State of the Science:

CLIMATE-RESILIENT AGRICULTURE IN SAN DIEGO COUNTY

A LITERATURE AND POLICY REVIEW

Prepared by the University of California Cooperative Extension, San Diego County

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STATE OF THE SCIENCE: CLIMATE-RESILIENT AGRICULTURE IN SAN DIEGO COUNTY

I. EXECUTIVE SUMMARY

San Diego County has a unique farming environment that has resulted in an exceptional combination of agricultural enterprises found nowhere else. Because of the region's high prices for land and imported water, as well as its complex and highly urbanized topography, most agricultural operations in the region raise either crops that have high value per acre, tree crops that can be grown on steep hillsides, or both. The county has the second highest value of nursery and cut flower crops of any county in the United States and produces over 10% of these crops by value in the nation. It also has a very small median farm size and the highest number of organic farms of any county in the United States.

The effects of anthropogenic climate change will primarily be felt in increasing temperatures, drying and increased variability of the already scanty precipitation regime, and an increased risk of extreme weather events like heat waves, droughts, floods, and a longer and more severe wildfire season. Many of these effects are already making themselves known in the heat waves and fire seasons of the last several years. The mosaic of urban development, agricultural land, and wildlands in San Diego means that wildfire poses a particularly great threat in the unincorporated areas of the county. Vegetable crops will consume more irrigation water and decline in quality and production under climate change, while fruit trees will suffer heat drop and defoliation, and non-irrigated rangelands will suffer drying and reduction in grazing quality. Less is known about the impact of climate change on ornamental plants, but they will also consume more irrigation water and may experience changes in photosynthesis and maturation during heat waves.

In order to mitigate these effects and increase the region's resiliency to climate change, growers can adopt climate-resilient agricultural practices, which both bolster agricultural operations against climate change and actively fight climate change by sequestering carbon. Several major practices that can help are irrigation system management to reduce water usage, energy efficiency audits and renewable energy adoption, and soil investment practices like cover cropping and mulching or composting. Since many San Diego County farms are organic or organic-adjacent, many soil health practices are already conducted in the county. Although nurseries that grow ornamentals in containers rarely engage in intensive soil health practices, some ornamental crops, such as perennials and trees, can nonetheless sequester a significant amount of carbon in their root biomass.

California is in the vanguard of climate change legislation and action, and a variety of funding programs exist to encourage mitigation in the agricultural sector and conservation of agricultural lands. San Diego food-based agriculture is in a strong position to contribute to climate mitigation but could be taking greater advantage of available funding. However, the majority of our county's agricultural producers are under-informed due to the lack of research on climate-resilient practices that specifically address the needs of the nursery and floriculture sector. This presents a major research need and an avenue for essential future work.

II. INTRODUCTION

Scientific evidence shows that anthropogenic climate change poses a clear and present danger throughout the world. While climate change is a global phenomenon, its consequences will be felt on local scales, with warming temperatures, changes in precipitation patterns, extreme weather events, and other potential changes occurring here in San Diego County. Mitigation of and resilience to these effects must therefore occur on a local scale as well, both to sustain food security and agricultural production in the county and to contribute to reduction of carbon emissions.

Agriculture has long been an important industry in San Diego County, but practices and priorities for climate-resilient agriculture are often different here than in conventional agricultural scenarios. Farms in San Diego differ from the norm both in California and nationwide: the dominance of nursery and horticultural production, the high number of small farms less than 10 acres in size, the proportion of economic value contributed by high-value specialty crops, and the proportion and overall number of organic farms are all unique to our county. Furthermore, the county has become increasingly urbanized as a result of population increase, resulting in a reduction in acreage devoted to farming over the last 15 years. As both urbanization and climate change ramp up in the region, challenges to profitable farming, ranching, and horticulture have increased. To meet these challenges and continue production, farmers and growers require science-based information that addresses the county’s unique placement in the agricultural landscape.

The University of California Cooperative Extension (UCCE) works with farm producers, county officials, and community leaders statewide to provide science-based information on local issues, tailored to meet each county’s specific needs. A critical part of the UCCE mandate is to provide information and research on improvements in farm practices to ensure the success of farm producers. This paper therefore addresses the state of the science on climate-resilient agriculture; discusses potential impacts of climate change on San Diego farms and nurseries; evaluates the regulatory environment with regard to climate-resilient agriculture; and makes recommendations for producers, policymakers, and other stakeholders.

III. SAN DIEGO COUNTY'S FARMING ENVIRONMENT

HISTORY OF FARMING IN SAN DIEGO COUNTY

Historically, agriculture has played an important role in the landscape, development, and economy of San Diego. The region's mild climate, water sources, and previously low population density allowed a variety of crops to be cultivated year-round. Although indigenous practices were different in intensity and production from today's agriculture, the Kumeyaay people engaged in farming and intensive plant husbandry for thousands of years before European contact, encouraging propagation of edible wild plants through controlled burns and broadcast sowing of seeds and grains saved from desired species such as chia (Anderson 2005; Shipek 2014). Squash, beans, and corn were grown as staples near springs and in areas that would receive runoff (Anderson and Blackburn 1993). Acorns, herbaceous perennial seeds, and pine nuts were collected as an important source of fat and protein (Pico 2012).

Kumeyaay land management practices were intensive, including levee and diversion dam construction to control irrigation in San Diego's unpredictable rainfall regime, coppicing and chaparral root harvesting to obtain wood without felling mature food trees, and a complex pattern of controlled burns. Burns performed a variety of functions. "Spot burns" managed the timing and abundance of food species regrowth; yearly burns controlled parasitic plants and other pests, while reducing fuel loads in forests; riparian burns encouraged the regrowth of cattails, reeds, and basket-grasses for use in household goods such as boats and baskets; and steeply sloping chaparral was burned to renew growth on a cycle of 5 to 15 years to reduce erosion. To mitigate risk, burns were timed according to harvests, plant community composition, and recent weather, such as windless days just after rains (Anderson and Blackburn 1993). Livestock was not kept, but Kumeyaay hunting practices involved detailed observation of game animals' behaviors, needs, and habits, including controlled burns that encouraged regrowth of browse plants for herbivorous game and flat stone deadfall traps to catch kangaroo rats (Anderson 2005).

The first Spanish mission in California was founded in 1769 in present-day San Diego, establishing what is thought to be the longest continuously used European-style agricultural land in California. Kumeyaay land husbandry practices continued into the 1880s, particularly in upland and mountain areas, where Kumeyaay people resisted Spanish rule (Anderson and Blackburn 1993). However, land use in San Diego County was increasingly dominated by the agricultural and livestock grazing practices of the missions, the ranchos, and, later, American settlers (Anderson 2005).

After the Mexican-American War ended in 1848, California's new status as a United States territory opened it to US trade and commercial activities, largely in beef production (Bowman 1973). Cattle grazing significantly altered the landscape, converting formerly Kumeyaay-managed coastal mesas and riparian habitat into rangeland and reducing native plant diversity. After the great drought of 1863-1865 severely damaged the cattle industry, the region shifted away from beef cattle toward diversified fruit and tree crops (San Diego History Center 2021a).

As the nineteenth century drew to a close, agriculture became a major driver of economic activity in San Diego County. The first San Diego County Fair was founded in 1880 by Frank Kimball, a contractor from National City who imported fruit trees from Europe and Asia through a partnership with the US Department of Agriculture (Visit National City 2012). The Horticultural Commission was established in 1881; it ultimately became the office of the San Diego County Agricultural Commissioner. Throughout the 1880s and 1890s, multiple engineering projects were completed to secure the region's irrigation water, including Cuyamaca Dam, Sweetwater Dam, and five other dammed reservoirs throughout the county (San Diego History Center 2021b). Railway service to the city of San Diego, established in 1885, further opened the county to rapid commercial developments and agribusiness.

With these increasing investments and a growing population, late nineteenth and early twentieth-century San Diego became well-known for its citrus farms, which were an important part of the economic base of the county. The citrus industry in Southern California expanded fifty-fold from 90,000 trees to 4.5 million trees in just 25 years (CDFA Fertilizer Research and Education Program 2016), and Chula Vista became known as the "Lemon Capital of the World" (Gustafsson 2011). A wide variety of other crops were grown, too. Japanese farmers in the South Bay area were known for their vegetable crops, which they fertilized with discarded fish offal from San Diego Bay canneries (Gustafsson 2011). Poultry and dairy operations were common, and many dairy farmers grew alfalfa on their own land for feed. The rich soil of Mission Valley hosted up to 20 dairies, and the "rattle of milk cans" could be heard across the valley (Crawford 2008). The San Diego County Farm Bureau was founded in 1914 to "promote and protect agriculture" in the county. Avocadoes were introduced in the 1920s as a subtropical cash crop optimal for San Diego's mild climate. As land values climbed and water assessments increased, grape and olive production gave way to avocado and citrus production, which commanded higher prices (Bowman 1973). Laura Hillebrecht, a descendant and owner of a farm founded in 1924, recalls the common crops in Escondido at the time her grandfather began farming there: poultry ranches, dairies, and cattle ranches were joined by farms that grew citrus, flowers, vegetables, grapes, and feed crops for livestock (Hillebrecht 2019).

The 1915 Panama-California Exposition, hosted at the newly christened Balboa Park, was an economic turning point for agriculture in San Diego County. In promoting the exposition, boosters touted systematic irrigation and easy agricultural profits in this "American Eden," to tempt eastern transplants weary of city life to invest and farm in San Diego. Year-round sunshine, a frost-free climate, and the rich soils of the inland valleys irrigated with federal water were all part of the attraction. Family farms of 40 to 160 acres were promoted, because only farms smaller than 160 acres were eligible for federally subsidized water within irrigation districts under the 1902 Newlands Reclamation Act (Bokovoy 1999).

However, despite the city promoters' plans for small-scale rural development on land held by family farmers, production trends after 1920 moved toward "increased acreage held in fewer hands" (Bokovoy 1999). What is now downtown and midtown San Diego had already been heavily developed through a series of boom-and-bust cycles since the 1870s, contributing to a slow and steady rate of population growth. However, after the Panama-California Exposition and the 1919 establishment of a naval base, urban development expanded outward from the downtown districts and into the greater San Diego area, consolidating farmland into fewer holdings and strengthening the urban/rural divide.

The county's Resource Conservation Districts were founded in the early 1940s, as an investment against runoff and flooding erosion that posed a threat to San Diego agriculture. However, after World War II, urban development took more and more arable land; from 1954 to 1969, over 200,000 acres (about 25% of farmland acreage) were lost in San Diego County (USDA National Agricultural Statistics Service 1956, 1971). By the late 1960s, the last crops were harvested in Mission Valley. Many dairies moved inland, while the off-season and winter crops moved to less desirable, steeper areas in the coastal climate zone. Laura Hillebrecht recalls "the last 'old Escondido' vineyard of muscat grapes" being plowed under in the mid-1970s (Hillebrecht 2019). While trends in mid-century agriculture tended toward larger farms held by fewer owners growing a diversity of crops, the use of former farmland for rapidly expanding urban development has increased the value of land, made farms smaller, and required farmers to maximize the profitability of every acre. Almost 70% of San Diego farms today are less than 10 acres in size, and a further 20% are less than 50 acres.

Today, agriculture is still a major part of the San Diego economy, and San Diego remains an important growing region. San Diego County is the highest-ranking county in California and the second-highest-ranking county in the US for total production value of nursery crops (California Department of Food and Agriculture 2021). In 2020, agriculture occupied about 8.9% (224,579 acres) of the county's total land area and contributed $1.81 billion to the San Diego economy (San Diego County Department of Agriculture Weights and Measures 2021), and in 2019 directly provided 23,396 jobs (San Diego Food System Alliance 2021c). Perhaps due to the small average size of farm operations, San Diego County hosts 5,082 farms, the most farms of any county in the United States. Additionally, 96% of farms are family-owned, and about 75% are owner-occupied (USDA National Agricultural Statistics Service 2019c).

Many farms grow specialty crops that take advantage of the region's unique microclimates and that have high profitability per acre, such as nursery and cut flower products, avocadoes and citrus, and specialty vegetables like tomatoes, peppers, and herbs. The county is a particular powerhouse in the ornamental and nursery industry. Nursery and cut flower products from San Diego County made up over 10% of total national sales in 2019 (USDA National Agricultural Statistics Service 2019f; San Diego County Department of Agriculture Weights and Measures 2020). In 2020, nursery crops made up 70% of San Diego County's total agricultural production value, almost four times the value of fruits and nuts, which is the category with the second highest production value. Ornamental trees and shrubs had the highest reported dollar value overall, while indoor flowering and foliage plants had the highest dollar value per acre (San Diego County Department of Agriculture Weights and Measures 2021).

PHYSICAL GEOGRAPHY

San Diego County is the most southwesterly county in the continental United States. It is the fifth largest county in the US, covering 4,500 square miles (almost 3 million acres) that extend 65 miles north-south and 86 miles east-west. It is bounded by the Pacific Ocean to the west, Imperial County to the east, Mexico to the south, and Orange and Riverside Counties to the north (Bowman 1973; San Diego County Health and Human Services Agency 2021).

The county has a varied and complex topography, making up 11 different watersheds. As a result, distinct climate and ecological sub-regions occur within relatively close distances (Gershunov and Guirguis 2012). The Tecate Divide, a mountain ridge that runs north to south on the southeastern fringe of the Peninsular Ranges, stretches from Campo and Pine Valley in the south through the Cuyamaca and Laguna Mountains to Palomar Mountain in the north. This ridge divides the county into three major farming regions: the western coast, the central foothills and mountains, and the eastern desert.

The level coastal terraces in the western third of the county are heavily developed and dominated by urban areas but still interspersed with rural areas and small farms. Many ornamental plant operations grow tropical plants, succulents, and herbaceous annuals in the coastal region, since temperatures are less extreme and morning fog frequently cools the coast. Farms in the western third are generally both smaller and grow higher-value crops out of necessity, since land is more expensive. Inland, in the central third of the county, foothills and winding valleys receive more precipitation than the coast, but much of this area has large granitic boulders and can be quite steep. Avocadoes and other frost-sensitive tree crops are frequently grown in the foothills, due to a lower risk of frost on the slopes, as well as the area's sandy, granitic loam, which offers good drainage (Bowman 1973). Many National Forest, State Park, and other protected land designations are found further east into the mountains, where rangeland grazing, orchard crops, and dryland oat and hay farming are practiced.

East of the Tecate Divide is the Colorado River Basin, a desert area with low population, low rainfall, and temperatures over 100°F for over six months of the year. Most farming in the eastern basin is associated with the town of Borrego Springs, where citrus, potatoes, and ornamental trees are grown. Farms are larger on average in this area than in the western region and primarily rely on groundwater pumped from the Borrego Basin (San Diego County Land Use and Environment Group 2015). This water is less expensive than the imported water used in the western part of the county, but groundwater is an extremely limited, non-renewable resource. As of 2016, Borrego Basin groundwater is in a state of critical overdraft (California Department of Water Resources 2016). Growers in the area who irrigate with groundwater are subject to the requirements of California's Sustainable Groundwater Management Act (SGMA) and must reduce groundwater pumping by an estimated 75% by 2040 (Borrego Valley Groundwater Sustainability Agency 2019).

Only 6% of San Diego County land is classified by the USDA as prime agricultural soil, most of which is found in the eastern desert. Most San Diego County soils are highly erodible and are found on relatively steep terrain, which limits agricultural potential to those specialty crops (like avocadoes) that can be grown on hillsides (San Diego County Land Use and Environment Group 2015). Flatter sites, while ranked as higher quality by USDA soil metrics and able to support a wider variety of agricultural products, are more likely to be targeted for urban development in the western part of the county, while available water is a limiting resource in the eastern part of the county.

CURRENT CLIMATE

San Diego County has a Mediterranean climate with warm, dry summers and cool, wet winters. The county's climate is highly variable over both space and time, due to the topography creating multiple microclimate areas in which temperature and precipitation can vary dramatically. Southern California has the largest year-to-year precipitation variability in the continental US, with some of the largest three-day storm totals in the country, and just 5 to 15 wet days needed per year on average to accumulate most of the region's annual precipitation totals (Dettinger et al. 2011). This pattern occurs as a result of eastward-moving frontal storm systems that affect the whole county. The region is accustomed to higher-than-average wet years that fill reservoirs and drive up the mean yearly precipitation value, followed by several years of moderate to severe drought (San Diego Integrated Regional Water Management 2019).

In all regions, July, August, and September are the warmest months and December and January are the coolest, but temperature extremes vary widely from area to area. (All values that follow are mean maximum or minimum values, sourced from the Western Regional Climate Center and based on 1981-2010 norms. All-time highs and lows are more extreme.) Coastal areas are typically cooler in the summer and warmer in the winter due to the moderating effect of the Pacific Ocean. Mean temperatures range from 56 to 71°F year-round, reaching highs of 75°F and lows of 48°F. Foothill areas experience more temperature extremes of both heat and cold and more precipitation variability than the coast. Mean temperatures range from 55 to 76°F year-round, reaching highs of 92°F and lows of 38°F. Mountainous areas are cooler year-round and receive more precipitation than either coastal or inland areas, ranging from 39 to 69°F year-round and reaching highs of 85°F and lows of 28°F. Desert areas see the most dramatic temperature variation, ranging from 57 to 92°F year-round and reaching highs of 106° and lows of 43°F (WRCC DRI 2021). The region exhibits a pattern of increasing precipitation with increasing elevation: coastal areas average about 10 inches of rain a year, desert areas average 5 inches or less, and mountains can receive more than 33 inches (American Farmland Trust and San Diego County 2009; San Diego Integrated Regional Water Management 2019).

One major cyclical climate pattern that affects San Diego County is the ENSO (El Niño Southern Oscillation), made up of a warm, wetter phase (El Niño) and a cool, drier phase (La Niña) that swings back and forth every three to seven years on average. In El Niño years, the tropical Pacific Ocean is warmer than average, which increases the chance of storms over Southern California (NOAA Climate.gov 2016). In La Niña years, the ocean is cooler than average, which leads to reduced chances of a wet, stormy winter. Strong El Niño conditions in the last 25 years occurred in 1991-1992, 1997-1998, and 2015-2016. Strong La Niña conditions in the last 25 years occurred in 1999-2000, 2007-2008, 2010-2012, and 2020-2021.

In San Diego, the increased rainfall and strong winter storms brought by El Niño conditions can increase flooding, mud slides, and debris flow. Agriculture is one of the economic segments of San Diego County affected most by El Niño. According to Eric Larsen, the former executive director of the San Diego County Farm Bureau, the biggest concern for farmers during these storms are high winds that "knock fruit off trees, flatten field crops, and damage greenhouses" (National University System Institute for Policy Research 2015). Conversely, La Niña can affect drought for years after the "end" of La Niña conditions, even when ocean temperatures and wind patterns return to their long-term averages. In the historic drought that California experienced from 2011 to 2016, NOAA models found that the La Niña conditions present in the first year of the drought persisted into the "neutral" years of 2012-2014 (Scott and Lindsey 2015).

In addition to the ENSO pattern, extremely high atmospheric pressure events have increased in recent years, which force storms further north. The result in San Diego County is fewer "average" rainfall years, causing more extremes of warm, dry periods with fewer wet years. The co-occurrence of reduced precipitation with warm temperatures also increases the risk of drought. One study found that precipitation deficits were more than twice as likely to produce drought years if they occurred when conditions were already warm (Diffenbaugh, Swain, and Touma 2015).

WATER RESOURCES

Reliable water availability is a perennial problem in Southern California agriculture due to the region's variable rainfall. Lack of substantial surface water, combined with a growing urban center and the need to irrigate high-value crops, has required the development of water storage, pumping, and importation technologies in the county for over 150 years. In addition, water availability in times of shortage requires a coherent water accounting system that spans California's independently governed and regulated water organizations (Lund et al. 2018), an infrastructure sorely undeveloped in California when compared to other drought-prone regions like Australia (Aghakouchak et al. 2014; Escriva-Bou et al. 2016). Legislative and regulatory improvements have occurred, such as the 2014 Sustainable Groundwater Management Act and the surface water reporting requirements instituted by SB 88, but further data collection and policymaking actions must be taken to establish a truly robust water accounting system (Escriva-Bou et al. 2016).

San Diego County imports the majority of its water from other water districts in Southern California, principally the Imperial Irrigation District (IID) in Imperial County and the Metropolitan Water District of Southern California (MWD). Agriculture is the third largest water user in San Diego County, making up 8% of water demand. Residential use accounts for 66% and commercial and industrial use accounts for 16%, while public and other uses make up the remaining 10% (San Diego County Water Authority 2021a). Per capita water use across the region has decreased almost 50% since 1991, when a devastating drought forced water supply cutbacks of up to a third delivered by the Metropolitan Water District. At that time, over 95% of San Diego water originated in the Colorado River (imported by and purchased from the MWD) and less than 5% was local surface water.

These aggressive cutbacks, sped by the recent drought and corresponding increases in water prices, have caused the San Diego County Water Authority to diversify its water sources over the past 30 years in the hope of reducing economic shocks from future droughts. In 2020, 37% of water supply was imported from the Colorado River and rivers in Northern California; 31% was imported from the IID; and the remaining 32% was sourced locally from groundwater, local surface water, recycled water, and the San Luis Rey Water District (San Diego County Water Authority 2021a). About one-third of locally sourced water now comes from the Claude Lewis Desalination Plant in Carlsbad, a public-private partnership that plans to transfer plant ownership from private investors to the Water Authority 30 years after its construction. Another water treatment facility was established in Escondido as part of the Agricultural Recycled Water and Potable Reuse program to remove accumulated salts and to distribute recycled water to eastern and northern agricultural land in the county (California Natural Resources Agency Bond Accountability Program 2021).

While increasing source diversification is a logical hedge against drought, the expense of developing new water capture, recycling, and treatment technologies is often unpopular. Agricultural users paid up to $1,800/acre-foot in 2021, compared to $20/acre-foot in nearby Imperial County (Imperial Irrigation District 2021; Smith 2021). Water purchased from public utilities operated by the City of San Diego is even more expensive, at about $3,000/acre-foot (City of San Diego 2019). Rates in San Diego County have risen an average of 8% a year over the last decade (Smith 2021), resulting in tensions between the County Water Authority, the municipal districts that buy their water (such as those in Fallbrook and Rainbow), and agricultural water consumers (who often allow land to go fallow in response to increased water prices). As drought conditions continue, conflicts over the price of water and land will likely worsen.

In California's most recent multi-year drought, which ran from 2012 to 2016, California experienced its hottest and driest years on record. NOAA analysis found that, in the winter of 2013-2014, the state experienced its most severe drought conditions since records began 122 years ago (Pathak et al. 2018). These exceptionally hot and dry conditions caused groundwater overdrafts, critically low streamflow, increased wildfire risk, and water shortages in all sectors throughout the state (Diffenbaugh, Swain, and Touma 2015; Mann and Gleick 2015), with a devastating result on agriculture.

Throughout the state, over half a million acres of agricultural land were fallowed, groundwater pumping increased by 5 million acre-feet to cover a 6.6-million acre-feet shortfall in surface water, and direct financial losses were about $1.5 billion due to lost crop and livestock revenue and increased groundwater pumping costs (UC Davis Center for Watershed Sciences 2014). Due to Southern California's reliance on imported Colorado River water, rather than local surface water like many Central Valley farms, San Diego County agriculture was not as severely economically damaged as agriculture in other regions of the state. However, water prices still increased dramatically; in response, avocado and citrus growers stopped watering trees, cut down water-thirsty mature trees, and even switched to less water-consuming crops such as vineyards (Mission Resource Conservation District, pers. comm.). Primarily due to increased irrigation costs, the total acreage of San Diego's avocadoes decreased by almost 25% in just ten years (San Diego County Department of Agriculture Weights and Measures 2011; San Diego County Department of Agriculture Weights and Measures 2021). The restriction that irrigation water imposes is therefore not due primarily to its availability, but to its price, limiting the ability of growers to make a living in a period of increasing consciousness about water conservation. Nonetheless, growers have reduced their operations' water demand and have increased efficiency, reducing their overall share of water used in the region to less than 10% (Rivard 2015).

In 2020, total water demand in the Water Authority's service area was about 470,000 acre-feet, of which 92% was for municipal and industrial use and 8% was for agricultural use. Total demand in 2020 was just 62% of the record-breaking 2007 demand, after which state legislators passed SB7 in 2009 to require a 20% statewide reduction in urban per capita water use by 2020. Future water demands are projected to increase slowly, in accordance with the Water Authority's increasing source diversification and the downward usage trend among efficiency-conscious water consumers. Demand is projected not to exceed 600,000 acre-feet, or a 29% increase over 2020 demand, in the next 15 years (San Diego County Water Authority 2021b).

AGRICULTURAL LAND AVAILABILITY

By 2050, the San Diego Association of Governments projects that approximately 29 square miles will be added to the developed area of San Diego County to accommodate expected population growth, with a general intensification of existing land uses in urban communities and along transit lines. Over half of corresponding housing growth is projected to occur in the City of San Diego itself, while about 12% of housing growth will occur in unincorporated areas, primarily centered around present towns such as Lakeside, Valley Center, and Spring Valley (SANDAG 2021). About 4,500 acres (4.2%) of current agricultural land are projected to be lost by 2050, while dedicated open space is projected to increase by almost 30% in the same period (SANDAG 2013), mostly from unincorporated county land. (While a new SANDAG Regional Growth Forecast, Series 14, was released in 2021, agricultural and land-use data comparable to that in the Series 13 report from 2013 has not yet been made available.) Over the last 15 years, the mean and median size of farms has not changed, but the overall acreage devoted to agricultural production has decreased by over 25% (USDA National Agricultural Statistics Service 2009; 2019b).

Southern California has historically lost the most farmland to urbanization of any region in the state since the 1984 establishment of the Farmland Mapping and Monitoring Project, only surpassed in the most recent report by the San Joaquin Valley region (California Department of Conservation 2019). However, San Diego County has been mostly exempt from this pattern; most agricultural land use change in the most recent survey is due to idling of irrigated land and conversion of irrigated land to non-irrigated uses and dryland grazing, rather than urban development. Urban development that has occurred over the survey period in San Diego County has been sourced primarily from infill, non-agricultural vacant land, and grazing land, and only to a lesser extent from typical-quality San Diego productive farmland (California Department of Conservation 2019).

On the other hand, agriculture in San Diego is rarely confined to "high-quality farmland," as defined in the Farmland Mapping and Monitoring Project, due to the county's high number of nurseries, hydroponic and greenhouse operations, and tree crops grown on steep slopes. According to San Diego County Farm Bureau director Hannah Gbeh, "agriculture is everywhere in San Diego County," and operations in even highly urbanized settings are only limited by regulatory requirements (pers. comm.). Installation of agricultural operations and, conversely, urban development of formerly agricultural lands are therefore both largely dependent on county and municipal zoning regulations rather than soil quality or availability of land "appropriate for agricultural use." Ultimately, the sharp increase in the Southern California population over the last several decades has driven both land values and decisions regarding urban development. Increasing land values have meant that farming is less likely to be profitable or even accessible for first-time and previously non-landowning producers.

As regional urban development continues over the next 30 years, the projected overlap between increasingly dense urban environments and urban and suburban farms may cause friction. Conflicts between the comfort and expectations of urban residents and the noise, smell, and operating hours of standard farm operations often arise on the urban-agricultural fringe. These interactions may increase in San Diego as development continues, with the prevalence of urban farms and the projected increase in housing development in unincorporated and rural areas. A UC publication found that local governments that establish firm urban-growth boundaries and buffer zones between urban and agricultural land uses can reduce urban-ag conflict, particularly in unincorporated areas where ag-adjacent communities may establish commercial centers that spur further development (Handel 1998). These boundaries are often defined poorly or not at all in a region's general plan. In San Diego, the county's general plan adopted in 2011 prioritizes urban development in the western unincorporated portions of the county, but the majority of unincorporated county land is nonetheless zoned for development, and urban-rural boundaries could potentially be drawn on formerly agricultural land. While converting land between agricultural and non-agricultural uses is often expensive in either direction, due to the need for environmental impact assessment, conversion toward agricultural uses is more frequently cost-prohibitive for potential farmers. This is because environmental mitigation costs or credits must be paid for by crop sales (farm profits) or personal capital, rather than by housing unit sales (development profits). Village boundaries in the unincorporated areas of the county limit building types and lot sizes outside of established villages, but semi-rural and rural land use definitions still permit up to two dwelling units per acre on certain parcels (San Diego County Planning and Development Services 2011).

However, the San Diego region is unusual in that local government bodies, policies, and mechanisms are present to mediate urban-ag conflicts, and do so frequently in a way that is rare for such conflicts in California. In two instances of urban-rural conflicts in San Diego County, the Agricultural Interface Board, Fly Abatement Appeals Board, and other city and county governmental bodies played key roles in mediating the conflict between agricultural practices and needs and the health and comfort of urban residents (Sokolow et al. 2010). These bodies were largely ad hoc and formed in response to mediation requests from both residents and agricultural operators, then dissolved after the conflict had been settled and Good Neighbor practices had been established in the area (Lobo, pers. comm.).

ENERGY USAGE AND EMISSIONS

In 2019, San Diego County used a total of 19,048 GWh of electricity across all sectors (about 65% non-residential and 35% residential) and a total of 533.9 million therms of natural gas across all sectors (about 43% non-residential and 57% residential) (California Energy Commission 2019). Agriculture makes up a relatively small share of both energy consumption and carbon emissions in the state and nationwide. US agriculture consumed about 2% of total energy in 2014 (USDA Economic Research Service 2016) and emitted about 10% of greenhouse gases (GHGs) in 2019 (US EPA 2021), while California agriculture consumed 8% of energy in 2007 (UC Agricultural Issues Center 2009) and emitted 8% of GHGs in 2018 (California Energy Commission 2021). In San Diego County, agriculture ranked fifth out of nine categories as a source of GHGs in 2014, contributing 5% of total emissions and trailing on-road transportation (45%), electricity production (24%), solid waste (11%), and natural gas (9%) (San Diego County 2018).

Most energy consumed in agricultural operations in California is due to indirect energy use, such as the production of fertilizers and pesticides and the operation of water pumps, rather than direct use, such as on-farm fuel use for heavy equipment

(UC Agricultural Issues Center 2009). Each year, agricultural irrigation in California consumes over 10 billion kWh of electricity, nearly enough to power 1.5 million residences (California Climate & Agriculture Network 2016). In terms of irrigation energy, San Diego is no different. Due to its importation over long distances, irrigation water available in the county is relatively energy-hungry, requiring between 570 and 620 kWh per acre-foot to complete delivery; pumping of irrigation water makes up between 1 and 6% of total energy use in the region (Irrigation Training and Research Center Cal Poly 2003), which is the majority of agricultural energy used in the county (San Diego County Climate Action Plan 2020). However, while it did not consume the most energy in absolute terms, heavy farm equipment accounted for approximately 52% of agricultural sector GHG emissions in the county in 2014.

Similar to the San Diego County Water Authority's diversification of water sources over the last 20 years, San Diego energy generation has also increased its diversity of sources, primarily by expanding the use of solar panels and other renewables. Looking at the broader picture of energy in the region, the county's most recent update reveals that all five measures of energy efficiency and renewable energy use either have met their 2020 targets or are on track to meet or exceed 2030 targets (San Diego County Climate Action Plan 2021). Native American reservations also have broken ground on local renewable energy initiatives; the Campo Kumeyaay Nation has developed a private partnership to lease reservation land to two utility-scale wind farms, and the Ramona Band of Cahuilla is one of the first tribes to make its reservation independent of the regional electric grid by using a local microgrid (US Energy Information Administration 2021). On the statewide level, including both large-scale photovoltaic and small-scale customer-owned facilities, solar energy provides about 20% of California's total net energy generation (US Energy Information Administration 2021). This share is projected to increase as state mandates require a larger share of energy to be generated sustainably over the next 30 years, with 100% of electricity retail sales required to be from renewable resources by 2045 (US Energy Information Administration 2021).

Projected future energy use in San Diego agriculture is unclear, due to the competing tensions of rising irrigation water prices and increased need for water under a warmer climate regime, as well as the updated requirements and guidelines provided by the county's new Climate Action Plan. In any case, electricity for water pumping and other indirect energy inputs such as nitrogen and pesticides will constitute the major energy uses in San Diego agriculture.

DEMOGRAPHY AND CULTURE

Demography

An estimated 3.34 million people live in San Diego County. By 2050, the population is projected to increase to over 4 million, primarily as a result of natural increase (total births minus deaths). As life expectancies increase, it is expected that nearly 20% of the population will be 65 years or older, compared with 12% in 2013.

Since 2010, the San Diego region has had a minority-majority population, in which no one race or ethnic group comprises more than 50% of the population. By 2050, the non- Hispanic white population is projected to decrease from 48% to 30%, while the Hispanic population is projected to increase from 32% to 46% (SANDAG 2013).

	CALIFORNIA [1]	SAN DIEGO COUNTY [1]	FARM PRODUCERS IN CALIFORNIA [2]	FARM PRODUCERS IN SAN DIEGO [2]
TOTAL POPULATION	39.2 M	3.3 M	128,535	8,597
RACE, %				
White	36.4	45.5	84.5	78
Hispanic/Latino	38.2	33.7	7.3	13
Asian and Pacific Islander	14.6	12.0	5.5	5.1
Black	5.5	4.7	0.3	0.5
American Indian and Alaska Native	0.4	0.37	1.1	1.2
Biracial and Other	4.9	5.2	1.3	2.0
AGE GROUPS, %				
20 to 34 years old	22.2	24.2	6.2	4.1
35 to 64 years old	38.3	37.5	54.2	53.6
65 years old or older	14.0	13.7	36.3	42.3
FEMALE, %	50.3	49.7	35.9	40.7
MILITARY VETERAN, %	3.9	6.5	9.4	14.4
BEGINNING FARMERS, %	--	--	26.9	35

1. Data from US Census Bureau American Community Survey: 2015-2019 Five-Year Data Profile (US Census Bureau 2020)

2. Data from USDA National Agricultural Statistics Service 2017 Census of Agriculture (USDA National Agricultural Statistics Service 2019c)

The average age of farm producers has increased since 2012 and is now about 62 years old; this is older than the national average age of 57 years. Only about 4% of producers in the county are younger than 35 years old; nationwide, the average proportion of young producers is more than double that number, at 8.4% (USDA National Agricultural Statistics Service 2019b). Despite the higher average age of farm producers, new and beginning producers are relatively common in the county. New producers, with less than 10 years of experience, account for about 35% of producers in the county. Their land holdings total 88,649 acres, or over 36% of all farmland in San Diego (USDA National Agricultural Statistics Service 2019c). This pattern may be due to a reduction in the number of multi-generational families still involved in farming. According to former San Diego County Farm Bureau director Eric Larsen, many people newly turn to farming after accumulating financial assets, or after they retire (pers. comm.). Agricultural land conservation coordinator Chandra Richards mentions that many new and beginning producers in San Diego turn to farming as part of a desire to participate in sustainable food systems and reclaim a relationship with the land (pers. comm.). While Agriculture Census statistics show that new producers are less diverse and wealthier than their generational cohort as a whole (Rosenberg and Stucki 2018), some argue that census counts of large conventional-production farms operating on owned or inherited land don't adequately capture the groundswell of diverse young farmers who may not be able to afford to own the land they farm on (Dixon 2018).

Women are farm producers at a somewhat higher rate in San Diego County (about 41%) than in California or the US as a whole (both 36%). Military veteran producers are more common in San Diego County (about 14% of producers) than in California (9%) or the US (11%), not surprisingly for a region with such a strong historic and current military presence. Farm producers in San Diego County are less racially diverse than the overall population of either San Diego or California as a whole, but are somewhat more racially diverse than California producers on average. Notably, Hispanic and Latino producers are almost twice as common in San Diego County as in California as a whole. San Diego's producer diversity, especially among Hispanic and Latino ethnicities, may partly stem from its status as a "majority-minority" county; another factor could be its proximity to the international border with Mexico, which allows cross-border communication and collaboration with Mexican farmers who are raising similar crops in similar climates.

Agriculture as a whole has shown pervasive racial, gender, and ethnic disparities in land ownership, farming income, and family wealth (Horst and Marion 2019; Rosenberg and Stucki 2019). This is no less true in California. The history of Black, Indigenous/Native American, Asian, and Hispanic and Latino contributions to California agriculture has often been erased in traditional farming narratives. For example, the town of Julian, today a mountain agritourism hub famous for its apple pie, started as a late-1800s enclave of Black pioneers and farmers, with a hotel still open today as the longest-running hotel in California, while 45% of all Japanese immigrants and their descendants were involved directly in food production before internment during World War II (Orona et al. 2021). Even within sustainable agriculture, the movement has been criticized for its lack of concern with racial justice and acknowledgment of indigenous sovereignty and practices, many of which are the inspiration for currently on-trend sustainable farming practices (Wozniacka 2021). These inequities, both past and present, still contribute to reduced numbers of farm producers of color.

Tribal Farming

Kumeyaay, Luiseño, Cahuilla, and Cupeño bands have a long history of farming in the county, producing a wide variety of crops and cultivated wild foods that varied throughout the seasons and across the area's microclimates (Pico 2012). There are 18 Native American reservations in San Diego County, more than in any other county in the United States, but their land area is very small (less than 5% of the county's total area), and only a small percentage of the 20,000 Native Americans in the county live on reservations (University of San Diego 2021). Nonetheless, Native Americans operate farms at a higher rate than predicted by population: 106 farm producers in San Diego County are Native American (USDA National Agricultural Statistics Service 2019c).

Several tribes currently farm on their reservation land and adjacent lands, including the Pauma Band of Luiseño Mission Indians, who grow mostly citrus and avocado on about 400 acres, and also host the carbon-sequestering and sustainable Solidarity Farms, which grows specialty vegetables and fruits on 10 acres of tribal land (Aguilar and Staff 2021). The Pala Band of Mission Indians recently received California Department of Food and Agriculture funding to develop an agricultural education and career awareness program for tribal students, including informational local farm tours, mentorship programs, and a student-planted school garden at the Pala Youth Center (Morning Ag Clips 2021). As recently as 2016, the Rincon Band of Luiseño Indians managed a tribal nursery that primarily focused on drought-tolerant native plants and those used for traditional ethnobotanic purposes, such as *Juncus* basketmaking reeds (Ogul 2015; Barona Cultural Center & Museum 2016). They plan to expand nursery operations in 2022 (pers. comm.).

Organic Farming

As the county with the highest number of organic farms in the nation, San Diego is heavily invested in organic and organic-adjacent agriculture, and the sustainable practices that characterize organic agriculture have a strong presence in the county. The USDA National Organic Program defines organic agriculture as a suite of methods that "integrate cultural, biological, and mechanical practices to foster cycling of resources, promote ecological balance, and conserve biodiversity. Synthetic fertilizers, sewage sludge, irradiation, and genetic engineering may not be used" (USDA National Organic Program 2011). Sales of organic agricultural commodities increased 31% from 2016 to 2019 nationally (USDA National Agricultural Statistics Service 2019d), reflecting consumer demand for wholesome, environmentally friendly food. Consumers prefer "natural" food, which can be associated with either local production or organic production methods, because it is perceived to be healthier (Printezis et al. 2017).

There are 358 certified organic growers in San Diego County, comprising over 10% of all organic farms in California, more than in any other single county in the US (USDA National Agricultural Statistics Service 2019a). Organic farms in San Diego County produce over 150 different crops (San Diego County Department of Agriculture Weights and Measures 2018). The county has long been a stronghold for organic growers, holding the record for the highest number of organic farms since at least 1992 (Stumbos 1993). In a 2018 survey, about 18% of farm operations were either certified organic or actively working toward organic certification, while an additional 18% used organic-style farming practices but were not officially certified (Lobo et al. 2018). This "organic and organic-adjacent" respondent group was equivalent to the number of conventional farm operations, which made up an additional 36% of respondents. (The remainder of respondents used controlled-environment production systems, a mix of organic and conventional practices, or other systems.) This high rate of "organic-adjacent" farming operations may have a relationship with the relatively high number of new and beginning producers in San Diego County, many of whom begin farming because of their desire to participate in sustainable and local food systems.

IV. CLIMATE CHANGE PROJECTIONS AND IMPACTS

Driven by anthropogenic greenhouse gas (GHG) emissions, global temperatures have increased at an average rate of 0.13°F per decade since 1880. This rate of increase has accelerated since 1981 to 0.32°F per decade (NOAA National Centers for Environmental Information 2021a). The most recent global land and ocean surface temperature anomaly showed that 2011-2020 was the warmest decade on record for the globe, with a surface global temperature of 1.48°F above the 20th century average. Five of the six largest wildfires in California history occurred during the fire season of 2020, and six of the ten largest historical flood events occurred within the past 25 years. While California and San Diego County have taken great strides both to address the causes of climate change and to mitigate its impacts, changes in statewide and local temperatures will depend on current and future actions to aggressively reduce GHG emissions.

Assembly Bill 32, passed in 2006, established a goal of reducing GHG emissions to 1990 levels by the year 2020. The more ambitious Senate Bill 32, passed in 2016, aimed to further reduce GHG levels to 40% below 1990 levels by the year 2020. While the state has achieved its first target, it has not been successful in achieving the second, and emission reductions have slowed since 2016 (California Energy Commission 2021). The target for California by 2050 is even stricter, setting target levels at 80% below the 1990 level. To achieve the target level of emissions unquestionably will require widespread decarbonization and electrification of the transportation sector, California's primary emissions contributor, as well as usage reductions and policy changes to encourage renewable energy from the local and community to the statewide level (Ghanadan and Koomey 2005; J. H. Williams et al. 2012).

The Fifth Assessment Report, produced in 2015 by the Intergovernmental Panel on Climate Change, adopted two models for projecting climate scenarios to the end of the century. In the higher emissions or "business as usual" scenario, assumed to be the most likely if no further steps are taken, GHG emissions continue to rise strongly until 2050 and then level off (but remain high) until the end of the century. The more moderate emissions scenario assumes that emissions will peak in 2040 and then decline to net zero emissions by the year 2100 (Fifth Intergovernmental Panel on Climate Change 2015). The first section of the Sixth Assessment Report was released in August 2021 with updated projected future impacts based on progress toward GHG emission reduction over the last six years, and the final version is slated for release in September 2022. Unfortunately, the 2021 report has only shown an increase in the severity of the situation as outlined in 2015; even in the best-case scenario, global surface temperature will continue to increase until at least 2050, and the window of opportunity to avoid drastic harm will close in the next 20 years. Unless deep and broad-reaching reductions in carbon dioxide (CO_2) and other GHG emissions to the extent of net zero are made in the next several decades, warming during the 21st century may exceed 2°C above historic averages (Sixth Intergovernmental Panel on Climate Change 2021).

TEMPERATURE

In San Diego County, the annual average maximum temperature between 1950-2005 was 74.9°F. By the end of the century, it is projected to rise by 4.9°F under the moderate emissions model and by almost 10°F under the high emissions model. The annual average minimum temperature, formerly 47.8°F, is projected to rise between 5.7°F and 10°F. Under the “business as usual” model, the temperature of the average hottest day of the year is projected to increase at the coast from 90-100°F to 100-110°F. In the desert area, the average hottest day of the year would rise from 105-115°F to 110-125°F (Scripps Institution of Oceanography, UC San Diego 2018). The greatest difference in the county will not be increased maximum or mean temperatures, but increased minimum temperatures, resulting in warmer winters, warmer nights, and a reduced number of the low-temperature “chill hours” that are needed by certain tree crops. Heat waves in California will become more severe and more humid, with disproportionate intensity in nighttime rather than daytime temperatures and later into the fall. Increased humidity and heat in coastal regions is strongly correlated with human mortality and heat-related morbidity (Gershunov and Guirguis 2012).

Increased temperatures will have a variety of impacts on San Diego’s climate and agriculture throughout the year. Increases in the frequency, intensity and duration of extreme heat days are likely to occur. Historically, San Diego has had 4.2 extreme heat days per year (defined as days from April 1 to October 30 with temperatures greater than 96°F). By the end of the century, that number is expected to increase to an average of 33 extreme heat days under the moderate emissions model, or 67 days under the higher emissions model. These extreme heat days may also occur over a more extended period: spring will warm earlier in the year, and autumn will be warmer for later into the year (Ascent Environmental, Inc. 2017).

Most specialty crop yields are strongly affected by temperature, such that yield is reduced by temperatures either below or above a certain preferred range (Lobell et al. 2006). The crops most under threat due to increased temperatures are heat-adverse specialty crops like strawberries and lettuce that rely on mild coastal summers (Kerr et al. 2018). Among perennial tree crops, heat events can cause heat drop, smaller or damaged fruit quality, and increased bacterial or sunburn damage to the trunk inflicted on already heat-stressed trees (Faber 2021). In addition, many fruit and nut trees require at least several hundred chilling hours (continuous exposure to temperatures below 45°F) in order to produce a crop. Requirements between cultivars and crops vary, and some that require less chill may still experience suitable conditions, but anywhere from 300 to 700 yearly chilling hours are projected to be lost by 2100 (Pathak et al. 2018). Conversely, heat-loving winter crops like citrus may benefit from fewer chill hours, since crop loss due to freezing is reduced in a warming California (Glenn et al. 2014). While avocadoes are a subtropical crop that may benefit from warm winters, several studies suggest that increasing summer temperatures will severely decrease avocado yields, although the mechanism for this decrease is not yet understood (Lobell et al. 2006; Kerr et al. 2018). By 2050, yields are projected to decline by 40% for avocadoes and 20% for table grapes, oranges, walnuts, and almonds (California Climate & Agriculture Network 2018). Similarly, increased temperatures put livestock at risk of overheating, dehydration, reduced weight gain, and increased disease transmission (Baumgard et al. 2012).

Ornamental crops also will be affected. Increased temperature accelerates evaporation and evapotranspiration of irrigation water from container-grown plants (Snyder 2017). This potential strain on photosynthesis and crop quality is greater for container-grown perennials and fruit trees that need to mature slowly than for annuals and other quick-growing, quick-selling crops. Little work has been done to evaluate the effects of climate change on the quality or production of ornamental crops; for example, it is unclear whether certain regions will become unsuitable for ornamental production in the future.

Hot weather can also increase the risk of heat-related illness among outdoor farm workers. Farm and crop workers in the United States are 20 times more likely to die from heat-stress illnesses compared to all United States workers (Tigchelaar, Battisti, and Spector 2020), and working in higher temperatures increases the risk of worksite injuries by 15% (Spector et al. 2016). One study found that 72% of surveyed farm laborers had experienced at least one symptom of heat-related illness in the week preceding the survey (Kearney et al. 2016). The workload and pace of work is a significant predictive factor for heat exhaustion (Pan et al. 2021), since many farm workers are paid at a piece rate (i.e., per task completed, rather than per hour of time worked) and piece-rate work can incentivize pushing through heat-related symptoms and disincentivize breaks for water or shade (Mitchell et al. 2018). As climate change increases the number of hot days per year and the maximum high temperature, farm workers will likely be increasingly threatened by heat-related illness. Even workers at farms compliant with Cal/OSHA shade and water regulations can still succumb, due to inadequate training and the aforementioned piece-rate incentivization among other factors (Langer et al. 2021).

Another potential hazard for San Diego farms is the urban heat island effect. In urban areas, which are characterized by impervious heat-absorbing surfaces like asphalt and concrete, air temperatures can reach 1 to 5°C higher than in less developed areas nearby (Taha 2017). These increased temperatures are caused by the higher heat-retaining capacity, albedo, and thermal conductivity of developed surfaces relative to rural areas; lack of vegetative evapotranspiration in areas with no trees; air heating in the "urban canyons" between tall buildings; and a variety of other factors. Urban heat islands also increase emissions of air pollutants such as ozone, because the formation of many pollutants is accelerated as temperature increases (Taha 2015). Given the high rate of small urban and semi-urban farms and the close proximity to urban areas of many coastal farming operations such as nurseries, the urban heat island generated by developed San Diego will produce a relatively strong temperature shift in these urban-adjacent farms. Pushed by San Diego's offshore winds, the increased heat generated by urban heat islands has the potential to move east into rural areas and unincorporated towns, possibly raising temperatures there as well.

As both average temperatures and the frequency of heat events increase, energy demand will increase in the county, primarily in the form of increased cooling requirements. One study projects that, by 2050, energy demand will rise by more than 25% in southern regions of the United States, including Southern California (van Ruijven, De Cian, and Sue Wing 2019). The desire for increased cooling is not simply a matter of disliking being hot and sweaty. Extreme heat is the top weather-related killer in the US, and the main function of air conditioning is to reduce negative heat-related health outcomes. Coastal San Diegans are more vulnerable than inland residents to heat-related illnesses and deaths, primarily due to a lower community penetration of air conditioning, a disparity that is correlated with income, race, and homeownership (Guirguis et al. 2018).

PRECIPITATION AND DROUGHT

Southern California already has the highest year-to-year precipitation variability of anywhere in the continental United States (Dettinger et al. 2011), but models predict even greater variability, with wetter winters, drier springs and autumns, and both more numerous and more severe droughts. Precipitation may decrease in the Southwest by up to 25% (Prein et al. 2016). When it does occur, it will come in the form of extreme precipitation events of two or more inches of rain per day, the presence or absence of which drives 80% of year-to-year precipitation variability (Scripps Institution of Oceanography, UC San Diego 2018). Comparing previous 30-year climate normals to the updated normals released this year (NOAA National Centers for Environmental Information 2021b), projections estimate that up to a

10% decrease in precipitation has already occurred. While anomalies in the jetstream may increase the likelihood of an active summer monsoon season, the majority of these storms will be high-based thunderstorms that drop little precipitation but increase the risk of fire (Snodgrass 2021).

Due to drastically varying total precipitation, increased temperatures, and more frequent extreme precipitation events, there may be increased frequency and magnitude of catastrophic weather events like coastal storms, mudslides, and flash floods (Ascent Environmental, Inc. 2017). Flash floods are of particular concern to farmers in the inland valleys, since most agricultural soil in this area is steeply sloped and relatively poor, and all watersheds in San Diego County meet the National Weather Service's definition of flash flood susceptibility (Ascent Environmental, Inc. 2017). Steep areas that have burned in the previous fire season are far more susceptible to topsoil loss and mudslides when an extreme precipitation event occurs.

Although rainfall will grow more variable and total precipitation may increase in some years with an increase in extreme precipitation events (Mosase et al. 2019), overall water access is predicted to decrease as climate change continues. With increasing temperatures and reduced precipitation, both constructed and naturally occurring reservoirs (lakes and snow) are increasingly sensitive to changed inflow. Snow acts as a reservoir, delaying the release of water into the spring and early summer when agricultural demand begins to increase. As snowpack is both reduced in overall volume and melts earlier in the year, reservoirs with limited capacity can hold water for a reduced time before being forced to provide outflow regardless of demand. Winter runoff is therefore projected to increase and shift to earlier in the season, while spring and summer runoff is projected to decrease (Irrigation Training and Research Center Cal Poly 2003; California Department of Water Resources 2015).

The loss of this summer water will increase water demand pressure throughout the county, especially when coupled with a state of drought (California Department of Water Resources 2015). Even though an increasing proportion of the county's water comes from recycled and desalinated water (13% in 2020), the decreasing availability of water from the Colorado River (about 60%) and local surface water (14%) will result in a decreased water supply. Since San Diego County pumps little groundwater of its own (5% in 2020), and several of its groundwater basins are already critically overdrafted (California Department of Water Resources 2016), groundwater to supplement reduced irrigation water availability is not an option in San Diego County to the same extent that it is in the San Joaquin Valley.

WILDFIRE

Higher temperatures, drier summers and autumns, a reduction in moisture delivered by jetstream winds, and longer periods of more severe drought all contribute to reduced moisture content of plants and soils. Wildfire has a historic presence in California ecosystems. However, as the climate in Southern California warms and dries, fires will increase in severity, acreage, and risk to human life, health, and property (Higuera and Abatzoglou 2021). The highest fire threat in San Diego County occurs in the central third of the county, where housing stock is medium- to low-density; the most common vegetation type is drought-deciduous chaparral, which dries out in the summer and fall; and the developed-rural interface is much more common than in the more populated coastal areas (Syphard et al. 2012). Fire recurrence also may be increased by a precipitation regime with sharper seasonality: after a wet winter and a much hotter, drier summer, the dramatically increased biomass produced during the late winter-spring growing season dries out rapidly and provides an increased fuel load (Swain 2021). Rapid fire spread, resistance to suppression, and escalated burned area are all strongly tied to fuel aridity, which is increased by atmospheric vapor pressure deficit as a direct result of climate change (Abatzoglou and Williams 2016; A. P. Williams et al. 2019).

A climate regime change may change the seasonality and force of northeasterly Santa Ana winds, which frequently drive California's most destructive wildfires (Scripps Institution of Oceanography, UC San Diego 2018). Santa Ana winds are characterized by adiabatic compression, in which a dry wind blowing down across a mountain range is compressed due to air pressure and reduces humidity at the base (Snodgrass 2021). Along with the extreme heat events that Santa Ana conditions often bring (Scripps Institution of Oceanography, UC San Diego 2018), this pattern dries out drought-impacted vegetation even further and can fan or spread the flames of anthropogenic or lightning-caused fires. One study has predicted that Santa Ana winds will begin later in the year and end earlier, but will not grow any weaker, which may contribute to a later and more intense fire season (Guzman-Morales and Gershunov 2019).

A growing wildfire regime also increases the amount and proportion of wildfire-generated organic aerosols in the western US. As urban air pollution declines, wildfire air pollution will grow in importance as an environmental hazard. Increased exposure to wildfire smoke causes higher rates of respiratory ailments, such as asthma, decreased lung function, chronic obstructive pulmonary disease, and many others. Children are among the worst affected by respiratory issues post-fire, especially children younger than 6; emergency room and urgent care visits to a San Diego children's hospital increased significantly during and immediately following several recent fires (Leibel 2019). These negative health outcomes can persist in populations years after the initial smoke exposure (Reid and Maestas 2019).

PESTS AND WEEDS

Outbreaks of arthropod pests (insects and mites) may increase in both frequency and severity as temperatures rise year-round. Insect life cycles and metabolisms are closely linked to temperature, with higher temperatures generally producing more activity and greater reproduction until a "dropping off" point, at which insects overheat and die. Pests may emerge earlier in the season and persist longer into the fall due to warmer temperatures in the "shoulder seasons," or seasons when insect activity is not at its peak. Other pests that are controlled by killing frosts, or those whose outbreaks are correlated with changing temperature, will be at a greater advantage in warmer winters, since their populations will be able to reproduce without threat of frost (Pathak et al. 2018; Daugherty 2021). Elevated temperatures and atmospheric CO_2 enrichment have been shown to reduce insecticide efficacy by accelerating insect metabolism or increasing the speed of pesticide detoxification in treated plants (Matzrafi 2019). Pests may be able to expand into new, formerly inhospitable areas, too. Range shifts in insect pests and crop pathogens have already been documented: since 1960, the ranges of hundreds of pest species have shifted poleward at an average speed of 3 kilometers a year (Bebber, Ramotowski, and Gurr 2013).

Because most agricultural pests are herbivorous, they are highly sensitive to plant quality, and plant-mediated effects such as the absorption of increased atmospheric CO_2 can cause leaves to become more palatable to insect depredation (Daugherty 2021). Drought stress, too, can weaken plants and make them more susceptible to potential attack. One dramatic example is the losses that western coniferous forests in the US have suffered due to bark beetles; the beetles preferentially attack drought-weakened trees and their infestations can cause landscape-wide mortality (Bentz et al. 2010). Plants in historically unsuitable pest ranges (i.e., plants that have not evolved defenses to those pests) are more susceptible when the pests' climate-driven range expansion brings them under threat (Cudmore et al. 2010). However, while the majority of insect pests in one evaluation showed climate responses that indicated increased pest damage, many pest species responded consistently with a mixed or decreased level of pest damage (Lehmann et al. 2020). This uncertainty about the potential future prevalence and severity of pest outbreaks, along with both anticipated and already occurring range shifts, will require an increase in monitoring activities and a reevaluation of treatment timings and applications. What worked in the previous seasonal reproductive cycle may not work in the future. An increasing application of integrated pest management (IPM) practices (holistic, multi-avenue, monitoring- and threshold-based pest control) will likely become necessary as traditional schedules and protocols of chemical control lose their effectiveness (Ehler 2006).

Vertebrate pests (rats, mice, ground squirrels, and other rodents) also may experience increased populations or severity of outbreaks. Many cities and jurisdictions are already receiving increased rodent complaints and requests for rodent vector control, primarily as a result of warming winter temperatures (Atkin 2017). Warmer winters allow rodent populations to climb throughout the year; normally, winter acts as a "rodent reset" when food supplies are scarce and animals are not breeding (Taitt 1981; Hansson and Henttonen 1988). Along with the immediate concern of rodent damage to crops and property, outbreaks can be a major human health concern as a potential vector for zoonotic disease transfer and as a source of fires from gnawed electrical equipment (Witmer and Proulx 2010). As extreme weather events increase in frequency and unpredictability, rodent populations can be expected to surge immediately following any such event. The relationship between agricultural rodent outbreaks and extreme weather is well documented in other parts of the world (Singleton 2010; Singleton et al. 2010; Htwe, Singleton, and Nelson 2013), but little information is available for Southern Californian rodent-weather relationships (Quinn 2021), particularly not for wildfire, our most common extreme weather event. On the management end, pesticidal or cultural control of rodents is rarely "one-size-fits-all." California restrictions on allowable baits, traps, and rodenticides are stringent, in order to avoid bykill of endangered rodents, domesticated animals, and humans (Quinn 2021). For more information on vertebrate pests in Southern California, visit www.ucSCURRI.com.

Weed assemblages may change over time, particularly in a hotter and drier scenario, but changes in the precipitation regime will result in more sudden effects on the corresponding patterns of weed growth, spread, and reproduction (Patterson 1995). Maintaining a consistent weeding protocol during drought years, if not intensifying it, is crucial to reduce weed populations and prevent explosions in wet years. During droughts, most native plants fail to set seed; therefore, weeds will be the only contributors to the seed bank during a drought, and an area that is poorly weeded can become a weed hotspot when the rain returns (McDonald 2021). As more crop irrigation is required over a longer season to offset hotter and drier conditions, the weed season may grow longer; in a non-irrigated San Diego, weeds mainly grow in the wet winter and early spring and dry out in the summer, just like other plants. Species new to this area may also extend their ranges or gain a greater foothold as the climate grows drier. Southern California hosts a wide variety of drought-tolerant weeds, such as mustards, spurges, grasses, thistles, knapweeds, tumbleweeds, and more, and a drier climate makes these species more competitive against less drought-tolerant crops and native plants (McDonald 2021).

Higher temperatures may also increase weed resistance to some herbicides, due in part to elevated weed metabolism of the active agents (Matzrafi et al. 2016; Jugulam et al. 2018). These changes in weed metabolism and physiology, in concert with the changing weed establishment and demography linked to increased CO_2

concentrations (Ziska 2016), could dramatically alter weed suites in the region; herbicides may decline in effectiveness, while changes in seasonal patterns or community species compositions could require new protocols altogether. Land managers and weed control specialists will need to adapt the spatial, temporal, choice of method, and precipitation-linked aspects of their weed treatment protocols in order to address these changes. Unfortunately, a majority of currently published weed research is devoted to chemical control, despite the rapid evolution and spread of herbicide-resistant weeds (Harker and O'Donovan 2013). The field of integrated weed management (IWM), similar to IPM but somewhat less developed and researched as a practice, will grow increasingly important to prioritize in research and in the field.

V. CLIMATE-RESILIENT FARMING PRACTICES

With many changes in climate already in effect, in addition to hotter temperatures, precipitation decrease and variability, and other changes projected to occur over the next 30 years, San Diego growers will be faced with an increasing challenge to maintain production, profitability, and sustainability. To achieve these goals, one methodology that growers can practice is climate-resilient farming. We define climate-resilient farming practices as those that either make farms more resilient to climate change (for example, by increasing irrigation efficiency and thereby reducing water demand in a hotter, drier landscape) or mitigate climate change itself (by sequestering carbon or reducing energy usage). A few major focus areas for San Diego County growers are discussed below.

WATER EFFICIENCY AND IRRIGATION MANAGEMENT

The 2012-2016 drought caused severe water shortages throughout California. These critical shortages motivated state government, water agencies, and the agricultural industry to prepare more urgently for climate change impacts, including passing water conservation legislation, mandating severe reductions in urban usage, and fallowing land or cutting down fruit and nut trees that heavily consume water (UC Davis Center for Watershed Sciences 2014; Lund et al. 2018).

Some of these drought responses, like decreasing water wastage and increasing accounting and transparency in water systems, are unquestionably good practices. However, some, like fallowing fields and orchards, have had unintended consequences beyond the loss of revenue in terms of meeting GHG emission reduction goals. From 2005 to 2015, 25% of orchard trees (approximately 1 million trees) were removed from San Diego County farms due to increased water costs (Batra Ecological Strategies 2018). A single mature tree can sequester 48 lb of CO_2 every year. The loss of these trees from San Diego farms has prevented the sequestration of 300,000 metric tons of CO_2 emissions over the last decade, the equivalent of an additional 64,000 cars on the road for one year (US EPA 2015). Furthermore, fallowing or abandoning orchards in Mediterranean climates can increase the risk of wildfire by increasing fuel load and discontinuing landscape irrigation (Duarte et al. 2008; Ascoli et al. 2021).

Therefore, while it is both important and achievable to reduce water usage in agricultural contexts, retaining some amount of the normal farm landscape productivity is equally important for its carbon sequestration potential alone (USDA Natural Resources Conservation Service 2016), let alone the economic and food-system impact of agricultural land loss. Although agriculture in San Diego County uses a relatively small fraction of net water availability in the region (Hanak et al. 2011) and both urban and agricultural water usage per capita have fallen over 20% statewide in the past two decades (Public Policy Institute of California Water Policy Center 2019), total Southern California water usage still vastly outstrips availability. Therefore, any efficiency that can be achieved in a still-functioning agricultural landscape is a net positive.

The most important factor in increasing irrigation efficiency is understanding where and when irrigation water is currently applied in a given system, plus the amount of water that crops actually need. A suite of basic knowledge (soil water retention capacity, crop sensitivity to drought stress, effective precipitation and irrigation received, and available soil moisture content) and specialized knowledge (daily changes in crop water use due to varying evapotranspiration rates) is required in order to calibrate irrigation amounts correctly (Montazar 2021). Measuring soil moisture on the spot using moisture sensors is one reliable way to monitor soil water content and receive reliable information about whether and when to irrigate. However, both sensor placement and accuracy can affect irrigation efficiency: unless soil moisture sensors are installed in appropriate places and their data is reliably checked, the amount of water that crops in different sections are actually receiving is unknown (Soulis, Elmaloglou, and Dercas 2015; Spinelli 2021). The crop and substrate can also affect moisture sensor effectiveness. San Diego's ornamental plant industry frequently uses soilless organic substrate to grow plants, which requires a different type of moisture sensor. Containers also can be weighed with simple scales at regular intervals to measure their gravimetric water content. Crop evapotranspiration (ET) models coupled with weather-based reference ET systems are another method for scheduling irrigation events, but one that requires specific information about crop type, growing phase, and access to reference ET data. Any of these models can be used separately or together to drive irrigation scheduling decisions.

The first step in improving irrigation efficiency is an irrigation system audit. According to Spinelli (2021), this entails establishing irrigation blocks equivalent in area to standardize flowrate, and ensuring that water pressure in different blocks is the same; this is necessary because pressure changes cause flowrate changes, which result in different amounts of water being applied over time. Then, it is necessary to evaluate crop ET using the appropriate crop coefficient (K_c) and data from the California Irrigation Management Information System (CIMIS), and to apply water in appropriate quantities based on current conditions. To drive irrigation scheduling decisions over time, the practice of irrigation system auditing requires continuous monitoring of pressure in order to evaluate distribution uniformity and soil moisture sensors.

An irrigation system may be set up to irrigate different fields at a nominally equal rate, but several issues can cause poor distribution uniformity and decrease overall irrigation efficiency. These issues include differences in pressure in the irrigation system, plugged emitters, leaks, and irrigation system drainage. Good solutions for improving and maintaining distribution uniformity include correct irrigation system design, pressure regulators, pressure-compensating emitters, and irrigation system maintenance. Even the simple technique of a dozen buckets placed at irrigation outlets to measure total flowrate over time can increase understanding of irrigation delivery and distribution uniformity. When producers are familiar with monitoring CIMIS and weather data to control irrigation, further climate-resilient practices are within reach, such as preemptive irrigation and above-canopy irrigation to mitigate orchard damage from heat events (Faber 2021).

The majority of these complex irrigation system controls can be performed only when an irrigation system is the major water delivery method. Controlling the relative amount of water applied is much more challenging when hand watering. Hand watering is a popular watering method for many San Diego floriculturists, despite its subjective and often uneven delivery of water (Spinelli pers. comm.). As many as 20 years ago, a study examining economies of scale in the greenhouse floriculture industry asserted: "A producer who hand-waters a large percentage of its crops has not adopted some of the latest technology available in automated watering systems. Furthermore, a grower who hand-waters a large percentage of production area has a different cost configuration than a grower who predominantly uses an automated watering system" (Schumacher and Marsh 2002). Overhead irrigation, while providing more consistent water delivery than hand watering and less labor than drip watering (Mitchell et al. 2016), requires a strict scheduling system based on day-by-day familiarity with crop evapotranspiration in order to achieve water efficiencies greater than drip while maintaining plant quality (Grant et al. 2009; Warsaw et al. 2009). Evapotranspiration data is highly crop-dependent and, when used to determine a watering schedule, requires that irrigation blocks be established to reduce over- or underwatering an adjacent crop with a different rate of evapotranspiration. On the other hand, efficient drip irrigation also requires the same use of water-demand-based scheduling using evapotranspiration, so this requirement is not unique to overhead irrigation.

Micro-irrigation systems such as drip lines, bubblers, and micro-sprinklers can conserve water by delivering it close to plant roots, reducing evaporation and maximizing plant uptake. Tomatoes grown with daily drip fertigation (combining fertilizer with irrigation) produced a 40 to 50% greater crop compared to plants with either fertigation every other day or hand-watering with fertilizer applied before planting (Nut, Seng, and Mihara 2017). In Borrego Springs, a citrus grower reported a reduction from 9 to 6 acre-feet of water when switching from flood irrigation to drip irrigation, along with added mulch to increase soil moisture retention (Nagappan 2019). One common misconception about drip irrigation is that, similarly to standard sprinkler irrigation, daytime or afternoon irrigation during the heat of the day should be avoided. On the contrary, daytime and afternoon drip irrigation showed no change in water loss or efficiency when delivered at depths greater than 6 inches, and actually increased soil moisture content over the next 72 hours when delivered at shallow depths (0 to 6 inches) compared to early-morning or night irrigation (Adams and Zeleke 2017).

Installing a drip system in a container-grown floriculture system, where containers of different species are constantly being added and removed as ornamentals mature, is certainly more challenging than installing the same in an orchard, where the same plants are located in the same spots from year to year. However, transitioning to a drip system has the potential to save not only irrigation water and the cost of hand labor, but also applied fertilizer, which can be delivered more efficiently through fertigation than through either surface application or hand watering (Dole, Cole, and Broembsen 1994; Nut, Seng, and Mihara 2017). In addition, improving irrigation efficiency reduces not only water use but energy use. Irrigation pumps can be a source of energy drain, using up to 30% excess fuel if they are not properly sized, adjusted, and maintained (Kansas State University Agricultural Experiment Station and Cooperative Extension Service 2006). Because irrigation pumps make up such a high proportion of San Diego agriculture energy consumption overall (Navigant Consulting 2013), reducing the amount of water that needs to be pumped is a net savings on both water and electricity expenses.

Another water conservation measure is deficit irrigation, in which less water is applied than the plant needs for full development. Many crops can tolerate deficit irrigation without reducing yield. This practice requires technical knowledge of the crop's drought tolerance, when and to what extent deficit irrigation can be applied, and how to treat any diseases or damage to which the crop might be subject when stressed (Oregon State University Extension Service 2013). Armed with this knowledge, deficit irrigation can be highly effective in reducing water usage. Many crops are tolerant to some drought stress (Goldhamer, Viveros, and Salinas 2006; Doll and Shackel 2015), including many ornamentals (Shober et al. 2009; Nazemi Rafi, Kazemi, and Tehranifar 2019). Almond trees experience little reduction in crop quality upon application of moderate drought stress, especially when timed correctly (Nanos et al. 2002; Goldhamer, Viveros, and Salinas 2006; Doll and Shackel 2015). In fact, drought-stressed citrus and avocado were visited by fewer glassy-winged sharpshooters (*Homalodisca vitripennis*), and suffered less feeding damage from this pest, compared to adequately irrigated plants of the same species (Nadel et al. 2008). This suggests that moderate deficit irrigation can even decrease a crop's attractiveness to pests in some cases.

Avocado trees are a thirsty crop that is common in San Diego County. One acre of avocadoes consumes 4 acre-feet of water per year (Stemke 2016). Nonetheless, avocado trees tolerate deficit irrigation and high-density planting to conserve water. One planting density and pruning study showed not only a much higher yield per acre, but less water use (Village News 2017; Takele, Stewart, and Sumner 2020). One avocado farmer uses CIMIS data to improve the accuracy of irrigation quantity and timing. He has also planted trees more densely and limited tree height in order to cut down on water use (Gong 2019).

Some growers in other regions have experimented with using brackish or other alternative water sources in ornamental crop irrigation to reduce the use of potable freshwater (Grieve 2011; Villarino and Mattson 2011; Cassaniti et al. 2013). Plants can be sensitive to inorganic salt exposure, frequently responding with symptoms of mineral deficiency and reduced and/or smaller flowers and foliage. However, in one study, most ornamental species did not noticeably suffer in appearance and health with a small to moderate increase in salinity; the most significant response across the spectrum of species studied was stunting in height (Grieve 2011). Shorter stems might be desirable for floriculture targeting the cut-flower market, since excessive stem length is a negative trait in many cut-flower crops. Engaging in this water-saving strategy requires selection of crops that are salt-tolerant and drought-tolerant, since many common ornamental species differ significantly in the amount of salt they will tolerate while remaining marketable (Niu and Cabrera 2010; Villarino and Mattson 2011). Conversely, avocado is highly sensitive to salinity, especially when caused by chloride ions, and is not a good candidate for brackish-water irrigation (Carr 2013). For more information on managing salinity in crops irrigated with recycled or reclaimed water, visit www.socalsalinity.org.

One analysis of production costs and emissions in Ventura County suggested that switching the irrigation water source from conventional sources (groundwater and surface) to recycled or desalinated sources would increase the lifetime GHG emissions of several specialty crops, including avocado (Bell, Stokes-Draut, and Horvath 2018). This is primarily due to the increased energy required to desalinate and treat brackish water sources. In addition, because treated water requires a greater investment of time and energy in its production and is therefore more expensive than untreated sources, its intensive use may not be financially viable for growers.

Finally, controlling agricultural runoff is a legal requirement in California (State Water Resources Control Board 2019). One practice to satisfy this requirement is establishing a catchment or retention basin to prevent nitrogen-rich irrigation water from penetrating the water table. Water capture in a catchment basin also allows its reuse, further saving irrigation water. However, this presents a co-management issue between food safety and environmental sustainability: requirements to reduce groundwater contamination are in conflict with requirements to reduce public exposure to foodborne illness, particularly with products that are normally eaten raw like lettuces and herbs (UC Davis Food Safety 2012). These stringent and often contradictory requirements can be challenging for growers to achieve, and a high level of support and collaboration is necessary among growers, food safety programs and audits, and sustainability agencies to ensure that all objectives are being achieved without sacrificing one for the other.

ENERGY EFFICIENCY AND RENEWABLE ENERGY

As in California as a whole, San Diego County's energy efficiency goals are some of the most rigorous in the country. The county is currently targeting two major strategies to reduce energy-based emissions: increase building energy efficiency, and increase renewable electricity use. (The county's latest Climate Action Plan has been retracted due to a court finding that it failed to conform with CEQA regulations (Coon 2018; San Diego County Board of Supervisors 2020). According to the county website, the new plan has an anticipated release date of 2023. All statements about county goals are based on the previous Climate Action Plan, since the court ruling did not find fault with its 26 GHG reduction measures.)

Many growers are unsure of how much energy their operation consumes and have estimated energy usage by anecdotal observation, rather than by well-supported cost accounting data (Navigant Consulting 2013). In a series of communication forums held among small growers in Southern California, many growers mentioned that a lack of specialized knowledge and financial and technical support from utilities, policymakers, and others were a major roadblock in implementing alternative energy programs (Fissore, Duran, and Russell 2015). A farm-level energy efficiency audit is the first step. Many other states have such audit programs, normally run by that state's extension service (AEP Ohio 2021; Colorado Energy Office 2021). In the case of San Diego, the federal Natural Resources Conservation Service (NRCS) performs audits to help growers develop an agricultural energy management plan.

Increasing energy efficiency and use reduction in controlled-environment operations is a more complex proposition than doing so in in-field or container production. Controlled environments have similar opportunities for energy efficiency when it comes to irrigation systems and farm equipment replacement (discussed below), but added to these energy concerns are lighting, heating, and cooling. Costs may vary dramatically between different controlled-environment production processes. For example, heated/lighted vs. unheated/unlighted greenhouses, cooling sheds and forced-air cooling for specialty crops and cut flowers, and requirements for hydroponic operations can take up a large proportion of on-farm energy use, while significantly varying in the expected amount of energy consumed (Darras 2020). Efficiencies can certainly be obtained in these systems (Beard 2019), since individual operations can vary by up to six times in their cooling per unit of energy expended (Thompson et al. 2010).

By contrast to these systemic management challenges, there are two specific types of equipment that can be adapted to reduce energy. As mentioned in the section on water efficiency and irrigation management, irrigation pumps can be a major area for energy efficiency improvement. Energy efficiency audits by the National Center for Appropriate Technology between 1988 and 2006 revealed that the vast majority of operators have at least one opportunity for irrigation equipment change or repair that would quickly pay for itself in energy savings alone (Morris and Lynne 2006). Often, these fixes are as simple as replacing a poorly sized or worn-out pump, or one that is too powerful or too weak for the discharge conditions required (Kansas State University Agricultural Experiment Station and Cooperative Extension Service 2006). When a correctly sized and adjusted pump is installed, operators can achieve equal or greater water delivery with fewer hours of total irrigation, saving both water and energy. Performing regular maintenance, such as renewing filters to keep trash from entering pump intakes and ensuring that pipes are not clogged with plant debris or soil, is also a highly energy-efficient practice (Montazar 2021).

Another sustainable-energy avenue encouraged in the county's Climate Action Plan is the replacement of gas-powered heavy farm equipment with electric-powered versions of the equipment, such as tractors and stationary irrigation pumps (San Diego County Climate Action Plan 2020). As noted above, farm equipment accounted for about 52% of agricultural-sector GHG emissions in 2014. As San Diego continues its transition toward renewable energy, replacing equipment that still uses fossil fuels with equipment run on renewable electricity will result in lower GHG emissions overall.

The transition to renewable energy continues throughout all sectors in California, including in agriculture. In just five years (2012 to 2017), renewable energy-producing system adoption almost tripled on California farms, primarily through solar panel installation (USDA National Agricultural Statistics Service 2019e). The rate of renewable energy adoption was even higher on San Diego farms across the same time period; over 95% of renewable energy production systems currently installed on San Diego farms are solar panels. This shift represents a transition toward not only renewable energy, but on-grid energy production. In 1995, 68% of solar energy was generated in relatively small off-grid systems for smaller tasks like watering livestock, charging electric fences, and lighting buildings. Just 13 years later, the same proportion of solar energy was generated by utility-tied on-grid systems for a much wider suite of residential, commercial, industrial, and irrigation uses (USDA Office of the Chief Economist 2011).

The relative size of renewable energy production systems can vary greatly (for example, just a few photovoltaic arrays rather than a large solar farm), enabling smaller operations with lower production values to adopt a cost-effective system without expending an unsustainable amount of capital. Beckman and Xiarchos (2013) found that, for California farmers, adopting an on-farm renewable energy production system is dependent not on the farm's acreage or total production value, but rather on electricity price, possession of an Internet connection, and environmental practices already being used on a given farm. Therefore, the main hurdle for renewable energy production adoption on California farms is farmer awareness and motivation rather than absolute economic infeasibility. The average on-farm renewable energy production system operating in California had 40-50% of its installation cost funded by outside sources (USDA National Agricultural Statistics Service 2011), which may imply that farmers see renewable energy installation as a sensible economic decision when bolstered by funding. On the other hand, it may also imply that installing renewable energy is not feasible for producers without grants, energy programs, or other financial assistance.

Installing photovoltaic systems on farms can help stabilize energy costs, delay the construction of infrastructure improvements for electric grid systems, and decrease pollution and GHG emissions from equipment run on fossil fuels (American Council for an Energy-Efficient Economy 2005). However, before converting land to solar energy generation, operators should carefully consider location, cost, and alternative uses. Opinions are mixed on the conversion of food-producing agricultural land to energy generation, particularly at the large scale required for “solar farms” (Heiniger 2015; Boyce 2019; Shemkus 2019; Carroll 2020).

However, at the relatively small scale required to fulfill the needs of most San Diego farms, very little land is needed, and solar arrays can be installed cost-effectively on preexisting roofs (USDA Office of the Chief Economist 2011). Additionally, California’s Net Energy Metering Aggregation program can significantly reduce payoff time on solar array installation expenses. The program allows multiple meters to be charged to a single meter on the property, providing greater flexibility in panel site choice and allowing the maximum amount of energy produced to be credited against the utility (California Climate & Agriculture Network 2015). A recent proposal by the California Public Utilities Commission, called Net Energy Metering (NEM) 3.0, would reduce payments by utility companies to rooftop solar owners for their solar-generated energy and instate a “grid participation charge” of $8 per kW solar capacity for homes with solar panels installed (Roth 2021; Kennedy 2022). As of June 2022, the public comment period on NEM 3.0 has closed, and a potential decision is expected by the beginning of 2023.

In contrast to the popularity of solar energy, wind farms as a source of renewable energy have been an embattled issue in San Diego County’s tribal history. Several wind farm project proposals have been in the works for years. The Campo Wind Project, proposed in 2009 (Campo Kumeyaay Nation 2009; North American Windpower 2009), was subject to petition for a revote in February 2020 (Raftery 2020) and finalized through a federal record of decision in April 2020 (Bureau of Indian Affairs Pacific Regional Office 2020). An environmental impact suit challenging the Ewiiaapaayp Band of Kumeyaay Indians’ lease of tribal land to a wind-energy company was thrown out of federal court in 2017 (Sommer 2018). The potential role of wind as a renewable energy source in San Diego County remains uncertain.

SOIL INVESTMENT

The term "soil investment" refers to any practice that increases the health and carbon content of soil, including adding organic material such as compost and mulch, reducing emissions from conventional practices like fertilizer application, and increasing carbon sequestration in both the soil and living vegetation. Carbon sequestration is defined in agriculture as the ability of agricultural lands to remove CO_2 from the atmosphere through photosynthesis and store it as biomass carbon in above-ground growth, roots, and soils (Schahczenski and Hill 2009). A network of related concepts that focus on increased soil investment include "carbon farming," "climate-smart agriculture," "regenerative agriculture," and many other farming practices or methodologies (UC Cooperative Extension San Diego County 2019). Organic farms must also engage in specific soil investment practices that, depending on the certifying body, may be required for organic accreditation (San Diego County Department of Agriculture Weights and Measures 2018). What all these practices have in common is the ability to build soil health, reduce GHG emissions, and increase the long-term sustainability of our food systems (UC Cooperative Extension San Diego County 2019).

Improving soil health has a wide variety of benefits for both the farmer and the greater community and ecosystem (Toensmeier 2016; Rhodes 2017). Healthy soils farmed using organic or regenerative practices can hold more water, increase water percolation, cleanse runoff, and increase tolerance to drought and flooding; sequester carbon at greater depths; contribute to greater fertility, yields, and plant health; and give plants greater capability to resist pests, reducing expenditure on both soil amendments and pesticides (Altieri and Nicholls 2003; Blundell et al. 2020). Some conventional farming practices can harm soil health by compacting wet soils, such as use of heavy equipment for tilling, pesticide spraying, and fertilizing (Magdoff and Van Es 2009), so reducing disturbance to soils is one major benefit of organic, regenerative, and carbon farming practices.

The most common forms of soil investment are compost and mulch application. Compost increases carbon sequestration in soil, increases soil organic matter content, reduces emissions from landfills and burning of green waste (Favoino and Hogg 2008), and acts as an organic nutrient supplement that may reduce the use of chemical fertilizers. (The nutrient contents of some composts are too low and may not provide enough nutrients to plants.) A single one-time addition of ¼ inch of compost to a rangeland plot in Santa Ysabel resulted in a maximum GHG reduction of 5.9 Mg CO_2 equivalent (CO_2e) per hectare—the equivalent of about 15,000 miles driven in a typical passenger vehicle. The treatment increased plant productivity up to 200% and should continue to sequester carbon for up to 75 years (Scripps Institution of Oceanography, UC San Diego 2018). Compost can also improve water quality by reducing erosion, leaching, and runoff losses, particularly on damaged soils such as post-construction scraped surfaces or those that have been burned (Crohn 2010). An application of compost on damaged soil reduced runoff water volumes by 80%, and in the remaining runoff water reduced sediments, total dissolved solids, and nitrates by 65 to 95% (Crohn et al. 2011).

Mulch application in citrus and avocado at an appropriate depth reduces root fungus, encourages healthy root systems, and suppresses weeds (Faber et al. 2001). It also conserves moisture and moderates soil temperature in all crops, both crucial goals as the San Diego climate warms and precipitation grows increasingly erratic. Both organic materials (straw, wood chips, chipped green waste) and inorganic substances (plastic, rubber, landscape fabric) are frequently used to mulch for a variety of objectives. However, organic materials should be used in order to obtain most of the soil health benefits, such as supporting beneficial bacteria and mycorrhizae (Rios 2021).

Reduced tillage, another healthy soil practice, helps mitigate the release of soil carbon into the atmosphere by reducing soil disturbance (Schahczenski and Hill 2009). Low- or no-till also reduces the total amount of fuel used by heavy equipment. Rotational grazing is a management-intensive grazing style that helps reduce tillage on rangelands and encourages plant productivity by redistributing carbon in the form of grazing stock manure (Kane 2015). Unfortunately, many low- or no-till systems rely on herbicides and pesticides to meet some of the needs that tillage often does (Roberts and Lighthall 1993). Avoiding this tit-for-tat approach requires a more holistic planning of IPM and weed control practices, some of which can be addressed through mulch application, as discussed earlier.

Cover crops assist with soil health by sequestering carbon in their biomass, preventing erosion or soil drying during droughts, and adding nutrients to the soil upon their eventual termination (Conservation Technology Information Center 2020). In this way, soil is protected and enriched when the cash-crop growing season is over, increasing its long-term health. Additional benefits of cover crops include more organic matter in soils, less soil erosion, weed management, and soil compaction reduction (Conservation Technology Information Center 2020). Horticulture operations that grow fruits, nuts, and specialty vegetables can benefit from cover crops; almost 20% of respondents to a cover-crop survey reported using cover crops on their horticultural lands, primarily for weed management and improved soil health (Conservation Technology Information Center 2020).

Cover crops can also be used to manage soil nitrogen and maintain nutrient balance (Clark 2012). Legume cover crops add plant-available nitrogen without phosphorus or potassium, while cereal cover crops take up residual nitrate-N that might otherwise leach to groundwater (Sullivan, Andrews, and Brewer 2020).

Finally, cover crops can be selected and managed to boost insect populations of both pollinators and beneficial pest-predators, improving yields and reducing the need for pesticides (Clark 2012; Lee-Mader et al. 2015). While cover crops present an added expense in seed purchase, irrigation expense, and labor (UC Cooperative Extension Santa Cruz County 2003), proponents argue that cover crops should be viewed not as a cost but as an investment in long-term soil health that pays back over time, and that cover crops do not reduce profits when all the benefits they provide are considered (Chen and Clark 2019; Conservation Technology Information Center 2020). On the other hand, many growers in the San Diego region farm on land held with short-term leases (Lobo et al. 2018) and may be reluctant to invest time and money into a long-term soil health practice whose benefits they may not see over the life of their lease.

Soil investment practices have been shown to provide both greater ecosystem services and greater profitability to farmers in a variety of systems. In one study, regeneratively farmed fields had 29% lower corn production but 78% higher profits when compared with conventionally farmed corn, primarily due to reduced expenditures on fertilizer and irrigation, increased livestock weight gain due to grazing controls, and an organic price premium in the marketplace. In addition, pests were 10 times more abundant in insecticide-treated fields than in insecticide-free regeneratively farmed fields, suggesting that pest-resilient food systems controlled through integrated pest management practices outperform conventional pest control (LaCanne and Lundgren 2018).

Conversely, ornamental production operations have fewer opportunities to directly increase carbon sequestration onsite, with relatively little sequestration occurring in container-grown production (Nicese and Lazzerini 2013; Lazzerini, Lucchetti, and Nicese 2016; Álvarez de la Puente et al. 2018). Most sequestration potential is found in the field-grown production and post-purchase installation of woody trees and shrubs (Marble et al. 2011). Nonetheless, opportunities exist for carbon sequestration in floriculture. One practice currently being studied is the use of biochar as a replacement or supplemental container medium for peat. Biochar is charcoal produced by burning plant biomass at low temperatures in oxygen-free environments, which produces a carbon-rich solid that can remain stable in soil for thousands of years (Galinato, Yoder, and Granatstein 2011). When added at a ratio of 25 to 50% with peat, pelleted biochar not only reduces media degradation and increases its longevity, but increases total plant growth and provides greater water availability to plants, especially in low-water or drought conditions (Dumroese et al. 2011; Tian et al. 2012). Care should be taken that biochar is appropriately sourced, as residues from an olive mill and hydrocharred (biochar with the addition of water) forest waste underperformed when compared to standard biochar forest waste (Fornes and Belda 2018). Little work has been done to evaluate the economic feasibility of biochar, particularly in mostly unforested regions like Southern California.

Several high-sequestration practices such as composting and mulching are already being performed in San Diego County, since so much of the county's edible agriculture focuses on orchard horticulture, but significant opportunity exists to increase carbon sequestration in San Diego agricultural landscapes (Batra Ecological Strategies 2018). It is estimated that, if 25% of riparian areas in the unincorporated county were restored, and all the county's current green waste were composted and applied to crop and rangelands, these two practices alone could deliver about a quarter of the county's total required GHG reduction (Scripps Institution of Oceanography, UC San Diego 2018). The Carbon Sink Demonstration Farm, a farming partnership founded in 2017 between Solidarity Farm and the Pauma Band of Luiseño Indians, is a demonstration farm that displays the potential of soil carbon sequestration practices that can be performed as a practical part of San Diego County sustainable agriculture. Using a variety of soil investment practices covered in this section including cover cropping, no-till, compost and mulch, perennial crop transition, and more, the farm's soil drew down almost 600 metric tons of carbon dioxide in 2020, about as much as 80 US households emitted in that same time (Lorwood 2021). Since many crops studied in typical carbon sequestration practice studies are not common crops in the San Diego region (e.g., corn, soybeans), local demonstrations of practical carbon sequestration measures on common area crops are vital.

When multiple soil health practices are combined in the same landscape, soil depths of carbon storage increase significantly compared to any one practice; some practices when performed alone actually decreased carbon sequestration in deeper soil levels (Tautges et al. 2019). Synergy of multiple soil investment practices can be much more powerful and both deep- and wide-ranging than any practice performed in isolation. One study found that cover crops and composting contribute different inputs of soil organic carbon (SOC), frequently altering the composition of SOC compared to the use of a single practice (White et al. 2020).

DIVERSIFICATION OF CROPS

Most crops grown in San Diego do not require chill hours, so selecting warmer-winter fruit and nut tree varieties is not as immediate a concern for San Diego growers as it is to California farmers as a whole (Lee and Sumner 2016). Yet, crop diversification can be a tool to help growers increase resilience to climate change. Any ecosystem that includes greater diversity also builds in greater resilience, since the seeming redundancy of similar crops or functional roles may become important when some environmental change occurs (Lin 2011). For example, a farm with only one major cultivar of one crop will suffer when that cultivar turns out to be vulnerable to an emerging pest or sudden heat wave, while a farm with several varieties of the same crop and several different crops to rely on may not be as badly affected by that same challenge.

Many adaptive tools of crop diversification in our region will involve water. One such tool is the selection of drought-tolerant and salt-tolerant varieties as both precipitation and irrigation water grow more scarce (Elias et al. 2018). Increasing crop diversity can also improve soil health, a climate resilience practice mentioned earlier. More diverse crop rotations consistently have higher soil carbon and soil microbial biomass than less diverse systems, due to the different carbon compounds that different types of crops contribute to the soil structure (McDaniel, Tiemann, and Grandy 2014; Kane 2015).

One challenge to crop diversification is the existing structure of economic incentives that support intensive monocultures. Diversified and less intensively farmed land has many benefits, including suffering less erosion, experiencing lower economic losses from natural disasters, and improving soil C balance (Lin 2011; Martínez-Mena et al. 2021). However, land in San Diego County is so expensive that growers must extract every cent of value per acre in order to stay in business. Diversification by choosing several crops and varieties, some of which may be less profitable per acre, rather than the one most profitable crop, may reduce the ability of growers to maintain a sustainable business. Furthermore, crop cultivars tolerant of various environmental conditions by their very nature require different environmental conditions to thrive. If growers do not tailor their irrigation, soil management, pest management, etc., practices to the requirements of individual cultivars, the benefits of diversified cropping may not be realized.

On the other hand, diversification has been shown to result in many economic benefits, primarily in pest suppression, disease suppression, and in some cases increased production (Lin 2011; Elias et al. 2018). Practices that involve spatial diversity (i.e., when crops of different varieties are planted together at the same time), like polyculture, agroforestry, silvopasture, and alley cropping, provide buffers against storm damage, temperature and precipitation variation, and pest damage. Practices that involve temporal, rotational, or non-crop diversity allow pollinators and natural enemies of pests to thrive in refugia, increase soil health and complexity, and disrupt soil disease cycles.

BIODIVERSITY SUPPORT

San Diego County is a biodiversity hotspot (Myers et al. 2000) with high plant species richness (Rebman and Simpson 2014) and a large number of endemic and rare species in many ecological function groups (Soulé, Alberts, and Bolger 1992; Rubinoff 2001; Hierl et al. 2008; Richmond et al. 2016; Hamilton, Wright, and Ledig 2017; Marschalek, Faulkner, and Deutschman 2019; Orr et al. 2021). Historically, San Diego farms and rangelands have coexisted with this rich ecosystem, and many agricultural lands have even contributed to biodiversity conservation through federal and state habitat creation programs (T. A. Scott, Standiford, and Pratini 1995; DiGaudio et al. 2015). However, the combined effects of climate change and land use conversion to urban development threaten this rare hotspot with loss of biodiversity and ecosystem function (Loarie et al. 2008; Riordan and Rundel 2014). Providing a buffer of biodiversity support as wildland habitat quality is degraded is one key role that San Diego agriculture can play in mitigating the effects of climate change.

A few methods that can be used to support biodiversity include soil investment, as discussed above; crop-field boundaries like hedgerows, windbreaks, trap crops (Parker et al. 2016), and flowering perennials; riparian restoration, a huge potential source of carbon sequestration in San Diego agriculture (Batra Ecological Strategies 2018); and practicing IPM and IWM in lieu of solely chemical control. Most of these techniques are applicable both to farms that grow edible crops and to ornamental nurseries. Furthermore, small farms (less than about 5 acres) have been shown to have higher yields and greater crop and non-crop biodiversity globally than large farms (Ricciardi et al. 2021). Given San Diego's wealth of small farms and organic practices, this has promising implications for local farms' potential to support biodiversity.

Not only do these methods produce habitat for San Diego natives and support biodiversity in the face of climate change, they can deliver benefits to growers as well. Hedgerows, tree windbreaks, flowering perennials, and other managed crop-margin habitat increase predatory bird and insect presence on farmed land, reduce pest incidence, and promote pollinator populations (Morandin and Kremen 2013; Sarthou et al. 2014; M'Gonigle et al. 2015; Heath et al. 2017). Even orchards in an otherwise cleared area can support an abundance of predatory birds that act as effective pest control (Heath and Long 2019). Riparian restoration supports native migratory and endangered bird species (DiGaudio et al. 2015) and reduces nutrient and sediment flowthrough, cleaning runoff (Vellidis et al. 2003; Laceby et al. 2017). Riparian restoration also creates thermal refugia in a warming climate (Seavy et al. 2009) and contributes to water security as surface water is increasingly diverted for human needs (Vogl et al. 2017).

However, one hurdle for grower and rancher involvement in biodiversity support programs is grower perception of conservation programs and wildlife in general. One study found that farmer perception of wildlife was directly correlated with actions taken to attract or deter that wildlife and with support of wildlife conservation programs (Kross et al. 2018). For example, while both organic and conventional farmers viewed perching birds, raptorial birds, and bats as beneficial for pest control, farmers differed in their level of investment to either attract or repel the three groups. This was particularly the case for fruit farmers, who sought to deter songbirds due to the damage they cause crops. In another study, San Diego County rancher involvement in conservation programs was limited, primarily due to the programs' requiring access to private lands and "other issues related to trust and social values" such as being unsure that agencies could truly address conservation issues or hesitant about potential income impacts (Farley, Walsh, and Levine 2017). Ranchers who participated did so because they felt a sense of trust and shared goals with managing agencies. In another study, hedgerow adoption on California farms was overall supported in theory, with over a third of surveyed farmers installing some form of native hedgerow, windbreak, or grassy edge; in practice, however, hedgerows occupied less than 4% of possible edge length (Brodt et al. 2009).

In all cases, positive grower perception of conservation practices, the wildlife they support, and the agencies that manage them is a requirement for grower participation in biodiversity support. Another determining factor is the level of financial support provided by a given conservation program. Growers who view wildlife more positively are more likely to invest in wildlife conservation, but the likelihood of grower investment is highly dependent on both proven benefits and agency subsidization of costly practices. Concerns about cost were a major factor in all studies. This suggests that locally sourced cost-benefit analyses regarding conservation practices can be an important tool in increasing the level of biodiversity support participation in the county.

VI. REGULATIONS AND POLICY

As the effects of climate change grow more severe, with greater consequences to health, life, property, and the environment, policymakers seek to reduce the causes and mitigate the effects of climate change via legislative mandate. Climate ordinances and legislation change rapidly from year to year and from sector to sector, but California has been in the vanguard on environmental issues and consistently adopts “some of the most aggressive climate policies in the country” (Hagemann 2020). Many sectors have been mobilized to reduce GHG emissions and increase energy efficiency, some to greater effect than others. Unfortunately, the state’s historic and present-day status as an economic giant of agriculture comes into frequent conflict with the industry’s shrinking share in the state economy, as well as a growing and increasingly urbanized population. Water rights for agricultural versus urban use are a particularly hot-button issue. Yet, climate-resilient agriculture has the potential to have a powerful impact on mitigating climate change, whether at the national, state, or local level. To this end, policymakers have passed bills that aim to address GHG emissions, reduce energy and water use, and promote carbon sequestration in agriculture.

Perhaps more important than any specific legislation is the power that legislatures can delegate to local, state, and federal agencies that manage resources or issues relevant to climate change. In many cases, waiting for new legislation on issues of water conservation is unnecessary, since most state and local agencies already retain the authority and expertise necessary to reform water policy (Hanak et al. 2011). The California Public Utilities Commission, too, has a great deal of leeway on the regulation of public utilities, the implementation of conservation actions, and the inclusion of climate change in projected risk assessment documents compiled by public utilities (Bedsworth et al. 2018). Therefore, bills and agencies are both discussed in this section, as both can have significant impacts on climate change policy and mitigation in agriculture.

FEDERAL

The historic absence of any comprehensive federal climate change legislation has caused advocates and policymakers to use existing federal laws to force mitigation and adaptation efforts, with uneven results (Wold, Hunter, and Powers 2013). The National Environmental Policy Act of 1969 (NEPA) and the Endangered Species Act of 1973 (ESA), along with other environmental laws discussed later in this section, are frequently invoked in national cases to achieve mitigation aims. NEPA requires that federal agencies evaluate the environmental impact of any proposed agency action before engaging in the action. ESA designates a category of “critically imperiled species” and directs federal agencies to use their authority in service of protecting these species. However, because the laws were originally authored to address issues other than climate change, interpretation and legal jurisdiction on climate-related issues are often questionable. In most cases, California policy requires stricter standards than federal policy, so emissions- and energy-related regulations will be addressed under the “State” subsection.

As this report goes to press, the Inflation Reduction Act (HR 5376) has just been signed into law, authorizing an unprecedented $369 billion in clean energy and climate change mitigation expenditure. Several major areas of climate-relevant funding include domestic energy security and decarbonization, funding for drought resiliency in western states, and consumer incentives to improve home energy efficiency. As the largest piece of federal legislation on climate change ever passed, the magnitude of its long-term effects on climate policy remains to be seen.

Water and Soil

Unlike air (the 1963 Clean Air Act) and water (the 1972 Clean Water Act, first introduced in modified form in 1948), soil in the US does not have its own sweeping protective statute. Several interlocking factors have contributed to the current state of soil protection. These include the relative lack of centralized federal power at soil’s crisis moment in the Depression-era Dust Bowl; soil degradation and erosion being incremental and mostly invisible to the public, with commercial fertilizer able to patch over some of its shortfalls until severe degradation has occurred; and the assumption that soil management techniques are land-use decisions to be regulated locally, rather than at the state or federal level (Desai 2018).

The Soil and Water Conservation Act (1977) was passed in an effort to resolve this gap. It requires that an appraisal be conducted every 10 years to inform a new program plan for soil and water conservation on private lands. However, the most recent appraisal, in 2011, was the first program-wide appraisal to be successfully completed since the 1980s (USDA Natural Resources Conservation Service 2011). Most conservation programs perform intra-program assessment and reauthorship rather than relying on a department-wide synthesis of soil and water conservation goals.

The major federal agency that conserves soil today is the Natural Resources Conservation Service (NRCS), which provides funding and technical support to enable farmers to practice conservation on their land. Currently, the NRCS administers two main programs to combat soil degradation: the swampbuster and sodbuster programs. These programs disincentivizes agricultural production on sensitive soil by conditioning farm bill subsidies on the implementation of certain conservation practices on land that is either highly erodible or wetlands (Desai 2018).

Conservation and Other

Many conservation funding sources and programs are also administered by NRCS, such as the Environmental Quality Incentives Program, Agricultural Conservation Easement Program, Healthy Forests Reserve Program, and many others that seek to encourage conservation practices. In most cases, landowners are given tax incentives or even NRCS contributions toward easement purchase in exchange for performing various conservation practices. These can include restoring wetlands or forests, or maintaining land for solely agricultural rather than development uses. Federal regulations limit the use of "USDA Organic" to only those food products that have been grown or produced in compliance with USDA standards (USDA Agricultural Marketing Service 2021). The USDA National Organic Program (NOP) accredits and audits organic certifying agents, who certify organic produce and handlers to ensure that all organic standards are being followed, and also maintains the National Organic Standards Board and the National List of Allowed and Prohibited Substances, which defines the practices allowed for a farm to be considered organic (USDA National Organic Program 2011). The Organic Certification Cost Share Program (OCCSP) is a yearly program that helps fund the costs of organic certification for growers who are applying for or renewing their NOP certification. Newly instituted in 2021 as an expansion of the OCCSP, the Organic and Transitional Education and Certification Program is a pandemic assistance program that covers certification and education expenses for organic producers and those transitioning their operations to organic (USDA Farm Service Agency 2022).

The 1990 Farm Bill includes an effort to ameliorate racial inequality in agriculture and farmland ownership by defining "socially disadvantaged farmers and ranchers." Federal efforts to make amends for this discrimination have largely focused on grants and educational outreach; California has its own policy regarding socially disadvantaged farmers, which will be discussed later.

STATE

Emissions and Energy

Several landmark bills require California to reduce GHG emissions dramatically. AB 32, passed in 2006, required the state to reduce emissions to 1990 levels by 2020; it was the first law ever passed in the US to regulate GHG emissions. In 2016, SB 32 tightened the reduction to 40% below 1990 levels by 2020.

Under SB 375, passed in 2008, the California Air Resources Board sets regional targets for reducing GHG emissions from passenger vehicles and requires regions to develop their own transportation, land use, and housing policies to achieve those targets. Of particular relevance to agriculture, SB 1383, passed in 2016, set a goal to cut emissions of highly potent GHGs such as methane from dairies to 40% below 2013 levels by 2030.

A similar rapid-fire passage of bills requires state targets for renewable electricity. In 2015, SB 350 raised the goal of electricity procurement from renewable sources from 33% by 2020 to 50% by 2030, and required that energy efficiency be doubled by 2030. In 2018, SB 100 increased the 2030 goal from 50% to 60% renewables and required all electricity to be carbon-free by 2045.
AB 32 established a cap-and-trade program, which sets a limit on GHG emissions and then auctions off permits that allow businesses and other permit holders to emit that amount and no more (California Climate Investments 2021). The California Climate Investments program (CCI) uses state cap-and-trade dollars to fund many of the state initiatives that aim to achieve these emissions reduction goals. Just a few programs funded through the CCI are the Healthy Soils Program, the Alternative Manure Management Program, the Forest Health Program, the Food Production Investment Program, and the Sustainable Agricultural Lands Conservation Program, all of which are discussed at greater length later in the document. The California Strategic Growth Council, affiliated with the governor's office, provides technical assistance in applying for the CCI.

This body of legislation, arguably one of the most comprehensive efforts in the nation to address climate change, relies primarily on regional efforts tailored to the most pressing local sources of GHG emissions. Therefore, the local impacts of the bills and the regional and municipal bodies created to address them will be discussed in the county and municipal section that follows.

Water and Soil

The California Irrigation Management Information System (CIMIS) was established by the CA Department of Water Resources (DWR) and UC Davis in 1982 to assist irrigators in increasing efficiency (CA Department of Water Resources 2021). CIMIS is a network of 145 weather stations providing detailed weather and climate data throughout the state, which enables irrigators to forecast upcoming periods of precipitation or heat and deliver sufficient water to crops. Although CIMIS predates California's "wake-up call" drought of 1986-1992, it has become an increasingly important resource for water conservation, both through its extensive statewide data collection on drought and precipitation conditions, and through the increasing need of agricultural consumers to reduce their water consumption as much as possible while still maintaining crop production.

The Water Conservation Act of 2009, SBX7-7, requires agricultural water suppliers serving more than 25,000 irrigated acres to adopt and submit to DWR an

Agricultural Water Management Plan (AWMP). Many water suppliers in San Diego County are also required to submit Urban Water Management Plans as part of the same legislation. An AWMP reports total potable water production and uses by the participating water supplier, certifies that all water usage is reasonable and beneficial, and guides the imposition of water restrictions in accordance with local needs and supplies. As of 2016, local San Diego water authorities are meeting the state-mandated 20% reduction in water consumption per capita (Water Resources Consulting 2016).

Passed in 2014, the Sustainable Groundwater Management Act (SGMA) has upended standards for groundwater in California by mandating similar standards for extraction reporting, water rights management, and long-term sustainability plans as those that regulate the use of surface water. San Diego County has several groundwater basins prioritized under the SGMA for monitoring and management, one of which (Borrego Valley) is listed as critically overdrafted. Proposed methods of addressing this overdraft include reducing groundwater pumping in Borrego Valley, trading pumping rights among agricultural users, and voluntary fallowing of agricultural land in favor of its conversion to low-water-use open space, public land, or other development (Borrego Valley Groundwater Sustainability Agency 2019). As a relatively new policy, the SGMA does not anticipate the implementation of a comprehensive sustainable groundwater management system in California until 2040, but its enactment marks a significant shift in the way groundwater pumping is handled in California water law.

Despite this legislation, California still has major gaps in its water policy. Following the example of Australia during its historic 2001-2009 Millennium Drought, the Public Policy Institute suggests that major reforms can be made in several areas: improving water monitoring systems, setting clear priorities to be followed during shortages, promoting reasonable use while preventing waste and unreasonable use, and managing environmental resources more effectively (Public Policy Institute of California 2015). All of these reforms can be met through agency action rather than addressed through legislation, as the State Water Resources Control Board and the Department of Water Resources hold great authority over the state's water policies and enacted practices.

As part of the reduction in GHG emissions mandated by SB 32, California implemented the Healthy Soils Initiative in 2016 to provide research, education, and financial and technical support to promote the development of healthy soils on California farms and ranchlands. The funding arm of this initiative is the Healthy Soils Program (HSP), a two-part program that funds either the demonstration or implementation of soil investment programs such as cover cropping, compost application, mulching, etc.

Conservation and Other

California's state-level response to NEPA is the California Environmental Quality Act (CEQA), a rigorous statute that mandates an environmental impact report similar to NEPA's to be prepared before a state or local agency takes an action that may affect the environment, and requires that any impacts be avoided or mitigated if at all possible. Some critics of the law, and even CEQA proponents, have argued that CEQA "nuisance lawsuits" are frequently filed by groups with no record of environmental advocacy to block a project for reasons other than its environmental impact (Varner 1991; Mackey 2014; Chung 2019). For example, four out of five CEQA lawsuits target infill development projects, despite the fact that infill, or building new development in already urbanized areas, is better for the environment than converting open space to development (Hernandez, Friedman, and DeHerrera 2015).

In an effort to reduce urbanization of farmland in California, the state passed the California Land Conservation Act in 1965, commonly known as the Williamson Act. The law provides tax relief for property owners of farmland and open space if the owners agree under contract to reserve the property for agricultural or open space uses for 10 years. However, many counties have struggled to support Williamson Act contracts in the last 12 years since the defunding of county subsidy payments in 2010 (California Climate & Agriculture Network 2018). Initially, California reimbursed counties for the loss of tax revenue from the program, but these reimbursements were eliminated from the state budget; as of August 2021, they have not been restored (CA Department of Conservation 2021a).

San Diego County subsequently placed a temporary moratorium on new Williamson contracts due to the unsustainable loss of unreimbursed property tax revenue (Village News 2010). Imperial County withdrew from the program altogether in 2011 due to state subsidy loss, and all Williamson Act-protected land contracts in that county have expired due to nonrenewal as of this year (CA Department of Conservation 2018). Although San Diego County's moratorium was terminated in 2011 (San Diego County Board of Supervisors 2011), no data on Williamson Act participation in the county is available after that date. According to the Division of Land Resource Protection, "some local governments question the value of reporting subvention claims when the state has given no indication that it intends to resume subvention payments" (CA Department of Conservation 2018).

Building on the state's history of Williamson Act updates, modifications, and piggybacking, SB 618 authorizes counties and Williamson Act landholders to rescind contracts in order to simultaneously enter into a solar-photovoltaic facility easement of up to 20 years (CA Department of Conservation 2021b). This facilitates a potential sustainable energy generation process that has been proposed as a use of Williamson Act lands, as California seeks to divest from fossil fuels and increase its proportion of renewable energy (CA Department of Conservation 2011). On the other hand, maintaining the "underlying agricultural use" of land adapted for solar power generation is a requirement. The potential to comply with all requirements and obtain approval is highly site-specific and dependent on details of the contract, the land, and its suitability for such a use. Furthermore, a variety of interrelated factors must be considered before using farmland as a site for solar power, not least the risk of governmental incentives and subsidies being discontinued (Carroll 2020).

One program that accomplishes similar goals as the Williamson Act but with a climate focus is the Sustainable Agricultural Lands Conservation Program (SALCP). Founded in 2015, the SALCP helps conserve productive agricultural lands from being developed by urban and suburban sprawl, specifically for the purpose of climate change mitigation. The SALCP has permanently protected over 129,000 acres of agricultural land since its establishment (California Climate & Agriculture Network 2018), and over 18.8 million tons of GHG emissions have been avoided in its first six rounds of funding (Richards pers. comm.). The program grants funds from the California Climate Investments revenue for local agencies to conduct either planning or easement acquisition of agricultural lands at risk of conversion to development or other non-agricultural uses (CA Department of Conservation 2021c).

In 2014, California implemented the Urban Agriculture Incentive Zone Act (AB 551), which allows landowners in cities to receive property tax incentives for putting urban land to agricultural use. Landowners in the City of San Diego may be eligible for a property tax reduction through a lower land assessment value if they use or lease their vacant property for small-scale production of agricultural crops for a minimum of five years (City of San Diego 2021a). This program will be in effect until 2029.

Two additional legislative schemes directly address food distribution and marketing concerns. In accordance with the federal USDA standards for organic produce, California administers its own State Organic Program, which conducts enforcement, education, and outreach (CDFA State Organic Program 2021). This agency maintains standards for produce grown in California and labeled as USDA Organic to ensure the trustworthiness of the organic label. In addition, AB 1616, passed in 2012, exempts home-based or cottage food production from certain provisions of the California Retail Food Code (Gatto 2012). This allows small home businesses to package and distribute food products under acceptable zoning and permits, while not being restricted by regulations that would be prohibitively expensive or impractical for a small in-home operation.

A bill from 2017 addresses racial inequity in agriculture and land ownership: AB 1348, the Farmer Equity Act, adds a definition of "socially disadvantaged farmer and rancher" as those who have been subjected to racial or ethnic prejudice in

California's history of agriculture, and who should therefore receive resources, outreach, technical assistance, and decision-making power to make amends for that discrimination. While the federal definition mainly resulted in grantmaking and outreach activities, AB 1348 requires that socially disadvantaged farmers and ranchers be incorporated into stakeholder engagement efforts, that grant distribution be performed equitably according to collected demographic data, and that state and federal agency processes and decisions be evaluated for their equity (Spitler 2018).

In the proposed 2022-2023 state budget, $25 million from the $1.1 billion agriculture package is allocated to California's Climate Catalyst Program to "promote climate-smart agriculture and support long-term sustainability and resilience" (California State Assembly 2022).

COUNTY AND MUNICIPAL

In the fall of 2020, the County of San Diego Board of Supervisors voted to retract its approval of the county's 2018 Climate Action Plan (CAP) due to a court finding of noncompliance with CEQA requirements, as discussed above. An update to the plan is currently being drafted with an anticipated completion date of 2024 (San Diego County Climate Action Plan 2021). When the updated Climate Action Plan is accepted, it is almost certain that new regulations and policies will go into effect regarding development in the County that is governed by the General Plan.

Further, the County is leading a collaborative effort to lower the region's carbon footprint by developing a Regional Decarbonization Framework (RDF). The technical report of this framework is a data-driven, science-based assessment of regional emissions and technically feasible ways to reduce emissions in the electricity, on-road transportation, and buildings sectors. Additionally, the report includes analyses of how natural and working lands, which includes agricultural lands, can sequester and store carbon dioxide while maintaining agricultural production. Several carbon farming techniques, such as composting, orchard tree retention, and riparian restoration on working lands, were considered in this analysis. The RDF is separate from, but complements, the Climate Action Plans in the region, and shows that the current regional CAP commitments do not put the region on track to reach net zero goals by mid-century. Public outreach and engagement on the strategies to implement the framework will begin in fall 2022 (San Diego County Sustainability 2022).

Many county and municipal regulations and programs are funded, established, or dependent in some way on state regulations, agencies, or programs—for example, the Urban Agriculture Incentive Zone Act mentioned in the previous section is executed and administered by the City of San Diego, even though it was initially passed at the state level—and many locally administered programs are bankrolled by the California Climate Investments fund. This section addresses local county and municipal programs whose jurisdiction falls or whose effects are felt within San Diego County.

Emissions and Energy

The county of San Diego defines nine sectors in its GHG emissions inventory: on-road transportation, off-road transportation, electricity, solid waste, natural gas, agriculture, water, wastewater, and propane (San Diego County Climate Action Plan 2021). Agriculture ranks fifth out of nine sectors, contributing about 5% to the unincorporated county's total emissions. Several principal emission reduction strategies in the Climate Action Plan involve replacing agricultural equipment that consumes fossil fuels, such as tractors, mulchers, chainsaws, and irrigation pumps, with electric versions. However, progress on these goals has been limited. So far, no irrigation pumps have been replaced with electric pumps, and the Clean Air for All Grant Campaign that funds replacements was not open for applications in 2021 (San Diego County Climate Action Plan 2020). Tree-planting programs by the county's Department of Parks and Recreation and in residential areas have been more successful.

As for the City of San Diego, its Climate Action Plan addresses climate change mitigation in agriculture primarily through an urban tree planting program called Free Tree SD. No other programs are directly relevant to agricultural emissions in the city. Many of the city's strategies that address other sources of emissions, such as increasing the use of mass transit and renewable energy, are ongoing or in progress (City of San Diego 2021b).

Program success in reducing energy usage or GHG emissions is highly dependent on financial feasibility. The Property Assessed Clean Energy (PACE) program is a payment system administered by the county that allows private property owners to fund water efficiency, energy efficiency, and sustainable energy projects by adding installment payments to their property tax bill. Incorporating sustainable upgrades to a residence or business is frequently cost-prohibitive if paid for up front with cash or a loan. Therefore, the PACE program's relatively low financial impact encourages the adoption of efficient and sustainable technologies.

Water and Soil

The San Diego Integrated Regional Water Management (IRWM) Plan is a collaboration between the San Diego County Water Authority, the County of San Diego, and the City of San Diego that seeks to achieve a coherent water management strategy across the fourteen water authorities, eighteen cities or incorporated communities, and unincorporated land in the county. While not technically a piece of legislation or regulation, the IRWM plan sets the priorities, objectives, and data collection and sharing for any water policy in the region established by these three governments and organizations (San Diego Integrated Regional Water Management 2019).

In 2016, the California Regional Water Quality Control Board (RWQCB) of the San Diego Region adopted a series of wastewater discharge requirements, which control discharge from commercial agricultural operations, such as runoff from irrigation and storm water. This order requires that waste discharge shall not cause or contribute to erosion, pH change, pathogen or bacteria concentration, sediment, and other substances that negatively affect the quality of surface or groundwater (San Diego Regional Water Quality Control Board 2016). Due to the potential for leaching, composting also must be conducted in a way that cannot contaminate and at a safe distance from surface water. To help growers more easily comply with these regulations, the San Diego County Farm Bureau formed the San Diego Region Irrigated Lands Group, which allows growers in the county (as well as in Riverside and Orange Counties) to enroll in an easier group testing and group reporting option, rather than individually maintaining compliance with the regulations. Another RWQCB plan currently under construction aims to require farm operations to collect and report data on the amount of nitrogen applied annually, to help regulators target specific regions for best management practices that are overapplying nitrogen (DuMond 2021). If successful, the plan will be implemented in 2023.

In accordance with the SGMA and the WCP, a plan has been drafted to address the critical overdraft in the Borrego Valley groundwater basin. The plan's primary management tool is to "require aggressive pumping cutbacks to a level that does not exceed the subbasin's estimated sustainable yield… before 2040," an approximately 75% reduction in pumping (Borrego Valley Groundwater Sustainability Agency 2019). The groundwater plan was completed and published as of 2019, and updates via legal settlements in 2020 and 2021 require a 5% yearly cumulative cutback of groundwater pumping allocations over the next 10 years, with a further reassessment in 2030 to evaluate progress toward sustainability goals (P. J. Wilson 2021).

In addition, the County of San Diego is developing a new organic materials ordinance that plans to reduce zoning restrictions on where and to what extent composting can occur in the county, and thereby divert an increased share of organic materials from the landfill (San Diego County Sustainability 2022). The ordinance is anticipated to go to the Planning Commission and the Board of Supervisors by the end of 2022.

Conservation and Other

For many years, the City and County of San Diego have prioritized the continued existence and support of local agriculture with a wide variety of policies. In collaboration with the American Farmland Trust, the San Diego County Board of Supervisors adopted a Farming Program Plan (FPP) in 2009 that promotes agriculture and encourages land use policies in the unincorporated county that "recognize the value of working farms to regional conservation efforts" (American Farmland Trust and San Diego County 2009). While many of the proposed policies suggested in the FPP have been adopted, such as increased IPM funding for specialty crops and the incorporation of farmers' concerns into the county's updated Multiple Species Conservation Plans, several of the suggestions have not come to pass, such as a countywide Agricultural Industry Development program and a Research and Extension Center similar to those operated by the University of California in Orange and Imperial Counties.

In addition to these county measures, the City of San Diego amended its general plan in 2012 to encourage the expansion of urban agriculture, in part to address food security in the face of climate change (San Diego City Council 2012). While the city holds several agricultural leases in San Pasqual Valley, significant changes in zoning or land use are not expected to take place in the future, so urban agriculture provides an avenue for agricultural production to occur without the conversion of developed land area to large-scale agricultural uses.

One prominent program adopted due to the 2009 FPP is the Purchase of Agricultural Conservation Easements (PACE, no relation to the sustainable-energy PACE) program. This program encourages the preservation of agricultural land in the county by compensating agricultural landowners based on a fair-market appraisal to place their land in permanent conservation easements. To reflect San Diego's unique agricultural environment, the county uses its own Local Agricultural Resources Assessment model rather than the statewide Land Evaluation and Site Assessment model, to ensure that the value of agriculture occurring on the "poor soil" typical of San Diego County soils is reflected accurately (San Diego County Planning and Development Services 2018; Nicholas Koutoufidis, pers. comm.). Since its inception, PACE has preserved over 3,260 acres with approximately $9.4 million in compensation paid to landowners (San Diego Food System Alliance 2021b). The annual acreage goal is 443 acres preserved per year and about 5,000 acres by 2030 (San Diego County Climate Action Plan 2020).

As awareness grows of both the need to mitigate climate change and the role of agriculture in doing so, funding and policies to address these issues is projected to increase. The Resource Conservation District of Greater San Diego, in a partnership with the San Diego County Local Agency Formation Commission, received a $250,000 grant this year from the Sustainable Agricultural Lands Conservation Program (SALCP) to identify the local causes of agricultural land conversion and determine effective methods to preserve and promote agricultural uses of land (San Diego County Local Agency Formation Commission 2021). The final report from this program is anticipated in 2023, and its findings will doubtless influence the state of county agricultural land conservation.

VII. ECONOMICS OF CLIMATE-RESILIENT AGRICULTURE

AGRICULTURAL ECONOMICS AND MARKETING

A crucial aspect of economically sustainable climate-resilient agriculture is the ability to market and sell products. However, the proportion of small businesses in San Diego agriculture, both by acreage and by yearly revenue, means that many farms and nurseries in the county struggle to remain economically viable. The San Diego Food System Alliance's Food Vision 2030 found that 72 to 74% of San Diego County farms, nurseries, and greenhouses had less than $20,000 in annual sales, and that 63% of principal producers listed a source of income other than sales of farm goods (e.g., a non-farm-related job, or grants and donations for nonprofit farms) as their main income (San Diego Food System Alliance 2021c, 2). In addition, the high cost of land and water means that prices for locally grown food and nursery products must be higher in order to maintain financial viability, which is frequently not competitive with imported produce from counties, states, or countries with cheaper production costs.

Despite these challenges, San Diego County is also well positioned to support sustainable and climate-resilient agriculture. The county has over 30 Certified Farmers' Markets (San Diego County Department of Agriculture Weights and Measures 2021) and has measures in place to permit any certified producer, nonprofit organization, or local government agency to open a new certified market anywhere in the county. County demographics in our "majority-minority" community, along with a local base of educated consumers willing to support local farms, also provide support to farmers seeking to expand operations and cultivate new crops (Lobo 2019). Direct sales, such as farmstands, community-supported agriculture (CSA) box deliveries, and cottage production of processed goods such as jam or salsa, are an underdeveloped avenue through which farm financial viability could increase. In the 2017 Census of Agriculture, only 1.9% of San Diego County's total agricultural sales were classified as direct sales (USDA National Agricultural Statistics Service 2019b). The COVID-19 pandemic presented a new potential for direct consumer sales through the disruption of traditional wholesale and restaurant market availabilities, but the direct-sales avenue is still seriously overlooked and presents a significant financial opportunity despite its risks (San Diego Food System Alliance 2021c, 2).

FINANCIAL AND TECHNICAL SUPPORT PROGRAMS

As an important agricultural region and a hotbed of small and organic farms, San Diego County is an epicenter for climate-resilient and sustainable agriculture planning and resources. The Climate Action and Agriculture Symposium, an annual event hosted by UCCE San Diego beginning in 2019, aims to bring together a broad spectrum of stakeholders and provide an opportunity to discuss the state of the science, current challenges, resource needs, and potential solutions for local production agricultural enterprises (UCCE San Diego 2022). The California Department of Food and Agriculture and the San Diego-based Climate Science Alliance hosted the 2020 Climate Change Consortium for Specialty Crops (CCCSC) to specifically focus on Southern California crops and concerns, as the previous CCCSC focused on Northern and Central California. The San Diego Food System Alliance's Food Vision 2030 was released this year as part of the region's recognition of the threats of climate change and the need to build food system resilience and equity. The Carbon Farming Task Force, a collaborative partnership between the San Diego County Farm Bureau, the San Diego Food System Alliance, Solidarity Farm, and over 50 other organizations, aims to bring together "growers, researchers, technical assistance providers, policymakers, and funders to develop and advance climate-smart agricultural strategies in the region" (San Diego Food System Alliance 2019). UCCE and local Resource Conservation Districts (RCDs) also provide education to growers about climate-sustainable farming practices and how they frequently overlap with best management practices for stormwater and erosion control, groundwater and agricultural water quality management, soil investment, and more. UCCE, local Resource Conservation Districts (RCDs), and the Solana Center for Environmental Innovation also provide education to growers about climate-sustainable farming practices and how they frequently overlap with best management practices for stormwater and erosion control, groundwater and agricultural water quality management, soil investment, and more.

However, when our focus changes to the dominant agricultural industry in the region, resources specifically to aid floriculture growers in adopting climate-resilient practices are almost nowhere to be found. While floriculture plants grown in soil are covered under California's Healthy Soils Program, potted plants (the majority of ornamental land use in San Diego County) are not covered (Mosase pers. comm.). Nursery growers can apply water- and energy-efficient practices in their fields and greenhouses, but the role they can play beyond this in climate-resilient agriculture is not frequently recognized or researched. The scientific literature is sparse when it comes to methods for nurseries to increase their rate of carbon sequestration, and what little information exists is normally based in other floriculture-heavy regions of the world.

A list of technical assistance tools, programs, databases, and resources relevant for San Diego agriculture and floriculture has been curated by UCCE San Diego. These tools have been selected to provide education on climate-resilient farming and inform the implementation of climate-resilient and sustainable farming practices on nurseries, farms, and ranches. For more information, see the website: ucanr.edu/sites/Climate_Resilient_Agriculture/Resources/.

Funding available for climate-resilient agriculture programs has increased in California the last 20 years; however, significant variability in funding availability due to state budget changes hamstrings the ability to make consistent forward progress on these issues from year to year. The California Climate Investments program has provided some of the most reliable funding toward these projects for the last several years. As an example, take two popular programs established in California in the last five years: the State Water Efficiency and Enhancement Program (SWEEP) and the Healthy Soils Program (HSP).

In response to the 2012-2016 drought and as part of the 2016 climate change legislative package, SWEEP was established in 2014 to fund the implementation of irrigation systems that save water and reduce GHG emissions. Since most state efforts to improve agricultural water efficiency prior to SWEEP focused on district-level efficiency questions, a funding gap existed regarding on-farm, grower-implemented efficiency projects that directly conserve water at the field level (California Climate & Agriculture Network 2016). Eligible system components include soil moisture monitors, drip and low-pressure irrigation systems, pump retrofits, variable frequency drives, and installation of renewable energy production. Since the inauguration of SWEEP, 835 funded projects have saved over 117,000 acre-feet of water per year statewide (CA Department of Food and Agriculture 2021).

While SWEEP was allocated $7 million in the 2019 budget and not funded at all in 2020 due to austerity and pandemic-related budgetary concerns, program funding was fully restored in the 2021 budget, with $50 million allocated for the 2021-2022 fiscal year and $50 million recommended for the following year (Merrill 2019; 2021). As the most popular Climate Smart Agriculture program in California despite its short tenure so far, and the only state-funded financial incentive for on-farm water conservation, SWEEP is a crucial program to viably fund irrigation efficiency projects. But one major stumbling block for San Diego SWEEP applications is the pattern of irrigation pump usage in the county. Floriculture producers are eligible for SWEEP if their irrigation systems meet the inclusion criteria, including the use of booster pumps or the installation of solar energy generation systems; however, many small ornamental producers do not have their own pumps on-site but rely on district pumps, making them unable to conduct the pump efficiency test required to qualify for the program (Mosase, pers. comm.).

HSP has been a robust source of soil investment funding since its establishment in 2016. It provides research, education, and technical and financial support to implement healthy soil practices on farm and ranchlands, in order to reduce GHG emissions, increase carbon sequestration, and improve soil health. Unlike SWEEP, which was defunded in the 2020 budget and restored in the 2021 budget, HSP has not only retained but dramatically expanded its funding, from $15 million in 2018-2019 to $28 million in 2019-2020, and $75 million in 2021-2022 (Merrill 2019; 2021).

As of 2019, San Diego County received the sixth highest number of HSP grants (Winzer 2019) and typically receives 10% of available funding for both the incentives program and the demonstration projects. Conventional farms receive the vast majority of HSP grants (California Climate & Agriculture Network 2020), which implies that many conventional farmers are interested in at least some aspects of organic production. Transitional funding toward a broader use of organic practices could provide promising results for climate change mitigation in San Diego agriculture.

While statewide programs like HSP and SWEEP provide meaningful funding to address climate-resilient agricultural practices, the substantial application requirements and volume of paperwork has "constrained the participation of smaller and more poorly resourced farmers." Although CDFA offers funding for technical assistance providers, technical assistance continues to be a major barrier for growers seeking to apply (Richards, pers. comm.). Very few awards have been distributed in Southern California at all (Mosase 2021). While San Diego County has received 10% of available funding, the Southern California region as a whole receives between 11 and 14% of successful applications for HSP, despite hosting over 60% of the state's population (Richards, pers. comm.). To address these issues, UCCE San Diego in partnership with CDFA has staff devoted to assisting growers to apply for these programs. See the website: ucanr.edu/sites/Climate_Resilient_Agriculture/Statewide_Climate_Smart_Agriculture

Finally, a list of financial assistance programs to fund the implementation of climate-resilient and sustainable farming practices on nurseries, farms, or ranches has been curated by UCCE San Diego. For more information, see the website: ucanr.edu/sites/Climate_Resilient_Agriculture/Resources/Funding/.

LONG-TERM VIABILITY WITHOUT SUPPORT

Although San Diego farmers are certainly interested in climate-resilient farming (as evident in the huge number of organic and "organic-adjacent" farms), many farmers perceive sustainable farming practices as too costly in the short term. In various forums and work groups held among Southern California farmers over the last 25 years, growers repeatedly have expressed interest and motivation to adopt sustainable, water- and energy-efficient, climate-resilient agricultural practices, but they name financial constraints as the single biggest factor preventing their adoption of such practices (Drost et al. 1996; American Farmland Trust and San Diego County 2009; Fissore, Duran, and Russell 2015; San Diego Food System Alliance 2021a).

Therefore, the single best way to achieve climate-resilient farming goals is through economic incentive. According to sustainable agriculture expert John Ikerd, “a system must be profitable in the long run or it cannot be sustained; a system must be sustainable or it cannot be profitable in the long run” (Ikerd 1990). Many state-level climate programs are funded from California’s cap-and-trade program (California Climate Investments 2021). In the last few years, cap-and-trade dollars have been primarily allocated toward programs that directly mitigate GHG emissions, which is seen as a better investment in terms of direct results (Lewis and Rudnick 2019). This pattern was broken in the most recent state budget cycle, with unprecedented funds being allocated to programs like HSP and SWEEP. The rewriting and expansion of San Diego County’s Climate Action Plan is anticipated to expand funding for carbon sequestration efforts and other climate-resilient projects. However, stable funding is required for municipalities and growers, both to maintain long-term mitigation and climate-resilient programs, and to feel confident when making the choice to invest time and labor into climate-resilient practices. All these factors are even more salient for nursery and floriculture growers, who are often restricted in the extent to which they can even participate due to a lack of research and funding.

A missing resource that could help secure the long-term financial outlay needed to maintain climate-resilient agricultural and floricultural practices is a body of cost-benefit analyses in the county, similar to the cost-return studies conducted by the UC Davis Agricultural & Resource Economics Center, but tailored to San Diego crops and (equally important) San Diego operating expenses like land and water. Several studies on avocado and citrus establishments have been published in the county in the last 20 years, but only two studies in the cost-return studies archive address floriculture crops at all (UC Davis Agricultural & Resource Economics 2020). As for conservation practices, the studies were all conducted in Central Coast agricultural conditions, and none specifically address climate-resilient floriculture practices (UC Davis Agricultural & Resource Economics 2017).

While the sale of carbon credits as GHG emission offsets could be one avenue of financial support, a study conducted by the University of San Diego’s Energy Policy Initiatives Center on carbon credit viability in the San Diego Region found limited opportunities in the region for reducing emissions and thereby selling carbon credits. This finding was in part because “the scale of agricultural activity in the... region is small,” while many carbon reduction practices that could feasibly be used are already required by state or regional regulatory bodies, and cannot be considered “additional carbon emission reduction” (Energy Policy Initiatives Center 2021).

In order to accomplish regional climate goals, more programs to fund climate-resilient agricultural practices should exist, especially for long-term soil health programs and in areas like nursery and floriculture that are drastically under-studied in San Diego County and Southern California more broadly. For example, installing hedgerows or crop-edge barriers and restoring riparian habitat are two practices that provide a huge swath of long-term benefits, but also require minimal but real long-term maintenance and labor costs. However, most federal and state grants only fund 1 to 5 years at most, enabling installation and the first few years of maintenance to be completed, but neglecting the long-term upkeep that provides the best and most lasting results in terms of carbon sequestration, water quality management, biodiversity support, and more. Even in practices with relatively low barriers to entry, like low- or no-till, changes in soil organic carbon and soil aggregates are more noticeable in long-term treatments than in the short term (Deen and Kataki 2003; G. W. T. Wilson et al. 2009). In higher-intensity projects like riparian restoration, rates of carbon sequestration are expected to rise even 50 or 100 years after initial restoration plantings (Matzek, Stella, and Ropion 2018; Matzek et al. 2020). Extended returns, beyond those achieved by a “one-and-done” project, require consistency in funding to maintain long-term viability.

VIII. CONCLUSION

A major, consistent theme throughout this report has been the dearth of data and resources on nursery and floriculture climate-resilient practices, their contribution to or mitigation of climate change, and potential avenues of resilience for nursery operations. As recently as 2020, the Climate Change Consortium on Specialty Crops made a note of nursery and floriculture crops as being drastically under-researched with regard to both climate change mitigation and resilience (Jasperse and Pairis 2020).

Since San Diego County is an industry leader in nursery and floriculture products—not only in the state, but in the country—the floriculture gap in climate change research disproportionately affects our agricultural industry's ability to react to upcoming changes and to contribute to mitigation efforts. The gap between climate mitigation potential and reality is much smaller for the food-producing sector of the industry. In the food-producing sector, the gap is not driven by a lack of resources or information on climate change effects and mitigation, but rather by grower sensitivity to cost in an expensive and often unprofitable farming environment. Increased long-term funding programs to incentivize climate-resilient practices, and increased efforts to assist growers in taking advantage of this funding, may help shrink this gap in food-producing agriculture. However, given the challenge of scale and the high number of small farms producing diversified crops in San Diego County, the majority of which rely on outside non-farming incomes to continue production, closing the gap altogether may prove challenging. As for nurseries and floriculture, the gaps in research, technical assistance, and resources are far larger, providing a greater opportunity for improvement in climate mitigation and resilience.

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X. METHODOLOGY

To compile our literature and policy review, we used a multi-step process to ensure a holistic, complete, and rigorous evaluation of the current scientific literature and public policy. We conducted multiple searches in academic search engines (JSTOR, Google Scholar, Web of Science) using different keywords. We visited two tribal libraries in the county to incorporate tribal information and perspectives not frequently acknowledged in the scientific literature. A cornerstone of our initial research process was the Climate Action & Agriculture Symposium (CAAS), an annual symposium hosted by our program at UC Cooperative Extension San Diego for the past 4 years. CAAS brings together researchers, educators and outreach professionals, policymakers, government agencies, consultants, growers, and other public and private agricultural service providers to develop and share programs, strategies, and resources relating to climate-resilient agriculture.

We reached out to multiple policy experts, including County and City of San Diego staff, San Diego County Farm Bureau staff, and National Agricultural Statistics Survey staff, and evaluated white papers, policy documents, and legislation from the last 30 years. California's rapidly changing legislative landscape in climate change mitigation required a comprehensive overview.

After putting together a first draft, we conducted a systematic internal review process in which multiple UC advisors in relevant fields, such as organic agriculture, horticultural irrigation, energy management in controlled systems, and tribal agriculture, provided their input and suggestions for missing topics or research. Finally, we conducted an external review process and solicited comments from partners across San Diego County, including policy institutes, advocacy groups, climate resiliency groups, and more.

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