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Intercropping for Water Conservation: Environmental and Economic Implications of a Sustainable Farming Practice in California's Central Valley

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Intercropping for Water Conservation: Environmental and Economic Implications of a Sustainable Farming Practice in California's Central Valley

A Thesis Presented

By

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ABSTRACT

California's agricultural sector is the biggest water consumer in the state and faces intense pressure to reduce its overall water usage. Industrialized monoculture systems dominate the industry and often disregard long-term environmental and economic externalities for short-term profit maximization. To maintain longstanding food security and economic stability as well as protect the state's water supply, it is critical that these systems transition to more sustainable and resilient production mechanisms. As an alternative to monoculture, intercropping affords greater potential to conserve water, protect soil quality, and increase crop yields, among other metrics of sustainability. However, there has been much controversy over intercropping's true potential to maintain the high crop yields of current commercial agriculture and whether it can effectively decrease water consumption in semi-arid and arid climates. Through meta-analysis and literature review of research completed in similar environments, this paper determines that if properly implemented, the methodologies of intercropping can be effective for long-term economic success in the Central Valley, while simultaneously increasing water conservation and protecting California's valuable resources. To encourage the transition to these systems, potential policies and strategies are provided as mechanisms to stimulate positive growth towards a sustainable future.

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1.0 INTRODUCTION

Although at present California may not be under major drought-stricken conditions, the state continuously experiences insufficient water supplies, with water scarcity and quality remaining ongoing issues with substantial environmental and economic repercussions. The state's agricultural industry consumes more water than any other economic sector in California, accounting for approximately 40 percent of all water use and 74 percent of all freshwater withdrawals (Morris & Bucini, 2016; Mount & Hanak, 2019). In an average year, approximately 9.6 million acres of agricultural land in California are irrigated with 34 million acre-feet of water, forming the highest water use per acre of any U.S. state (California Department of Water Resources, 2020; Johnson & Cody, 2015). Although there have been some initiatives towards increased water conservation (e.g. through more efficient delivery systems and irrigation techniques), water use still remains unsustainable in the long term. Water sustainability is especially challenging for the San Joaquin Valley, the state's largest agricultural region, and home to high surface water scarcity and diminishing groundwater levels (Hanak et al., 2019; Griswold, 2016). With crop yield predicted to decrease in the coming years (Bittman, 2012; Hanak et al., 2019), even more farms and land cultivation will be necessary for food production to meet the demands of rising populations.

Approximately 50 percent of the water utilized for irrigation in the Central Valley comes from the Sierra Nevada Mountains snowpack and is transported thousands of miles through dams, pumps, and canals to reach the agricultural hub (Hanak et al., 2019). However, as temperatures warm as a repercussion of climate change, precipitation becomes more inconsistent and increasingly falls as rain instead of snow (Schapiro, 2019; Kasler, 2019). Resultantly, water can no longer be stored as snowpack throughout the winter and instead runs off too quickly for reservoirs to capture safely, and thus most is lost to the ocean (Schapiro, 2019; Kasler, 2019). As a result, farmers will look more and more to pumping groundwater to meet the needs of non-drought tolerant plants. In 2014 alone, groundwater pumping increased by 62 percent (Morris & Bucini, 2016). Central Valley aquifers do not have the ability to be drained at this rate, as many are already considered critically overdrafted (Figure 1) (Hanak et al., 2019). Farmers have already begun to see repercussions of over pumping, including increasingly high pumping costs as well as salt intrusions into aquifers, leading to high rates of soil and water salinization (Morris & Bucini, 2016). Compaction is another externality, reducing the soils ability to utilize inputted water, leading to greater water waste (Morris & Bucini, 2016; United States Department of Agriculture Natural Resources Conservation Service, 2008). Additionally, groundwater depletion has led to land subsidence in the San Joaquin Valley, at a rate of approximately 8.5 meters since the 1920s (Greicius, 2017; Schapiro, 2019). This subsidence has caused damage to thousands of groundwater wells in the San Joaquin Valley, and can permanently reduce storage capacities of aquifers, threatening future water supplies (Greicius, 2017).

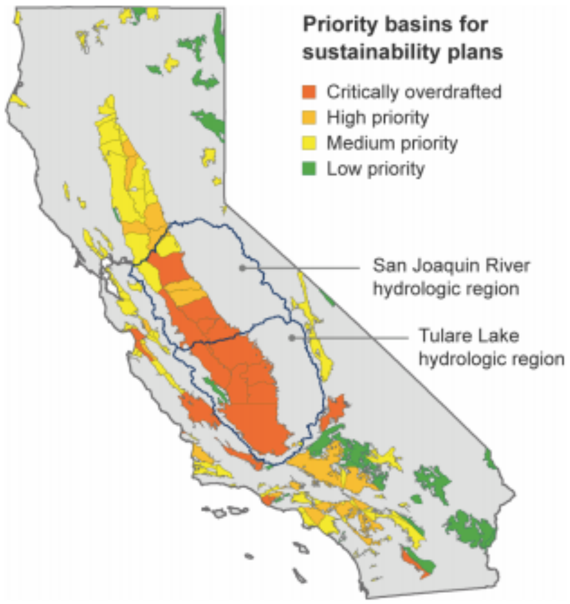


Figure 1. Groundwater overdraft in the Central Valley (Hanak et al., 2019)

Current groundwater depletion will come with intense economic externalities if the agricultural sector fails to transition towards sustainable water consumption. In 2014, drought cost the agricultural industry $1.5 billion dollars and 400,000 acres of agricultural land had to be taken out of production due to water shortages (Morris & Bucini, 2016). The Public Policy Institute of California (2019) predicts that a further 535,000 to 750,000 acres of agricultural land will have to be retired to bring the Valley's aquifers back into balance (Hanak et al., 2019), which would be catastrophic for the Valley's economy. If 750,000 acres were to be fallowed, or 14 percent of current cropland, crop revenue would decrease by $2 billion and result in 14,000 job losses (Hanak et al., 2019).

To protect the agricultural sector, more sustainable practices are necessary. Specifically, the utilization of intercropping as opposed to monoculture could be potentially effective. Intercropping is an agricultural practice that utilizes two or more plant species grown in proximity to each other, with some level of spatial and temporal overlap while monoculture only uses a single species. There are many variations of intercropping including agroforestry, which utilizes trees, and permaculture which utilizes many species in a closed system (Table 2). However, these practices are seldom used on a larger industrial scale in the Central Valley (Bittman, 2012; Knapp & Sardorsky 2000; Kutz, 2019). Nevertheless, intercropping systems are both environmentally and economically more sustainable than conventional monoculture and are promising to ensure of prolonged food security and minimization of environmental degradation (Geno & Geno, 2001; Morris & Garrity, 1993). Although there is little peer-reviewed research on intercropping in the Central Valley, it has been found in the Mediterranean, as well as in many tropical climates, to increase water use efficiency, increase productivity, increase carbon storage, and increase organic matter content, along with positive correlations in total crop yield, when compared to conventional monoculture systems (Daryanto et al., 2018; Geno & Geno, 2001; Krishnamurthy et al., 2017; Schoeneberger et al., 2012). These promises of intercropping lead to the following questions:

1. Is intercropping a viable solution to decreasing water usage in California's Central Valley?
2. Will intercropping save farmers money or have economic viability in the Central Valley?
3. If the answer to the preceding questions is yes, why has there been so few instances of intercropping in the Central Valley?

To properly ascertain the answers to these questions, it is important to understand that these systems can be complicated with regard to quantifying their potential to save water, as water conservation is affected by many different factors including, climate, precipitation levels, soil properties, crop species, planting methodologies, plant density, level of tillage, etc. This range of variables makes it difficult to predict the actual results of intercropping on water conservation, as each site and planting option will produce varied outcomes. Past studies (e.g., Franco et al., 2018; Mao et al., 2012; Morugán-Coronado et al., 2020) have found contrasting results in terms of water conservation and crop yields and it is necessary to attempt to quantify these differences to best understand intercropping's potential.

Nonetheless, increased or maintained soil quality is one factor that is constant throughout the utilization of intercropping, with nutrients being continuously added to soils rather than extracted (Daryanto et al., 2018; Franco et al., 2018; Mao et al., 2012; Morugán-Coronado et al., 2020). Maintaining high quality soils plays a critical role in water regulation, as healthy soils are found to reduce water evaporation levels by 4 to 5 inches each year (Schapiro, 2019). Thus, if widely adopted, intercropping could reduce water usage throughout the Central Valley by millions of acre-feet per year, as soil properties including structure, organic matter content and other variables remain adequate to properly utilize inputted water (Lawson et al., 2019; Schapiro, 2019). In contrast, farming techniques that disrupt natural soil properties, which is typical of large scale monoculture, will require heightened water usage over time to combat the effects of increases in evaporation due to rising temperatures in the Valley (Schoeneberger et al., 2012; DiPietro, 2017). Utilizing multiple crop species will also hypothetically increase economic stability as it diversifies a farmer's assets and increases land use efficiency as more crops can be planted on a single plot of land. Thus, if there is promising data for intercropping as an economically and environmentally sustainable practice, one must turn to state and federal governments to understand the practice's limited implementation in the Central Valley, as current policies disincentivize transition away from the prevalent monoculture practices that are currently utilized by most California farmers.

California globally impacts food security and nationally impacts water availability. Therefore, it is paramount that the State of California remodels its agricultural industry for long term conservation rather than short-term profit maximization, using government intervention to ensure proactive management of diminishing water resources. Polyculture offers one promising solution for long term sustainability, yet we must further examine its applicability to a commercial scale in semi-arid and arid environments. Through literature review and meta-analysis, this paper examines the potential of intercropping to reduce agricultural water consumption in an economically efficient manner, while striving to maintain the high crop yields expectant of commercial farms. Based on the literature, this paper then outlines ways in which such a practice could be implemented in the semi-arid climate of California's Central Valley.

2.0 METHODS

To understand the impacts of intercropping on water conservation, research on a variety of different regions, crops and intercropping methodologies was analyzed. Importantly, each study examined measures water conservation differently, including changes in water use efficiency (WUE), soil properties, water runoff ratios, etc., so it is difficult to directly compare the outcomes of all intercropping research studies. Watering mechanisms also differ widely, from drip irrigation to sprinkler and subsurface, each mechanism affects plants and yields differently depending on how much water is provided. This adds another degree of complexity, as every study is influenced by a wide array of variables that do not align perfectly to each other.

To understand the potential benefits of widespread intercropping in the Central Valley, only certain studies that consider crops, climates, and soil substrates that are at least roughly comparable to the Central Valley can be applied. Even so, the Central Valley hosts a diverse variety of climates, soil types, and precipitation levels. According to Köppen Climate Classifications, the majority of the northern region is considered hot-summer Mediterranean climate, but the San Joaquin Valley is mainly Cold semi-arid, with other more southern areas in the hot desert and cold desert categories (Figure 2) (Kauffman, n.d.). Precipitation also varies between the Valley's northern and southern regions, with the Sacramento Valley experiencing an average of between 11-15 and 21-25 inches, and the San Joaquin Valley receiving significantly less at an average of 5-6 and 11-15 depending on location (Figure 3) (Conservation Biology Institute, 2020). Temperatures also vary from average minimums and maximums of 39°F and 97°F, although stay fairly constant throughout the Central Valley (Figure 4; Figure 5) (U.S. Climate Data, 2020).

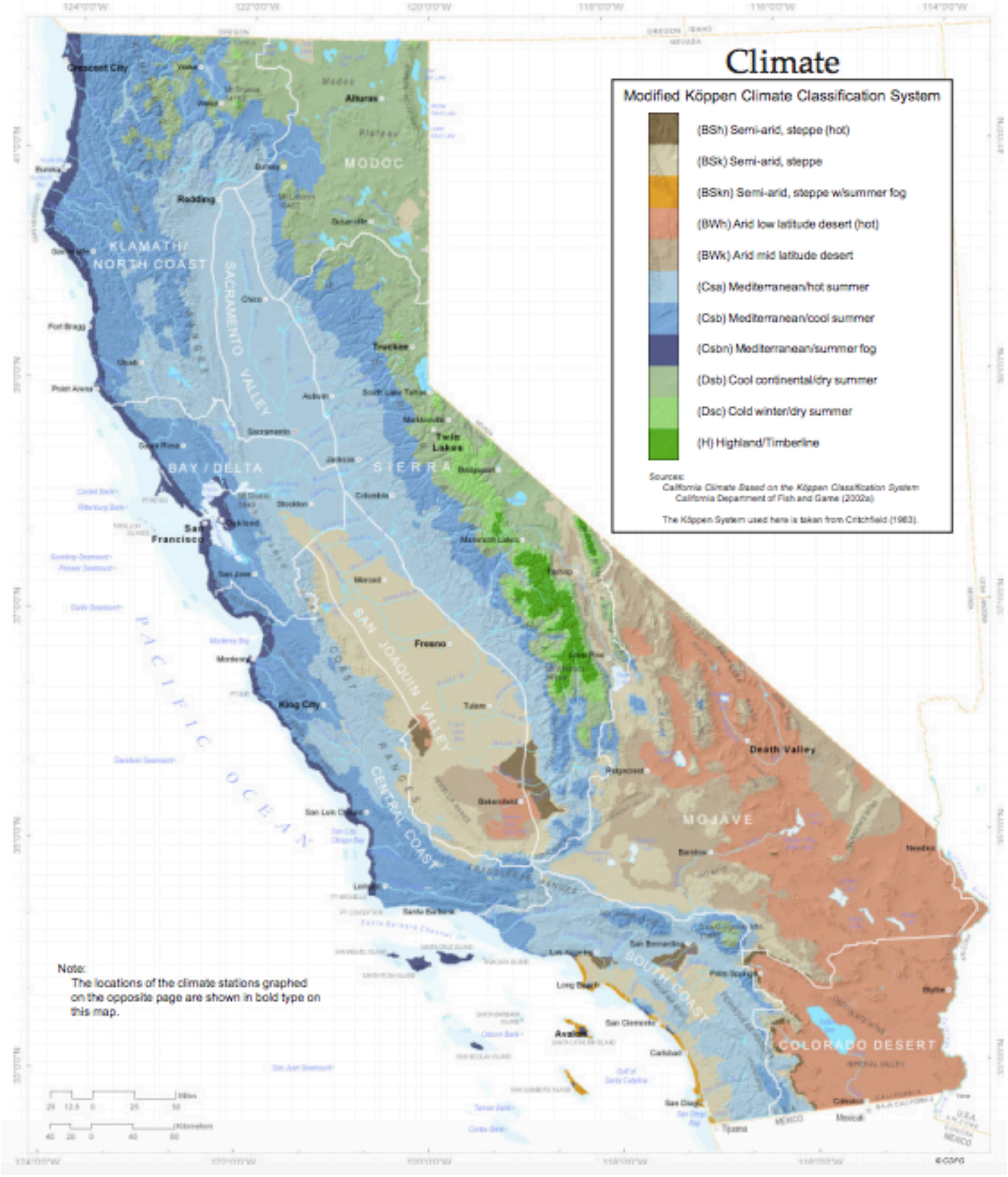


Figure 2. Modified California Köppen Climate Map (Kauffman, n.d.)

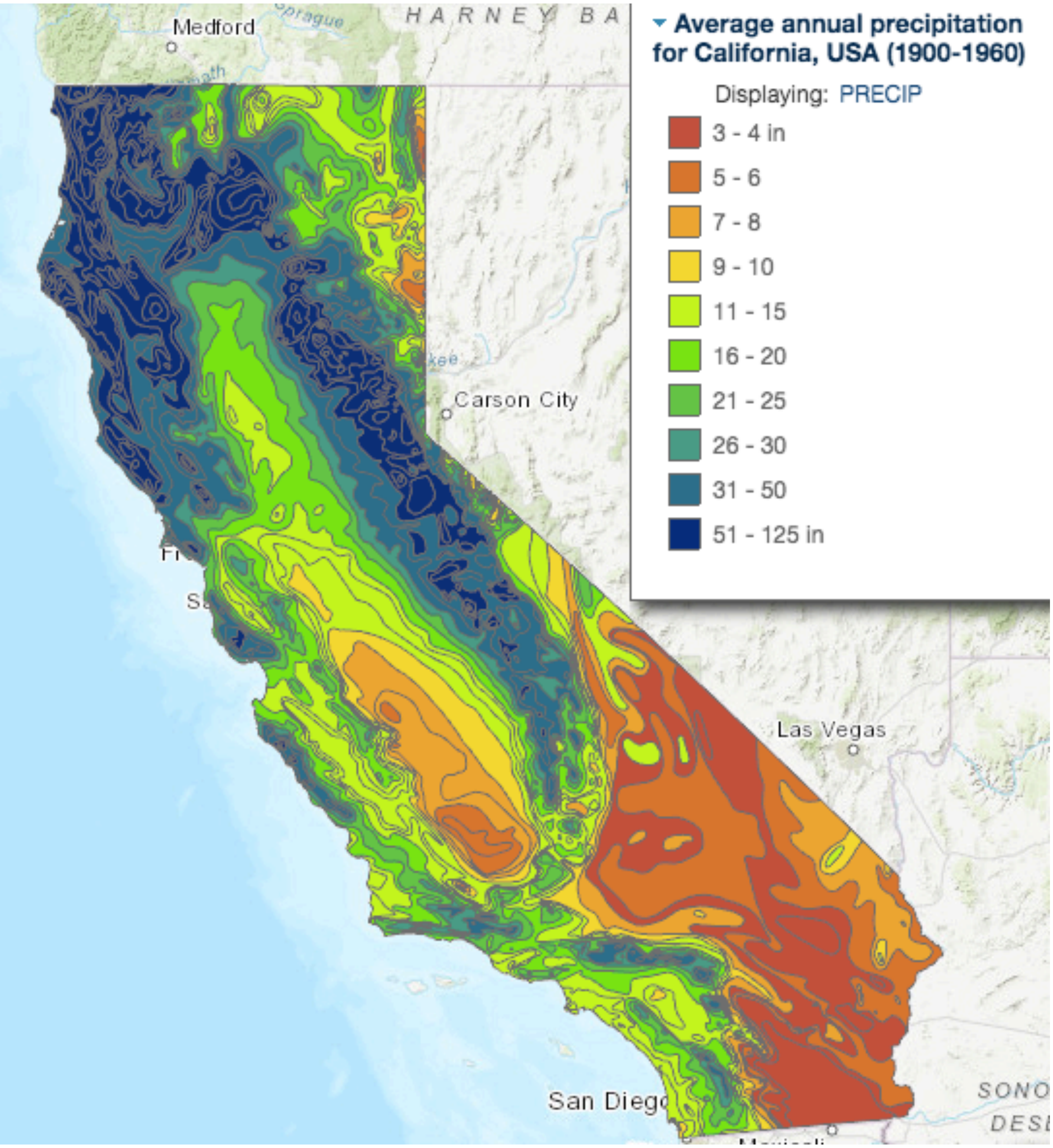


Figure 3. California Average Annual Precipitation from 1900-1960 (Conservation Biology Institute, 2020)

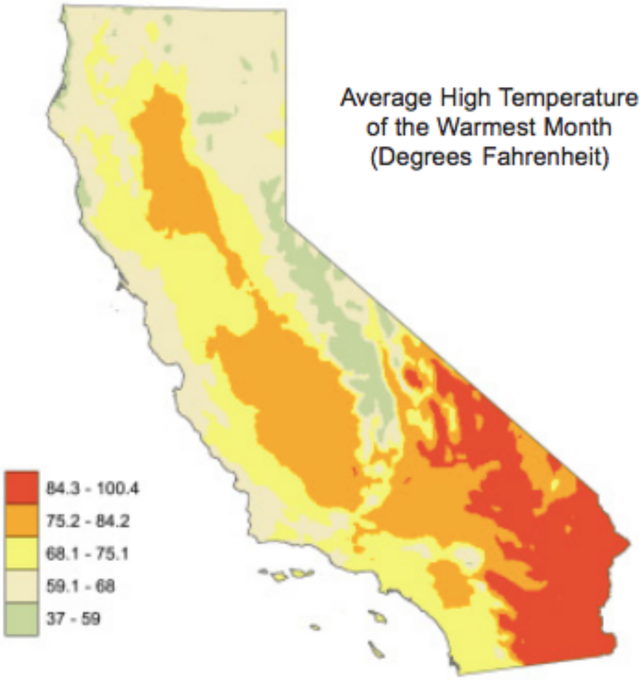


Figure 4. California Mean Annual Maximum Temperature of Warmest Month (Kauffman, n.d.)

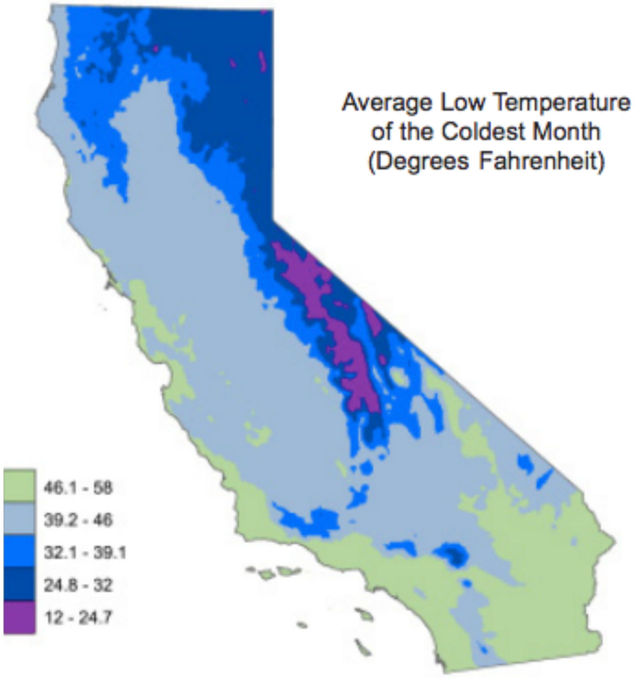


Figure 5. California Mean Annual Minimum Temperature of Coldest Month (Kauffman, n.d.)

Additionally, it is important to note that the term ‘intercropping’ incorporates a high variance of practices. This paper uses intercropping as synonymous to polyculture—as an umbrella term for most multiple cropping practices, bar a select few (e.g. hedgerows, windbreaks, aquaculture). Table 1 defines terminology relating to intercropping and demonstrates how some practices may be considered subcategories of others (Table 1). Furthermore, it attempts to examine these practices’ scalability to large scale industrialized agriculture.

Table 1. Types of Intercropping practices

Method	Description	Scalability to Industrial Agriculture
Strip Intercropping	Species grown in different rows; not completely intermixed	Highly feasible due to spatial gaps
Mixed Intercropping	Species grown together with total spatial and temporal overlap	Somewhat difficult due to spatial and temporal overlap
Relay Intercropping	One species planted during the life cycle of another species before harvest occurs	Feasible due to temporal spacing
Cover Cropping	Utilizing an additional crop (typicallywith the purpose of covering exposed soils	Dependent on arrangements; highly feasible when cover species grown during a different season from cash crops, less feasible when total temporal on special overlap, but also dependent on species
Agroforestry	Utilizes trees with other crops; can be intermixed or separate rows	More feasible when in separate rows for spatial gap (see alley cropping)
Alley Cropping	Form of agroforestry; planting rows of trees widely spaced apart with a companion crop in alleyways between rows	Highly feasible due to spatial gap
Permaculture	Complex system involving many different species grown together; attempts to mimic nature in a system with minimal human inputs	Difficult due to the complexity and planning required to undertake effectively. Many different crops mean a wide array of equipment is necessary to harvest. Extreme spatial and temporal overlap.

(Adapted from Geno & Geno, 2001)

3.0 EFFECTS OF INTERCROPPING ON WATER USAGE IN SEMI-ARID AND ARID CLIMATES

Most research on the effects of intercropping demonstrates the methodology's ability to conserve water when implemented properly (Droppelmann et al., 2000; Geno & Geno, 2001; Lawson et al., 2019; Zhang et al., 2012). In turn, such water conservation is partially due to intercropping's ability to improve soil quality and enhance soil nutrients. Intercropping practices increase soil organic matter, carbon, and nitrogen contents, which inherently increases the soil's ability to store water and also boosts related properties that further improve soil water retention, for instance soil structure, reduced bulk density via decreased compaction, and increased porosity (Daryanto et al., 2018; Morugán-Coronado et al., 2020; Palese et al., 2014; Schoeneberger et al., 2012). Lessened need for tillage also leads to decreases in compaction (Lawson et al., 2019; Morugán-Coronado et al., 2020). In addition, intercropping increases microbial biomass, which is key in determining nutrient cycling and availability, further ensuring increases in long term water storage capacity (Krishnamurthy et al., 2017; Lawson et al., 2019). Resultantly water retention is increased, and leaching becomes less prevalent, decreasing water waste (Iglesias & Garrote, 2018). Furthermore, intercropping decreases evaporation and runoff, both of which are sources of water loss for conventional farms, as groundcover is increased and the amount of barren soil is reduced, thus obstructing water movement and decreasing the amount of soils in direct sunlight (Daryanto et al., 2018; Droppelmann et al., 2000; Lawson et al., 2019). Implementing trees in particular has been found to increase water holding capacity, infiltration rate, water regulation, soil temperature regulation, and soil hydraulic conductivity of agricultural soils (Jose & Gordon, 2008; Krishnamurthy et al., 2017; Lawson et al. 2019; Nyawade et al., 2019; Schoeneberger et al., 2012).

Overall, intercropping has found to have positive effects on water usage and water use efficiency (WUE) in semi-arid and arid climates (Gaiser et al., 2004; Grema & Hess, 1994; Morris & Garrity, 1993; Rezig et al., 2010). One meta-analysis found that cover cropping decreased water loss by 18% across all soil conditions, climates and agronomic practices (Daryanto et al., 2018), and another found agroforestry to increase soil moisture by 18% (Krishnamurthy et al., 2017). An intercropping study utilizing okra, peanut, watermelon, cowpea and pepper in an arid region of Texas determined WUE to be highest for watermelon and okra when four or five of the crops were grown together. However, when watermelon was grown in a two-species strip-intercropping system WUE remained the same as in a sole cropping system (Franco et al., 2018). For peanut, WUE was higher when grown within two, three and four combinations, however, both pepper and cowpea had highest WUEs when grown as a monoculture (Franco et al., 2018). This is due to the varying needs of each plant species, as some plants may not function together as well as others and may compete for water and nutrients. Thus, the WUE of dominant, more competitive crops in the mixture benefitted, while subordinate crops' WUE declined.

In an arid region of Gansu, China, strip intercropping with short season-pea and long-season maize increased WUE by 24% and grain yield by 25% (Chen et al., 2018). The two species apparently avoided competition; the peas used soil water in the top 20 cm while maize had much deeper roots and could obtain water from deeper horizons, and each crop matured at different points in time, thus decreasing spatial and temporal overlap (Chen et al., 2018). Intercropping of apricot trees with millet, peanut and sweet potato in a semi-arid region in Liaoning, China led to increases in WUE of apricot, but at various rates depending on component crops and row organization (Bai et al., 2016). In an arid region of northwestern China wheat-maize intercropping increased WUE by 14% over sole wheat and 35% over sole maize, and decreased soil evaporation by 9% to 16%. This system also decreased total water consumption by 3.6% and 4.5% in respective years, while simultaneously increasing crop yields (Hu et al., 2017). A study in a semi-arid region in South Africa also found increases in WUE in a sorghum-cowpea-bottle gourd intercrop, with the cowpea and bottle gourd improving water availability for sorghum under water restricting circumstances (Chimonyo et al., 2016). Other studies have also found significant increases in WUE when intercropping has been implemented in arid and semi-arid conditions (Daryanto et al., 2018; Gaiser et al., 2004; Grema & Hess, 1994; Rezig et al., 2010).

On the other hand, a sorghum and cowpea intercropping experiment in semi-arid Riverside, California found no differences in water usage between intercropped and monocropped study groups in both rainfed and drought stricken conditions (Shackel & Hall, 1984). Such results indicate that these crops can be effectively grown together without enhanced water demand than when grown individually, however, the combination will not necessarily decrease overall water usage. In addition, an experiment in an arid region of Northern Kenya analyzed intercropping of trees and annual crops and determined increases in water use efficiency in addition to increases in water use for intercropping plots (Droppelmann et al., 2000). However, when trees were pruned, water consumption decreased, demonstrating that pruning in addition to agroforestry is a viable strategy for water conservation (Droppelmann et al., 2000). Lastly, another study in semi-arid regions of Latin American found that agroforestry also increased overall water usage, potentially due to the higher water requirement of most tree species (Krishnamurthy et al., 2017). However, this study did find improvements of hydrological behavior in agroforestry plots (Krishnamurthy et al., 2017).

All of these findings indicate high levels of variation between regions, cropping arrangements, cropping species, and cropping methodologies, indicating that no one study can be applied uniformly. Although, the practice has proven to consistently improve WUE and soil quality, intercropping will have site specific results in terms of total water usage. This is further dependent on geological factors and physical soil properties, which also are highly variable between regions, including within the Central Valley.

4.0 INFLUENCE OF GEOLOGICAL FACTORS

4.1 SOIL PROPERTIES

Ultimately, soil properties determine water efficiency, as finer-textured, organic rich, well-structured soils hold water much more effectively than coarse, organic-matter poor, structureless or hard-panned soils, and therefore need less water over time to remain moist (Brady & Weil, 2008). Available water capacity, infiltration capacity, texture, and organic matter content of soils are all important factors that affect the way soils and water interact. Available water capacity (AWC) measures a soil's ability to retain water that can then be used by plants. Soil water content is described by the soils hydraulic potential, in which gravity, matric or capillary suction, hydrostatic potential, and osmotic differences all dictate how tightly water is held (Brady & Weil, 2008). The water content of a soil is further described at key benchmarks, spanning the soil's saturation point, its field capacity, and its permanent wilting point. Field capacity is the amount of water remaining in a soil subsequent to its drainage by gravity (the point at which the adhesion of water to soil mineral surfaces (surface tension) is stronger than the pull of water by gravity, while permanent wilting point is the moisture content of soil which plants wilt – when water is held too tightly to mineral surfaces for plants to adsorb (Brady & Weil, 2008).

AWC is affected by inherent soil qualities of soil texture, presence/abundance of rock fragments, soil depth and layers, and dynamic properties of organic matter, soil compaction and salt concentration (Table 2) (Hudson, 1994; USDA Natural Resources Conservation Service, 2008). All of these variables determine how effectively a system can use inputted water, and thus, are important to consider when determining the effects of agricultural practices on water usage. Although soil texture, presence/abundance of rock fragments, and soil horizons are inherent and fixed in a system, organic matter, soil compaction and salt concentration are dynamic and can be impacted by the implementation of agricultural practices (USDA Natural Resources Conservation Service, 2008). These dynamic properties are factors which can be altered and improved by intercropping, which ultimately has proven to increase organic matter, decrease compaction and decrease salt concentrations, all of which improve AWC (Geno & Geno, 2001; Minhas & Dagar, 2016; Morugán-Coronado et al., 2020; Posnikoff & Knapp, 1996; Schoeneberger et al., 2012; USDA Natural Resources Conservation Service, 2008).

Soils that are coarse in texture, such as sand, have less ability to hold water, due to their characteristic large pores which result in low capillary suction and rapid, free drainage under the influence of gravity (Brady & Weil, 2008). Fine soils like clay, on the other hand, have smaller pores which allow them to hold tightly onto water via surface tension, and prevent drainage. Although clay soils may have the highest field capacity (e.g. are able to hold the most water), well aggregated loam and silt soils have been found to have the highest AWC, as predominately clay soils tend to have higher permanent wilting points and low infiltration rates (Brady & Weil, 2008; USDA Natural Resources Conservation Service, 2008). Nevertheless, clay soils in arid areas or areas with low precipitation have been found to be the most effective for crop management and water conservation as they hold water more effectively in water stressed conditions (Brady & Weil, 2008).

Strong textural contrasts between horizons and root restricting soil horizons including those cemented by silica, carbonate or salts can limit soil available for root growth, thus affecting AWC. The characteristics of plant roots are an important factor is understanding how soil depths will affect plants, as shallow rooted plants are less likely to be affected by this variable than deep rooted plants (USDA Natural Resources Conservation Service, 2008).

High organic matter also increases AWC as the polar nature of most organic compounds, in tandem with the polar nature of water molecules, imparts organic matter with a greater ability to hold water than coarse, mineral soil (Brady & Weil, 2008; USDA Natural Resources Conservation Service, 2008). Organic matter improves soil structure and stability, leading to increasing pore size and volume, and thus increased infiltration, water movement through soils, and AWC.

High soil compaction and high salt concentrations can also adversely affect soil's ability to hold water. Compaction decreases AWC as it reduces total pore volume, which reduces water storage, while soils with high salt concentrations typically have lowered AWCs through osmotic potential, as it is difficult for plants to uptake water across an unfavorable salt concentration gradient (USDA Natural Resources Conservation Service, 2008).

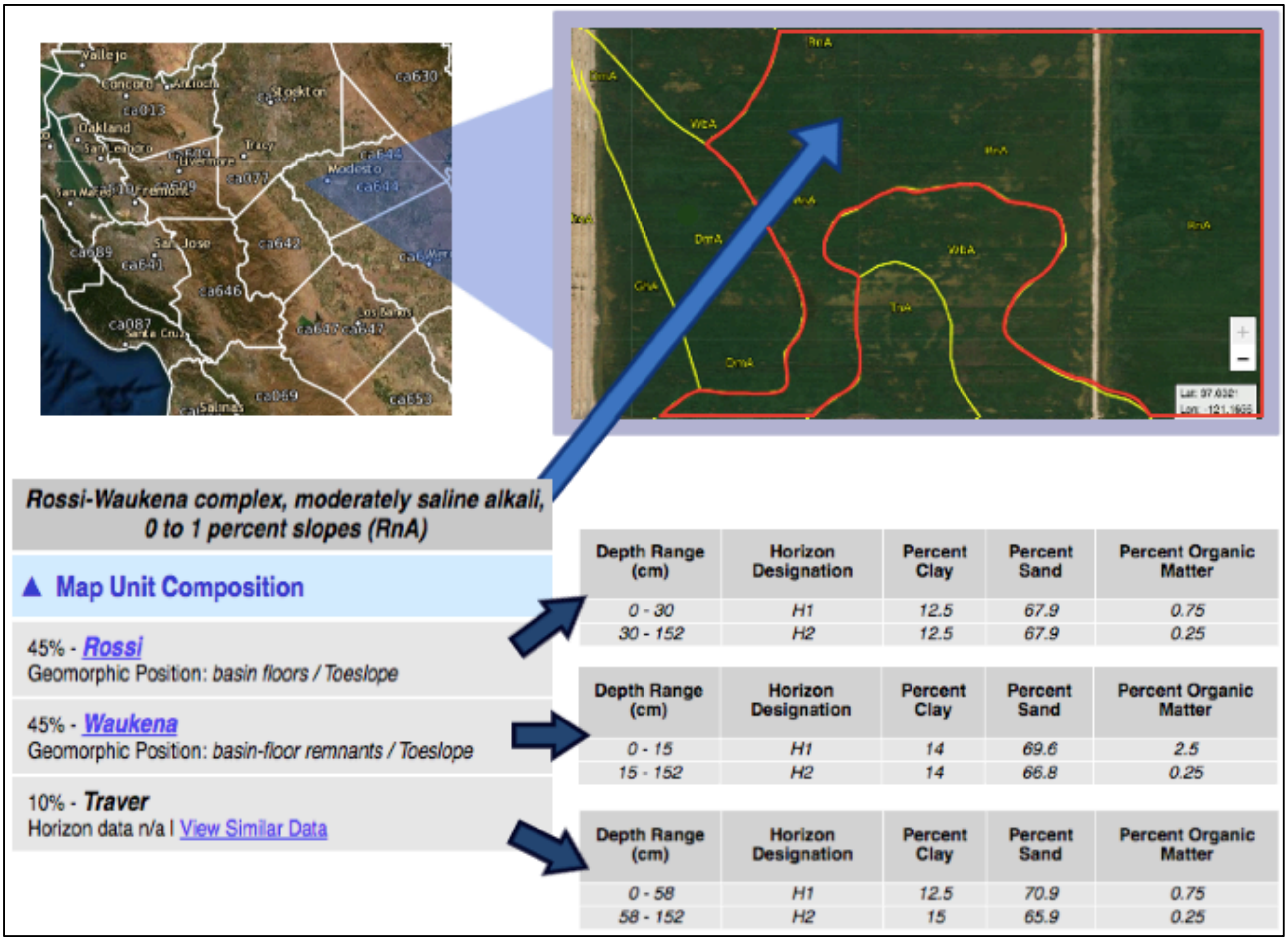
Table 2. Factors Affecting Available Water Capacity (AWC)

Inherent		Dynamic	
Soil texture	Coarse texture= lower AWC; fine = higher AWC	Organic matter	Increase in organic matter = increase in AWC
Rock fragments	Increased rock fragments decrease AWC (unless rocks are porous)	Compaction	Increase in compaction=decrease in AWC
Soil depth and horizons	Shallow soil depth and root restricting layers decrease AWC for deep rooted plants	Salt concentration	High salt concentrations typically decrease AWC

4.2 SOIL VARIATIONS

Soil type and composition vary not only throughout California, but within the Central Valley as well, depending on various geological factors (Figure 6). Soil properties can very within meters, with differences in organic matter and clay and silt content fluctuating depending on a multitude of variables, such as geologic history, topography and local vegetation. Slope is another factor that affects soil properties, as steeper slopes can increase erosion and hinder profile development. Soils on level or concave positions tend to be wetter and less permeable than those on sloped lands, as well as vary in mineral and nutrient concentrations (Brady & Weil, 2008).

A randomly selected plot of approximately 68 acres in Modesto, CA demonstrates this soil variability well (Figure 6). Soil Survey maps the land into 6 different polygons, each with different properties including variations in horizon depth and layering, organic matter content, and clay and sand content (Soil Survey Staff, 2020; University of California Davis & USDA Natural Resources Conservation Service, 2020). Within this one polygon, crops may grow incongruously due to such soil variation. Furthermore, each adjacent polygon also has unique distinctions in soil properties, further enhancing variance in growth patterns.



Rossi-Waukena complex, moderately saline alkali, 0 to 1 percent slopes (RnA)

▲ **Map Unit Composition**

45% - **Rossi**
Geomorphic Position: *basin floors / Toeslope*

Depth Range (cm)	Horizon Designation	Percent Clay	Percent Sand	Percent Organic Matter
0 - 30	H1	12.5	67.9	0.75
30 - 152	H2	12.5	67.9	0.25

45% - **Waukena**
Geomorphic Position: *basin-floor remnants / Toeslope*

Depth Range (cm)	Horizon Designation	Percent Clay	Percent Sand	Percent Organic Matter
0 - 15	H1	14	69.6	2.5
15 - 152	H2	14	66.8	0.25

10% - **Traver**
Horizon data n/a | View Similar Data

Depth Range (cm)	Horizon Designation	Percent Clay	Percent Sand	Percent Organic Matter
0 - 58	H1	12.5	70.9	0.75
58 - 152	H2	15	65.9	0.25

Figure 6. Soil Composition of a 68 acre farm plot in Modesto, California. The polygon selected in red depicts a soil type called Rossi-Waukena complex (RnA), which is composed of three different soils types (Rossi, Waukena and Traver) (Soil Survey Staff, 2020; University of California Davis & USDA Natural Resources Conservation Service, 2020).

4.3 GEOLOGICAL INTERACTIONS: A CASE STUDY ON ALMONDS

Both climate and soil properties are critical in determining what crops are viable and profitable for farmers in different areas, as each plant species reacts differently to each variable. For example, almonds thrive in a climate with mild, wet winters and hot, dry summers and in deep loam soils made up of clay, sand and organic material (University of California Davis Western Institute for Food Safety and Security, 2016). As a result, almonds are productive in the hot-summer Mediterranean climates of places like the Sacramento Valley, but cannot be effectively planted in colder areas like the Sierra Nevada range. However, they also require large amounts of water at approximately one gallon per almond, a quantity that exceeds the precipitation levels in the Central Valley, so must be regularly irrigated (Johnson & Cody, 2015; University of California Davis Division of Agriculture and Natural Resources, 2020a). Additionally, they also require high amounts of nitrogen, potassium, phosphorous, boron and zinc, meaning they will do well in soils that have high concentrations of these nutrients (University of California Davis Western Institute for Food Safety and Security, 2016). These nutrient requirements are necessary for the crop to be productive, and so, if soils are lacking in these nutrients, farmers engaging in conventional systems must apply fertilizers to ensure productivity. Furthermore, they are susceptible to pests and diseases dependent on regions, requiring various pesticide inputs in conventional farming systems that cannot regulate pest intervention (University of California Division of Integrated Pest Management, n.d.). This brings into question the expenses of monoculture practices utilizing intensive irrigation systems and costly inputs such as fertilizers and pesticides, and whether intercropping can be a more economically viable solution.

5.0 ECONOMICS OF INTERCROPPING

5.1 EFFECTS ON CROP YIELDS

Overall, intercropping demonstrates increases in productivity and improved crop stability in semi-arid areas (Abadi, 2003; Bai et al., 2016; Daryanto et al., 2018; Iverson et al., 2014; Jose & Gordon, 2008; Morris & Garrity, 1993). The practice allows for maximum yield of a set plot, as multiple species can overlap when it comes to special requirements between same species stems (Iverson et al., 2014; Jose & Gordon, 2008; Mao et al., 2012). One meta-analysis found cover crops to increase cash crop yields in most studies (Daryanto et al, 2018), while another found that additions of multiple crops did not negatively affect primary crop yield (Iverson et al., 2014). In a semi-arid region of South Africa, maize-bean intercropping was found to increase productivity, both in terms of crop yield and land use, while sorghum-cowpea-bottle gourd intercropping had a 46% increase to monoculture (Chimonyo et al., 2016; Tsubo et al., 2004). Wheat-maize intercropping in an arid region in northwestern China also significantly increased productivity as did potato intercropping in Mediterranean conditions in Tunisia (Hu et al., 2017; Rezig et al., 2010). However, in some studies, yield depended on cover cropping species. For rice cropping, Poaceae cover crops (grasses) decreased yield, while legumes increased it (Daryanto et al., 2018). A study in a Mediterranean agroforestry system determined that intercropping of walnut and barley increased yields by 55% in the first year and 15% in the second year when compared to monoculture (Arenas-Corraliza, et al., 2018). On the other hand, a system of walnut and wheat did not experience increases in production, yet grain quality did improve substantially. In both cases, the land equivalent ratio showed that the agroforestry systems were more productive than sole cropping (Arenas-Corraliza et al., 2018).

Certain lands will also bring higher profitability than others, as intercropping will have greater impacts in areas with infertile or saline soils where conventional monoculture may no longer be viable (Abadi, 2003; Geno & Geno, 2001; Kermah, 2017). Land with low opportunity costs are ideal plots development of intercropping systems; land that has depreciated in value is often a result of infertility, a barrier for most monocultures, but not for certain intercropping systems (Abadi, 2003; Geno & Geno, 2001). Furthermore, soils with low clay content are more responsive to the implementation of intercropping (Morugán-Coronado et al., 2020). Low clay content typically indicates lower potential fertility; however, intercropping can increase fertility and improve soil structure in soils with low clay ratios, resulting in higher increases of crop yields than in soils that originally had high fertility (Geno & Geno, 2001; Morugán-Coronado et al., 2020).

5.2 ECONOMIC RESILIENCE

Integrating multiple species within a plot not only provides increases in crop yields, but also allows for greater long-term economic stability. Intercropping has shown to stabilize yields in addition to increasing total returns, decreasing economic risk over time (Geno & Geno, 2001; Singh et al., 2013). By ensuring prolonged soil health and avoidance of soil degradation, agricultural lands have a much longer life span (Geno & Geno, 2001). Industrialized monoculture that utilizes synthetic fertilizers and pesticides destroys soil communities and limits the long-term productivity of farmlands, potentially leading to complete futility due to salinization, infertility, pest disturbances, or other issues that result from unsustainable management (Morugán-Coronado et al., 2020; Stevens, 2001). Such declines are exacerbated by climate change, emphasizing further fragility of current agricultural systems (Perrone, 2018; Schoeneberger et al., 2012). In fact, productivity of many species in the Central Valley is predicted to decline significantly by the 2060s (Pathak et al., 2018). This includes predictions of 40% declines in avocado production and up to 20% declines in almond, walnut, grape, and orange yields, as well as reduction in cherry, strawberry and apricot yields (Pathak et al., 2018). While currently revenue from the San Joaquin Valley is declining at a rate of around 10%, switching to intercropping has the potential to combat and reverse such intense economic consequences of conventional monoculture and decrease agricultural systems vulnerability to climate change (Hanak et al., 2019).

Furthermore, intercropping systems with multiple cash crops are more resilient to external variables and resource use efficiency. By diversifying cash crop production, farmers are greater protected from species-specific market volatility and crop failures, as well as from pests and disease incidents (Araújo et al., 2017; Brito, 2010; Morugán-Coronado et al., 2020; Schoeneberger et al., 2012). They also have greater ability to withstand intense weather events such as droughts (a prevalent issue in the Central Valley) and the changing conditions that result from climate change (Morris & Bucini, 2016; Daryanto et al., 2018; Krishnamurthy et al., 2017; Schapiro, 2019; Schoeneberger et al., 2012). One reason that these crops experience greater drought tolerance is due to interspecies competition, as crops develop more complex rooting systems to obtain necessary nutrients, with trees and other cash crops often developing deeper roots (Balbinot Junior et al., 2017; Cardinael et al., 2015; Droppelmann et al., 2000; Schoeneberger et al., 2012). These deep rooting systems also cause hydraulic lift to shallower roots, allowing them to access water that would typically be lost from monoculture systems (Lawson et al., 2019; Schoeneberger et al., 2012). As temperatures are predicted to rise in the Central Valley by 3.5 to six degrees Fahrenheit and water availability will decrease while precipitation become more erratic, it is critical that agricultural systems be resilient to such changes (Schoeneberger et al., 2012; DiPietro, 2017).

5.3 POTENTIAL COSTS

There are some additional costs to intercropping, which is one reason some farmers are hesitant to transition from monoculture practices. The increased costs of purchasing seeds and propagation for additional crops is one factor, although the extent of this cost is dependent of the additional species. For example, if farmers aim to plant cover crops such as clover, seed costs and propagation efforts will be minimal, while these costs for cash crops such as almonds or other tree species will be much higher (Holtz et al., 2016). However, cash crop seeds with higher initial costs will often lead to higher profits over time, ultimately outweighing initial production costs (Singh et al., 2013). Nonetheless, if additional crops are planted and remain in the system, initial costs will not be tangibly returned unless yields of cash crops increase (Holtz et al., 2016).

Furthermore, labor costs are also higher when multiple species are present, as a diverse array of crops have to be cultivated, each often requiring different tools and techniques (Singh et al., 2013). Due to the lack of diverse mechanical equipment required for planting, maintaining and harvesting multiple crop species, mechanical work often has to be replaced with human labor, thus increasing labor costs (Geno & Geno, 200; Kass, 1978; Schapiro, 2018). However, this labor is found to have high efficiency of yield per unit of manual labor input, often resulting in higher incomes (Geno & Geno, 2001). Some of these costs can be balanced by the ability farmers gain to charge higher prices for organic foods, also known as the "organic premium" (Schapiro, 2019). Ultimately, intercropping requires a higher initial investment and higher cultivation cost, which could be a deterrent to some farmers, but also results in higher net returns and net returns per U.S. dollar invested than sole cropping practices (Geno & Geno 2001; Singh et al., 2013)

Difficulties of utilizing machinery in intercropping plots poses challenges for large scale industrialization. Agricultural mechanization is often dependent on uniformity, which is often uncharacteristic of most intercropping systems (Geno & Geno 2001). However, some systems have been found to be capable of mechanization utilizing existing machinery, including barley-red clover, oat-lucerne hay, canola-field peas, wheat-peas and barley-field beans (Geno & Geno, 2001). Scalability to large scale industrial agriculture is also dependent on spacing patterns, as with mixed intercropping and permaculture, utilizing mechanical technology can be more difficult than under strip cropping or alley cropping, as species overlap disrupts machinery's ability to operate (Table 1) (Geno & Geno, 2001; Schapiro, 2019; Stinner & Blair, 1990). Alley cropping systems can be implemented without much disruption to conventional harvest techniques, and thus have higher commercial viability (Table 1) (Abadi, 2003). Relay cropping has similar implications, as limited overlap of interacting species increases the system's ability to handle mechanization (Table 1) (Sinner & Blair, 1990). Although the goal of these practices is to this decrease either time or space overlaps of diverse species to increase uniformity, this may decrease the functional ecological relationships between component crops (Geno & Geno, 2001).

Furthermore, due to the high diversities of cropping arrangements, climates, inputs, soil properties etc., each system needs individual management, requiring farmers to have greater specialized expertise, and making the application of generalizations of input factors almost impossible (Geno & Geno, 2001; Gomez & Gomez, 1983; Perrin, 1980). Farmers must have greater knowledge of ecological interactions and individual crop properties to effectively manage the complexities of intercropping systems, rather than using cookie cutter models promoted by industrialization (Conway, 1987; Geno & Geno, 2001). Therefore, intercropping practices are more time and management intensive than the implementation industrial systems.

6.0 WHAT WOULD WORK IN THE CENTRAL VALLEY?

6.1 RESULTS OF EXISTING INTERCROPPING FARMS

Within the California Central Valley, very little research has been completed in regard to the effects of intercropping on water conservation. However, farms that have transitioned from monocultures have found it to have positive effects on soil health and water holding capacity (Andrews et al., 2002; Schapiro, 2019). Research by the University of California Cooperative Extension and University of California, Davis has focused on the implications of cover cropping on soil communities within the San Joaquin Valley and found positive results, however the studies were mainly focused on winter cover crops instead of implementation alongside primary crops (Mitchell et al., 2015; Mitchell et al., 2017; Schmidt et al., 2018; Veenstra et al., 2006).

Fortunately, there is more evidence of success from anecdotal reports of commercial farms that have utilized sustainable practices than from peer-reviewed research. For example, the *Burroughs Family Farm* in Denair has implemented year-round cover cropping on almond orchards and found it to greatly increase soil health as well as the soil's ability to absorb water. The farm has reported decreases in dependence on groundwater and greater overall resilience with similar net-revenues as conventional farmers in the area (Schapiro, 2019). Jose Robles has also instituted cover drops on his Modesto almond farm, a decision he made as a result of having to cut down on water. As a result, the farm's almond tress hold moisture much longer, decreasing water usage and water costs (Sommer, 2019). Although, intercropping has increased his overall inputs costs and labor costs, his business has increased net profits due to a $21,000 grant from the state of California (Sommer, 2019).

Several other farms have also found positive results from implementing intercropping in the Valley. For example, *Windfall Farms* has successfully plants alfalfa and cotton together, alongside hedgerows (Sustainable Cotton Project, 2019). In Firebaugh, *Lone Willow Ranch* also successfully utilizes intercropping of a plethora of different crops, including emmer, clover, wheat, winter rye, daikon, bell beans, peas, and vetch (University of California Division of Agriculture and Natural Resources, 2020b). Additionally, *Paicines Ranch Vineyard* has utilized rye, barley, vetch, crimson clover and radish cover cropping in between grape vines to increase soil nutrients through alley cropping (University of California Division of Agriculture and Natural Resources, 2020c). Overall, Central Valley farmers utilizing intercropping have found increases in environmental and economic sustainability while remaining profitable.

6.2 INTERCROPPING OPTIONS

The most effective way to implement intercropping is to utilize crops that do not directly compete for resources (Coolman & Hoyt, 1993; Lawson et al. 2019). Many farmers believe that introducing more crops will create greater competition within their systems, particularly for water and nutrients (Morugán-Coronado et al., 2020). This is especially the case in Mediterranean climates, as they undergo dry seasons in which water stress is often an issue (Morugán-Coronado et al., 2020). However, over-competition can be avoided through intensive planning to ensure the species are complementary (Coolman & Hoyt, 1993; Iverson et al., 2014; Morris & Garrity, 1993). The best option for arid regions is to plant crops that fill niches within the ecosystem where resources are underutilized by existing species (Ong & Leakey, 1999). For example, planting shallow rooted crops alongside deep rooted crops allows each species to exploit a different portion of the soil profile for water and nutrients. Another example is planting a species with high nitrogen intake in a system where current plant species (e.g. legumes) supply that nitrogen. Differing patterns and durations of rooting and resource capture can ensure that species will avoid intense competition (Ong & Leaky, 1999). In dry conditions, planting deeper rooted crops such as trees can also improve the water availability for short rooted crops through hydraulic lift, as plants with deep roots can obtain water and nutrients from deeper horizons and move them up into more shallow horizons to help crops who have roots in said horizons (Lawson et al., 2019; Morugán-Coronado et al., 2020). Drought tolerant crops are the most suitable choice overall for San Joaquin farmers, as they require less water and are more resilient to water stress, meaning minimal input would be required to ensure their success.

Intercropping with legumes seems to be the most economically and environmentally sustainable option for Central Valley growers. Legume cover cropping has found to have more positive effects on yields than non legumous cover crops (Collman & Hoyt, 1993; Daryanto et al., 2018; Iverson et al., 2014; Morugán-Coronado et al., 2020). For example, one meta-analysis found that out of 1005 studies with leguminous cover crops, there was a 27% average increase in crop yields, while 1282 studies with non legumous cover crops found to increase crop yields but just 6% (Daryanto et al. 2018). An additional meta-analysis found legumes to be good candidates for alley cropping in arid areas as they result in lower transpiration rates than members of the Poaceae family (Morugán-Coronado et al., 2020). Figure 7 illustrates a potentially viable intercropping option for a semi-arid environment utilizing legumes and the factors that would be affected by its implementation (Figure 7).

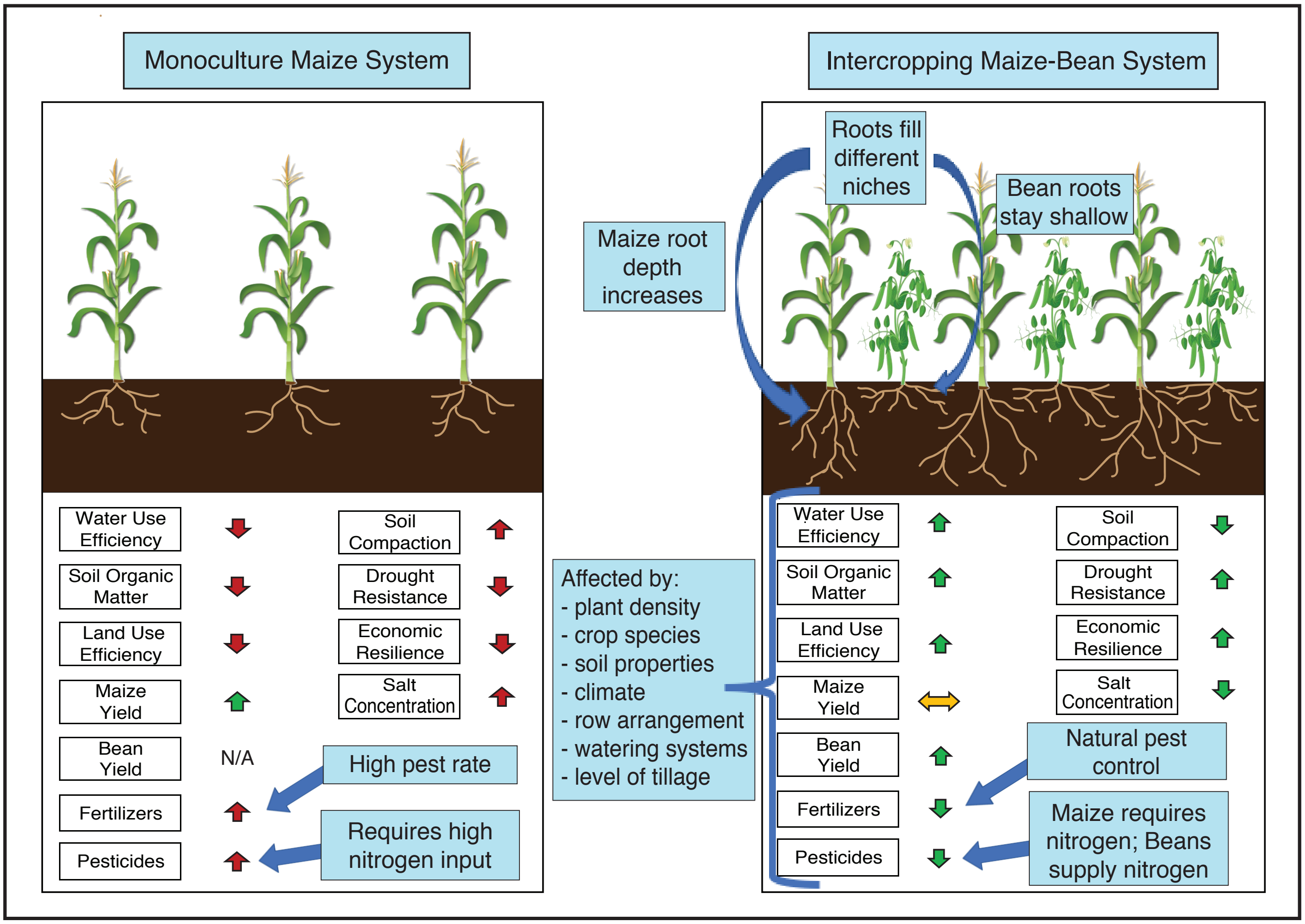


Figure 7. An ideal intercropping option for a semi-arid region and its potential impacts

The option of substitutive versus additive designs provides farmers with further options of how to implement intercropping. Additive designs increase plant density by intergrading new crop species into the same number of primary crops, increasing land usage efficiency and ensuring productive yields of a secondary crop when a legume species is used (Iverson et al., 2014). If farmers are focused on yield optimization of their primary crop and worried about competition when not utilizing legumes, a good option is to utilize substitutive designs for intercropping. These layouts hold plant densities constant, but replace primary stems with a secondary crop to reduce intraspecific competition. Utilizing this type of design has found to improve primary crop yields, regardless of whether the secondary crop was legumous or not (Iverson et al., 2014).

For cover crops and crops planted for non-harvest reasons, there are other effective strategies to managing water competition and to avoid increased water use under dry conditions. This includes planting annual crops instead of perennials, which can be removed during critical periods when resources such as water and nutrients are most critical for cash crops. This is especially relevant for tree yields, as removal of alley crops during this time prevents competition while fruit is forming, while still providing other benefits to the ecosystem (Morugán-Coronado et al., 2020). Cover crops can also be planted during the off season of primary crops, still functioning to improve soil properties such as water holding capacity and infiltration, but ensuring no competition occurs between cash crops and these additional species (Daryanto et al. 2018).

6.3 ECONOMIC LIMITATIONS

Economic viability of utilizing additional crops is also dependent on the market values and plasticity of such crops within California markets. Eucalyptus for example, has high potential as an option for mitigating water quality issues, but there is not much market for the product within the Central Valley (Knapp & Sardorsky, 2000). That being said, utilizing agroforestry with timber trees is currently not an economically viable option for implementation in the Valley without further development of markets for agroforestry products, as well as establishment of shadow values for drainwater and soil maintenance (Knapp & Sardorsky, 2000). Agroforestry utilizing timber trees is likely to only be financially sustainable in areas where trees can directly compete on commercial terms with conventional agriculture (Lefroy & Stirzaker, 1999).

Additionally, land costs can be high in many regions of the Central Valley limiting the number of species that would be economically viable. These prices depend on soil quality and water availability, as well as crop varieties (Fitchette, 2020; USDA National Agricultural Statistics Service, 2019). In 2019, almond orchards were priced from $32,000 to $40,000 per acre and fruits groves ranged from $25,000 to $30,000 per acre in the Central Valley, while the average cropland value in the U.S. was $4,100 per acre (Fitchette, 2020; USDA National Agricultural Statistics Service, 2019). Due to these high input costs, crops must have high returns in order for farmers to have incentive to incorporate them into planting regimes, thus limiting the diversity of applicable intercropping systems in the Central Valley. These high land costs increase the risk of intercropping investments within the Valley, as the high opportunity costs can make farmers hesitant to engage with unfamiliar methodologies (Lynam et al., 1986). If crops currently have high returns, such as almonds, farmers are much less likely to dabble in new cultivation practices, as they don't want to risk losing current profits (Bittman, 2012; Lynam et al., 1986). Resultantly, in the current political climate, intercropping has greatest potential as a restorative practice on land that has either depreciated in value or been retired due to infertility and salinity issues, or for farmers who have slim returns (Abadi, 2003; Geno & Geno, 2001).

7.0 POTENTIAL TO IMPROVE WATER QUALITY IN THE VALLEY

7.1 SALINIZATION IN THE VALLEY

Agroforestry systems effectively manage drainage waters in irrigated areas, and decrease problems associated with salinization in regions such as the San Joaquin Valley (Knapp & Sardorsky 2000; Hanak et al., 2019; Schapiro, 2019). High salinity levels can build up in both soils and groundwater, and are often caused by water mismanagement and fertilizer application in combination with drainage issues (Dagar & Minha, 2016). Salts from fertilizers and irrigation water leach into groundwater, increasing its salinity and making it harmful to crops (Knapp & Sardorsky 2000). When too much irrigation water is added to a plot which cannot drain efficiently due to impervious geological strata, the water table rises, causing salinized groundwater to deposit salt into shallow soil horizons (Dagar & Minha, 2016; Hanak, et al., 2019). Over time, these salts build up in root zones of crops, preventing them from taking up water, which leads to yield declines (Howitt et al., 2009; Hanak et al., 2019). In addition to decreasing yields, salinization leads to increased production costs, reduced groundwater availability, and land degradation, as soils become unsuitable for agricultural use as well as wildlife habituation (Dagar & Minha, 2016; Hanak et al., 2019).

The Central Valley is no stranger to salinization issues of both its groundwater and soils. Groundwater salinity levels have reached thresholds that have led to decreased crop yields in many regions of the Valley (Figure 8), while soil salinity has led to the retirement of roughly 250,000 acres, with another 1.5 million acres considered to be salt-impaired (Hanak et al., 2019; Kelly, 2011). To combat decreasing yields due to salinity issues in impaired regions, farmers are forced to grow lower value, salt tolerant crop varieties and face costs of salt removal (Howitt et al., 2009). If salt accumulations are not managed properly in the Valley, direct economic costs are projected to reach more than $1.5 billion annually by 2030 and job losses could reach 27,000 to 53,000 jobs within the Valley (Howitt et al., 2009). These salinity issues can be explained through over watering with salt intensive water and water mismanagement within systems with poor soil quality as a result of unsustainable practices (Hanak et al., 2009). These drainage issues need to be addressed in order to prevent further decreases in economic productivity and to protect groundwater for future use (Hanak et al., 2019).

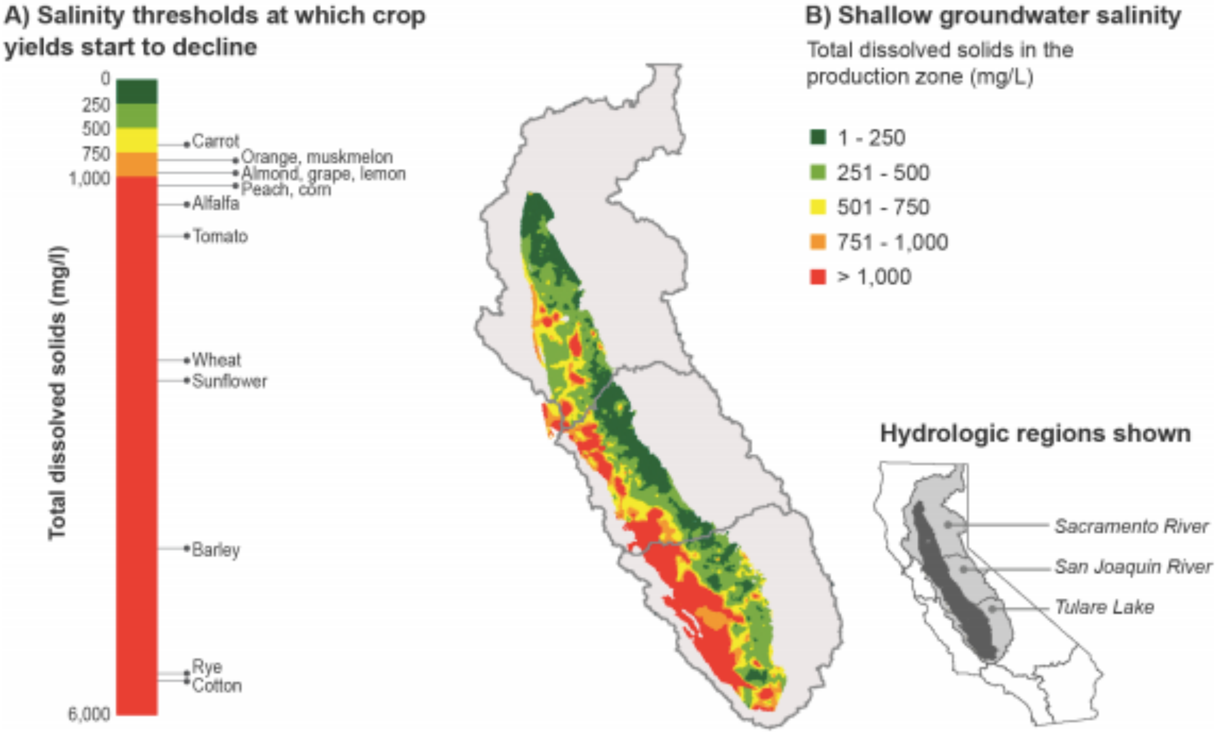


Figure 8. Salinity thresholds at which crop yields decline and corresponding groundwater salinity levels in California's Central Valley (Hanak et al., 2019)

7.2 PROMISES OF INTERCROPPING

Intercropping can address salinity problems via reduced water and fertilizer use, as well as decrease drainage issues through enhancements of soil quality, ultimately increasing productivity and decreasing production costs (Gupta et al., 2016). Problems with drainage have historically been "solved" with tile drainage systems which disposed of waste water into rivers, lakes and other bodies of water, causing contamination from fertilizers and pesticides, eutrophication, and salinity issues (Howitt et al., 2009; Knapp & Sardorsky 2000; Kasler, 2019; Posnikoff & Knapp 1996; Schapiro, 2019). Statewide, approximately 9,500 miles of streams and rivers and 513,000 acres of lakes and reservoirs are considered impaired by irrigated agriculture (Howitt et al., 2009). One instance of this impairment occurred during the 1980s when hundreds of dead waterfowl and deformed embryos were discovered in the Kesterson Wildlife Refuge due to agricultural runoff that was tainted with salt and selenium as a result of poor soil drainage (Kasler, 2019; Ohlendorf, 2002). In response, over 85,000 acres of farmland in Fresno was shut down in an attempt to prevent further contaminated run off from draining into the environment (Kasler, 2019). Such a substantial loss in agricultural land leads to significant and long-lasting declines in productivity and other direct economic costs, such as job losses and intensified food insecurity. As one of a suite of intercropping practices, agroforestry provides a sustainable alternative to more water-intensive monocropping systems, decreasing externalities from run off contaminated with fertilizers and salts, thus reducing long term economic clean-up costs (Posnikoff & Knapp 1996). Simultaneously, crop yields will also increase as soils remain healthy and salinity is minimized (Posnikoff & Knapp 1996).

Certain salt tolerant tree species, such as eucalyptus, can be planted for the purpose of reducing salinization issues, as well as removing other contaminants from drain water. These trees can utilize contaminated water to reduce hazardous drainage flows (Marcar, 2016; Minhas & Dagar, 2016). In turn, this decreases saline water runoff and reduces the amount of polluted water that would otherwise leach into groundwater beyond the root zone (Marcar, 2016; Minhas & Dagar, 2016; Posnikoff & Knapp, 1996; Turner & Ward, 2002). Such decreases in contamination are in part the characteristic ability of trees to function as sinks for water, certain nutrients (e.g. nitrogen) and pollutants (e.g. metals) (Yadav et al, 2016). As so, drainage water is further cleansed of pollutants, as heavy metals and nitrates and phosphates are stored in tree bark and wood rather than disposed of into local water ways or leached into groundwater (Yadav et al., 2016). Eucalyptus has found to be especially effective at removing contaminants, reducing nitrate and phosphate leaching by 75% in one study (Rockwood et al., 2004). As a result, groundwater used for irrigation holds higher quality and poses less health risks to both farmers and consumers of grown products (Yadav et al., 2016). Agroforestry has also been found to effectively decrease saline groundwater table rises (Marcar, 2016; Theiveyanathan et al., 2016). In one semi-arid region of Australia, planting trees led saline groundwater tables to decline by 1 to 2 meters, and overall decreased salinity levels of the groundwater by 6% to 9% (Bari & Schofield, 1991). By decreasing saline water tables, salt accumulation in the root zones of crops declines and crop production increases in turn (Dagar & Minhas, 2016).

Agroforestry also enables effective implementation of drain water reuse, as decreases in salinity as a result of soil health, diversity of species, and decreased use of fertilizers and pesticides increases water's potential to be viable for second time usage (Knapp & Sardorsky 2000; Theiveyanathan et al., 2016). With the implementation of drain water reuse, agroforestry systems have been found to be even more economically profitable and further decrease water waste (Knapp & Sardorsky 2000). However, it is critical that water be properly treated before reuse to ensure salt and minerals are at safe levels for reapplication to avoid downstream contamination such as what happened at the Kesterson Wildlife Refuge (Ondrasek et al., 2014). Historically, treatment technologies are expensive, but agroforestry and other intercropping systems can decrease such costs by improving soil quality, including decreasing soil salinity levels, and reducing fertilizer and pesticide residues in drainage water, and thus other treatment may sometimes be unnecessary due to the higher quality of the water (Ondrasek et al., 2014; Theiveyanathan et al., 2016; Yadav et al., 2016). Healthy soils are a critical part of water use efficiency, and thus, improving soil quality comes with the potential of less water waste.

8.0 WHY IS THERE AN ABSCNECE OF INTERCROPPING IN THE VALLEY?

8.1 CORPORATE AND INDUSTRIAL CONTROL

The lack of intercropping and use of sustainable practices can be explained by several reasons. First of all, policies within the Central Valley encourage agriculturalists to continue to use unsustainable practices. Industrial agriculture that utilizes pesticide and fertilizer receives billions of dollars in subsidies from the state government, and the majority of Research and Development (R&D) funding is focused on improving efficiency of such practices (Morris & Bucini, 2016; Schapiro, 2019). The majority of industrial agriculture is focused on maximizing profits and therefore, maximizing product outputs. As a result, farmers are often forced to prioritize producing as much as possible in the short term to achieve profitable returns by utilizing practices that result in long term consequences such as ground water depletion and soil degradation (Edwards, 2018). Both of these factors will lead to declines in long term productivity and have the potential to devastate the agricultural industry, as once soils are completely depleted, conventional monoculture systems are no longer viable (Geno & Geno, 2001). Removing government subsidies and R&D funding from these destructive practices and rerouting funds towards sustainable development is a critical step in achieving long term stability.

Currently, funding for intercropping and other sustainable practices is insufficient to increase their implementation, as conservation funding is often allocated to increase sustainability within industrial systems. In fact, the largest proportion of USDA's sustainable agriculture grants are allocated for this purpose instead of actually increasing the system's long-term sustainability (Morris & Bucini, 2016). As of 2014, only 10% of the United States Department of Agriculture's (USDA) Research, Extension and Economics (REE) grants funded environmentally sustainable projects, or approximately $294 million of $2.8 billion (DeLonge et al., 2016). Of this funding, 36% went towards conservations strategies within conventional systems, with a focus on increasing yields rather than implementing long-term sustainable practices (DeLonge et al., 2016). On the other hand, less than 1% of conservation funding went to agroforestry projects and only 6% went towards cover cropping, less than 0.1% and 0.6%, respectively, of the total USDA REE budget (DeLonge et al., 2016). Such allocation of funding demonstrates that the government's focus on conservation developments remains secondary to larger, more profitable ventures of industrial agriculture (DeLonge et al., 2016)

Various farm bills are another example of how federal policies have emphasized the importance of maintaining industrial practices over the implementation of sustainable ones. Although these bills claim to focus on increasing sustainability, only a small portion of its programs are focused on such, with insignificant funding going towards encouraging sustainability (Congressional Research Service, 2019; Morris & Bucini, 2016). The 2018 Farm Bill (P.L. 115-334, 2018) totaled at $867 billion, yet only $29 billion was been designated for conservation, own from $56 billion from the 2014 Farm Bill (P.L. 113-79, 2014) (Congressional Research Service, 2019; Lustgarten & Sadasivam, 2015). Additionally, funded conservation efforts encompass a focus on reducing water consumption through modern equipment and other technologically motivated conservation strategies, rather than through ecologically sustainable ones (Congressional Research Service, 2019; Lustgarten & Sadasivam, 2015). In fact, both 2014 and 2018 bills cut funding for the Conservation Stewardship Program, a program which encourages sustainable practices such as cover cropping and crop rotations (National Association of Conservation Districts, 2019; Olmstead, 2018). Instead, the farm bills have consistently focused on protecting industrialized, large scale commercial agriculture, providing farmers that engage in unsustainable practices with large subsidies, including $38 billion through crop insurance and $31 billion through crop support and disaster relief in the 2018 bill (Congressional Research Service, 2019). This is after the 2014 bill designated $130 billion in protections against economic and environmental instability, both of which could be ameliorated through intercropping practices (Geno & Geno, 2001; Lustgarten & Sadasivam, 2015).

Financial and political influence of large corporations also play a role in the impediment of sustainable practice developments in the agricultural sector. In particular, their overwhelming influence on legislative processes. Farm bills and annual presidential budget requests govern food aid policies, requiring the U.S. Congress to approve policy changes. This process has enabled private actors to penetrate policy formation processes through lobbying efforts and promises and threats regarding political support (Clapp, 2009). In doing so, corporations are able to pressure governing bodies into increasing funding into their desired areas and strengthen their overall power over the agricultural sector. This causes government agencies to enact policies that promote industrial systems that utilize corporate products, including the cultivation of certain crops such as wheat, rice, and soybeans, as well as discouraging transitions away from pesticides and fertilizers usage (Clapp & Fuchs, 2009). As a result, corporate systems command market pressures throughout the U.S. and Central Valley, controlling agrochemical markets, dominating seed markets, and governing food processing and retail (Clapp & Fuchs, 2009; Morris & Bucini, 2016).

8.2 UNSUSTAINABLE SUBSIDIES

Through these political frameworks, large corporate farms hold influence over the amount of aid they receive from government handouts, thus decreasing funds directed towards sustainable practices. These farms receive the majority of government subsidies, with 60% of subsidies from the three largest handout programs allocated to farms with the highest 10% of crop sales (Bekkerman, et al., 2018; Edwards, 2018). Between 1995 and 2017, the top 1% of subsidy recipients were allocated 26% of the $205.4 billion distributed, averaging $1.7 million per company (Amadeo, 2019; Edwards, 2018). As so, corporate farms are rewarded with more subsidies for higher production rates, encouraging excessive cultivation while disregarding the compounding environmental issues that pursue (Olmstead, 2018). Additionally, there are no income limits on some forms of farmer handouts, such as crop insurance, enabling millionaires and billionaires to be funded through taxpayer money, with fifty individuals on the Forbes 400 list of wealthiest Americans doing so (Amadeo, 2019; Edwards, 2018). Ultimately, this leads to greater incentive to maintain large scale conventional monocropping systems, resulting in externalities for the environment as a whole. Decreasing corporate power in governing bodies and placing income limits on handout programs are thus critical steps in increasing the implementation of sustainable systems.

In part due to corporate lobby groups, the majority of crop subsidies are allocated to a select few crops, several of which are high water consumers, encouraging water intensive agricultural systems within areas of high water scarcity (Clapp & Fuchs, 2009; Edwards, 2018; Zamora et al., 2015). Cotton growers are one of the biggest recipients of government subsidies in California, receiving over $3 billion from farm bills in since 1995 (Lustgarten & Sadasivam, 2015; Zamora et al., 2015). Cotton is also one of the biggest water users in the agricultural industry, requiring 20,000 liters to produce one kilogram (World Wildlife Fund, n.d.). However, California cotton producers lack the incentive to be concerned about high water usage amidst drought conditions because they are ensured funding from the government (Lustgarten & Sadasivam, 2015). Specifically, these subsidies alone are often enough to keep farmers afloat, at times covering their entire premium and ensuring they will be financially protected regardless of climatic conditions (Amadeo, 2019; Lustgarten & Sadasivam, 2015).

Similar circumstances are prevalent for other water consumptive crops, such as rice and corn (Amadeo, 2019; Lustgarten & Sadasivam, 2015). Highly subsidized crop insurance programs further encourage and maintain these cropping systems, as such programs protect farmers against crop failures and market fluctuations in monoculture systems (Morris & Bucini, 2016). Growing cotton, corn and other water intensive crops is simply not viable in arid and semi-arid conditions, and with increasing water scarcity increasing in the Central Valley, crop failures will inevitably increase (Amadeo, 2019). Yet, farmers remain protected with a false sense of economic stability due to government funding, disincentivizing them to transition to genuinely economically resilient systems (Amadeo, 2019; Morris & Bucini, 2016).

The security of these government subsidies discourages farmers from utilizing more drought tolerant species, as ultimately growing subsidized crops is the safest, most risk adverse option for producers (Lustgarten & Sadasivam, 2015; Zamora et al., 2015). As a result, land use and crop choices are distorted, creating moral hazards for farmers as they are incentivized to engage in monoculture systems with crops that maximize their subsidies, regardless of market efficiency (Edwards, 2018). These subsidies also discourage crop rotations, intercropping practices and diversification of crop planting in favor of only planting subsidized crops, in turn leading to higher pesticide and fertilizer usage (Edwards, 2018). Although corporate lobby groups may make it near impossible in the current political climate, it is critical that these water intensive crops not be subsidized (or at least to a lesser degree) and that the allocation of these subsidies be revised to stimulate increases in sustainability.

Since 1997, the federal government has in part acknowledged high water usage as an issue in arid and semi-arid areas, providing around $1 billion dollars in subsidies to increase irrigation efficiency through better irrigation equipment, with half of this budget going to states with water deficiencies (EWG, 2004; Nixon, 2013). However, this has ultimately increased overall water use, enabling farmers to pump groundwater more efficiently and faster than before, rather than searching for water efficiency through ecologically sustainable systems (Edwards, 2018; Nixon, 2013). Studies have shown that when irrigation is available for cropping, less intercropping occurs as farmers have less reason to implement strategies that conserve water (Geno & Geno, 2001). Irrigation systems and external water outputs encourage farmers to disregard the limiting climate factors in which they reside (Geno & Geno, 2001; Nixon, 2013). Plant growth is dependent on precipitation, but when a farmer can substitute precipitation with irrigated water supplies, they become less reliant on precipitation levels in a region, enabling them to grow more water intensive species (Geno & Geno, 2001). Thus, overall water usage increases and climatically fit systems are not implemented.

Currently, Central Valley farmers also receive subsidies for water through the Central Valley Project (CVP), incentivizing high usage due to decreased costs (Environmental Working Group (EWG), 2004; Kelly, 2011.; Schapiro, 2019;). As of 2004, CVP farmers were estimated to receive annual water subsidies of $416 million, funded by taxpayer dollars (EWG, 2004; Kelly, 2011.). The majority of these subsidies are controlled by the largest farms, with the largest 5% of farms receiving 49% of the funded water, averaging a worth of $513,000 at the market rate for replacement water (EWG, 2004). One farm in Fresno County, *Woolf Enterprises*, received more water than 70 CVP water districts, at a price equivalent to $4.2 million at market rate (EWG, 2004). As a result of these subsidies, CVP farmers pay an average of $17.14 per acre foot, an equivalent to 2% of what Los Angeles residents pay at $925.00 per acre foot (Figure 9) (EWG, 2004). These relatively low costs of water incentivize increased usage, especially for industrial farms. Instead of subsidizing water itself and providing subsidies for water intensive systems, it would be more effective to provide subsidies to farmers that utilize drought tolerant crops and water conservation strategies, as well as providing rebates or tax credits for decreased water usage. If water subsidies cannot be demolished, regulation preventing farmers who receive subsidies from increasing their water usage would be a smaller, yet still important, step.

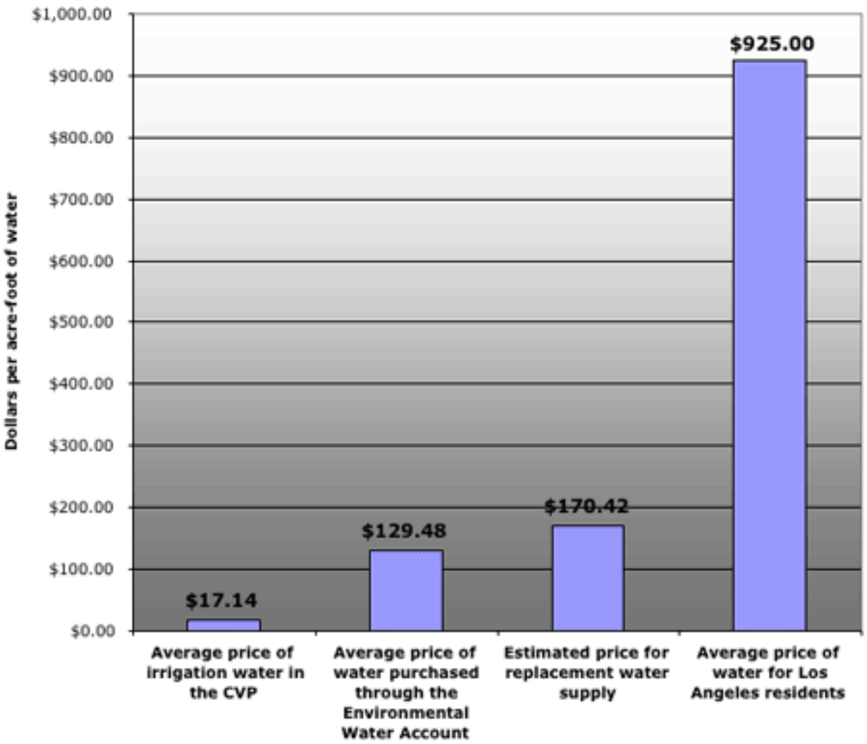


Figure 9. Central Valley Project (CVP) water subsidies lead to low water prices for CVP farmers

8.3 CURRENT AND POTENTIAL REGULATIONS

There are two main ways of encouraging the transition away from industrialized monoculture towards intercropping and sustainable practices. The first is to increase the economic costs of engaging with industrial systems to the point where costs outweigh the benefits. The second is to decrease the costs of sustainable systems so that they are cheaper to implement than conventional monocultures. Both incentive implementation of sustainable systems as overall costs would be lower than industrialized monoculture. Potential economic mechanisms for such include increasing taxes, fees and charges on harmful behavior relating to conventional systems, and subsidies rebates, and tax credits to beneficial behavior relating to sustainable systems. However, due to corporate lobbying and political power, these economic changes can be difficult to implement, nonetheless, are important considerations when encouraging sustainability.

While much progress still needs to be made towards environmental regulations that promote sustainability, there are some current policies in place that are making positive strides towards encouraging farmers to transition to sustainable practices such as intercropping. The California Department of Food & Agriculture's (CDFA) 2017 Healthy Soils Initiative is one such program. The goals of this program include encouraging the protection and restoration of soils and to provide for research, education and technical support to facilitate such (Desai, 2018). From 2017-2019, the program allocated approximately $17.8 million in grants for subsidies to farmers and demonstration programs, an important step towards educating local stakeholders (California Climate & Agriculture Network, 2020; California Department of Food and Agriculture, 2019). As for 2020, $25.2 million in grants has been made available, indicating positive growth in the program (California Climate & Agriculture Network, 2020). Farmers that utilize cover crops, agroforestry, and other soil management methodologies are eligible for these grants, thus encouraging both ongoing and developing intercropping practices (California Department of Food and Agriculture, 2018). Although this is progress, these allotted funds cannot compare to the billions of dollars in subsidies that fund farms engaging in unsustainable practices (Desai, 2018; Schapiro, 2019).

The 2014 Sustainable Groundwater Management Act (SGMA) was one of the first policies instituted to in address the issue of high water use in California, requiring agriculturalists in the Central Valley to bring groundwater usage to a sustainable rate by 2040; one that matches the same rate at which it is replenished (Hanak et al., 2019; Kasler, 2019). As a result, farmers will have to cut groundwater use by one third of their current usage, or as much as 90,000 acre feet (Kasler, 2019). This will relieve Central Valley aquifers, reduce salinization issues, and decrease rates of compaction and subsidence, resultantly increasing water quality and reducing drainage issues (Hanak et al., 2019). However, many farmers in the Valley view SGMA as detrimental to their businesses, as it will force them to reduce production, retire land, and institute remanagement plans, ultimately decreasing economic proliferation when engaging with monoculture or other methodologies that require high water input (Kasler, 2019). Nonetheless, this requirement to decrease water usage is likely to create incentive for farmers to transition to less water intensive practices, such as intercropping, to lessen economic losses.

Regulation of water waste is another critical part of ensuring sustainability and could be another means of discouraging monoculture. Waste Discharge Requirements (WDRs) established through California's Porter-Cologne Water Quality Control Act (1969 & Amend. 2019) enable such regulation through a set list of conditions to which stakeholders must comply. Within the Porter-Cologne Act, Order WQ 2018-0002 (2018) issued by the Central Valley Regional Water Quality Control Board regulates WDRs from agricultural lands within the Valley and requires parties to monitor and report pollution levels. Under W.Q. 2018-0002 (2018), farmers must comply with Total Maximum Daily Loads (TMDLs), which limit the total pollution levels agriculturalists can emit. TMDLs include limits on nitrates, heavy metals, pesticides, salts, and pathogens, as well other harmful concentrates often present in waste discharge (Howitt et al., 2009). Parties subject to WDRs must pay an annual fee established by the State Water Resources Control Board at $0.56 per acre (WQ 2018-0002, 2018). If stakeholders do not comply with these regulation, they will face a $5,000-$15,000 fine per day of noncompliance (WQ 2018-0002, 2018). Increasing WDR fees, decreasing TMDLs, and increasing penalties for noncompliance are all proactive measures of incentivizing transition away from industrialized monoculture as increasing economic costs of utilizing synthetic chemicals and water mismanagement will encourage practices with minimal waste pollution, such as intercropping.

Greater regulation of fertilizer and pesticide usage through environmental protection policies as pollution caps or emission taxes and fees would be another mechanism to incentivize the shift towards intercropping, as with intercropping there is less reliance on both fertilizers and pesticides. This is due to the practice's characteristic ability to function itself as a pest management tool, while also increasing soil nutrient contents naturally (Coolman & Hoyt, 1993; Geno & Geno 2001; Iverson et al., 2014). Currently, pesticide and fertilizer use is indirectly managed through WDRs, and there are some regulations on their usage (e.g. more hazardous pesticides are restricted and user must be licensed and certified), but there are no total applied nitrate caps and application levels are mainly managed through self-reporting (California Department of Pesticide Regulation, 2017; Cheng & Thesing, 2017). To decrease negative externalities such as decreased soil quality and increased salinization rates, agrochemicals must be more directly regulated through maximum application levels and more reliable reporting systems. Subsidies for avoiding fertilizer and pesticide utilization would also be proactive, as farmers would look to natural ways to manage pests and nutrient contents, to which intercropping would be a viable solution. In addition, it also decreases input costs, as neither fertilizers nor pesticides or the machinery for their dispersal would need to be purchased, both of which can be expensive (Schapiro, 2019).

8.4 INCREASING RESEARCH AND RESOURCES

In order to validate intercropping's ability to conserve water and be economically viable, more studies need to be conducted specifically within the Central Valley. Research in other Mediterranean, semi-arid and arid environments may be applicable to some degree to the Central Valley, but the results cannot be overall generalized to ensure success within the Valley itself. Without research that proves economic viability in the Valley, intercropping is unlikely to expand. Financial uncertainties and economic risks are likely one of the biggest deterrents for industrial farmers to transition to sustainable practices, yet this is the area that in which research is most sparse (Geno & Geno, 2001; Zinkhan & Mercer, 1997). In order for transition to occur, more public funding must be made available through the state, both through subsidies directly to farmers to ease financial concerns, as well as for increased research in the Valley to determine economic and environmental viability. Furthermore, greater research on potential mechanization within intercropping must be completed, including development of technologies that can be applied to multi species system. The ability to mechanize systems on a large scale is an important factor in encouraging the industrialized part of the agricultural sector to implement sustainable practices.

Due to the complexity of intercropping systems and the necessary management expertise that comes alongside, it is difficult for farmers to engage with the practice without proper training or education on how the systems function. The number of components within an agricultural system directly limits the ability to create overarching models that can be applied on a wide scale (Geno & Geno, 2001; Vandermeer et al., 1998). Pesticides, fertilizers, mechanization, and irrigation have increased uniformity between systems and decreased component variabilities, enabling overarching models to replaced farmers' needs to understand ecological interactions, substituting nature within synthetic solutions (Geno & Geno, 2001). Such industrialization is typical in the Central Valley, as large, industrial farms head the agricultural industry (Bittman, 2012). As so, most Central Valley farmers lack the necessary knowledge and resources to effectively implement intercropping systems (Hanak et al., 2019). This being said, multi species systems incorporate a wide array of factors, meaning they are extremely site specific, so farmers must regain this understanding of their lands to properly comprehend how to alter individual components within a system to achieve maximum efficiency without synthetic inputs.

To promote this form of management would require a greater hull of resources, such as informational booklets, video demonstration or training workshops that could be implemented by the state. Research Conservation Districts (RCDs) are one potential option for increasing these resources for farmers. RCDs are third party entities that directly partake in conservation efforts with farmers and other stakeholders, providing scientific and engineering expertise (California Association of Resource Conservation Districts 2005). They are primarily funded by grants and private contributions, so are a prime resource for farmers (Hanak et al., 2019). However, annual budgets of RCDs in the Valley are some of the lowest in California, and their reach does not expand to many regions of the San Joaquin Valley, so many farmers do not have access to their resources (Figure 10) (Hanak et al., 2019). Increasing funding for RCDs and enhancing their reach, while ensuring that they have expertise in intercropping, could play a major role in supporting land transitions in the Central Valley. Additionally, greater funding for the Soil Health Initiative Program to expand its demonstration program, as well as to other resource entities such as the National Research Conservation Service (NRCS), UC Cooperative Extension and Farm Advisor systems would also be beneficial.

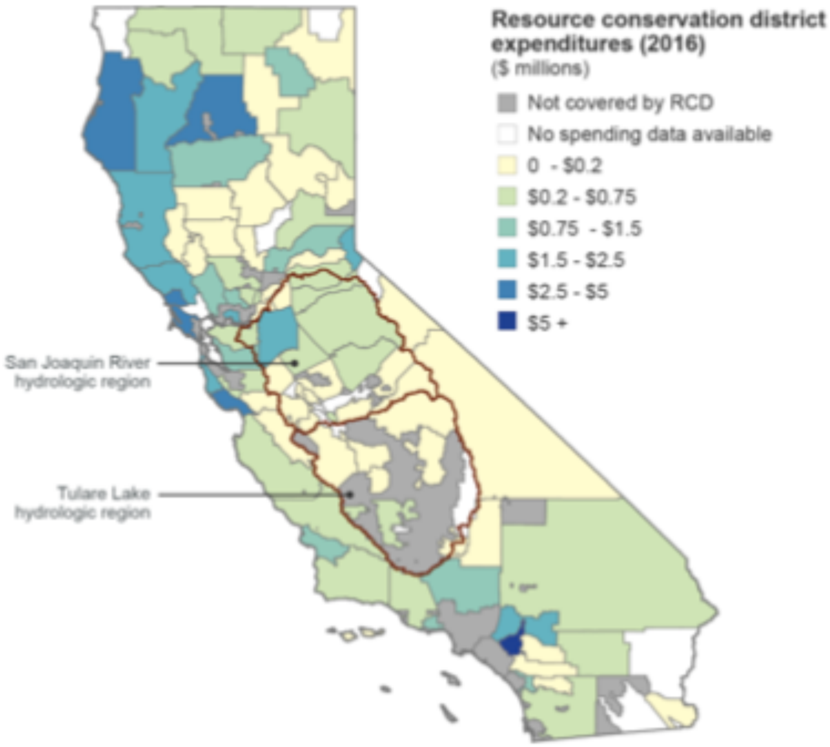


Figure 10. Research conservation district (RCD) coverage and funding in California (Hanak et al., 2019)

9.0 CONCLUSIONS

When implemented carefully and with attention to region- and site-specific physical geographic attributes, intercropping has the potential to save water for long term sustainability by increasing soil health, increasing water use efficiency and decreasing the total water wasted in a system. This practice can also increase yields, increase land use efficiency and enable farmers to be protect themselves against unexpected market fluctuations. Furthermore, it increases resilience to changing climatic conditions, such as droughts and rising temperatures. This type of sustainability and resilience is critical to achieve prolonged food security and maintain a healthy agricultural economy. Nevertheless, more effort is needed to incentivize the transition to this type of farming, to prioritize long-term needs over short-term profit maximization, and to reduce the over-dependence on increasing efficiency through industrialization. Technological advancements in the industrialization of agriculture have diverted attention away from the broader picture and taken valuable resources, such as government funding, away from sustainable solutions.

Although some progress has been made towards a sustainable future, greater research must be completed to better understand how best to protect the fragile environment which capitalism has created. Government policies need to be rerouted towards long term sustainability instead of funding corporate interests, ultimately requiring the reconstruction of governing institutions. As so, intercropping is only part of the solution to a problem that is intertwined in the foundation of American agricultural industry, an issue that spans beyond what changes it could accomplish.

Even if widely implemented, intense water usage and environmental degradation will continue at alarming rates. It is simple fact that many of the crops grown in the Central Valley plainly do not belong there. They are not designed to endure arid climates and intense droughts, yet humanity has attempted to work against nature rather than alongside it to achieve maximum profits. We must change our view of nature as the enemy and instead work with it to accomplish positive changes in our production cycles. It is our responsibility to future generations to begin to make proactive and tangible changes towards long term sustainability for all sectors of the Californian economy.

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