

APPENDICES

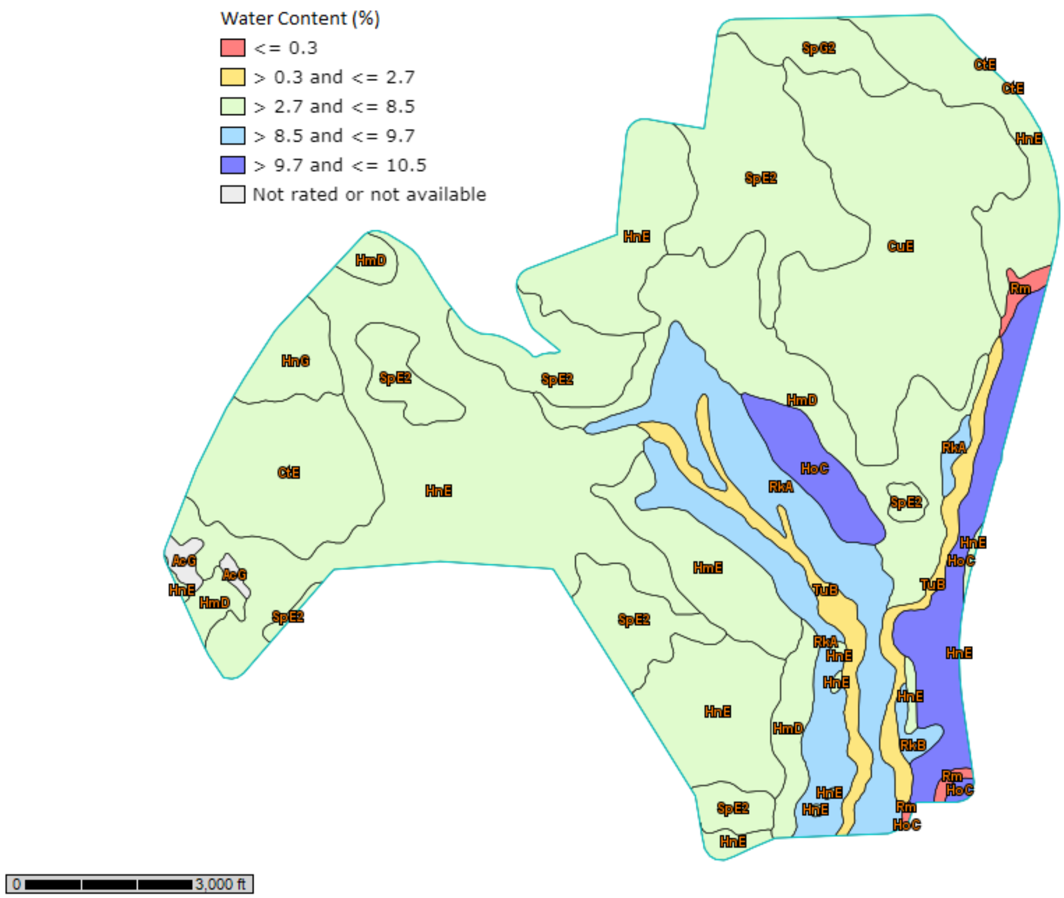

Figure 11. Water content (%) for each soil type across Montado Farms (from NRCS Web Soil Survey).

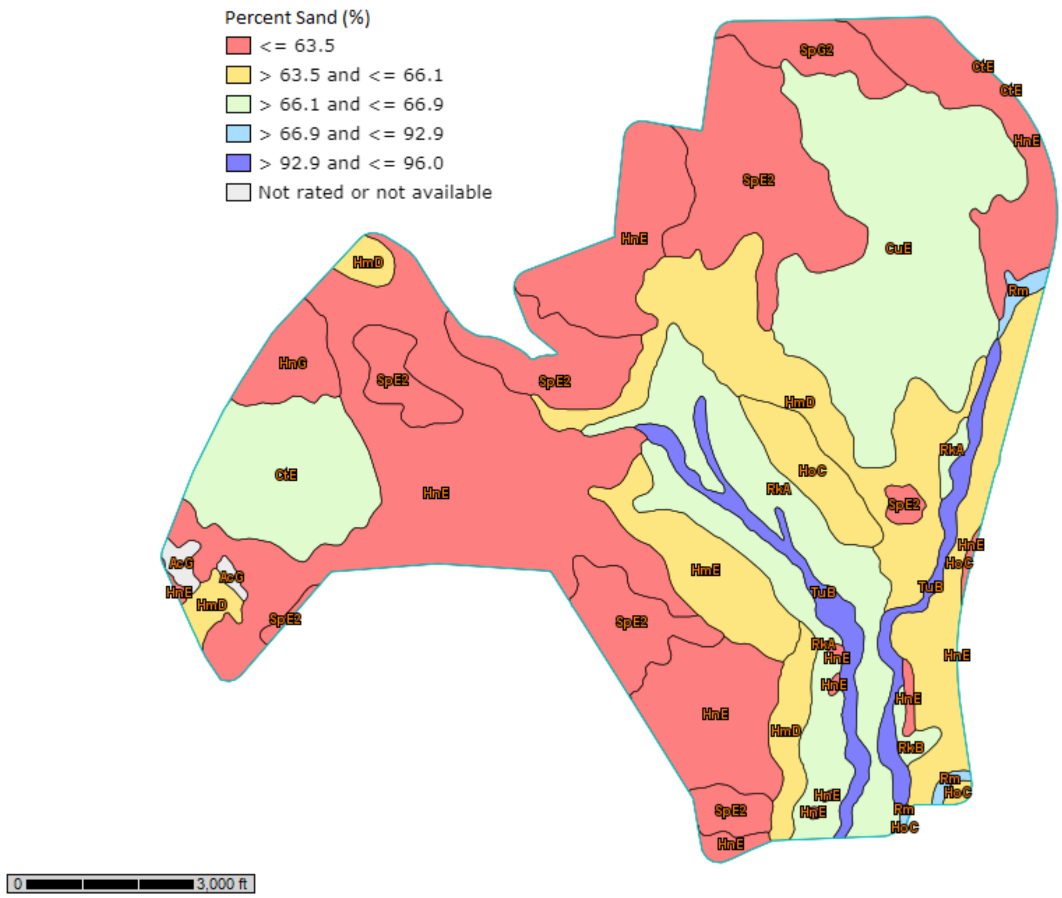

Figure 12. Percent sand (%) for each soil type across Montado Farms (from NRCS Web Soil Survey).

APPENDICES

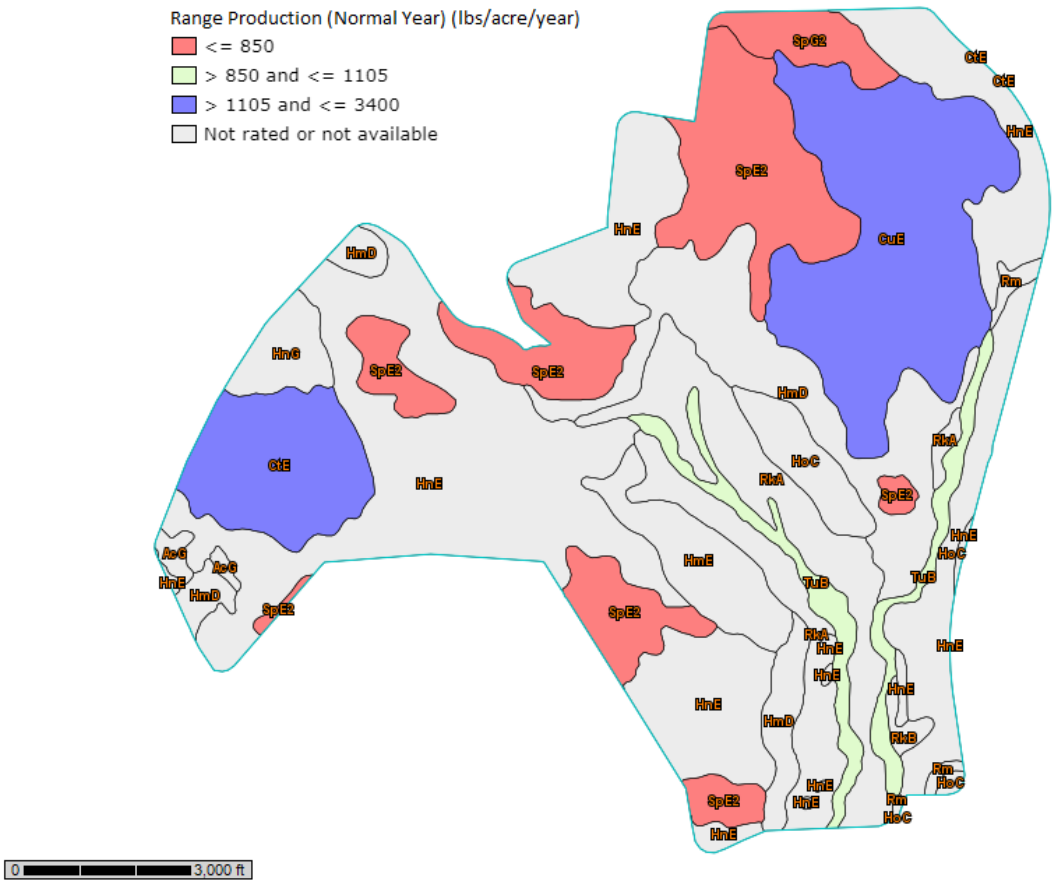

Figure 13. Range production in a normal forage year for each soil type across Montado Farms (from NRCS Web Soil Survey).

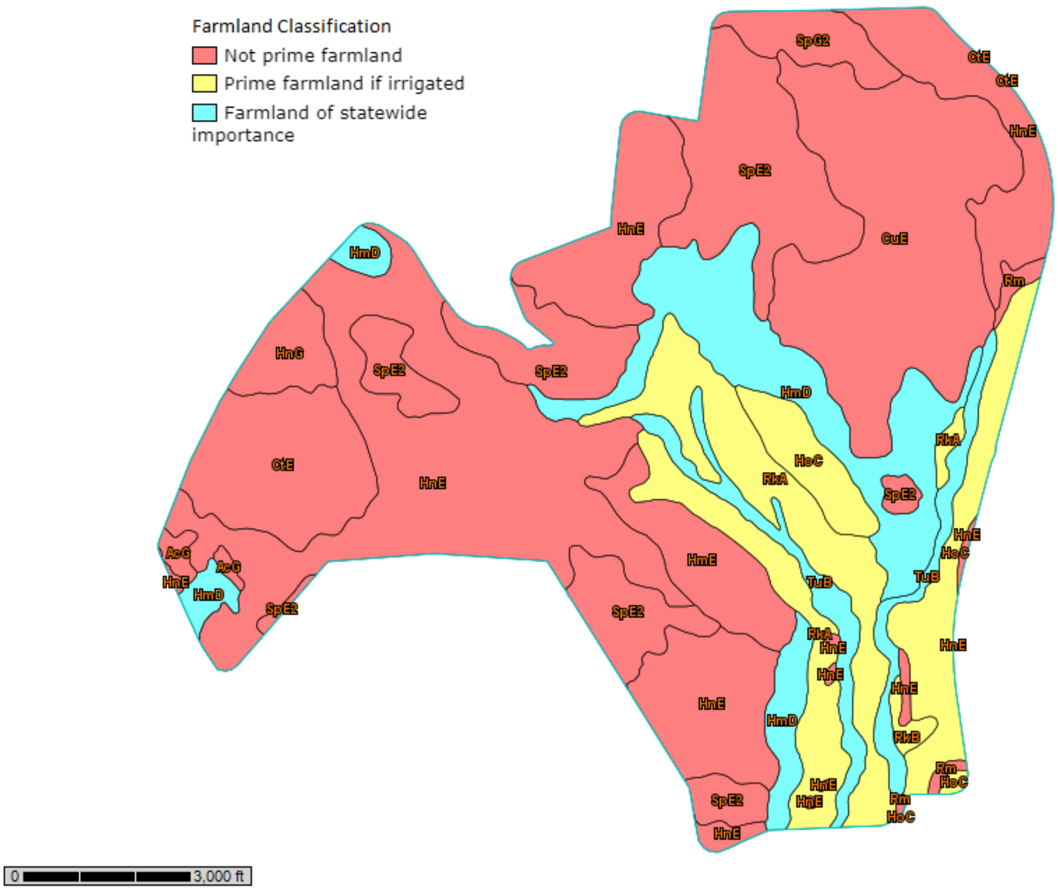

Figure 14. Farmland classification for each soil type across Montado Farms (from NRCS Web Soil Survey).

Template of carbon-farming plan

A timeline and outline of the process to create a carbon-farming plan is outlined below. These components include key interviews with questions, data collection for each assessment, and assembly of the carbon-beneficial conservation practices in line with the ranch goals.

A. Initial interview with farmer(s) to obtain ranch information and other details regarding:
    a. Ranch: operation type, size, watershed and water board region, plans and certifications, eligibilities
    b. Coordinates and parcel boundaries, location of infrastructure (fencing, padlocks, roads), grazing area, croplands, forests, and livestock sustenance (feedlots, water)
    c. Current farm operations (ex. as a ranch, dairy, farm),
    d. Short-term and long-term goals for production and business, quality of life, natural resources, and water quality
    e. Goals specific to carbon farming: riparian restoration, grazing management, agroforestry, cover cropping
    f. Historic land use and assessment
    g. Land profile and assessment: vegetation (grasses, trees, etc.), irrigated vs. non-irrigated plots, pasture plots, grazing management strategies
    h. Riparian areas: water bodies, stream lengths, perennial status, current issues
    i. Identification of ecological hotspots: dominant vegetation and soil regions
    j. Infrastructure: springs, wells, dams on the property, current estimates of monthly water consumption, fences, roads
    k. Energy assessment: renewable energy production, equipment, economic efficiencies
    l. Land challenges: erosion, flooding, fire hazards, invasive species, predators for grazing

B. Interview with farmer(s) – Evaluation of grazing and carrying capacity
    a. Overall condition and trend of pastures and rangelands on the ranch
    b. Hotspots with potential for increased pasture productivity
    c. RDM goal, targets, and minimums recommended for the ranch pastures
    d. Livestock: herd sizes and composition (species, age, gender), estimated carrying capacity, and current carbon emissions
    e. Grazing system: current grazing regime and frequency of grazing movement per year
    f. Manure management system

Data collection for each assessment

C. Data collection: Landscape
   a. Digital elevation model (DEM) from WebGIS (2009)
   b. Aspect, slope, hillshade calculated for the farm from the DEMs using ArcGIS

D. Data collection: Soils
   a. Soil type, acres, and percent of ranch area from NRCS Web Soil Survey (WSS)
   b. Interpretation of soil types from NRCS

E. Data collection: Grazing and carrying capacity
   a. Farmland classification, annual range (forage) production in normal, favorable, and unfavorable year from USDA NRCS Web Soil Survey (WSS)
   b. Estimates for RDM from Bartolome, J. et al. (1970)

F. Data collection: Agroforestry
   a. Datasets of vegetation and national forests from SanGIS (2017a) and SanGIS (2017b)

G. Data collection: Riparian restoration
   a. Watersheds in San Diego County from USGS (2016)
   b. Location of rivers and streams from USGS National Hydrology Dataset (NHD) (2017) and SanGIS (2004)

H. Assembly of relevant carbon-beneficial conservation practices and their benefits to air, soil, water, plants, wildlife, and land
   a. CO_2E emission reduction coefficient estimates from COMET-Planner2 (http://www.comet-planner2.com)
   b. Whole-farm analysis of carbon and greenhouse gas emissions using COMET-Farm (http://cometfarm.nrel.colostate.edu/)

I. Monitoring and record-keeping
   a. Water properties: temperature, pH, hardness, salinity, dissolved organic and inorganic carbon, total dissolved solids (TDS), water quantity (flow rates), and nutrients (nitrate, sulfate, and other major and minor metals)
   b. Soil properties: temperature, texture, bulk density, pH, moisture, water content, infiltration rates, alkalinity, total organic carbon and inorganic carbon content, nutrient (nitrogen, heavy metals) contents
   c. Plant properties: biomass, productivity, species composition, residual dry matter, and percent cover
   d. Frequency: 10 samples per 100 acres depending on soil heterogeneity

J. Finishing interview with farmers
    a. Thoughts and suggestions regarding the proposed carbon-beneficial conservation practices identified in the carbon farming plan
    b. Outlook on carbon farming: Incentives (funding, monitoring, tax compensations, technical assistance etc.) and other priorities that might sway other farmers toward these practices

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