Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops

Part 4 of 5

Crop Switching in the Colorado River Basin: A Literature Review and Case Studies

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December 2017

CWI Completion Report No.232

Colorado Water Institute

Colorado State University

Acknowledgements

This report was financed in part by the U.S. Department of the Interior, Geological Survey, through the Colorado Water Institute. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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Project Background

This document is one of four separate reports created under a grant from the Walton Family Foundation to investigate ways to minimize harm to agriculture as water scarcity in the Colorado River Basin forces growing municipal and environmental water users to look at existing uses as potential sources of supply. Agriculture, the largest water user in the basin, is a frequent target in these efforts. The project, "Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops" was undertaken to create detailed reports of the four common methods used to temporarily transfer water from agriculture to other purposes. The four reports consider the following methods:

- Deficit Irrigation of Alfalfa and other Forages
- Rotational Fallowing
- Crop Switching
- Irrigation Efficiency and Water Conservation

After the reports were drafted, three workshops were held, one in the Upper Basin in Grand Junction on November 4, 2016, one in the Lower Basin in Tucson on March 29, 2017, and one in Washington, D.C. on May 16, 2017. All of the reports are available from the Colorado Water Institute website.

Acknowledgements

First, Greg Peterson and I thank the Walton Family Foundation for making this project possible. Without their funding and support, the project would not have happened.

Many people assisted with this project by reading and providing comments on drafts. We want to especially thank Perri Benemelis, Mike Bernardo, Perry Cabot, Aaron Citron, Michael Cohen, Bonnie Colby, Terry Fulp, Robert Glennon, Bill Hasencamp, Chuck Howe, Carly Jerla, Dave Kanzer, Doug Kenney, Kelsea MacIlroy, Jan Matusak, Sharon Megdal, Peter Nichols, Wade Noble, Michael Ottman, Ron Raynor, Adam Schempp, Tina Shields, MaryLou Smith, Pete Taylor, Reagan Waskom, John Wiener, and Scott Wilbor. Paul Kehmeier contributed a lovely photograph and important story. The work product was much improved by these insightful comments. It must be noted that any mistakes are solely mine.

Nancy Grice at the Colorado Water Institute provided critical support with financial reporting, travel assistance, and working with Colorado State University. MaryLou Smith was instrumental in organizing and chairing the outreach workshops. Reagan Waskom provided much needed intellectual support throughout the project. Beth Lipscomb assisted with overall editing at the end. Finally, a very special thanks goes to my co-author, Greg Peterson, who did much of the early, difficult research and writing. Much of the value of this project is in the extensive bibliographies that Greg created by painstakingly acquiring, reading, and summarizing hundreds of documents.

We thank Senator Michael Bennet and his staff for acquiring a room at the Capitol Visitor Center for the D.C. event. Finally, we extend our sincere appreciation to the approximately 100 participants who shared their precious time to join us for our outreach workshops. Thank you, all.

Brad Udall

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Abbreviations

AF	Acre-feet
ET	Evapotranspiration
FRIS	Farm and Ranch Irrigation Survey
IID	Imperial Irrigation District
MAF	Million Acre-feet
NASS	National Agricultural Statistical Service
PVID	Palo Verde Irrigation District
SARE	USDA Western Region Sustainable Agriculture Research and Education Program
USDA	US. Department of Agriculture
WMIDD	Wellton-Mohawk Irrigation and Drainage District

1 Summary

Crop switching has been proposed as a way to save large amounts of water in the West, including the Colorado River Basin. While in theory this technique is appealing as a way to save water, numerous studies and publications have shown that crop switching is difficult to implement because there are many complicated and potentially expensive issues to resolve. For a farmer, crop switching implies modifying much of what they depend upon to generate income.

1.1 Calls for Crop Switching Often Ignore Larger Economic and Market Forces

Large economic and market forces encourage farmers to produce many traditional, water-intensive crops. These crops have an entire production and risk management system built around them.

1.2 The Lower Basin has More Crop Switching Opportunities

For crop switching to work, the new crop must offer lower water usage, relative to the old crop. Unfortunately, the consumptive-use difference between crops in the Upper Colorado River Basin is often relatively small, because the Upper Basin has lower evapotranspiration due to cooler temperatures and a shorter growing season. This decreases the crop-switching advantages in the Upper Basin. A few locations in the Upper Basin, such as the Uncompahgre and Grand Valleys, do have climates that allow for many different crops. There are more crop-switching options in the Lower Basin because the climate there allows for greater crop selection, and because the longer growing season increases the water-use difference between high- and low-consumptive-use crops.

1.3 Farm Level Concerns

Soils, irrigation systems, farm equipment, labor, and risk management instruments are all farm-level issues that must be surmounted in order to switch crops. These are discussed below.

a. Climate and Soils Constrain Crop Selection

In the West, alternative crops must be able to survive, and even thrive in extreme conditions, including aridity, wind, hail, maximum and minimum temperatures, and other unusual weather. Compared to alfalfa and other forage crops, vegetables and fruits are only suitable for certain soils, and are generally less resilient to weather extremes. The risks from insect pests, crop diseases, and weeds are often tied to soils and climate, and with new crops these risks are not well understood.

b. Vegetables Generally Require Higher Water Quality Than Forage Crops

With a switch to vegetables, either a new source of water may be necessary, or investments may be needed to improve the quality of the water being used.

c. Water-Delivery Methods May need to change

To shift crops to orchards and vineyards, a farmer may need to invest in micro-irrigation. Micro-irrigation and sprinklers require clean water and a pressurized delivery system.

d. Crop Switching Can Reduce Drought Resiliency

Perennial tree and vine crops, unfortunately, require consistent irrigation and cannot be fallowed or reduced in acreage in times of drought like forages. Switching to these crops can thus reduce resiliency when a drought occurs. This can impact the individual farmer as well as entire basins if large transitions to these crops occur. This has been the case in California with the large-scale switch to highly profitable nut trees.

e. Farming is Very Specialized and New Knowledge May Be Necessary

In many headwater streams, ranching is the predominant activity, with irrigation used to grow grass forages. Even if the climate allowed it, asking ranchers to transition to growing crops is extremely unlikely and would represent a dramatic shift in their agronomic knowledge. Acquiring the knowledge and skills to grow a new crop requires a significant investment. There needs to be an effective network, including extension services, to disperse and share knowledge on any new crop.

f. Significant On-Farm Investment May Be Needed for New Equipment and Inputs

Ideally, with crop switching farm investments would be minimal. Especially compared to alfalfa and other forages, the most common crops in the Colorado River Basin, most crops require more fertilizers, herbicides, pesticides, and/or other inputs, thus raising farm operating costs.

g. Labor Needs May Change, Impacting Costs

Most high-value crops like lettuce require intensive labor, unlike forage crops. Production of labor-intensive crops in some parts of the basin may not be competitive due to the lower cost of labor in countries like Mexico. On the other hand, transitioning from an existing, labor-intensive crop can reduce rural labor demand, depress rural wages, and threaten agricultural households and communities.

h. Financial Risk Management Mechanisms, Such as Insurance, May Not Be Available

The supporting bank will want to know that the farmer has the necessary knowledge to plant, harvest and market a crop. The ability to store the crop before shipment, if needed, may be important. Knowledge of how markets might affect the final price is necessary, as are hedging mechanisms for that price.

i. Alfalfa, Often the Crop to Replace, Has Significant Benefits

Alfalfa consistently has the highest consumptive use of any crop in the basin. For this reason, it is often a target for replacement. By switching out of alfalfa, however, farmers forego significant benefits. Alfalfa is planted once and lasts for several years, thereby reducing annual input costs. Pesticides and herbicides are often not used. As a nitrogen-fixing legume, it can be an important crop in a rotation, and it does not require nitrogen fertilization. It is relatively easy to grow, and is robust to varying weather and climate conditions. It is drought-tolerant.

Because humans do not consume it, alfalfa is less susceptible to quality concerns, although these can certainly affect its market price. It can be readily stored and sold later when prices are high. It has a widely available and growing market, thanks in part to the emergence of a strong dairy sector in the

West. Until recently, prices have been high. In short, farmers know how to grow this crop, it is relatively low risk, and it provides decent, reliable returns. Any other crop can look risky by comparison.

It seems unlikely that unknown non-forage niche crops will replace alfalfa, at least in the short term. A better strategy might be to replace one forage (alfalfa) with another, less water intensive forage, such as forage sorghum. This approach would affect the overall forage market less by providing a substitute crop. If large declines were to occur in alfalfa production, surely alfalfa prices would rise, thus encouraging more alfalfa production.

1.4 Broad Scale, Off-Farm Issues

There are also significantly larger economic, political, and business factors that can limit a farmer's options of what to grow. Even though switching to low-water-use crops may conserve water, such a change may be economically unviable due to these off-farm issues.

a. Large Shifts in Output May Impact Prices, Farmers' Incomes and Other Agricultural Sectors

One proposal to shift a significant amount of acreage from alfalfa to fresh tomatoes in California would likely have a dramatic effect on prices. Processing facilities and a market for the new crop need to exist. The market for vegetables and high-value crops can also be much more volatile, with more market fluctuations in price than traditional crops.

b. Politics and International Competition are Significant Factors in Crop Selection

There is also a competitive disadvantage for U.S. growers for produce that can be grown less expensively in other countries. Many areas in the Colorado River Basin are well-suited economically for alfalfa and forage production, but cannot compete with the low-cost production of certain crops in other countries, thus encouraging continuation of current cropping patterns

c. Subsidies May Constrain Changes in Crop Production.

Cotton, a crop with high consumptive water use, has been supported by federal subsidies. These subsidies encourage production and discourage switches to alternative crops.

d. An Entire Supporting Infrastructure Often Must Be Built Around New Alternative Crops

This new business infrastructure includes seed and fertilizer supplies, marketing and distribution networks, and even processing and storage facilities. Plus, processing a crop often requires a certain amount of the crop to justify the investment in processing and storage facilities.

e. Water Law Disincentives

In most Western states, there are strong water law disincentives against switching crops to save water. The key disincentive is the loss of historical crop consumptive use when switching to a crop that uses less water. When selling a water right, an historical consumptive-use analysis, based on the actual crops grown, determines how much water can be transferred. Only this historical consumptive use can be sold, not the far larger decreed headgate diversion amount. This, unfortunately, provides a strong incentive for growing crops with large consumptive water use.

Colorado farmers know that alfalfa uses lots of water, and they believe that growing it will preserve their water rights and maximize their return in a future sale. If a farmer wanted to monetize the water savings from crop switching, the savings would need to legally quantified and transferred at the time of the switch, not later when lower consumptive use numbers would apply. Finally, a farmer's water rights are his or her most valuable asset, and selling these assets are often the only retirement plan the farmer has; this fact further encourages maximum use.

1.5 Case Studies

There are very few documented cases of switching crops to save water. The Walker River Basin in Wyoming is one case, although this example was funded by the federal government in an unusual experiment. There are many cases of crop switching encouraged by market forces. Avocados took decades to become a mainstream crop. Nuts, on the other hand, became a very large and valuable crop in California in about two decades. Both of these crops provide interesting lessons. Since the mid-1970s, growers in the Yuma area have switched from citrus, cotton, and other crops into more sophisticated multi-cropping oriented around very profitable winter vegetables. As a result, this has saved about 250,000 acre-feet of water per year. Some of the Yuma savings also arise from irrigation efficiency improvements.

2 Introduction

Switching from traditional low-value, high water consuming crops (i.e. alfalfa, cotton, corn) to high-value crops that use less water — like lettuce, grapes, or tomatoes — or even switching from one kind of forage (alfalfa) to other kinds of forage (Sudan grass, sorghum, teff) have all been proposed methods for conserving water in the Colorado River Basin, and elsewhere in the West. These proposals typically compare the water use of alfalfa to the water use of other crops, concluding that the significant difference in consumptive use could then be transferred to municipalities or environmental purposes. In addition, these studies state that switching to high-value, low water use corps would be economically beneficial for farmers. In theory, the increased profits from the new crop should provide enough incentive for farmers to make such a switch. Crop switching, unfortunately, involves substantial disincentives that outweigh a simple increased profits analysis.

This chapter discusses some of the proposals for crops switching and the knowledge needed to successfully pursue such a strategy. It first provides some historical background on how and why crop shifts have occurred. Two interesting cases, one involving avocados and one nuts, are presented as lessons in how slowly – and how quickly – transitions to new crops can occur, and how obstacles can be overcome. A brief discussion on how climate change might affect crop selection is next. This is included because climate change has the potential to upset many long-standing assumptions about crops and markets regionally, nationally, and internationally. The chapter then discusses published western Extension Service farmer adaptation strategies when water is short. Next, several crop-switching proposals for unusual and lesser known crops are discussed. An overview of the existing crop mix in the Colorado River Basin follows. This information is critical to understanding what and where crop switching opportunities exist. A number of Colorado River Basin-specific proposals to switch crops with the express purpose to save water have been made in recent years. These are discussed, as are the some of the published objections to these studies. Finally, the chapter ends with several case studies on crop switching.

3 Selected History and Insights from Past Crop Shifts

U.S. farmers have changed crops for many reasons through the years. Most often, changing climates and changing markets have forced shifts. In the American West, periodic drought in the Southern Great Plains, including Oklahoma, and portions of Kansas, Texas, Colorado, and New Mexico, induced farmers to shift crops from corn to wheat after a drought from 1889 to 1892. Farmers also adopted a series of agronomic practices that became known as “dry farming.” Eastern Colorado farmers early in the twentieth century learned to grow winter wheat and fallow in the summer and following winter to maximize soil moisture accumulation. The region continued to see periodic drought and dust storms, and each time farmers experimented with new crops and new forms of soil management. One of the largest changes in Great Plains agricultural practices was after a series of droughts and dust storms in the 1950s. The federal government sponsored the Great Plains Conservation Program, which offered 10-year contracts to farmers with assured sales and subsidized credit if they agreed to adopt conservation measures and shift from agriculture to grazing. The program also supported the transition to irrigated alfalfa for livestock (Orlove, 2005).

In more recent times, changing consumer tastes in the United States and around the world have driven shifts to crops that now seem normal but not so long ago seemed exotic or minor. Avocados and nuts in California provide two good case studies of how production and demand can change over time. In the case of tree nuts, the shift reduces flexibility in water supplies because water must always be supplied, no matter the cost, in order to protect the large investments. Indeed, during California’s recent drought, nut farmers were able to outcompete even municipal interests in markets to acquire water (Howitt & MacEwan, 2015) and in another case a large water wholesaler decided against competing against these high valued, perennials (Hasencamp, 2016). Cotton has seen a very large decline in the Colorado River Basin in recent years due to economics but federal crop subsidies may be preventing an even greater shift.

Irrigators often change the crops they grow for economic and agronomic reasons, but water savings appear to be almost never a driving force. Market forces seem to be the primary reason for these changes. In recent years, there is evidence in some locations that a changing climate is allowing farmers to plant different crops. Crop shifting to save water is certainly possible, but it will take significant investments if it is to be successful on a large scale. Expecting individual farmers to shift crops to save water without substantial incentives seems highly unlikely, especially given that Western water law promotes as much use as possible[1] and that there is no easy way to monetize saved water currently.

3.1 Growing Avocados in California

Crop shifting can involve foods unknown to consumers and in such cases consumers need time to literally acquire a taste for the food. The rise in popularity of avocados, for example, took decades. Even though it is a water-intensive-crop, avocadoes are now produced in large quantities almost exclusively in California to meet the sharp increase in consumer demand in recent years.

[1] In Colorado, for example, there are two legal forces pushing farmers to maximize their water use. The first is the idea that if they do not use their entire decree, they may be forced to abandon the portion that is not used. The second force is that in a water rights change case the amount that can be changed is the historical consumptive use amount. This encourages farmers to grow the most water consumptive crops. One legal scholar has suggested that converting decrees to set consumptive use amounts rather than headgate diversions would encourage conservation and trading (Squillace, 2013).

Avocados have been cultivated in California since the late nineteenth century, but growth in the industry did not begin until approximately 1970. Several problems initially hindered consumer acceptance and, in turn, limited demand. The original name was unfamiliar and hard to pronounce. The first association of California avocado growers was called the California Ahuacate Association, the word commonly used in Mexico. The word avocado was not in dictionaries and often people used the term “alligator pear.” There was a basic lack of knowledge about color and even how to tell if the fruit was ripe. Changing the type of avocado to dark-skinned varieties like Hass from green skin avocados also took time for consumers to understand (Arpaia, 2012). From 1970 to 2000 consumption of avocadoes doubled (Brunke, 2003). Since then the increase has been even more dramatic. In 2014, 1.9 billion pounds of Hass avocados were sold. That is double the amount in 2005 and four times the amount in 2000 (Ferdman, 2015). Now, California produces 95 percent of the nation’s crop and avocados are grown year-round in southern California. San Diego County produces 40 percent of all avocados in the state (Brunke, 2003).

The rise in demand occurred for three reasons. In 1914, a U.S. ban on Mexican avocados was enacted to prevent invasive pests. This ban allowed the California industry to mature and grow without competition (Arpaia, 2012; Brunke, 2003). Second, the Hass avocado has a longer shelf life and is easier to ship. This allowed farmers in California to export the crop throughout the rest of the country. Third, the country’s growing Hispanic population and the expansion of Mexican cuisine created a much larger market. There are almost 40 million Hispanics of Mexican origin in the U.S. and guacamole is now a mainstream food (Ferdman, 2015). All of these changes took time, especially the shifting demographics and palate of the U.S. population. Several different factors had to align for the demand of avocados to increase to where it is today.

Interestingly, U.S. avocado production has recently suffered. In light of the recent drought in California and competition from cheap imports, more farmers have been fallowing acres of avocados. Irrigating has not been cost-effective for some farmers, and some have shifted to growing grapes which consume far less water (McClurg, 2015; Nagappan, 2014; Sofia Knauf, 2015).

3.2 California Nut Production

Three nut crops are in the top five agricultural products by value in California from 2012 to 2014. Almonds were first in value, followed by dairy products, walnuts, wine, and pistachios (CDA, 2015). Total tree nut production in the U.S. was over $10 billion, with almonds, walnuts, and pistachios making up over 93 percent of sales. California is the nation’s major producer of these three crops, and is the main global producer. California is the number one global producer of almonds and pistachios, making up 80 and 40 percent, respectively, of the global production. It is also the second largest walnut producer in the world after Iran. (CDA, 2015).

Almonds were a niche crop in California for about 150 years before vaulting to prominence. European varieties of almonds were first planted in California in 1853 but early production was poor. Almond varieties did not consistently bear nuts and the cultivars were not well adapted to the environment. In the 1880s, local varieties were introduced and cross pollination of almond trees became more common in the early 1900s. These improvements boosted production, but it was not until the 1930s that farmers even began irrigating the crop. Production and acreage continued to grow, especially from the 1960s to 1980s when new product development and marketing increased the demand for almonds. Also, irrigated acreage expanded significantly in the San Joaquin Valley, where the soil and climate are ideal for almond trees. In decades since, acreage has not increased as much, but farmers have made considerable strides in producing more yield per acre (Geisseler & Horwath, 2014).

Almond acreage, yields, and value began making significant gains from 1960 to 2000. However, since 2000, increases dwarfed the prior decades (Figures 1 & 2). Almond cultivation has increased from 510,000 to 870,000 acres. In 2000, 703 million pounds of almonds were produced. In 2014, production was over 1.8 billion pounds, almost 260 percent more. The total value of California almonds was $666 million in 2000. Fourteen years later it was 900 percent more, almost $6 billion.

The same story holds true for pistachios and walnuts, where significant growth occurred from 2000 to 2014. In 2000, there were 74,600 acres of pistachios producing 243 million pounds with a total value of $245 million. By 2014, acreage nearly tripled to 221,000, production more than doubled to 514 million pounds, and the total value was almost $1.6 billion, a 6.5 fold increase (CDA, 2015). For walnuts, acreage steadily increased 102,900 in 1920 to 200,000 in 2000. It took nearly 80 years for an increase of almost 100,000 acres. From 2000 to 2014, the acreage increased by another 90,000. Production more than doubled from 478 million pounds to 1,140 million pounds. During the same time period, the increase in total value has been dramatic: $286 million to $1.8 billion, a 630 percent increase (CDA, 2015).

Rising global and national demand for nut crops spurred this production increase (Figure 3). For 2013-2014, 642 million pounds of almonds were shipped in the U.S., but twice this amount, 1,296 million pounds, was exported to other countries like Spain, China, Germany, India, the United Arab Emirates, and Japan (Almond Almanac, 2014). Since 2000 almond and walnut exports have about tripled, and pistachios exports have increased by six times (USDA, 2014).

In 2014, during the height of the recent California drought, the water use of almonds was widely discussed. Headlines from prominent news sources read *It Takes How Much Water to Grown an Almond?!*, *The Dark Side of Almond Use*, *Stop Water Abuse by the Almond and Pistachio Empire*, and *Here's the Real Problem with Almonds (Hamblin, 2014; Hauter, 2015; Park & Lurie, 2014; Philpott & Lurie, 2015)*. It became common knowledge that a single almond requires more than a gallon of water (which is actually similar to most nut and fruit crops) and that almond farmers in California use more water than all California families use indoors. During the drought, significant quantities of water continued to be used for these crops because nut farmers, unlike many other farmers, could afford the high price of water in spot markets and had to water their plants. When residential mandates on water conservation began, many argued that farmers of water-intensive crops like almonds should also conserve. Articles from *The New York Times* and *New Republic* argued that exporting almonds was exporting water (Bittman, 2015; Hamblin, 2014; Park & Lurie, 2014; Philpott & Lurie, 2015). One lesson from this massive California crop switch is clear: crop switching to high value perennials that cannot be fallowed clearly reduces water flexibility during times of drought.

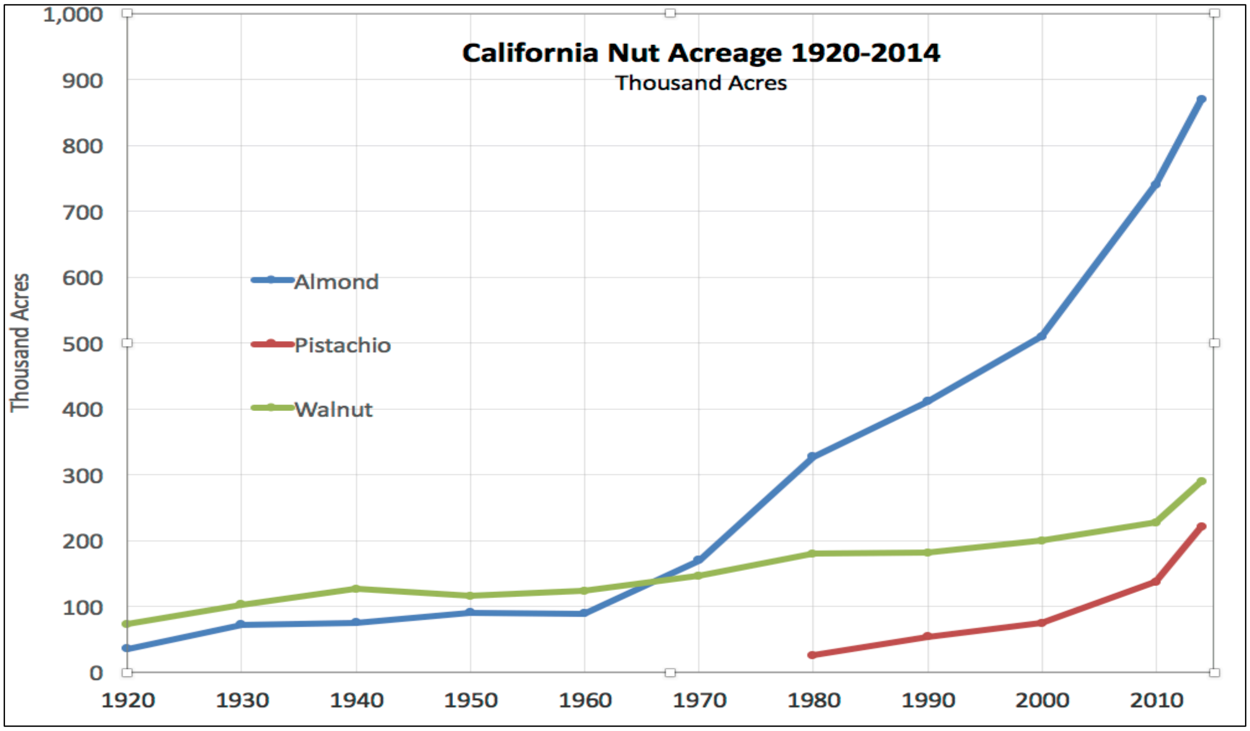

Figure 1. California nut acreage 1920-2014. Source: NASS.

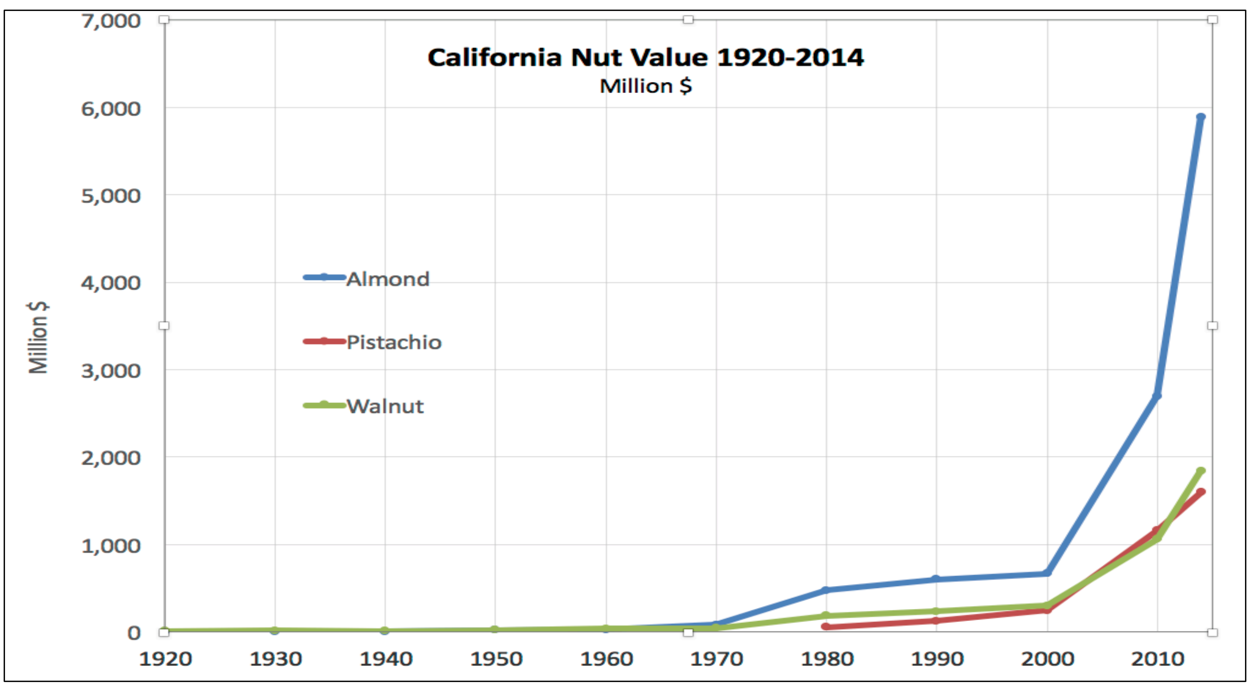

Figure 2. California nut value, 1920-2014. Source: NASS.

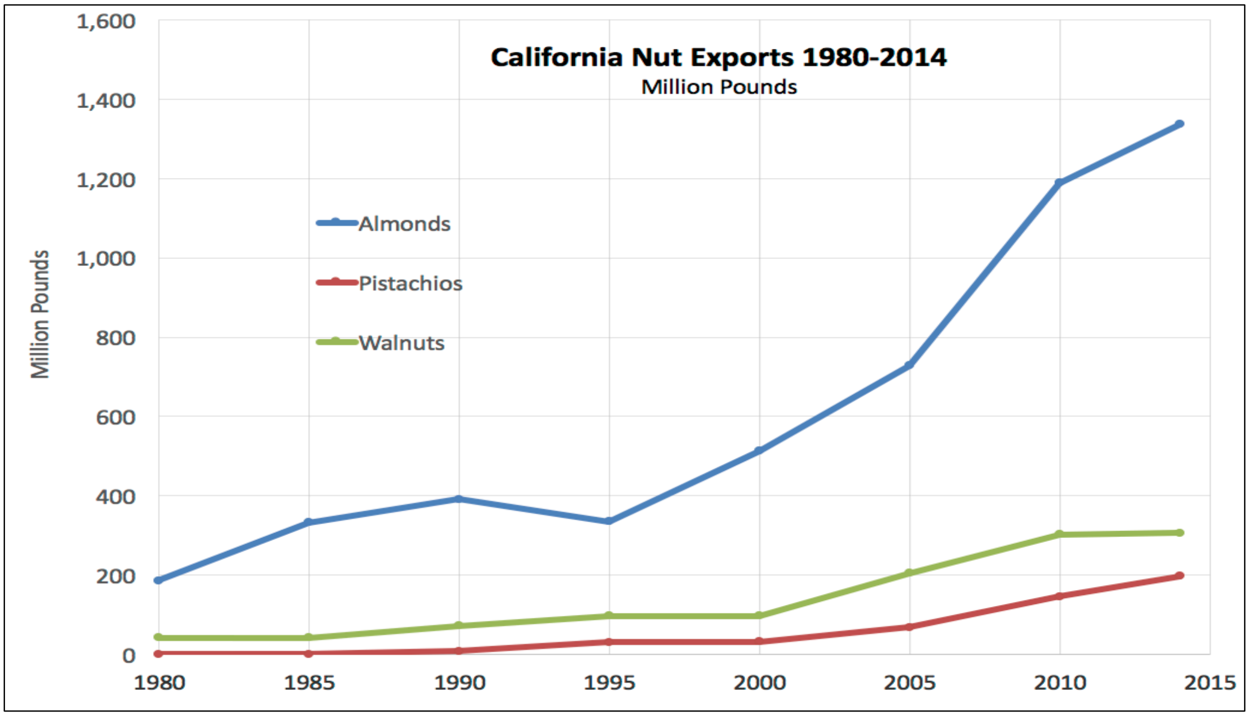

Figure 3. California nut exports, 1980-2014. Source: NASS.

4 Changing Crops in Response to Climate Change

Researchers have extensively studied the impact to agriculture by climate change with a focus on future yields and if enough food will be grown to feed expanding populations. Many of these projections show varied future outcomes in terms of crop yields (Easterling, 1995; Fischer et al., 2005; Gustafson et al., 2016; Howden et al., 2007; Parry, Rosenzweig, Iglesias, Livermore, & Fischer, 2004). Most assert that rising temperatures, changing rainfall patterns, and extreme weather will harm crop yields worldwide if greenhouse gas emissions remain unabated (Gustafson et al., 2016). Large temperature changes at the end of the century are expected to lower crop yields, while shifting patterns of precipitation may either increase or decrease yields (Malcolm et al., 2012). Smaller temperature changes may increase yields in the short term by expanding the growing season, provided that precipitation patterns do not change too much and extreme events do not hamper production.

Some studies show that food production will increase in developed countries and decrease in developing nations. Overall, in the short term the negative impact on total world crop yields may be minimal but will increase the disparity between developed and developing countries (Fischer et al., 2005; Parry et al., 2004). Cold-limited climates like mountainous regions may benefit significantly from climate change (Easterling 1995). Some cropping systems, like wheat-growing regions, may also benefit from climate change (Howden et al., 2007). Acreages of corn, wheat, and soybeans may shift from the eastern United States to the Central Plains or mountain states. Carter and Culp (2010), state that there will be an increase in locally produced crops in response to overall decreases in crop yields, which will raise prices and transportations costs.

Many parts of the country are already undergoing climate-induced crop switching. Planting of hard red winter wheat in the Great Plains and southern Canada has moved northward. Warming of the region will most likely expand the wheat growing area, especially with the development of hybrids that can deal with arid climates, cold temperatures, and shorter length of day (Easterling, 1995). Conversely, the changing climate in North Dakota has allowed farmers to shift from durum wheat to growing corn and soybeans. In the area known as the "durum triangle," rainfall has been 2 to 3 inches greater in the past 20 years and the growing season has increased by 2 weeks over the past century. The increased moisture and humidity contributes to disease like scab in wheat, while at the same time it has led to better yields and hence more profit in corn. Corn and soybeans now make up 15 percent of North Dakota's cropland, a region that was used to be almost exclusively wheat (Ydstie, 2014). In recent years, copious spring precipitation has delayed planting in the Northern Great Plains. Growing zones have shifted significantly over the past 50 years and will continue to shift as the planet warms.

It is clear that farmers change crops in response to changes in climate. Crop shifting plans to conserve water should consider how a warming climate and water supply changes will affect the viability of all crops in a given area. In addition, many markets will respond to global production changes, thus impacting farmers' profits and ultimately crop selection at the local level. In the short term, climate change may increase yields due to longer growing seasons and CO_2 fertilization. Extreme events of all kinds, however, may offset these potential gains. In the longer term, significant warming appears to be harmful to agriculture. Climate change, therefore, has the potential to change agriculture significantly as the 21st century unfolds, especially if substantial warming occurs.

5 Extension Investigations of Irrigating with Less Water

State Extension services in the West sometimes investigate the water savings associating with growing different crops (Amosson et al., 2005b; Bauder et al., Hansen, Lindenmeyer, Bauder, & Brummer, n.d.; MSU & CSU, 2006; Schneekloth & Andales, 2009). These studies have been driven by the need to inform farmers about what to grow when water supplies are short, typically during drought, not necessarily how to conserve water for other purposes. Nonetheless, this information is also useful for considering crop switching to produce water savings.

The guides make similar recommendations including choosing "short season" cultivars that likely reduce yields somewhat, but take less time to mature (which helps to decrease total water consumption). This practice can include using dwarf species that consume less water than full size crops, switching to altogether different crops that use less water, using conservation tillage to conserve moisture, scheduling irrigation based on known evapotranspiration to minimize soil evaporation loss, and even converting irrigated crops to rain fed crops. They note that annuals generally use less water than perennials because they need water for a shorter period of time. The studies also touch on deficit irrigation of different crops if needed due to short water supplies. For example, they note that "indeterminate" crops[2] such as grains are less sensitive to water shortages when small, and more sensitive during their grain-producing phase. "Determinate" crops such as potatoes, are very sensitive during their early life stages, and less so later. Perennials such as grasses and alfalfa are quite drought tolerant and many go dormant if dried significantly.

[2] Indeterminate crops grow until killed by frost or some other factor. Determinate crops stop growing once a genetically predetermined structure is created.

6 Switching to Unusual or Lesser Known Crops

Extension services occasionally investigate the suitability of unusual and unknown crops for several reasons including lower water use. Teff, a gluten-free grain consumed by humans in Africa but used in the U.S. as a high-quality horse forage; jojoba, an oil producing desert shrub; guayule, a rubber substitute; and forage sorghum are four examples of unusual or lesser-known crops that use less water than alfalfa. These crops could be grown in the Colorado River Basin and each has been studied as an alternative crop. With the exception of forage sorghum, these are very unusual crops, however.

The primary water savings available with teff is due to its shorter growing season compared to alfalfa (Davison, Laca, & Creech, 2011a). Multiple studies have demonstrated the crop's viability in the West. Teff is a warm season grass that needs high temperatures to maximize yield. It can produce 5 to 6 tons of hay per acre over a relatively short growing season and has a consumptive use of approximate 2.5 af/acre in Nevada. Since 2005 its price has closely tracked alfalfa hay. It was even recently been promoted as a new 'super grain' for humans (O'Connor, 2016).

Foster and Wright (1980) examined the potential to grow jojoba near Tucson, a shrub native to the Sonoran Desert, which contains an oil that can be extracted from its seeds. Jojoba's low consumptive use, 1.5 AF per acre, would represent a significant savings compared to the 4.0 AF per acre for most crops grown in the area. The 2.5 AF / acre water savings could be exported from farms to meet municipal demand, with 1.5 AF / acre left to irrigate the jojoba. The authors proposed a variety of financial schemes for cities like Tucson to subsidize the crop, which could be cheaper than purchasing the water outright.

Guayule has recently been promoted as a rubber substitute("Native Crops," 2012). It is a low bush that grows wild throughout the Chihuahuan Desert. The bark is harvested from a perennial plant to create a low allergy rubber product. It was commercially produced during World War II when other rubber supplies were not available.

McCorkle et al. (2007) presented a more thorough study on potential and actual crop switching to sorghum silage as an alternative forage for beef and dairy industries in the Texas Panhandle, an area dependent on groundwater. Water demand projections show that water demand will surpass supply by 2020, and there will be a significant water deficit in the Texas Panhandle, hence the interest in alternative crops. Sorghum silage uses one-third to one-half less water than corn silage. Acreage planted to sorghum silage has increased by 30,000 acres, a 40 percent rise, from 2003 to 2007 in the Texas study area. Field tests have shown that sorghum silage: (1) has roughly the same yield as corn; (2) uses far less water — up to 50 percent less — which reduces fuel costs for pumping; and (3) has nutritional quality equal to corn. Feed quality trials show that sorghum silage did not lower the rate of gain or the feed efficiency of cattle. Prices for sorghum silage are becoming more competitive, but corn silage has a long history with growers, feedlots, and dairies. Sorghum is a warm season crop, is very drought tolerant, provides a useful rotation with corn, and has seen a spike in interest from growers in recent years, in places like Oklahoma and eastern Colorado, in addition to Texas.

7 Colorado River Basin Crop Mix

The current mix of crops in the basin and each basin state are an important starting point to understand the overall crop-switching potential in the basin. Most of the recent data comes from the 2013 Farm and Ranch Irrigation Survey (FRIS) by the USDA. The survey is a supplement to the 2012 Census on agriculture that focuses on irrigation activities in the nation. Figures are extrapolated from 35,000 participants across the country to detail acreage, crop types, irrigation methods, and crop yields. The irrigation survey shows just how much of the irrigated acreage in the basin is used for livestock forage (i.e. alfalfa, hay, silage, etc.). Forage is a significant irrigated crop in both the Upper (~90 percent of irrigated acreage) and Lower basins (~40 percent of irrigated acreage). The Upper Basin's high elevation, short growing season, and harsh climate limits the types of crops that can be grown to mostly pasture, grasses, and alfalfa. In the lowest and warmest parts of the Upper Basin, (areas like Colorado's Grand and Uncompahgre Valleys), corn, onions, orchards, grapes, and other row crops can be grown. By contrast, the Lower Basin provides the climate and long growing season for a much wider array of crops.

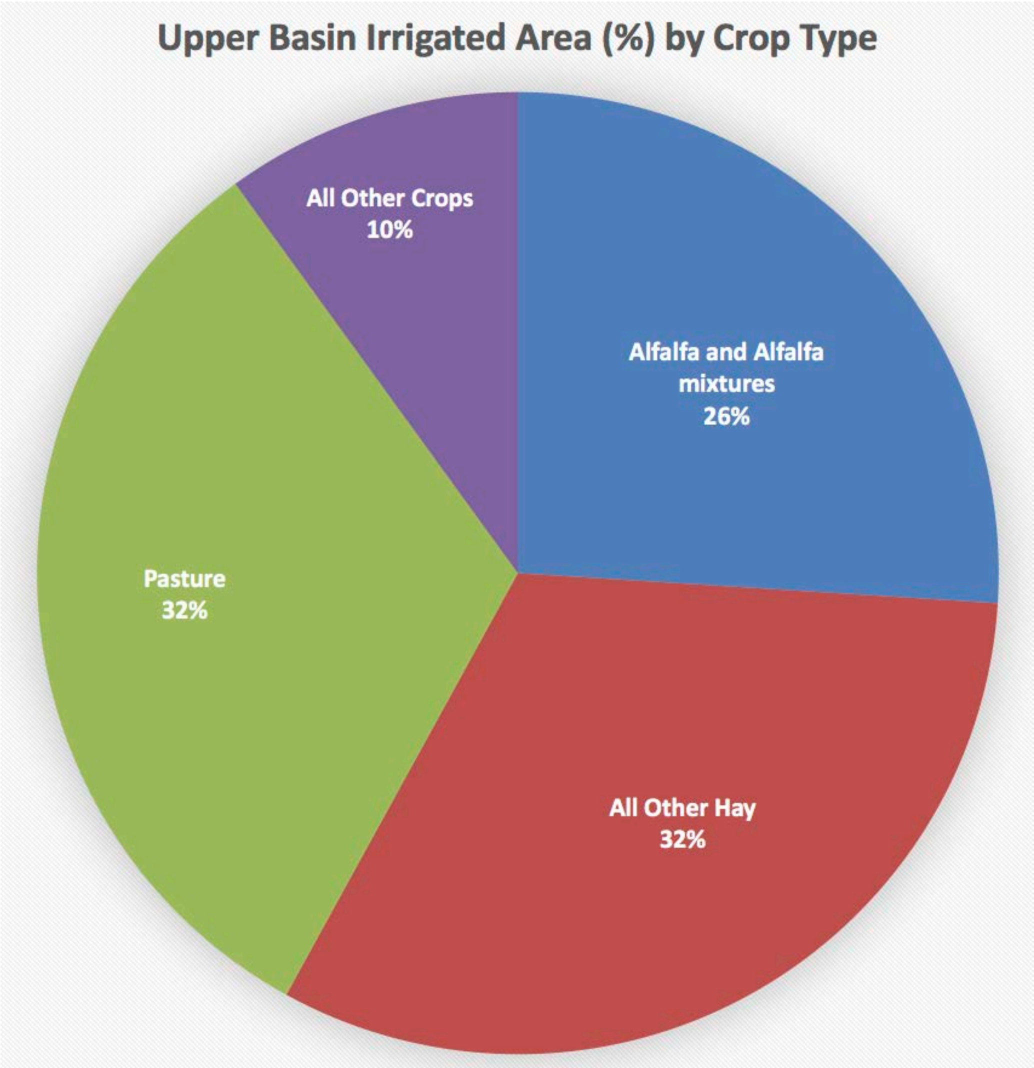

Figure 4. Irrigated acreage in the Upper Basin by crop type. Source: 2013 Farm and Ranch Irrigation Survey.

7.1 Upper Basin

As mentioned by American Rivers (2014), Moving Forward (2015), and Cohen et al. (2013), the crops grown in the Upper Basin are fairly consistent and not as diverse as in the Lower Basin. The climate, lack of access to markets, and short growing season limit the options for widespread cultivation of many crops. The Upper Basin is therefore mainly devoted to livestock feed (Figure 4). Alfalfa and alfalfa mixtures are the single most dominant crop types, making up 26percent of the Upper Basin acreage. All other hay and pastureland each make up 32 percent of irrigated acreage. Ninety percent of the irrigated acreage in the Upper Basin is therefore devoted to some sort of forage crop or pasture. That leaves only 10 percent of irrigated acreage devoted to all other crops; this acreage is typically in the lowest and warmest parts of the basin.

The crop mix in each of the Upper Basin states (including the lands outside of the basin irrigated with Colorado River water) is similar and is predominantly livestock feed and irrigated pasture (Table 1). The production of these crops is closely linked to the livestock and dairy industry in each state. In many locations of Wyoming, western Colorado, and eastern Utah, hay grown for forage is mainly consumed by the grower's herds, but some is sold locally or exported (Cohen et al., 2013). Alfalfa, hay and pasturelands make up the majority of irrigated acreage in Colorado (56 percent), New Mexico (53 percent), Utah (82 percent) and Wyoming (81 percent). The next highest group of crops in terms of acreage is corn for grain or livestock feed, ranging from 7 percent in Wyoming to 29 percent in Colorado. There is significant acreage devoted to other crops, like wheat and orchards in New Mexico, and vegetables in Colorado, but they are still a small fraction compared to irrigated forage (FRIS, 2013).

Table 1: Irrigated acreage and percent of total irrigated acreage of crops in the Upper Basin states. Source: 2013 Farm and Ranch Irrigation Survey.

	1,000s of Irrigated Acreage by Crop / % of Total Irrigated Acreage			
Crop	**Colorado**	**New Mexico**	**Utah**	**Wyoming**
Alfalfa and alfalfa mixtures	558 / 24	195 / 28	521 / 46	356 / 25
All other hay	428 / 19	86 / 12	160 / 14	452 / 32
Pasturelands	296 / 13	90 / 13	243 / 22	344 / 24
Other small grains	58 / 3	12 / 2	44 / 4	75 / 5
Corn for grain or seed	583 / 25	47 / 7	37 / 3	54 / 4
Corn for silage or greenchop	104 / 4	77 / 11	57 / 5	37 / 3
Wheat for grain or seed	102 / 4	56 / 8	41 / 4	8 / <1
Land in orchards, vineyards and nut trees	2 / <1	45 / 7	6 / <1	0 / 0
All other crops	177 / 8	86 / 12	15 / 1	92 / 6

7.2 Lower Basin

The crop mix is much different in the Lower Basin, where the climate allows more options for farmers and some crop switching has already occurred (Noble, 2015a). Even though the climate supports a greater variety of crops, irrigated livestock forage is still about 40 percent of the total acreage (Figure 2).

Alfalfa (32 percent) is the single most widely cultivated crop in the Lower Basin, and other hay adds another 6 percent. Cotton (19 percent), vegetables (11 percent), and wheat (8 percent) are next. Even though the climate in southern California and Arizona allow the growth of a wide array of crops, high value crops like lettuce and other vegetables (11 percent) only make up a small fraction of the total area (FRIS, 2013).

The irrigated agriculture in all of Arizona, California, and Nevada is more diverse, but that is mainly due to central and north California, where significant acreage is devoted to vegetables, tomatoes, and orchards (Table 2). For Nevada (which, like California, lies mostly outside of the Colorado River Basin), the crop mix is very similar to the Upper Basin states. Alfalfa, pastureland, and other hay make up over 92 percent of the limited irrigated acreage in the state. The crops grown in Arizona are more diverse. The major irrigated crops are alfalfa (28 percent), cotton (18 percent), vegetables (11 percent), wheat (7 percent), small grains (6 percent), and other hay (5 percent). Crops like lettuce and citrus orchards that are widely grown in areas like Yuma, Arizona, are only 5 and 3 percent of total irrigated acreage, respectively (FRIS, 2013).

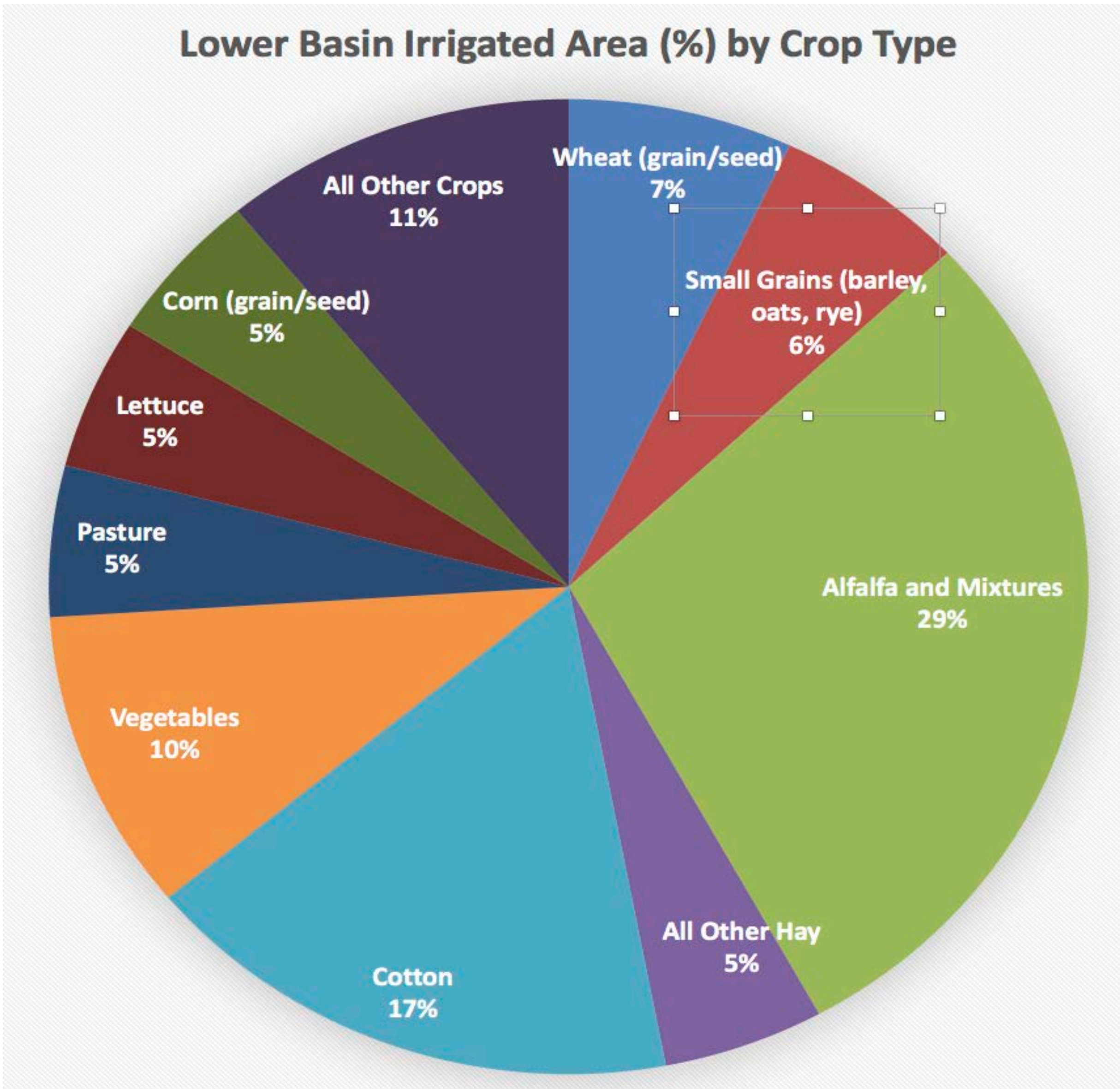

Figure 5. Irrigated acreage in the Lower Basin by crop type. Source: 2013 Farm and Ranch Irrigation Survey.

Table 2: Irrigated acreage and percent of total irrigated acreage of crops in the Lower Basin states. Source: Data from 2013 Farm and Ranch Irrigation Survey.

	1000s of Irrigated Acreage by Crop / % of Total Irrigated Acreage					
Crop	**Nevada**		**Arizona**		**California**	
Wheat for grain or seed	17	2	65	7	339	4
Alfalfa and alfalfa mixtures	322	47	270	28	664	8
All other hay	115	17	48	5	437	5
Pastureland	190	28	35	4	434	5
Cotton	0	0	173	18	275	3
Land in vegetables	9	1	103	11	1018	12
Other small grains	10	1	61	6	78	1
Lettuce and romaine	0.01	<1	47	5	198	2
Land in orchards, vineyards, and nut trees	1	<1	25	3	2577	34
Tomatoes	0	0	0	<1	283	3
Rice	0	0	0	0	1051	13
Corn for silage or greenchop	10	1	30	3	364	4
All other crops	10	1	92	10	576	6

Over the past ten years, there has been an increase in field crop acreage, and a decline in vegetables and citrus in all of Arizona. Acreage for vegetables declined by about 25 percent while alfalfa and hay acreage has increased by more than 30 percent. The increase in forage crops has paralleled an increase in the number of cattle and sheep in the state over the same period. In California, alfalfa acreage fell during the time period shown, and acreage of field crops and vegetables increased. The acreage planted in fruits and vegetables is much greater in terms of total acreage and percentage than any other states in the basin with the exception of Arizona. Still, alfalfa and field crops are a significant portion of the crop mix (Cohen et al., 2013).

7.3 Evapotranspiration of Crops in the Basin

Crop evapotranspiration (ET) or water use is a function of the climate and the type of plant. Plants use water for a variety of purposes. It is as medium and substrate for biological reactions. Water provides structural support for plants; wilting is the absence of water. The act of transpiration from the leaves pulls water and water-soluble nutrients from the soil. Finally, transpiration allows the plant to absorb carbon in the form of CO_2 from the atmosphere. Leaf openings, called stomata, release water vapor while they absorb CO_2. This exchange cools the plant while providing carbon for growth. Higher temperatures and lower humidity drive higher evaporation; therefore, plants use more water in hot, arid areas. The consumptive use of different crops throughout the basin shows the large variation of ET in the region (Table 3) and the possible water savings from crop switching (Table 4). ET in the Lower Basin is significantly higher than the Upper Basin, an expected finding given the hotter temperatures and longer growing season. This difference in ET between the basins provides dissimilar opportunities for water savings.

In the Lower Basin, there is a significant water use difference between a high-ET crop like alfalfa (~60 inches) and a low-ET crop like lettuce (~ 10 inches) or dry beans. Throughout all of the Lower Basin, alfalfa has the highest ET, requiring more water than any other crop including corn (~25+ inches), other forages (~40 inches), and even citrus (~40 inches). In Yuma, Arizona, comparing the ET of other forages like Sudan grass (~43 in.) and Bermuda grass (~40+ inches) to alfalfa (~64 in.) shows the substantial consumptive use savings (~ 20 inches) by switching from alfalfa. The consumptive use savings are even greater when compared to potatoes, onions, and small grains like barley (~20 inches). In general, in the Lower Basin, crop switching from alfalfa to any other crop will save significant amounts of water.

In the Upper Basin, however, switching from alfalfa to other crops will result in significantly less consumptive-use savings. The ET of the alfalfa ranges from ~29 to ~43 inches in the Upper Basin states. This is half to two-thirds of the ET of alfalfa in the Lower Basin. Alfalfa's consumptive use in the Upper Basin is not that much greater than other crops like corn (~25 inches), potatoes (~25 inches), onions (~30 inches), or sugar beets (~25 inches). In Utah, the ET of alfalfa can even be lower than orchard ET. The lower alfalfa ET in the Upper Basin is a combination of lower temperatures and the much shorter growing season.

Far fewer alfalfa cuttings are possible compared to the year-round growing season in the Lower Basin. For a given acre in production, the water savings by switching out of alfalfa in the Upper Basin is therefore less than in the Lower Basin. Importantly, however, much more of the Upper Basin is planted in alfalfa and other forages than in the Lower Basin, thus providing more theoretical potential crop switching acres even if the water savings per acre are less. Unfortunately, much of this acreage is at high elevations, where alternative crops are not possible.

Table 3: Consumptive use of crops in the Lower and Upper Colorado River Basins (inches/growing season). Data for Arizona and California is from the 2010 Bureau of Reclamation report "Estimates of Evapotranspiration and Evaporation Along the Lower Colorado River". Data for Colorado is from the CoAgMet by Colorado State University and the USDA. Data is from 2015 and can be found at http://ccc.atmos.colostate.edu/~coagmet/index.php. Data for Utah is from the Utah State University's 2011 report "Crop and Wetland Consumptive Use and Open Water Surface Evaporation for Utah" by Robert W. Hill, J. Burdette Barker, and Clayton S. Lewis. Data for New Mexico is from the National Resources Conservation Service. Data is from 2005 and can be found at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nm/technical/?cid=nrcs144p2_068704.

	Lower Basin					Upper Basin						
	Fort Mohave, AZ	Wellton-Mohawk, AZ	Yuma, AZ	Parker Dam, CA	IID and Coachella, CA	Cortez, CO	Hayden, CO	Montrose, CO	Bloomfield, NM	Eastland, UT	Maeser, UT	Green River, UT
Alfalfa	61.98	58.45	64.25	62.69	61.22	39.83	36.54	42.62	36.68	34.53	28.91	33.98
Corn	28.77	26.58	27.54	28.76	34.69	25.6	24.78	26.35	33.76	23.61	19.94	21
Potatoes	13.34[a]	27.5	30.47	12.89[a]	30.1	23.95	21.82	25.8	41.65	21.17	17.72	18.15
Onions	17.51[a]	19.56[a]	21.72[a]	17.19[a]	23.03[a]	28.7	26.74	30.25	-	30.71	26.29	29.86
Field grain	28.77	26.58	27.59	28.26	34.69	-	-	-	11.52	22.37	17.36	19.59
Sugar beets	24.47[b]	22.74[b]	24.42[b]	24.22[b]	27.73[b]	30.96	28.01	32.93	-	-	-	-
Dry beans	13.34[a]	27.5	30.47	12.89[a]	30.1	29.25	26.93	31.72	24.35	-	-	-
Small grains	22.02	19.4	20.97	21.95	24.76	22.59	21.57	23.86		-	-	-
Wheat (spring & fall)	22.02	19.4	20.97	21.95	24.76	-	-	-	-	-	-	-
Winter wheat	-	-	-	-	-	29.18	24.4	32.77	32.4	-	-	-
Citrus (mature)	41.68	39.9	44.05	42	43.17	-	-	-	-	-	-	-
Orchards	-	-	-	-	-	-	-	-	-	38.41	32.59	41.81
Cotton	32.64	37.41	41.54	34.48	38.84	-	-	-	-	-	-	-
Bermuda grass	39.57	36.6	40.01	38.48	53.28	-	-	-	-	-	-	-
Grapes	35.19	33.99	36.9	35.72	36.52	-	-	-	-	-	-	-
Lettuce (spring, late)	6.88	8.08	8.92	6.95	12.41	-	-	-	-	-	-	-
Sudan grass	40.74	39.37	43.05	40.83	36.92	-	-	-	-	-	-	-
Tomatoes	27.08	25.79	26.76	26.61	26.38	-	-	-	-	-	-	-

a – grown only in the spring and fall
b – grown only in the summer

8 Proposals for Crop Switching in the Basin

Several sources have advocated crop switching in the Colorado River Basin and the West (Aylward, 2013; Cohen et al., 2013; Cooley et al., 2008; Hardest Working River, 2014; Moving Forward, 2015). One recent effort has proposed crop conversion as a way for "impact investors" to make a difference in Colorado River Basin water use (Squire Patton Boggs & Encourage Capital, 2015). Alfalfa is usually the recommended crop to switch out because its high-water usage provides the most water savings, and because it is a very common crop in the Basin and throughout the West. Water savings from switching from alfalfa to other crops have been discussed in a number of studies (Davison, Laca, & Creech, 2011b; Foster & Wright, 1980; Santhi, Muttiah, Arnold, & Srinivasan, 2005; SARE, 2005, 2007, 2009).

These studies discuss some of the factors that determine what can be grown in a given area. American Rivers (2014) mentions that soil conditions, climate, water availability, and market conditions can all limit options for what producers can grow. Most of the studies state that crop switching would be more difficult in the Upper Basin because higher elevations, colder temperatures, and shorter growing season limit the selection of possible new crops. They agree that the Lower Basin presents more opportunities for crop switching due to its long growing season and more hospitable winter climate. High-consumptive-use forage crops like alfalfa make up a significant irrigated acreage in the Lower Basin and provide significant opportunity. It should be noted, however, that both the beef and dairy industry provide significant and growing demand for these forage crops. (Cohen et al., 2013; Hardest Working River, 2014; Moving Forward, 2015). The dairy industry in California, for example, is a $5B/year enterprise (either the 2nd or 3rd highest value agricultural industry in the state, depending on the year) and has experienced significant growth in the last 30 years. Were crop switching out of alfalfa effective on a large scale, alfalfa prices would surely increase — ultimately providing economic pressure to grow more alfalfa. Finally, no study mentions the value of alfalfa, a nitrogen fixing legume, as part of a crop rotation, and what might replace it.

There is very little information in these studies on exactly how to go about switching crops, and there are few examples of successful crop-switching. The Bureau of Reclamation's *Moving Forward Report* (2015) does briefly mention one example in the Wellton-Mohawk Irrigation and Drainage District of switching to a lower-water use alfalfa cultivar that produces less in the summer when yields are already low, and water use is high. (This is known as "summer slump." See the Deficit Irrigation Chapter for details). There is generally no analysis of the costs of switching farming operations, the need for different planting and harvesting equipment, changes in labor, the distance to processing facilities, insurance, water quality, marketing assistance, soils, etc. There is also usually just a cursory analysis on the economic component of crop switching, often only comparing the gross receipts of different crops to calculate net returns from the change.

One of the more detailed proposals comes from the Pacific Institute. "Water to Supply the Land: Irrigated Agriculture in the Colorado River Basin" (Cohen et al., 2013) discusses current crops in the Colorado River Basin and the potential water savings from crop switching. The study presents a series of crop shifting scenarios: shifting from cotton to wheat, from alfalfa to sorghum, and from alfalfa to wheat and cotton (Table 4). The economic analyses did not consider hard to quantify third party impacts. They assume that other interests would compensate irrigators for making the conversion. Mean crop water use was used to determine the consumptive use savings between crops. Net returns above operating costs were determined by subtracting the total annual operating costs by the total annual revenue (gross receipts) per acre. This was used to determine the cost per acre-foot of water saved.

Table 4: Water savings from crop switching scenarios. Source: Cohen et al. (2013).

Scenario	Consumptive Use Savings (Acre-feet/Year)	Base Cost (per AF)
70,000 acres from cotton to wheat	>90,000	$112
74,000 acres from alfalfa to sorghum	>140,000	$96
74,000 acres from alfalfa to cotton and wheat equally	>250,000	$36

Another report by The Pacific Institute, “More with Less: Agricultural Water Conservation and Efficiency in California: A special Focus on the Delta” (Cooley et al., 2008) presented crop shifting scenarios of a small percentage of lower-value, water-intensive crops to higher-value, water-efficient crops in California. They indicated this could free up nearly 1.2 MAF per year if 25 percent of irrigated field crop acreage were shifted to irrigated vegetable crop acreage. Cooley et al. assessed the economic impact of crop switching by evaluating changes in the gross production value. They do identify market value, local weather, crop subsidy programs, the need to rotate crops, and other factors, and state that future assessments should evaluate how shifting crop types affects the net production value.

Burt et al. (2008) of the Irrigation Training & Research Center at Cal Poly responded to Cooley et al. (2008) in “Agricultural Water Conservation and Efficiency in California – A Commentary.” They argued that Cooley et al. neglected the impact of crop shifts on the overall market. Prices for the new crops would decline due to increased production and thus the farmer’s profits would be significantly less. They noted that the vegetable market is stable with no significant shortages at the current acreage level yet the proposal recommended nearly doubling the acreage. They also indicated that no economic analysis was done on what this would do to prices or where the additional demand would come from. Current production matches demand and long-term contracts between tomato growers and processors have stabilized the acreage. Finally, vegetables are a high-risk endeavor and irrigators are likely to apply more water and/or use double cropping to minimize risk. (In Yuma, double cropping with lettuce, for example, is common). Burt et al. (2008) concluded that the predicted large water savings are unlikely.

The Cohen et al. (2013) study has some of the same issues. Two of the scenarios (cotton to wheat and alfalfa to sorghum) require irrigators to switch from high-value to equal- or lower-value crops. There is no analysis on demand or price. Switching from alfalfa to cotton may be problematic given that U.S. produced cotton has plummeted in recent years and it is much more labor intensive than alfalfa (See Decline of Cotton Section below).

9 Crop Switching Cases

There are very few examples of crop switching specifically to conserve water for other uses, although there are a number cases of switching due to drought or declining groundwater supplies. Crop switching for economic reasons is relatively common as discussed above. Future projects that want to utilize crop switching to save water must take into account the larger political, economic, agronomic, and climatic forces that support the production of the existing crop mix. The cases below occurred either in the Colorado River Basin or near the Basin.

9.1 Wellton-Mohawk Alfalfa Cultivar Switch

The Wellton-Mohawk Irrigation and Drainage District (WMIDD) is one published case where crop switching has taken place to specifically reduce consumptive use. In 1980, improved varieties of alfalfa were planted in the WMIDD. Approximately 25,000 acres were converted and the annual water savings are approximately 15,000 AF (Moving Forward, 2015). This appears to be a very simple way to save water, but details are lacking on the costs and other aspects of the transition. The biggest cost would be a likely decline in yield, and hence, economic returns associated with a lower water using crop.

9.2 Yuma, Arizona Switch to Winter Vegetables

Over the past 40 years, Yuma growers have changed much of their acreage from perennial citrus and full season crops to multi-crop systems that include high-value, and shallow-rooted vegetables. They now focus on high profit, low water use winter vegetables rather than on lower profit, high water use summer crops (Table 6). The main driver for this crop shifting was higher profits but significant water savings also accrued from these changes.

In 1970, the dominant winter crop was wheat, which was the transition crop from cotton to alfalfa. Less than 17 percent of acreage was in vegetables and only 10 percent was multi-cropped. Today, acreage devoted to vegetables has increased 6-fold while the acreage of traditional crops has decreased by 43 percent. Acreage of citrus, cotton, and sorghum have declined 70, 50, and 85 percent, respectively. The acreage of irrigated alfalfa has remained relatively the same (15-20 percent of the area) but it fluctuates due to dairy-driven market demand. Now, nearly 70 percent of irrigated acreage has been converted to a multi-crop system (Noble, 2015b).

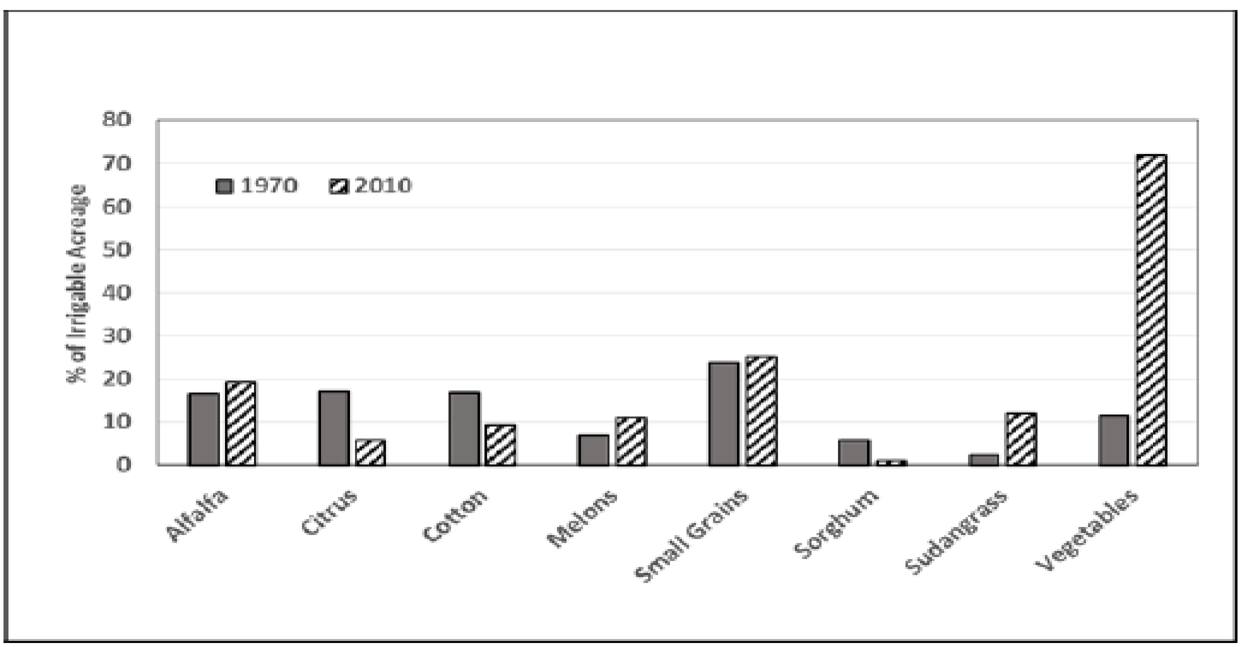

Figure 6. Change in irrigated acreage by crop in Yuma 1970-2010. Note: 2010 numbers include double cropping. Source: Noble, 2015.

During this period of transition, water diversions decreased (Figure 7). The amount of water diverted for irrigation has decreased 15 percent since 1990 (0.8 AF/acre) and 18 percent since 1975 (1 AF/acre)

(Figure 4). Even though multi-crop production now dominates the area, the total water requirement is less than the perennial and full season production systems of the past. Relative to 1970, the only months with increased water deliveries are October through December, when water is used to establish winter vegetables. Compared to the traditional cropping systems, less water is now applied during the hot summer months of July, August, and September, when more water would evaporate due to high temperatures, and when crops have higher ET requirements.

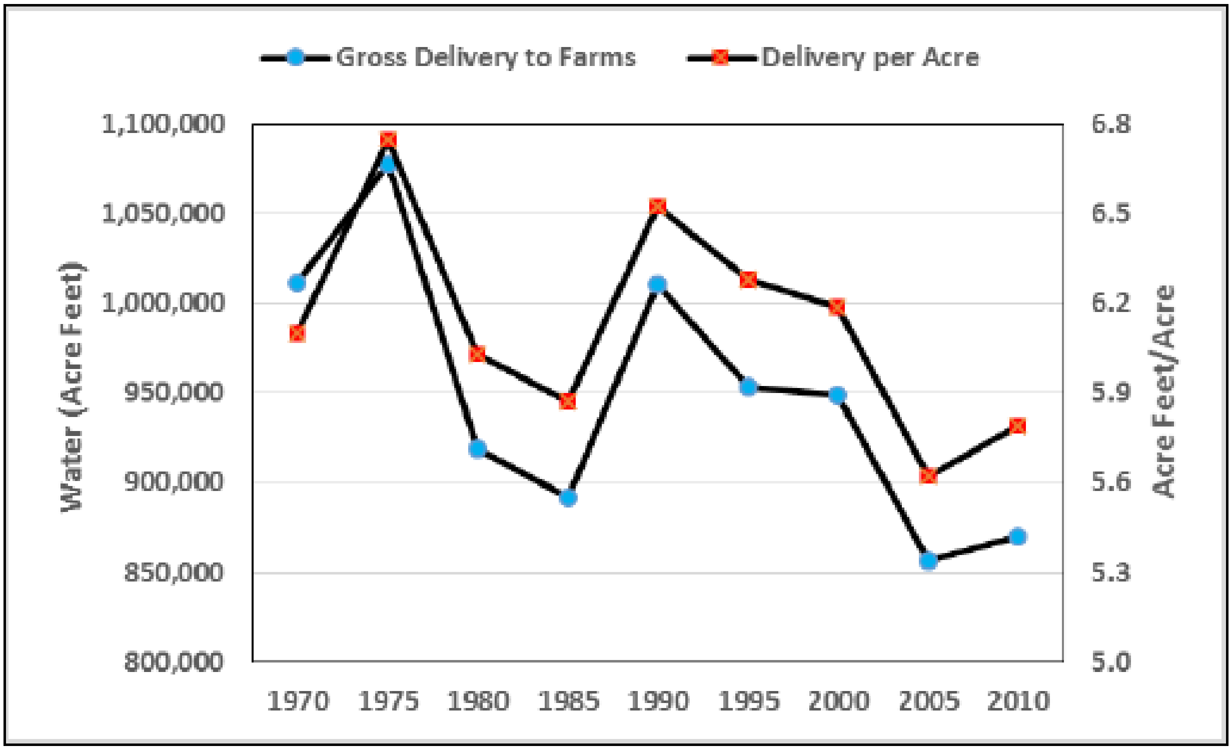

Figure 7. Water delivered to Yuma farms 1970 - 2010. Source: Noble, 2015.

Compared to the traditional cropping systems of the 1970s, the consumptive use of leafy green vegetables, broccoli and cauliflower combined with a second crop of durum wheat, Sudan grass, spring melons, or short season cotton is less (Figure 7). From about 1975 to the mid-1980s high salinity drove declines in water use and led to an international agreement to limit salinity[3]. In the late 1980's as water quality improved, water delivery to farms increased as acreage dedicated to vegetables climbed. At the time, it was standard practice to uniformly germinate newly planted vegetable fields and promote early crop growth using "subbing", which consisted of filling the furrows with water for seven to ten days to induce sub-irrigation[4]. This technique greatly increased the demand for water from September through November. The practice led to excess water lost though deep percolation below the root zone and high groundwater tables.

Several water-saving infrastructure changes accompanied this crop shifting. Rather than sub-irrigating vegetables, growers now use sprinklers to start the crop which saves 8 to 30 inches of water each year.

[3] Minute 242 of the U.S. – Mexico water treaty.

[4] Sub-irrigation is the practice of overfilling the root zone with water from surface irrigation.

Laser leveling[5] of fields occurs frequently, in some cases annually, and many canals were lined. When laser leveling is combined with high flow turnouts and pressed furrows using bola wheels, the on-field water application efficiency rates are very high. Because of these techniques, water deliveries to farms have declined substantially since 1990 and are at their lowest since 1970 (Noble, 2015b).

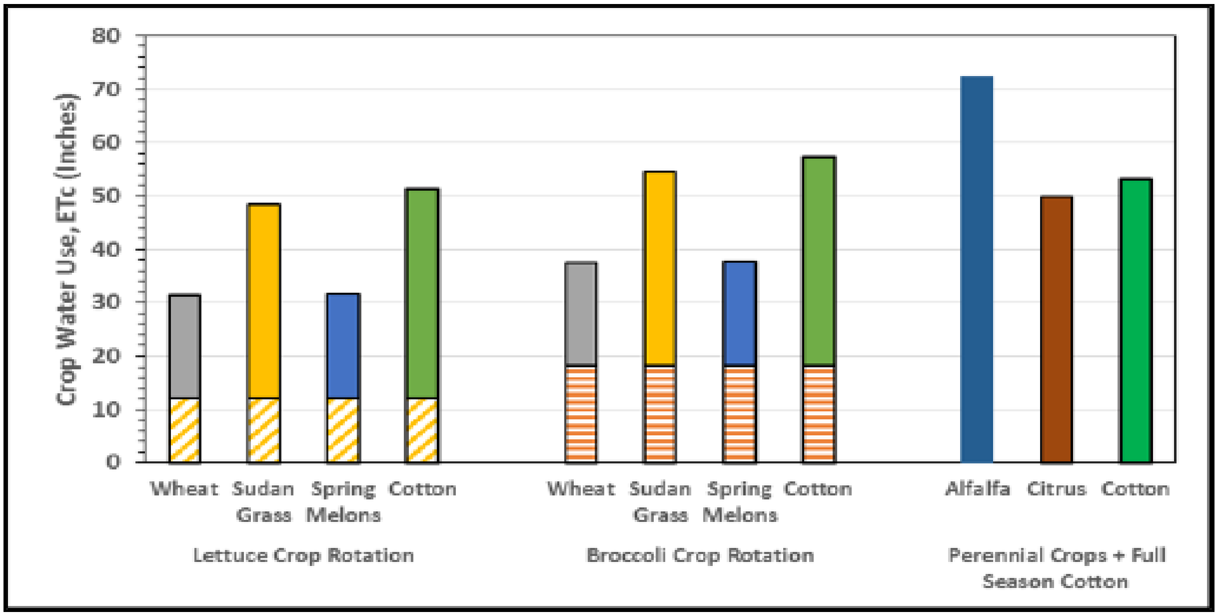

Figure 8. Crop water use of different crop mixes. Note. Solid bars above the hatching represent the water use of the 2nd crop in the annual rotation. Source: Noble, 2015.

The crop transition in Yuma was not a response to save water, but to meet growing demand for high-value winter produce. Shifting crops on this scale took years, on-farm investment, significant knowledge, and a ready supply of labor. District-wide infrastructure efficiency measures also helped with the water savings. Most importantly, the unique climate of Yuma allows irrigators to grow high-value, low-water-use produce in the winter, a situation that exists only in southernmost portions of the basin, and almost nowhere else in the United States.

9.3 Farmers Investment Company Switch to Pecans

Fifteen miles south of Tucson, the Green Valley Pecan Company, a subsidiary of the Farmers Investment Company, switched from cotton into pecans around 1965. The founder of the company was concerned that synthetic fabrics would replace cotton, so he began methodical experiments growing other crops. Stone fruits, grapes, and tree nuts were all planted. Grapes and pecans both did well, but pecans were ultimately selected because they have a longer harvest window and can be harvested by machine. Pecan trees, carefully managed, can produce for centuries, although they take five years to mature. By 1970, the first trees were producing and now over 100,000 trees exist on 5900 acres, the largest pecan orchard in the world. The company has a vertically integrated operation with a 120,000 square-foot

[5] In the absence of laser or GPS leveling during flood and furrow irrigation, water either flows too fast, or too slow, for optimal root zone application. In the summer, standing water from unleveled fields can become too hot for the plant and can damage roots. This is known as “scalding”.

processing facility on site. In 2000, they began converting some of the acreage to organic, and now have 1200 acres certified (Buchanan, 2011).

9.4 The Decline of Cotton Production in the Basin

In the last few decades, the global cotton market has changed significantly with impacts rippling into United States including the Colorado River Basin. The U.S. is still a leading producer and exporter of cotton but developing countries have ramped up production during this period while U.S. production has declined significantly (Figure 9). Since 2000, China has become a dominant consumer and importer of cotton while India and Pakistan have increased production to meet national and international demand. These competing countries can take advantage of exceedingly low labor costs in both cotton farming and in cotton mills (Seock, Giraudo, Gauteaux, & McLaughlin, 2013). Subsidized prices in other countries have also put pressure on U.S. producers.

In the U.S., the predominant type of cotton is American Upland, which makes up 97 percent of the annual U.S. cotton crop and is mainly grown in the Southern Cotton Belt. The other type, American Pima, is produced mainly in California and other arid regions of southwest Texas, New Mexico and Arizona. The market for Pima, or extra-long staple (ELS), is mainly for high-value products. Consumption of cotton by U.S. textile mills peaked in 1997, then dropped by 50 percent by 2005 and 70 percent by 2009 reflecting lower production costs overseas (Meyer, Kiawu, & McDonald, 2015).

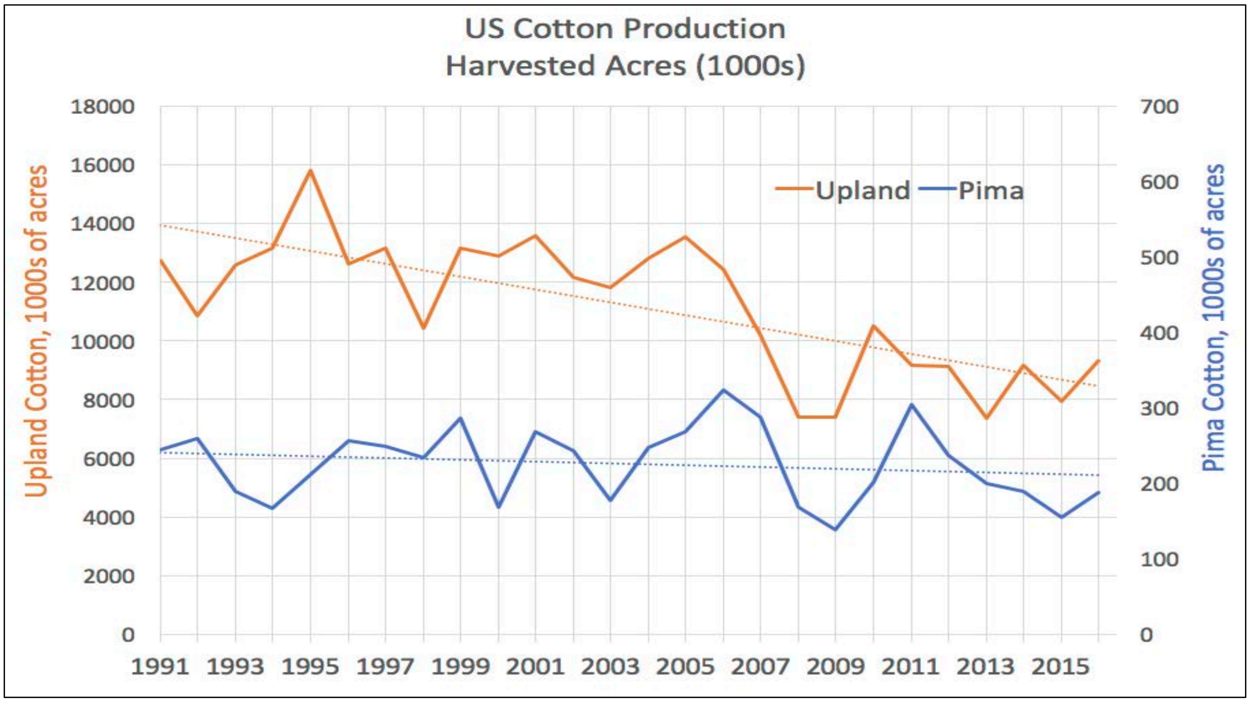

Figure 9. U.S. cotton harvested acreage over time. Source: National Cotton Council of America http://www.cotton.org/.

In the major cotton producing states in the basin (Arizona, California, and New Mexico), cotton acreage has significantly decreased in all three states for almost every type of cotton since 1995 (Figure 10). In Arizona, cotton acreage of both Pima and Upland amounted to 466,000 in 1991. Acreage declined by nearly two-thirds to 165,000 in 2014. In New Mexico, 88,600 acres were planted in 1991, but only 48,400 in 2014. In California, acreage of Upland Cotton decreased from around 1 million acres in the early 1990's to 57,000 in 2014. The California climate and soils can support crops that are much higher-value, thus aiding the shift. In the Palo Verde Irrigation District (PVID), cotton has been replaced with alfalfa, which brings in reliable prices with little effort (Barlow, 2016). Currently, there is no cotton production in the IID service area based on latest crop reports and there has been little production in the past 10 years (Bali, 2016).

The one relatively small exception to this trend is Pima, a luxury cotton. Production of luxury cotton began in the San Joaquin Valley of California in the 1990s, and seen as a rival to premium Egyptian cotton, sought after by high-end retailers. In 1994, only 64,000 acres were planted. In 2006, it reached as high as 260,000 acres, but it has leveled-off with only 155,000 acres in 2014 (NCC, 2014). The demand for Pima cotton by manufacturers was so high that cotton farmers could afford high water prices. This trend peaked in 2011, when manufacturers started to shift to synthetic fibers because they were wary of high prices, and China began increasing cotton production after several years of decline. Cotton demand and prices then fell (Tabuchi, 2015).

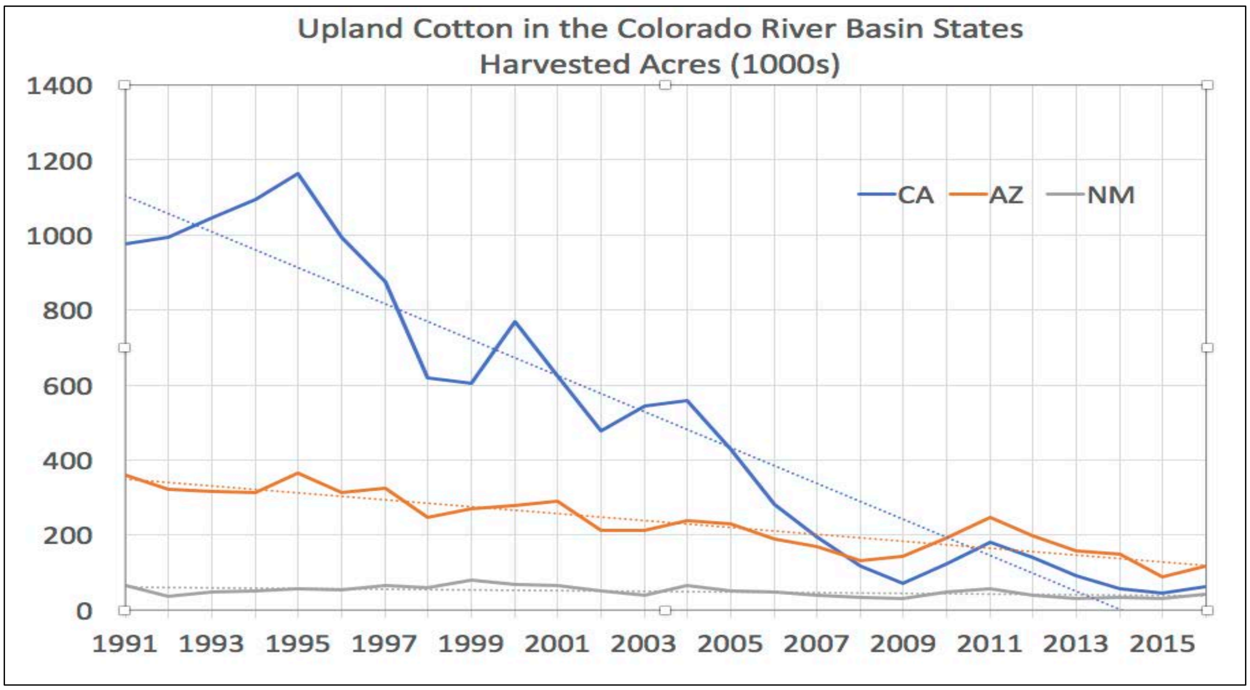

Figure 10. Upland cotton acreage in Colorado River Basin states. Data from the National Cotton Council of America http://www.cotton.org/2014.

A recent series of articles by Lustgarten and Sadasivam (2015) looked at cotton production in the Colorado River Basin. According to this series, cotton requires six times as much water as lettuce[6], and 60 percent more than wheat. In the past, the federal government has subsidized cotton and offered price protection. Over the last 20 years, Arizona and California farmers have collected more than $1.1 billion and $3 billion respectively in cotton subsidies. The authors claim that without government subsidies, even less cotton would be grown in the basin.

[6] This comparison is not entirely fair as lettuce is generally multi-cropped in a year. Cotton, by contrast, takes much longer to mature. Wheat, too, can be multi-cropped. See Figure 8 for examples of total water use by different multi-cropping systems.

The story of cotton in the West highlights how the global market can affect farmers. Even federal subsidies cannot completely remove the impact of global prices on demand for American cotton. Unlike some other common crops, cotton is much more of an international crop. In part, this is because it is a fiber that is easily stored and shipped. About 30 percent of the world's cotton consumption crosses international borders *before* processing. A significant amount of U.S. produced cotton is shipped to India, Pakistan, and China for processing, and shipped back in the form of material goods. This is larger than other traditional crops like wheat, corn, soybeans, rice, and alfalfa (NCC, 2014; Seock et al., 2013).

This case study highlights how government subsidies and the global market including labor costs can influence the production decisions of U.S. farmers. In this case, U.S. subsidies likely provide incentives against switching crops. Despite this market intervention, however, cotton acreage has decreased dramatically throughout the country (Figure 9). Cheap labor in developing countries for both cotton production and in mills, and transportation costs to and from these counties can influence the price U.S. cotton farmers receive. Proposals to shift crops should consider the interplay of all of these factors.

Table 5: Change in irrigated acreage in California. Source: CIT (2011).

	YEAR REPORTED				
TYPE OF ACREAGE	1978	1987	1997	2007	% CHANGE 78-07
Total Irrigated Land (acres)	8,505,824	7,596,091	8,712,893	8,016,159	- 5.8%
Rice Acreage	484,822	399,193	574,081	531,075	9.5%
Cotton Acreage	1,517,980	1,083,811	1,036,316	471,378	- 69%
Total Bales	1,911,050	2,619,934	2,543,194	1,418,751	- 26%
Bales/Ac	1.26	2.42	2.45	3.01	139%
Hay Acreage	1,501,143	1,532,777	1,698,773	2,183,761*	45.5%
Vegetable Acreage	900,401	882,741	1,209,259	1,169,786	30%
Orchard Acreage	1,892,077	2,152,664	2,582,084	2,826,291	49%
Dairy Cows	836,675	1,070,366	1,403,217	1,840,730	120%

9.5 California Crop Switching Thru Time

Since 1978, there have been major shifts in crops grown in California (Table 5: Change in irrigate acreage in California). Most of these shifts over the last nearly 40 years appear to have been the result of market forces. As discussed earlier, cotton acreage in California has declined significantly (-69%), and avocado and nut production has increased substantially. Acreage of hay (+45%), vegetables (+30%) and orchards

(+49%) has increased to meet rising demand for these products. Also, forage pasture acreage for dairy cows has increased significantly to support the expanding dairy industry (CIT, 2011).

In the Imperial Irrigation District (IID), the crop mix has been fairly consistent over the past ten years with forage crops (alfalfa, Bermuda grass and Sudan grass) at approximately 50 percent of the total land area. There have been some year-to-year changes in acreage of major crops in the district, but overall the six most common crops (alfalfa, Bermuda grass, Sudan grass, wheat, sugarbeets, and lettuce) have been mostly consistent (Figure 11). When changes have occurred, they were likely due to changing markets. This is certainly the case with cotton, which has decreased significantly to the point where it isn't even cultivated in the district anymore. The case is similar for asparagus. The acreage of the crop has declined due to competition from countries like Mexico and Peru, where labor costs are very low (IID Crop Report, 2004; Karp, 2010).

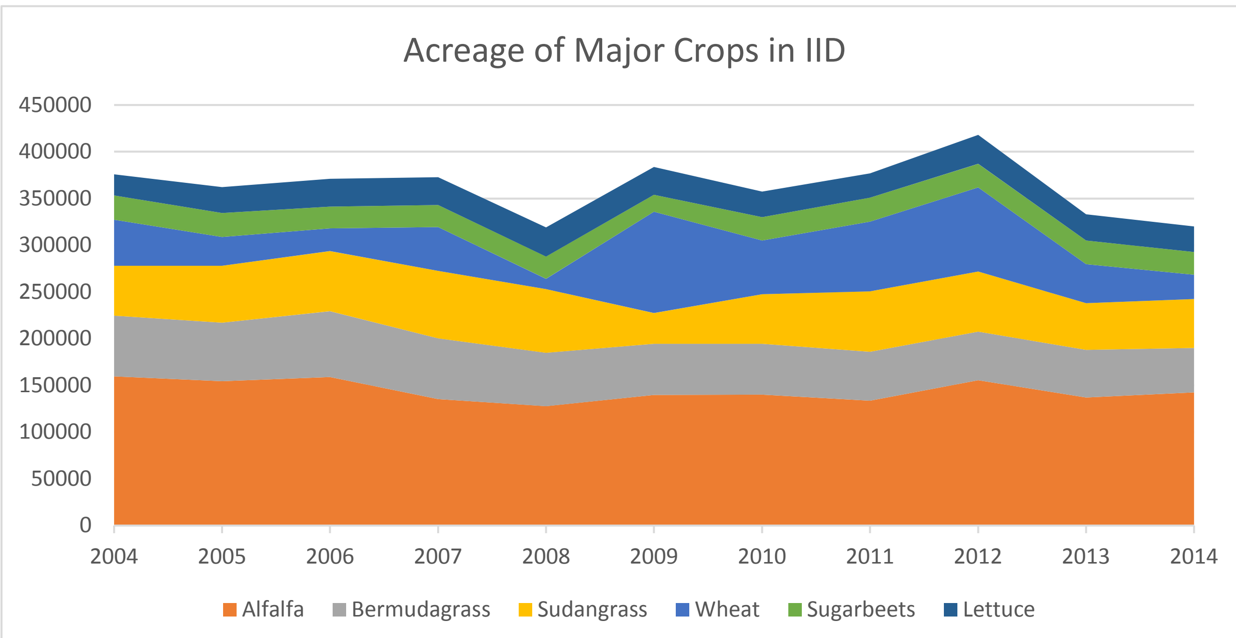

Figure 11. Changes in major crops in the Imperial Irrigation District. Source: Imperial Irrigation District Crop Reports.

9.6 The Walker Basin in Nevada – Water for the Environment

In the Great Basin of Nevada and Utah, the USDA supported Western Region Sustainable Agriculture Research and Education Program (SARE) has created a comprehensive educational program with five modules to inform farmers about the opportunities and obstacles when switching to lower-water-use crops (SARE, 2012a). The educational program derives in part from a peer-reviewed study that modeled a number of relevant issues when crop switching (Bishop, Curtis, & Kim, 2010b). The peer-reviewed study modeled yields of alternative crop production using different amounts of water, while considering costs, returns and numerous other factors. The study also conducted producer interviews, and field trials in the Walker Basin where the main crop is alfalfa. The researchers found that alternative crops do exist that could reduce water consumption by one-half.

One of the motivations behind the study was to increase environmental flows in the Walker River. To achieve this aim, producers would have to grow a crop that would use less water, withstand the harsh climate, and match or exceed the current farm returns. Fruits, cereals, legumes, and industrial crops were investigated as potential new crops. Of all the crops examined, and considering issues of climate, water use, market demand, prices, and infrastructure, they found that onions showed the most potential.

The accompanying SARE educational program has been used in the Great Basin to assist farmers switch crops with some success. The program consists of five modules: (1) introduction and water issues, (2) agronomics of alternative crops, (3) market opportunities for alternative crops, (4) selecting alternative crops, and (5) sources of assistance when moving to alternative crops. The section on evaluating alternative crops includes assessing the dominant soil types and what already grows. SARE also provide numerous information sources and a guide where producers can find information on potential markets, distribution networks, and how to evaluate the profit potential. Farmers using the modules create an enterprise budget and determine what agronomic practices are associated with the alternative crop. The section on assistance includes information on federal funding sources, USDA Conservation Programs, Farm Bill details, and how to obtain information from local university extension (Bishop, Curtis, & Emm, 2010).

There have not been wide scale crop changes in the Walker Basin despite the program, but farmers who have participated in the program have helped other producers plant lower-water-use crops on their farms (SARE, 2012b). Even though conserved water is not protected from use by other diverters, there are some recent efforts to provide a legal foundation for such protection. This SARE program provides a useful framework for how to navigate crop switching, including the realities and difficulties behind actual crop changes to conserve water.

9.7 The Rise of Organic Agriculture

Organic agriculture is growing rapidly, in large part because of increasing consumer demand. In the Four Corners States, the majority of organic producers are planning to either maintain or expand acreage. Some organic crops use less water than the crops they replace. There is potential to save water in this evolving sector, but there are also significant barriers. More organized marketing and distribution networks need to be established to assist producers with finding markets. Most importantly, there needs to be a significant effort to establish regional production facilities (SARE, 2008).

Transitioning to organic crops is the purpose behind one project in western Colorado being funded by the Colorado River System Conservation Pilot Projects. According to USDA regulations, conventional fields must be transitioned to organic fields over a three-year period when no pesticides or herbicides are used. In this pilot project, a low-water-use cover crop is being planted on conventional fields that will be converted to organic production. Specifically, corn is being replaced, and the difference in the consumptive-use of the cover crop will be counted as water savings. It is likely that the cover crop is contributing to soil health, another benefit. This project is the first year of the required three-year transition.

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