Impact of Agricultural Extension on Irrigated Agriculture Production and Water Use in California

By Diti Chatterjee, Ariel Dinar, and Gloria González-Rivera

Diti Chatterjee is Agricultural Economist/Evaluation Specialist, A2F Consulting LLC, Bethesda, Maryland. Ariel Dinar is Distinguished Professor of Environmental Economics and Policy, School of Public Policy, University of California, Riverside, INTS 4135, (o) 951 827 4526, (em) adinar@ucr.edu (corresponding author). Gloria González-Rivera is Professor of Economics, Department of Economics, University of California, Riverside.

Acknowledgement

Funding for the research leading to this paper was provided by the Office of the Vice President Division of Agriculture and Natural Resources (ANR), and by The Giannini Foundation for Agricultural Economics Mini Grant Program. We would like to thank Doug Parker and David Zilberman for their helpful comments.

Abstract

University of California Cooperative Extension (UCCE) disseminates irrigation information with the aim of enhancing productivity, using irrigation-efficient technology and water management practices. We estimate the impact of UCCE as a source of irrigation information and knowhow, on irrigated agriculture production and water use for California's farmers. Using census data from 2003 and 2008, we find positive effects of UCCE on irrigated agriculture production ($3,035/ acre), and water use rise (1.17 acre-feet/ irrigated acre), suggesting selection of more profitable cropping patterns that, through the use of water-saving irrigation systems, increase the average value of output per irrigated acre.

INTRODUCTION

Climate change can potentially alter agricultural systems (Parry et al., 2004) and affect yield quantity and quality of annual as well as perennial crops via rising temperatures and shifting patterns in precipitation (Adams et al., 2001; Southworth et al., 2000; Lobell et al., 2006). Climate change will result also in an increased demand for irrigation water because of the combination of decreased rainfall and increased evaporation (Bates et al., 2008) and in a change in water quality (Masmoudi et al., 2010). Climate change, therefore, has and is expected to have a considerable impact on the agricultural sectors of the western coast of the U.S., especially in the Southwest, which already experiences harsh climatic conditions. California's agricultural sector, which depends on irrigation, will need to adapt to these changes in the future.

The agriculture sector in California is the largest consumer of water for irrigation, accounting for 80 to 90 percent of human water usage (Olen et al., 2015). California's agricultural sector produced $53.5 billion in total value of sales receipts in 2014 (California Agricultural Statistics Review, 2014–2015). Water is one of the main inputs in California's agricultural production. The state has experienced many droughts, which affected agricultural productivity in the short and long run.

The University of California Cooperative Extension (UCCE) has been working on research aimed at improving productivity and resource use in the state (Chatterjee et al., 2018). Irrigation efficiency has been an important subject in the UCCE disseminated knowledge portfolio since the 1950s (Hayden-Smith & Surls, 2014), when farm advisors started working on applying water based on soil and crop type. Each county office in the UCCE system has developed and implemented irrigation programs over the years to help farmers with irrigation information, such as irrigation requirements for various crops, soil types, and weather conditions.[1] Over time emphasis has been given to water conservation technologies, because of water shortage issues in California. Farm advisors have introduced irrigation technologies that reduce water wastage and improve yields, such as sprinkler and drip irrigation. UCCE personnel have been responsible for the introduction of drip irrigation in San Diego county (Taylor et al., 2014), which later spread to other parts of the state and the country. According to Taylor et al. (2014), UCCE's efforts in implementing drip irrigation in California have led to $78 million to $238 million in annual water savings. Allen-Diaz (2009) reports that UC-led researchers have developed a technique that increases drought tolerance in plants, which can help farmers maintain productivity as well as make irrigation more sustainable.

The University of California and the California Department of Water Resources have developed a network of monitoring stations across the state — the California Irrigation Management Information System (CIMIS), which has been operational since 1982,[2] to provide irrigation requirement estimates to farmers, based on crop evapotranspiration (ET), and other weather conditions. Parker et al. (2000) estimates that statewide benefits outweigh the costs of operating CIMIS, and lead to reduction of water use by nearly 100,000 acre-feet, annually. Parker and Zilberman (1996) report that CIMIS led to higher gains for farms with modern irrigation technologies, and it is more effective for high value crops in terms of cost-benefit considerations. UCCE efforts toward improving irrigation efficiency have been significant in the state of California. Empirical studies aimed at estimating the overall impact of UCCE irrigation information on irrigated agriculture production and water use are rare.

The extension efforts (activities, number of factsheets and decision tools published, attendees and frequency of meetings, delivery methods, and platforms, etc.) are the mechanism by which UCCE disseminates the knowledge and affects its clientele. UCCE knowledge production consists of direct and indirect contacts with clients, its own research projects, and its publications. Over the period 2007–2013, the total number of counts of knowledge produced through all direct contact methods, statewide, rose from 15,059 in 2007 to 21,479 in 2011 and then it fell to 8,282. Total number of indirect contacts with growers in 2007 was 259,065, picked up to 405,386 in 2009, fell to 43,000 in 2010, and rose again to reach 100,919 in 2013. Own research projects and publications went down from 3,349 in 2007 to 506 in 2013. Distribution by county is available upon request (Chatterjee, et al., 2018).

In this paper, we empirically estimate the impact of UCCE as the farmers' source of irrigation information and knowhow on irrigation water use efficiency. We use the Farm and Ranch Irrigation Survey as our main data source (with several limitations discussed below). Our objective is to quantify the impacts of UCCE on agricultural outcome. Two variables of irrigation efficiency are used as outcome variables — total value of agricultural output per irrigated acre, and water applied per acre of irrigated land. We choose these two variables keeping in mind UCCE's role in working toward improved farmer productivity. Our irrigation efficiency models account for on- and off-farm water availability, irrigation systems installed in the farm, climate, available irrigation information sources, farmland characteristics, and demographic characteristics. For the empirical analysis, we use farm level data collected by United States Department of Agriculture (USDA) as part of the Farm and Ranch Irrigation Survey (FRIS). This data set is arguably the most comprehensive irrigation information data collected in the country. The results of our analysis shed light on the relationship between UCCE as a source for irrigation information and other inputs, on irrigated agriculture production as well as farmers' irrigation water use decisions in California. We also estimate the impact of farmer age on adoption of irrigation knowledge disseminated by UCCE. The paper contributes to the literature by providing quantitative evidence of the level of impact of UCCE toward irrigation efficiency in the state.

The remainder of the paper is organized as follows: Section 2 outlines the econometric methodology, followed by data description, and summary statistics. Section 3 analyzes the empirical results. We end the paper with conclusion and policy implications in section 4.

2. EMPIRICAL MODEL AND DATA

2.1 Empirical Model

We use two variables to represent farmers' irrigation water use efficiency: Total value of agricultural output per irrigated acre, and water use per irrigated acre. We estimate the impact of UCCE disseminated irrigation knowledge, and other factors, on each of these two variables. We use data for 2003 and 2008 taken from USDA-FRIS dataset as is explained below. Productivity is measured usually by yield per acre (Datt & Ravallion, 1998), and it includes both irrigated and unirrigated acres. However, we extend the notion of irrigation productivity by including only irrigated acres and denote value of yield per irrigated acre as a measure for productivity. Assuming profit maximizing farmers, we multiply the yields by market prices of each crop, to obtain the dollar equivalent value for each crop. All individual values are then aggregated, to create the total value of agricultural output for each farmer in our data set. Because we consider two periods of time, five years apart, part of the difference in value of agricultural sales between the two periods results from difference in output prices brought about by inflation, and not necessarily rise in agricultural productivity. Guiteras (2009) addresses this issue of price changes over time by using a constant price to calculate the value of agricultural output for different periods. Variation in the resulting variable captures the change in average value of output resulting from change in yields, and not prices. We follow this methodology in our analysis to eliminate the impact of inflation on value of agricultural output; and obtain the impact of UCCE on irrigated agriculture. We use value of agricultural sales to measure agricultural productivity in this paper, following a similar methodology in OECD (2001).[3]

The empirical model for irrigated agriculture described above represents farm level value of agricultural output per irrigated acre P as a function of: water availability *A*, irrigation system in the farm *I*, climate *C*, irrigation information system U, farmland characteristics *O*, and farmer demographics *D*. The model in its general form is represented by:

$$P_{it} = f(A_{it}, I_{it}, C_{it}, U_{it}, O_{it}, D_{it}) \qquad (1)$$

where i = 1,....., I is index of farms, and *t* = 2008, 2013, represents time.

The second model is a farm level model representing water used for irrigation, per acre of irrigated land. The covariates remain the same as in equation (1), but the dependent variable in this case is V, representing water usage per irrigated acre. The general form model is:

$$V_{it} = g(A_{it}, I_{it}, C_{it}, U_{it}, O_{it}, D_{it}) \qquad (2)$$

UCCE's irrigation scheduling services and outreach programs that encourage farmers to install water-saving irrigation systems are aimed at reducing irrigation water usage. These efforts have led to considerable amounts of water savings in California, according to Taylor et al. (2014), and Parker et al. (2000). However, not all water saved is returned to the sources, given the "use it or lose it" water allocation system in the state and the effective water constraint relative to land constraint, leading to an expansion effect (Dinar & Zilberman, 1991; Ward & Pulido-Velazquez, 2008), namely under non-limiting land resources any savings in water from use of more efficient irrigation technology will be translated to expansion of irrigated land and thus increased use of irrigation water on the farm.

Water availability variables are represented by vector *A* and include two variables: well depth of three primary wells used by the farm, and cost of off-farm surface water per irrigated acre. On-farm water availability is directly correlated with well depth, and cost of obtaining groundwater is a function of well depth (Caswell & Zilberman, 1986). We include a square term of well depth to understand how rising well depth will affect irrigated agriculture production and water use. Cost of off-farm water is an economic indicator of the farm's water availability. These variables are likely to affect a farmer's decision of irrigated agriculture production and water use.

The vector I includes dummy variables for each existing irrigation system used by farmers, such as gravity, sprinkler and drip, trickle and sub-irrigation systems. These variables measure whether the farmer used the said irrigation system on the farm. Gravity system, (furrow or basin irrigation), which is known to be water- inefficient, has been the traditional and preferred method of irrigation system in the last century. There has been a big push from the government to generate awareness among farmers, and to promote adoption of more water-conserving irrigation methods such as sprinkler and drip (Negri & Brooks, 1990; Caswell & Zilberman 1985).

Climate plays an important role in irrigation use efficiency and is represented by the vector C, which includes county level temperature and precipitation as covariates. Quadratic terms for each are introduced to capture second order effects (Schuck & Greene, 2001). Indicator variables representing farm level frost control and heat control measures are also included in C; farmers implement these measures to account for local weather changes, which affect irrigation water use efficiency decisions. There is evidence of frost damage to vegetables, such as potatoes (Grewal & Singh, 1980), and heat damage to field crops, such as alfalfa (Li et al., 2013) and maize (Hatfield & Prueger, 2015). Therefore, measures to control heat and frost damage likely affect productivity as well as water use and hence, are included as covariates in our model.

Irrigation information systems, represented by vector *U*, play an important role in educating farmers about environmental issues such as climate change and resource availability, and provide solutions to dealing with these issues. The irrigation information system included in our model is UCCE, our covariate of interest; it enters the model as a dichotomous variable indicating whether or not the source of irrigation information for the farmer is UCCE. It has been the most important source of freely available information for California farmers, and we expect to see positive impact of UCCE on irrigated agriculture production and volume of water applied.

Caswell and Zilberman (1986) mention that land quality, captured by our farmland characteristics variables *O*, is an important factor in the farmer's irrigation choice problem; hence it has bearing on irrigated agriculture production and volume of water applied. In this vector, we include variables such as crop mix and salinity of the soil. Crop mix is measured by the inclusion of dummy variables for different major crop types, which indicate whether the farm produced and harvested them. Soil salinity is captured through a dummy variable that indicates whether the farmer used irrigation water for leaching the soil of salts.[4]

Farmer demographic variables *D*, include farmer age, primary occupation of the farmer, whether the operation has a hired manager, and farmer experience. Dinar and Yaron (1990) report that older farmers with more experience are less likely to implement water-saving methods in their operations. Many empirical studies support the hypothesis that land ownership encourages adoption of water saving technologies, but there are studies that report results contradicting this hypothesis. Bultena and Hoiberg (1983) found no support for the hypothesis that land tenure has a significant influence on adoption of conservation tillage. Farmer experience is the final demographic variable in the model. Years of experience can lead to greater understanding of the production process; it can also establish social networks, which enable higher farmer awareness of available technology in the agricultural sector. Experience has the potential of enhancing farmer productivity (Kalirajan & Shand, 1985), and social networks affect productivity as well as adoption of technology (Birkhaeuser et al., 1991). We include these variables as important factors influencing irrigation decisions. Interaction terms between UCCE and farmer age are also included in our econometric model, to test the hypothesis that older farmers are less likely to adopt new knowledge and technology imparted by UCCE.

The econometric models we estimate for equations 1 and 2 are the following:

$$\begin{aligned} P_{it} = \alpha_1 + \beta_1 A_{it} + \beta_2 I_{it} + \beta_3 C_{it} + \beta_4 U_{it} + \beta_5 O_{it} + \beta_6 D_{it} \\ + \beta_7 (UCCE_{it} * Age_{it}) + \gamma\theta_j + \ \delta\lambda_t + \varepsilon_{it} \qquad (3) \end{aligned}$$

$$\begin{aligned} V_{it} = \alpha_2 + \rho_1 A_{it} + \rho_2 I_{it} + \rho_3 C_{it} + \rho_4 U_{it} + \rho_5 O_{it} + \rho_6 D_{it} \\ + \rho_7 (UCCE_{it} * Age_{it}) + \gamma\psi_j + \ \delta\varphi_t + \varepsilon_{it} \qquad (4) \end{aligned}$$

where all variables are defined above. We also include county *j* and year *t* fixed effects to control for common factors across counties and common conditions between the two years under consideration (2003 and 2008) in the analysis. We consider clustered standard errors ε_{it} at the county level because our climate variables vary at the same level of aggregation.[5]

2.2 DATA AND VARIABLES

2.2.1 Farm and Ranch Irrigation (FRIS) data

For the empirical analysis, we use the Farm and Ranch Irrigation Survey (FRIS) for information on farm level irrigation methods, water application from different on-farm and off-farm sources, acres irrigated and harvested for each crop, irrigation costs, sources of information on irrigation methodologies, and farmer demographics. This survey was introduced as a complimentary study to the Agricultural Census by USDA in order to obtain further information on farmers' irrigation decisions based on their location, available water sources, and available irrigation options and costs. FRIS was first implemented in 1979 and it is carried out on a five-year basis, usually in the year following the Agricultural Census. The survey is sent out to a sample of farmers who indicate on the Agricultural Census survey that they used irrigation on their farm. FRIS data is published at the aggregated state level; we obtained farm-level data for our analysis, from the USDA-NASS Pacific headquarters in Sacramento.

A survey question to identify the farmer's source of irrigation information was introduced. To answer the question, farmers are provided with various options, one of which is "extension agents or university specialists"; we use this indicator variable to represent the presence and influence of cooperative extension (UCCE), our independent variable of interest. For the empirical analysis, we use farm-level FRIS data for the years 2003 and 2008, which include data on irrigation practices as well as farm and farmer demographics.[6] The data set represents a repeated cross section of farmers in California, for the two census years.

The survey contains information on average crop yields per irrigated acre for a group of field and vegetable crops, including corn (all types, including grain or seed, and silage or green chop), sorghum, wheat (grain or seed), barley (grain or seed), beans (dry, edible), rice, alfalfa and alfalfa mixtures, hay, sugar beets, cotton, and vegetables such as potatoes, lettuce, tomatoes, and sweet corn. However, it excludes this information on all berries, fruits and nuts, and pastureland production per irrigated acre, which therefore excludes these crops from the first part of our analysis. Hence, our value of agricultural output includes field crops and vegetables only.[7] The issue of aggregating outputs of a variety of crops measured in different units has been addressed by multiplying each crop yield with the corresponding price per unit of crop output. The data on crop prices has been obtained from the 2003 California Agricultural Statistics,[8] published by the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS). The average crop output per irrigated acre for both years 2003 and 2008 were multiplied by the 2003 prices to obtain the inflation-adjusted dollar amount of average value of agricultural output per irrigated acre — the dependent variable of interest in equation (3). Figure 1 presents the distribution of the values in our sample of 1953 (farm) observations. Fifty-five percent of the farmers report average value of output per acre of irrigated land within the range of $0–$500, 11 percent within the range $500–$1,000, 11 percent within the range $1,000–$2,000, and 9 percent in $20,000–$40,000. Only 0.6 percent farmers are in the range of $40,000–$70,000, which is the highest range in our sample.

FRIS includes information on volume of water used for irrigation from all on-farm and off-farm sources, measured in acre-feet. The aggregated volume of irrigation water is divided by number of irrigated acres to obtain our dependent variable for estimating equation (4), water use per irrigated acre. Distribution of the values of volume of water per irrigated acre is presented in Figure 2. Twenty-nine percent of the sample stays within the range of 0–1 acre-foot/acre, followed by 27 percent in the range of 2–3 acre-feet/acre. The highest range in our sample is 11-12 acre-feet/acre, which includes only two observations.[9]

UCCE is included as one of nine sources for irrigation information in the FRIS dataset. Figure 3 reports the number of farmers who choose each of the different sources for information on irrigation. The most popular (35 percent) source of irrigation information, as indicated by farmers, is neighboring farmers, followed by nearly 33 percent of the farmers indicating UCCE as a source of irrigation information and 27 percent indicating hired private irrigation specialists or commercial crop consultants as their source of information.[10]

We include three irrigation systems from the survey data: (1) gravity, (2) sprinkler, and (3) drip, trickle and sub-irrigation systems. Farmers in the dataset either exclusively use a single system, or some combination of the available irrigation systems. Nearly 31 percent, 7 percent, and 12 percent indicate gravity, sprinkler, or drip, trickle and sub-irrigation, respectively, as the only irrigation system on their operation, and 7 percent indicate some combination of all three systems.

Information on cost of off-farm water, and average well depth is recorded for each farm in the FRIS data set.[12] Higher cost of off-farm water is indicative of scarcity of water, as is high well-depth values. Off-farm water cost has been converted to constant 2003 US dollars for the analysis and divided by number of irrigated acres reported. For the construction of the variable representing well depth, we calculated the mean depth (feet) of the three major wells, which were reported for irrigation purposes by the farm.

Irrigation water is used as crop freeze and heat mitigation mechanisms in California's agriculture. Freeze damage to vegetable and fruit crops leads to loss of output (Carman & Sexton, 2007), and therefore, mitigation mechanisms are employed to minimize the loss. Harsh weather conditions, and low precipitation rates in agriculturally important regions, such as the San Joaquin and Imperial Valleys, need control and mitigation mechanisms, which have bearing on farmers' irrigation decision. We include indicator variables representing the farmer's usage of irrigation water for each mechanism as indicators of weather conditions (Olen et al., 2015). For our sample, 13 percent of the farmers report using irrigation water for freeze control and mitigation measures, and 7 percent for heat mitigation and crop cooling measures.

FRIS includes data on farmer's crop choice, average output per irrigated acre, and irrigated acres harvested for all crops grown on the farm. Farmer's crop choice is an indicator of suitability of the crop to the soil type. We use the data on irrigated acres harvested to create indicator variables representing types of crops grown on the farm. We generate these variables for a number of crop types, including all fruit and nut crops, vegetables, corn, wheat, alfalfa, hay, and pasture. Thirty-eight percent of the farmers indicate harvesting fruit and nut crops, followed by 29, 21, 19, 17, 14, and 9 percent indicating harvesting alfalfa, vegetables, wheat, corn, hay, and pasture, respectively. Soil salinity is another indicator for soil quality, and remains an important issue in California's agriculture, especially in the San Joaquin Valley and Imperial Valley regions (Letey, 2000). Using irrigation water for leaching the soil of salts is common practice, and likely impacts farmers' irrigation decision. Six percent of the farmers report using irrigation water for salinity control. We use a dichotomous variable representing usage of irrigation water for leaching (salinity control) as an indicator of soil quality of the farm.

Farmer demographic variables included in the model are farmer age, tenure type (whether primary occupation of the operator is farming), type of operation represented by whether the principal manager of the operation is a hired manager, and experience. Figure 4 presents the age distribution of farmers in the sample with a mean of 57 years. Nearly 86 percent of farmers report themselves as "farm or ranch operators," and 18 percent report the principal manager as the hired manager of the operation. Mean farming experience is 25 years.

Table 1 reports the summary statistics and description of the variables included in the empirical analysis.[12] On average, nearly 2 acre-feet of water is applied per irrigated acre in our sample. Mean value for the variable representing average output per irrigated acre is nearly $4,100.[13] Mean off-farm water cost amounts to $39 per acre-foot. Mean well depth is 63 feet. The average precipitation and temperature values are 1.3 inches and 62 degrees Fahrenheit, respectively.

2.2.2. National Oceanic Atmospheric Administration (NOAA) Data on Precipitation and Temperature

Data on average monthly precipitation and temperature for our study are collected from NOAA, for all active weather stations in California that are geo referenced. These data are used to create annual averages for each weather station. Then, these stations are matched to the counties in our sample following Burgess et al. (2011). County level weighted annual average temperature and precipitation variables are generated using a weighted average formula; the weights are the inverse of the distance between a station and centroid of a county, for all stations within 50 miles of the centroid.[14]

2.2.3. Data Limitations

The data that we use were made available to us on ad hoc arrangements for a limited period of research and analysis. The FRIS data set is a repeated cross sample, and we were able to use the years 2003 and 2008. Several caveats are mentioned. Farmer endogeneity is known in repeated farm level cross sectional data. We were limited in using appropriate control variables to reduce unobserved factors, which may affect our dependent variable. Our climate data are at the county level. To match between the production data and the climate data we had to calculate per acre values for the production data at the county level and county climate measures.

3. EMPIRICAL RESULTS

3.1. Farmer age and UCCE information adoption, and the combined impact on irrigated agriculture production and water use per irrigated acre

To realize the impact of UCCE, we have to identify which group of farmers utilizes the irrigation information, and how this information, in turn, affects their irrigation water use. For this, we break the data into two groups — the first consisting of those who report UCCE as a source of irrigation information, and the second of those who report UCCE as not their source. For each of the two groups, we calculate the mean of the dependent variables, for each age level in our sample. We do this for both average value of output per irrigated acre and volume of water applied per irrigated acre. Figures 5 and 6 report the results, respectively.

In Figure 5, we observe that on average, farmers of all ages who report UCCE as a source of irrigation information have a higher average value of output per irrigated acre. The gap between users and non-users of UCCE information is higher for younger farmers, gradually diminishing for older farmers, and finally converges for the oldest farmers in the sample (probably capturing also the experience effect). Average value of output per irrigated acre is a diminishing function of age according to the data, much like the empirical results reported by Tauer (1995). According to that study, farmer productivity generally increases, and then decreases with age; farmers of different ages display different productivities in utilizing the existing technology. We also observe similar trends in Figure 5; the output per irrigated acre values for age groups 17–40 years are lower on average, for both users and non-users of UCCE information. For age groups 45–65, the values increase, and then around 70 years they start declining.

In Figure 6, we observe that farmers of all ages who report use of UCCE information use on average more irrigation water per irrigated acre than the reported non-users. The gap between users and non-users is lower for older producers (capturing also the impact of experience). Compared with non-users of UCCE information, users employ nearly an additional 1 acre-foot per irrigated acre. Crop-specific water requirements can be a possible reason behind this phenomenon. From the data, we observe that 17 percent of farmers who use UCCE information harvest fruit and nut crops, field crops, and vegetables; 33 percent harvest vegetables as well as field crops, and 9 percent use their land as pastureland. Because field crops in general have higher water requirement, the higher percentage of farmers who harvest them can raise the average water usage for all age groups.

Scrutiny of the 95 percent confidence intervals for the fitted values in Figure 5 and Figure 6 could be useful. There is an overlap of the 95 percent confidence interval for value of agricultural output per irrigated acre for the “with” and “without” UCCE information. This implies that UCCE information has an impact on the value of agricultural output per irrigated acre on average, but there is no differential impact (slope very similar between the two groups) of UCCE’s information by age. There is no overlap of the 95 percent confidence interval for the “with” and “without UCCE information” groups. This implies that UCCE information has a statistically significant impact on the volume of water applied (acre-feet) per irrigated acre on an average, but there seems to be no differential impact (slope very similar for the two groups) of UCCE’s information by age. These findings are very important for extension policy and outreach programs and will be discussed in the Conclusion and Policy Implication section.

By controlling for crop types we can introduce the selection of crop mix and its effect on water use; this allows us to estimate the impact of UCCE on irrigated agriculture production and water use per irrigated acre.

3.2. Impact of UCCE irrigation information on irrigated agriculture productivity

Table 2 reports the regression coefficients of the model in equation (3), where the dependent variable is the average value of output per irrigated acre. Coefficients of specific variables are interpreted while holding all other values constant. UCCE information U, on irrigation has a positive, statistically significant impact of $3,035 on average value of output per irrigated acre. This increment amounts to 74 percent of the mean for the sample. With increasing farmer age, UCCE knowledge has a significant negative impact of $53.22 per year of farmer’s age. This result hints toward age-related difference in the degree of implementation of available knowledge, as Tauer (1995) and Tauer and Lordkipanidze (2000) suggest, such as differences in implementation of the prescribed methods.

We do not observe any significant impact of off-farm surface water availability (Variable *A*) represented by cost per irrigated acre or by well depth, on farm productivity per acre. This finding, while initially unexpected, could mean that farmers are able to adapt to higher water scarcity levels by using advice of UCCE, such as moving to higher value, less water-thirsty crops.

We do not observe positive coefficient for any of the standalone irrigation systems.[15] Sprinkler as a standalone irrigation system has a significant negative impact of $1,864 on farm level irrigated agriculture production, whereas a combination of all three systems has a significant positive impact of $3,091. Sprinkler system may be associated with water wastage caused by evaporation in regions of high temperatures, which raises water cost. The high, statistically significant positive impact of the combination of all systems has important implications. This implies that a combination of all irrigation systems is beneficial for irrigated agriculture productivity, enhancing farm level average value of output per irrigated acre. This finding is also in line with irrigation practices, where different irrigation systems are employed in different periods of the growing cycle (for field crops for example): sprinklers during pre-season, and prior to planting, if needed, and drip during the entire irrigation season.

Significant climate-related variables (variables *C*) are those for frost and heat control. Channeling irrigation water to deal with frost damage has a negative impact of nearly $965. Although this seems counterintuitive, frost mitigation measures could have been responsible for diminishing an even bigger loss for farmers.[16] On the other hand, irrigation water usage for heat mitigation adds a statistically significant positive amount of $1,563 to average value of output per irrigated acre. Both weighted mean temperature and precipitation have positive impacts, but the coefficients are not significantly different from zero. The quadratic terms are not significant as well. In the category of farmland characteristics (variables *O*), vegetables, corn and hay production have positive significant coefficients of $15,906, $1,362 and $569, respectively. Farmer demographic variables (*D*), are not statistically significant. The sign for farmer age is negative, which supports the results in Figure 5. The interaction between UCCE and farmer's age is negative and significant for the higher range of the age group. Tenure characteristics such as principal occupation, hired manager, and experience on the farm do not affect irrigation efficient productivity significantly.

3.3. Impact of UCCE on irrigation water use per irrigated acre

Table 3 reports the regression coefficients for the model (equation 4) with volume of water applied per irrigated acre (acre-feet/acre) as the dependent variable. Coefficients of specific variables are interpreted while holding all other values constant. We observe that UCCE information has a positive significant impact of 1.17 acre-feet/irrigated acre on irrigation water use. This impact of UCCE amounts to nearly 50 percent of the mean water use per irrigated acre for the sample. With increasing farmer age, UCCE irrigation information has a significant negative impact of 0.01 acre-feet/acre. This implies that older farmers who are users of UCCE information tend to apply less water per irrigated acre. This may be the result of such farmers growing less profitable crops, which are characterized by lower water consumption per acre. Among water availability variables (A), off-farm water cost per irrigated acre has no statistically significant impact on water use per irrigated acre. This could be explained by the fact that the marginal productivity of water is much higher than the cost of water, which we already know as a fact in California. This result could also indicate that surface water is considered as a quantity rationed input, and therefore, marginal changes in price do not lead to alteration of farmer irrigation decisions or conservation, as reported by Moore and Dinar (1995). Average well depth has a small, significant positive effect of 0.006 acre-feet/irrigated acre on water usage.[17]

We observe a significant negative coefficient of 1.04e-05 acre-feet/irrigated acre for the quadratic term for average well depth, indicating decreasing marginal impacts of that variable. Therefore, rising well depth discourages water pumping but does not affect average output per irrigated acre. Standalone irrigation systems all have significant impacts on water use/per irrigated acre. Gravity system leads with the highest positive impact on water use, at 1.33 acre-feet/irrigated acre, followed by sprinkler at 0.46 acre-feet/irrigated acre, and drip, trickle, and sub-irrigation at 0.38 acre-feet/irrigated acre.

These results are expected because gravity system is known to be the most water-intensive irrigation system and leads with the highest water usage among all three systems. According to our results, sprinkler systems lead with more irrigation water use compared to drip, trickle, and sub-irrigation systems. The additional water usage could be the result from loss of water via evaporation from the plant surface. A combination of all three irrigation systems does not have any significant impact on water usage/irrigated acre. Therefore, our results imply that not only does the combination of irrigation systems have no significant incremental impact on water use per irrigated acre, but it also has a positive impact on irrigated agriculture productivity. This may have important implications in terms of policy decisions.

Among climate variables, *C*, mean temperature and precipitation do not have statistically significant coefficients.[18] We find a positive significant coefficient of 0.24 acre-feet/irrigated acre, for irrigation water used for frost mitigation. Fruit and nut crops, alfalfa, vegetables, pasture, and hay have significant positive increase on water use/irrigated acre of 0.75, 0.63, 0.65, 0.43, and 0.44 acre-feet/irrigated acre, respectively.

We observe a reduction in water usage/irrigated acre with increasing farmer age, when farmers indicate UCCE as the source of irrigation information. To capture the impact of farmer age on water usage, we divided the farmer ages into groups, which are: less than 40, 40–50, 50–60, 60–70, 70–80, and above 80. We interact the dummy variable representing the age group to which each observation belongs, with the dummy variable representing UCCE as the information source. We estimate the same model as before (Equation 4), but with the addition of all age groups, keeping the first age group as the benchmark and all interaction terms except the first.[19] According to the regression results reported in Table 4, farmers younger than 40 who indicate UCCE as a source of irrigation information have a significant positive rise in water use, amounting to 0.61 acre-feet/irrigated acre. In comparison to the reference group (users of UCCE information in the age group of less than 40 years), we observe that for age group 70–80, UCCE users have a significant negative impact on water use of

0.78 acre-feet/irrigated acre,[20] and for the age group of 70–80 age group, this negative impact amounts to 0.75 acre-feet/irrigated acre. Therefore, UCCE irrigation information has a significant positive impact on water use for farmers less than 40 years of age, and a significant negative impact on water use for farmer ages of 70 and above. These results imply that older farmers who are users of UCCE information use less water than younger users, which is opposite to the results reported by Dinar and Yaron (1990). Other coefficients reported in Table 4 are comparable with those reported in Table 3.

Using the average cost of irrigation water per acre-feet across the two census years, the cost of the additional 1.17 acre-feet amounts to approximately $40. This means that value of production to farmers who use UCCE irrigation information amounts to approximately $2,995 per irrigated acre.[21]

The results indicate that UCCE's irrigation information leads to higher farmer irrigation water use, on average. This goes against the perception that irrigation-efficient technology leads to water savings. UCCE advocates the use of irrigation-efficient technology such as drip irrigation systems, which save water and produce more output (Taylor et al., 2014; and Peterson & Ding, 2005). A plausible reason for irrigation-efficient technology accompanied by increase in water use is suggested by Huffaker and Whittlesey (2003), and Scheierling, et al. (2006), explaining the coefficient estimates reported in Table 3 and Table 4. With the investments in irrigation-efficient technology suggested by UCCE, farmers save irrigation water. Given that land is still available, they increase their irrigated acreage and use this saved water to attain maximum yield; this higher yield leads to higher demand for water, which is met by increase in water application. Dinar and Zilberman (1991) coined this increase in irrigated land and water use as "expansion effect." As Ward and Pulido-Velazquez (2008) suggest, irrigation water-saving technology solutions lead to increase in crop production; but the greater yield leads to increase in evapotranspiration (ET), which ultimately leads to higher water consumption and overall depletion, in the presence of return flows. In the absence of return flows, water use increases by the amount of applied water use from both on- and off-farm sources, to maintain the higher yield. Therefore, our results suggest that UCCE's irrigation information does not lead to overall reduction in water use through water-saving irrigation systems. However, through the use of the water-saving irrigation systems, farmers do increase the average value of output per irrigated acre, with the increased irrigation water use.

3.4. Impact of the combination of UCCE and other sources of irrigation information

While UCCE as the major source of irrigation information has a significant impact on irrigated agriculture production and water use per irrigated acre, there are other sources of irrigation information indicated in the survey that may have a significant impact as well. We infer whether or not obtaining knowledge from at least one additional source (Figure 3) besides UCCE is better on the margin than obtaining it from a single source. For this purpose, we created a variable that indicates whether the farmer obtained irrigation information from at least one out of the eight other sources of irrigation information mentioned on the survey. We incorporate the interaction term between this variable and our dummy variable indicating UCCE as a source of irrigation information into our original regression equations (3 and 4). Remaining variables are kept unchanged in the new models. The regression results are reported in Tables 5 and 6.

In Table 5, we observe a statistically significant positive impact of the information source combination on irrigated agriculture production, amounting to $2,813 per irrigated acre. This amount is lower than the impact we observe for only UCCE in Table 2, hinting at a reduced impact of the combination of irrigation information sources. Other coefficients are similar to those in Table 2: increase in farmer age and the irrigation information source combination has a significant negative impact of $51; sprinkler system as the standalone irrigation system has a significant negative impact of $1,854, combination of all three irrigation systems has a significant impact of $3,100. Irrigation water use for frost mitigation has a significant negative impact of $944, and heat mitigation has a significant positive impact of $1,586; vegetable production has a significant positive impact of $15,913, corn $1,370, and hay $574 per irrigated acre.

From the results in Table 2 and Table 5, we test whether the difference in the impact between having only UCCE as the source of irrigation information and a combination of sources is significant or not. This has policy implications because of the expenditures involved in the provision of irrigation information from these other sources. These expenditures are incurred by the government as well as the individual farmers. Our t-test results indicate that this difference in coefficients across the two models is not significantly different from zero.[22] This result implies that the additional source of information does not make any significant change to irrigated agriculture productivity. This could be because of the fact that some of the information provided by other sources may be borrowed from the free and publicly available information disseminated by UCCE.

Regression results for water use/irrigated acre as the dependent variable are reported in Table 6. We observe a positive, significant coefficient for the information source combination on water use, which amounts to 1.03 acre-feet/irrigated acre. This impact on water use is lower than that obtained for only UCCE as the source of irrigation information, as indicated in Table 3. The results of the t-test indicate that the difference between the coefficients obtained in Table 3 and Table 6 is statistically insignificant. Therefore, obtaining knowledge from UCCE and at least one other source of irrigation information does not significantly change the impact of the information on irrigation water use.

4. CONCLUSION AND POLICY IMPLICATIONS

We estimate the impact of UCCE on irrigated agriculture production (inflation-adjusted value of average output per irrigated acre), and water use, represented by volume of water applied per irrigated acre. Results indicate that UCCE as a source of irrigation information has significant positive impact on irrigation productivity as well as water use per irrigated acre. Taking into consideration this increase in irrigation water use, the net increase in productivity goes up by approximately $2,095 per irrigated acre. Our results suggest that irrigation-efficient systems advocated by UCCE may be counterproductive in terms of overall irrigation water use. However, UCCE's irrigation information does lead to rise in output, and hence farmer revenue (which doesn't necessarily mean increase in profit). In terms of policy interventions regarding reduction of water use, research projects aimed at improving the understanding of the hydrological system of river basins can be commissioned; irrigation-efficient technology can be more effective with more comprehensive understanding of issues such as return flows and aquifer recharge rates. As Ward and Pulido-Velazquez (2008) point out, allocating water rights based on water depletion and not water use, reducing evaporation from soil or supply sources, restricting acreage and water application expansion in cropped areas, and deficit irrigation can lead to real water savings. Another pertinent issue is the difference between water applied and water consumed; the water applied may not be consumed by crops in its entirety, and typically returns to the river as runoff or to the underlying aquifer through deep percolation (Hartmann & Seastone, 1965). Therefore, changes in water applied because of irrigation-efficient technologies may not accurately capture water saved. Better understanding of underlying hydrological system, economic systems such as water and other input prices, water rights, crop mix, and farmer demographics, can lead to water savings and productivity rise from irrigation-efficient practices and technologies, recommended by UCCE.

Joint effect of UCCE and other sources of irrigation information are also estimated and have important policy implications. We observe that the combination of UCCE and at least one other source of irrigation information does not lead to any significant change in the impact on irrigated agriculture production or water use per irrigated acre. This does not necessarily mean that other irrigation information sources are not important. This is because other sources of information may borrow the information that is already made available by UCCE. Therefore, other sources of irrigation information can play the role of substitutes in dissemination of knowledge, through greater collaboration with UCCE. This could reduce UCCE costs of outreach.

Because of unavailability of data for all variables in our model, we are unable to estimate the impact of UCCE on value of output per irrigated acre per unit of water. This is a possible direction for future work to improve our understanding of farmer decisions regarding water use and irrigation-water use efficiency, for policy perspective.

Several caveats need to be discussed. Farmer endogeneity is a relevant issue in case of repeated farm level cross sectional data. We have included as many relevant control variables as possible in the empirical analysis, to reduce unobserved factors, which may affect our dependent variable. However, one can still argue the existence of unobservable factors, which may lead to overestimation (or underestimation) of the coefficients in our model, and especially that of UCCE. More detailed data can address this issue of endogeneity better. Another issue we have not dealt with in this paper is the improvement of efficiency of other agricultural inputs, made possible through UCCE's research and information dissemination. Future research could address this issue through the incorporation of interactions of inputs and UCCE's irrigation information availability in the empirical analysis.

More studies on this topic can improve our understanding of how UCCE information can improve water use efficiency and enhance productivity. Better understanding of the demographic characteristics and efficiency level of the users of UCCE knowledge can help in designing more targeted outreach programs, both for users and non-users; this can increase the effectiveness of the programs and improve adoption of UCCE prescribed technology among farmers. Special programs can be designed, which will target older farmers, to enhance irrigation-efficient productivity. Based on our results, collaboration among UCCE and other private and government sources of irrigation information can potentially reduce water use; creation and improvement of networks of collaboration can potentially lead to reduction in irrigation water use, with higher irrigated agriculture production.

APPENDIX

The FRIS surveys a sample of farmers surveyed in the Agricultural Census. The website states that chances of larger farms being sampled for the FRIS is higher. We can observe that county average farm size in our FRIS sample is higher than that reported by the Census a year earlier, for both the FRIS years 2003 and 2008. Therefore, based on our coefficient estimates, it seems that our results could be specific to farmers owning bigger sized farms, for 2003 and 2008. Because the FRIS is the most comprehensive national level survey, it is the best data that is publicly available for empirical analysis. Given the scope of this data set, we cannot reject the issue of endogeneity rising from selection of bigger farms. Bigger farmers could be driven by the profit motive rather than the conservation motive, especially in the pre-drought years of 2003 and 2008. Extending our analysis to a longer repeated cross section could provide us more accurate answers on the issue of the impact of UCCE on water use efficiency.

ENDNOTES

1. All county offices have their own irrigation programs. Some examples include Monterey, Fresno, and Tehama, the links to which are provided below.

   http://cemonterey.ucanr.edu/Custom_Program567/

   http://ucanr.edu/sites/irrigation_and_soils_/

   http://cetehama.ucanr.edu/Water___Irrigation_Program/

2. http://wwwcimis.water.ca.gov/cimis/welcome.jsp

3. We use value of agricultural sales to measure agricultural productivity in this paper. Although these two terms are not the same because we do not account for cost of production. Value of agricultural sales is used in this analysis as a proxy of the county's agricultural sector productivity, following a similar methodology by OECD (2001).

4. Leaching the soil of salts is important in the Central Valley and may not necessarily be used everywhere in California.

5. On its face location and climate (temperature and precipitation) are expected to be highly collinear. However, given the similarity in climate across many of the agricultural areas in the 50 counties, and given the fact the county fixed effects control for many other variables, the correlation between county fixed effects and climate was relatively low at 0.18 and 0.22 for temperature and precipitation, respectively.

6. We obtained data for all FRIS years except 1979; but we were unable to use all censuses since 1994, which include the question to identify farmers' source of irrigation information. This is because the FRIS data set for some years did not include farmer demographic variables.

7. The exclusion of fruit and nut crops from the analysis is a caveat of this paper, given the importance of these crops in California's agricultural receipts. Therefore, our coefficients should be seen as a lower estimate of the UCCE contribution to the agricultural sector of the state of California.

8. https://www.nass.usda.gov/Statistics_by_State/California/Publications/California_Ag_Statistics/Reports/2003casall.pdf.

9. Crops for which reported irrigation water usage is above 10 acre-ft. per irrigated acre include field crops such as alfalfa, hay, wheat, pasture, and vegetable crops.

10. The survey does not include information on whether UCCE was the main source of information for a farmer. Therefore, there could be some overestimation of the impact of UCCE. However, throughout interactions with UCCE officials it was revealed that UCCE's publicly available information is used by other private agents, which reduces the possibility of a very large overestimation of the coefficient of UCCE in our analysis.

11. There is no information in FRIS on the quantity of riparian water rights that farmers are using.

12. The data set consists of 1953 observations for all variables except farmer age and experience, which have 36 missing observations. The summary statistics for each variable are calculated for all observations in the data set.

13. The mean value of average agricultural output per irrigated acre is about four times that for the values in the agricultural census. There could be two possible explanations for this: a) irrigated acres are less than total acres, which reduces the value of the ratio of output to acreage, and b) according to USDA, FRIS has a higher chance of sampling the bigger farmers with higher output per irrigated acre.

14. NOAA data do not include information on growing degree days for California counties, which is why we have used the following temperature and precipitation values, based on the literature.

15. All coefficient estimates for the I variables are to be interpreted as comparisons to two baseline cases of "no irrigation system" and "combination of two irrigation systems."

16. This implies that the negative regression coefficient is not because frost mitigation measures lead to a fall in the output; but the negative correlation is due to frost damage of an even bigger magnitude, which may have been partially reduced by the use of frost mitigation measures.

17. There could be possible endogeneity associated with the variables because of the fact that richer farmers can dig deeper wells. With the availability of more detailed data on farmer income, this issue may be addressed. (See Appendix)

18. The signs for precipitation, temperature, and their square terms are intuitive; those for precipitation indicate that water use will be reduced with increasing precipitation, and the rate of reduction of water use decreases with higher precipitation. For temperature, increase will gradually lead to a rise in water use, which will change the coefficient from negative to a positive.

19. The first group (less than age 40) is the reference group here. Its coefficient is represented by the coefficient of "UCCE" in Table 4.

20. We add the coefficient of the reference group represented by first row of Table 4 to the coefficient for "UCCE*(70–80)" and "UCCE*(80 above)" age groups to obtain the total impact.

21. We use the average cost of irrigation water from the Farm and Ranch Irrigation Survey, for the years 2003 and 2008. We express the 2008 value in constant 2003 USD, and then obtain the mean across the two years.

22. We use the "suest" command in Stata to test whether the difference in the coefficients from the two models equals zero. Based on the value of the chi-squared statistic and the P-value, we cannot reject the null hypothesis that the difference equals zero.

REFERENCES

Adams, R., J. Wu, and L.L. Houston. 2001. "Changes in crop yields and irrigation demand." *The Impact of Climate Change on Regional Systems: A Comprehensive Analysis of California:* 1451–1460.

Allen-Diaz B. 2009. "Climate change affects us all." California Agriculture 63(2):51–53.

Bates, B.C., Z.W. Kundzewicz, S. Wu, and J.P. Palutikof, (eds) 2008. "Climate Change and Water." Technical Paper of the Intergovernmental Panel on Climate Change. Geneva: IPCC Secretariat.

Birkhaeuser, D., R. Evenson, and G. Feder. 1991. "The economic impact of agricultural extension: A review." *Economic Development and Cultural Change* 39 (3):507–521.

Bultena, G.L., and E.O. Hoiberg. 1983. "Factors affecting farmers' adoption of conservation tillage." Journal of Soil and Water Conservation 38(3):281–284.

Burgess, R., O. Deschenes, D. Donaldson, and M. Greenstone, 2011. "Weather and death in India." Cambridge, United States: Massachusetts Institute of Technology, Department of Economics. Manuscript.

Carman, H., and R.J. Sexton. 2007. "The 2007 Freeze: Tallying the toll two months later." *ARE Update* 10(4):5–8.

Caswell, M., and D. Zilberman. 1985. "The choices of irrigation technologies in California." *American Journal of Agricultural Economics* 67(2):224–234.

Caswell, M.F., and D. Zilberman. 1986. "The effects of well depth and land quality on the choice of irrigation technology." *American Journal of Agricultural Economics* 68(4):798–811.

Chatterjee, D., A. Dinar, and G. González-Rivera, 2018. "An Empirical Knowledge Production Function of Agricultural Research and Extension: The Case of the University of California Cooperative Extension." *Technological Forecasting and Social Change* 134:290–297.

Datt, G., and M. Ravallion. 1998. "Farm productivity and rural poverty in India." *The Journal of Development Studies* 34(4):62–85.

Dinar, A., and D. Yaron. 1990. "Influence of quality and scarcity of inputs on the adoption of modern irrigation technologies." *Western Journal of Agricultural Economics*: 224–233.

Dinar, A., and D. Zilberman. 1991. "The economics of resource-conservation, pollution-reduction technology selection: The case of irrigation water." *Resources and Energy Economics* 13:323–348.

Grewal, J.S., and S.N. Singh. 1980. "Effect of potassium nutrition on frost damage and yield of potato plants on alluvial soils of the Punjab (India)." *Plant and Soil* 57(1):105–110.

Guiteras, R. 2009. "The impact of climate change on Indian agriculture." Manuscript, Department of Economics, University of Maryland, College Park, Maryland.

Hartman, L.M., and D.A. Seastone. 1965. "Efficiency criteria for market transfers of water." *Water Resources Research* 1(2):165–171.

Hatfield, J.L., and J.H. Prueger. 2015. "Temperature extremes: Effect on plant growth and development." *Weather and Climate Extremes* 10:4–10.

Huffaker, R., and N. Whittlesey. 2003. "A theoretical analysis of economic incentive policies encouraging agricultural water conservation." *International Journal of Water Resources Development* 19(1):37–53.

Hayden-Smith, R., and R. Surls. 2014. "A century of science and service." *California Agriculture* 68(1):8–15.

Kalirajan, K.P., and R.T. Shand. 1985. "Types of education and agricultural productivity: A quantitative analysis of Tamil Nadu rice farming." *The Journal of Development Studies* 21(2):232–243.

Letey, J. 2000. "Soil salinity poses challenges for sustainable agriculture and wildlife." *California Agriculture* 54(2):43–48.

Li, W., Z. Wei, Z. Qiao, Z. Wu, L. Cheng, and Y. Wang. 2013. "Proteomics analysis of alfalfa response to heat stress." *PLOS One*, 8(12):p.e82725.

Lobell, D.B., C.B. Field, K.N. Cahill, and C. Bonfils. 2006. "Impacts of future climate change on California perennial crop yields: Model projections with climate and crop uncertainties." *Agricultural and Forest Meteorology* 141(2):208–218.

Masmoudi, M.M., K. Nagaz, and N.B. Mechlia. 2010. "Perception of drought by farmers and its impact on farming and irrigation practices." *Options Méditerranéennes* 95:323–327.

Moore, M.R., and A. Dinar. 1995. "Water and land as quantity-rationed inputs in California agriculture: Empirical tests and water policy implications." *Land Economics*. Pp.445–461.

Negri, D.H., and D.H. Brooks. 1990. "Determinants of irrigation technology choice." *Western Journal of Agricultural Economics*. Pp. 213–223.

OECD (Organization for Economic Co-Operation and Development) (2001). Measuring Productivity: Measurement of Aggregate and Industry-Level Productivity Growth, OECD Manual. Paris, OECD. Retrieved on December 2018 at https://www.oecd.org/std/productivity-stats/2352458.pdf.

Olen, B., J. Wu, and C. Langpap. 2015. "Irrigation decisions for major West Coast crops: Water scarcity and climatic determinants." *American Journal of Agricultural Economics* p.aav036.

Parker, D.D., and D. Zilberman. 1996. "The use of information services: The case of CIMIS." Agribusiness 12(3):209–218.

Parker, D., D. Cohen-Vogel, D. Osgood, and D. Zilberman. 2000. "Publicly funded weather database benefits users statewide." *California Agriculture* 54(3):21–25.

Parry, M.L., C. Rosenzweig, A. Iglesias, M. Livermore, and G. Fischer. 2004. "Effects of climate change on global food production under SRES emissions and socio-economic scenarios." *Global Environmental Change* 14(1):53–67.

Peterson, J.M., and Y. Ding. 2005. "Economic adjustments to groundwater depletion in the high plains: Do water-saving irrigation systems save water?" *American Journal of Agricultural Economics* 87(1):147–159.

Rasmussen, W. D. 1989. *Taking the university to the people. Seventy- five years of cooperative extension*. Iowa State University Press, Ames, IA.

Scheierling, S.M., R.A. Young, and G.E. Cardon. 2006. "Public subsidies for water-conserving irrigation investments: Hydrologic, agronomic, and economic assessment." *Water Resources Research*, 42(3).

Schuck, E.C., and G.P. Green. 2001. "Field attributes, water pricing, and irrigation technology adoption." *Journal of Soil and Water Conservation* 56(4):293–298.

Southworth, J., J.C. Randolph, M. Habeck, O.C. Doering, R.A. Pfeifer, D.G. Rao, and J.J. Johnston. 2000. "Consequences of future climate change and changing climate variability on maize yields in the midwestern United States." *Agriculture, Ecosystems & Environment* 82(1):139–158.

Tauer, L. 1995. "Age and farmer productivity." *Review of Agricultural Economics*. Pp. 63–69.

Tauer, L.W., and N. Lordkipanidze. 2000. "Farmer efficiency and technology use with age." *Agricultural and Resource Economics Review* 29(1):24–31.

Taylor, R., D. Parker, and D. Zilberman. 2014. "Contribution of University of California Cooperative Extension to Drip Irrigation." *ARE Update* 18(2):5¬–8. University of California, Giannini Foundation of Agricultural Economics.

Ward, F.A., and M. Pulido-Velazquez. 2008. "Water conservation in irrigation can increase water use." *Proceedings of the National Academy of Sciences*, 105(47):18215–18220.

Table 1. Variable description and summary statistics

Variable	Mean	Standard Deviation	Minimum	Maximum	Description
Average value of output per irrigated acre	4094.83	9383.69	0	60449.1	Inflation-adjusted $ value of average crop output per irrigated acre ($/acre)
Applied water per irrigated acre	2.35	1.84	0	11.97	Volume of water applied from all sources (acre-foot), per irrigated acre of farm land (acre-ft./acre)
UCCE	0.33	0.47	0	1	Dummy variable indicating if the source of irrigation information for the farmer was cooperative extension
Off-farm water cost per acre	38.8	135.98	0	3147.07	Cost of water per acre, for all off-farm sources (constant 2003 USD)
Average well depth	63.30	100.24	0	726.67	Average well depth of three major wells used for irrigation by the operation (feet)
Only gravity system	0.31	0.46	0	1	Dummy variable indicating if the farm used only gravity system for irrigation
Only sprinkler system	0.07	0.26	0	1	Dummy variable indicating if the farm used only sprinkler system for irrigation
Only drip, trickle and, sub-irrigation	0.12	0.32	0	1	Dummy variable indicating if the farm used only drip, trickle, or sub-irrigation system for irrigation
All irrigation systems	0.07	0.25	0	1	Dummy variable indicating if the farm used some combination of all three systems for irrigation
Frost mitigation	0.13	0.34	0	1	Dummy variable indicating whether the farm used irrigation water for frost mitigation
Heat mitigation	0.06	0.23	0	1	Dummy variable indicating whether the farm used irrigation water for crop cooling, or heat mitigation
Mean annual precipitation	1.29	0 .69	0 .21	4.30	Weighted mean annual county precipitation (inch)

Table 1. Variable description and summary statistics (continued)

Variable	Mean	Standard Deviation	Minimum	Maximum	Description
Mean annual temperature	61.90	4.44	44.98	75.30	Weighted mean annual county temperature (degree F)
Leaching	0.06	0.24	0	1	Dummy variable indicating whether the farm used irrigation water for leaching the soil of salts
Fruit and nut crops	0.38	0.49	0	1	Dummy variable indicating whether the farm harvested fruit and nut crops
Corn	0.17	0.37	0	1	Dummy variable indicating whether the farm harvested corn
Vegetables	0.21	0.40	0	1	Dummy variable indicating whether the farm harvested vegetables
Wheat	0.19	0.39	0	1	Dummy variable indicating whether the farm harvested wheat
Alfalfa	0.29	0.45	0	1	Dummy variable indicating whether the farm harvested alfalfa
Pasture	0.09	0.28	0	1	Dummy variable indicating whether the farm harvested pasture
Hay	0.14	0.35	0	1	Dummy variable indicating whether the farm harvested hay
Farmer age	57.10	12.70	17	96	Farmer age (years)
UCCE*farmer age	18.42	27.56	0	96	Interaction between UCCE and farmer age
Principal occupation farmer	0.87	0.33	0	1	Dummy variable indicating whether the operator's principal occupation is farming or ranching
Hired manager	0.18	0.39	0	1	Dummy variable indicating whether the principal operator is a hired manager
Farmer experience	24.87	14.25	1	73	Farmer experience, represented by number of years the farmer has been working on the farm

Table 2. Coefficient estimates for model with value of agricultural products per irrigated acre as dependent variable

Dependent variable	
Value of agricultural output per irrigated acre	**Coefficient estimates**
UCCE	3,035* (1,628)
UCCE*farmer age	−53.22** (24.91)
Farmer age	−6.79 (61.60)
Farmer age squared	0.11 (0.49)
Off-farm water cost per acre	1.63 (1.10)
Average well depth	2.45 (4.80)
Average well depth squared	0.0005 (0.007)
Only gravity system	−9.63 (392.8)
Only sprinkler system	−1,864*** (471.4)
Only drip, trickle, and sub-irrigation	−402.7 (399.5)
All irrigation systems	3,091** (1,180)
Frost mitigation	−964.5* (505.8)
Heat mitigation	1,563** (689.1)
Leaching	−390.9 (876.6)
Mean annual precipitation	2,078 (1,588)
Mean annual temperature	358.4 (1,212)
Mean annual precipitation square	−353.6 (263.3)
Mean annual temperature square	−0.70 (8.90)
Vegetables	15,906*** (1,855)
Corn	1,362** (516.8)
Wheat	660.3 (697.5)
Alfalfa	−28.00 (1,016)
Pasture	−580.4 (441.9)
Hay	569.0* (287.0)
Principal occupation farmer	−0.51 (357.0)
Hired manager	−57.82 (422.0)
Farmer experience	-3.99 (10.08)
Constant	−20,570 (40,222)
Observations	**1,917**
R-squared	**0.613**
County FE	**YES**
Year FE	**YES**

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 3. Coefficient estimates for model with water applied per irrigated acre as the dependent variable

Dependent variable	
Water applied (acre-ft.) per acre of irrigated land	**Coefficient estimates**
UCCE	1.17*** (0.33)
UCCE*farmer age	−0.014** (0.006)
Farmer age	0.007 (0.02)
Farmer age squared	−4.49e-05 (0.0002)
Off farm water cost per acre	0.0009 (0.0006)
Average well depth	0.006*** (0.0008)
Average well depth squared	−1.04e-05*** (2.10e-06)
Only gravity system	1.33*** (0.13)
Only sprinkler system	0.46*** (0.16)
Only drip, trickle, and sub-irrigation	0.38** (0.16)
All irrigation systems	0.07 (0.16)
Frost mitigation	0.24** (0.11)
Heat mitigation	0.15 (0.13)
Leaching	0.16 (0.15)
Mean annual precipitation	−0.07 (1.14)
Mean annual temperature	−0.43 (0.47)
Mean annual precipitation square	−0.02 (0.22)
Mean annual temperature square	0.004 (0.004)
Fruit and nuts	0.75*** (0.09)
Vegetables	0.65*** (0.10)
Corn	0.09 (0.16)
Wheat	0.05 (0.09)
Alfalfa	0.63*** (0.14)
Pasture	0.43*** (0.16)
Hay	0.44*** (0.16)
Principal occupation farmer	−0.14 (0.11)
Hired manager	−0.11 (0.10)
Farmer experience	0.001 (0.003)
Constant	12.75 (14.83)
Observations	**1,917**
R-squared	**0.508**
County FE	**YES**
Year FE	**YES**

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 4. Coefficient estimates for model with water applied per irrigated acre as the dependent variable, including farmer age groups as covariates

Dependent variable Water applied acre-feet/acre of irrigated land	Coefficient estimates
UCCE	0.61*** (0.17)
Age 40–50	0.04 (0.16)
Age 50–60	−0.05 (0.23)
Age 60–70	−0.08 (0.29)
Age 70–80	0.24 (0.30)
Above age 80	0.03 (0.36)
UCCE*(40–50)	−0.09 (0.21)
UCCE*(50–60)	−0.13 (0.21)
UCCE*(60–70)	−0.23 (0.22)
UCCE*(70–80)	−0.75** (0.30)
UCCE*(above 80)	−0.78** (0.38)
Farmer age	0.01 (0.04)
Farmer age squared	−0.0001 (0.0003)
Off-farm water cost per acre	0.0008 (0.0006)
Average well depth	0.006*** (0.0008)
Average well depth squared	-1.04e-05*** (2.09e-06)
Only gravity system	1.33*** (0.13)
Only sprinkler system	0.43*** (0.15)
Only drip, trickle, and sub-irrigation	0.37** (0.17)
All irrigation systems	0.07 (0.16)
Frost mitigation	0.25** (0.11)
Heat mitigation	0.14 (0.13)
Leaching	0.16 (0.15)
Mean annual precipitation	−0.06 (1.15)
Mean annual temperature	−0.45 (0.48)
Mean annual precipitation square	−0.02 (0.22)
Mean annual temperature square	0.004 (0.004)
Fruit and nuts	0.75*** (0.09)
Vegetables	0.64*** (0.10)
Corn	0.10 (0.16)
Wheat	0.04 (0.09)
Alfalfa	0.64*** (0.14)
Pasture	0.43** (0.16)
Hay	0.45*** (0.15)
Principal occupation farmer	−0.15 (0.11)
Hired manager	−0.12 (0.10)
Farmer experience	0.001 (0.003)
Constant	13.32 (15.12)
Observations	**1,917**
R-squared	**0.511**
County FE	**YES**
Year FE	**YES**

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 5. Coefficient estimates for model with value of agricultural products per irrigated acre as the dependent variable, and a combination of UCCE and at least one other source of irrigation information as an independent variable

Dependent variable Value of agricultural output per irrigated acre	Coefficient estimates
Information combination	2,813* (1,650)
Farmer age* Information combination	−51.12* (26.28)
Farmer age	−0.36 (62.02)
Farmer age squared	0.036 (0.48)
Off-farm water cost per acre	1.62 (1.10)
Average well depth	2.53 (4.76)
Average well depth squared	0.0004 (0.007)
Only gravity system	−8.04 (389.0)
Only sprinkler system	−1,854*** (471.8)
Only drip, trickle, and sub-irrigation	-390.2 (397.7)
All irrigation systems	3,100** (1,183)

Table 5. Coefficient estimates for model with value of agricultural products per irrigated acre as the dependent variable, and a combination of UCCE and at least one other source of irrigation information as an independent variable

Dependent variable **Value of agricultural output per irrigated acre**	**Coefficient estimates**
Frost mitigation	−943.6* (516.8)
Heat mitigation	1,586** (684.2)
Leaching	−378.9 (876.7)
Mean annual precipitation	2,108 (1,588)
Mean annual temperature	319.9 (1,203)
Mean annual precipitation square	−364.8 (264.0)
Mean annual temperature square	−0.34 (8.86)
Vegetables	15,913*** (1,856)
Corn	1,370** (514.3)
Wheat	649.2 (694.9)
Alfalfa	−16.96 (1,024)
Pasture	−600.6 (445.7)
Hay	573.5* (286.3)
Principal occupation farmer	−9.434 (361.3)
Hired manager	−55.45 (425.0)
Farmer experience	−4.087 (10.08)
Constant	−19,547 (39,810)
Observations	**1,917**
R-squared	**0.613**
County FE	**YES**
Year FE	**YES**

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 6. Coefficient estimates for model with water applied per irrigated acre as the dependent variable, and a combination of UCCE and at least one other source of irrigation information as an independent variable

Dependent variable **Water applied (acre-ft.) per acre of irrigated land**	**Coefficient estimates**
Information combination	1.03*** (0.30)
Farmer age* Information combination	−0.01** (0.006)
Farmer age	0.009 (0.02)
Farmer age squared	−6.98e-05 (0.0002)
Off-farm water cost per acre	0.0009 (0.0006)
Average well depth	0.006*** (0.0008)
Average well depth squared	−1.04e-05*** (2.11e-06)
Only gravity system	1.34*** (0.14)
Only sprinkler system	0.46*** (0.16)
Only drip, trickle, and sub-irrigation	0.38** (0.17)
All irrigation systems	0.07 (0.16)
Frost mitigation	0.25** (0.11)
Heat mitigation	0.16 (0.12)
Leaching	0.16 (0.15)
Mean annual precipitation	−0.09 (1.13)
Mean annual temperature	−0.46 (0.48)
Mean annual precipitation square	−0.01 (0.22)
Mean annual temperature square	0.004 (0.004)
Fruit and nuts	0.76*** (0.10)
Vegetables	0.65*** (0.10)
Corn	0.09 (0.16)
Wheat	0.05 (0.09)
Alfalfa	0.64*** (0.14)
Pasture	0.44*** (0.16)
Hay	0.44*** (0.16)

Table 6. Coefficient estimates for model with water applied per irrigated acre as the dependent variable, and a combination of UCCE and at least one other source of irrigation information as an independent variable

Dependent variable **Water applied (acre-ft.) per acre of irrigated land**	**Coefficient estimates**
Principal occupation farmer	−0.14 (0.11)
Hired manager	−0.11 (0.10)
Farmer experience	0.001 (0.003)
Constant	13.77 (14.92)
Observations	**1,917**
R-squared	**0.506**
County FE	**YES**
Year FE	**YES**

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

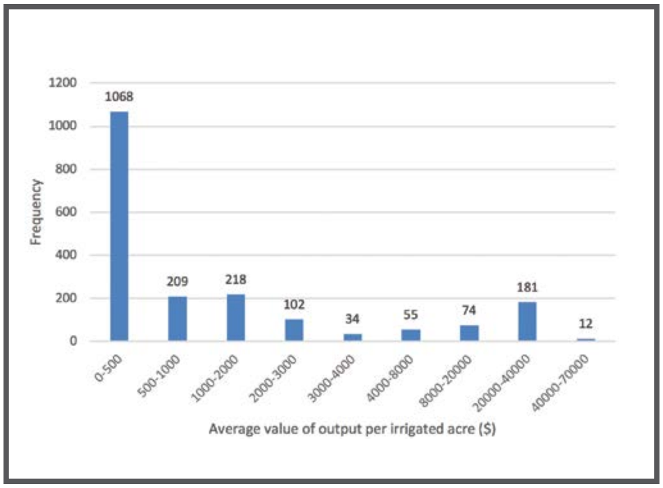


Figure 1. Distribution of average value of agricultural output per irrigated acre (2003 prices)

Source: Elaborated by authors, based on FRIS.
Note: Values on top of bars represent number of farms in that category.

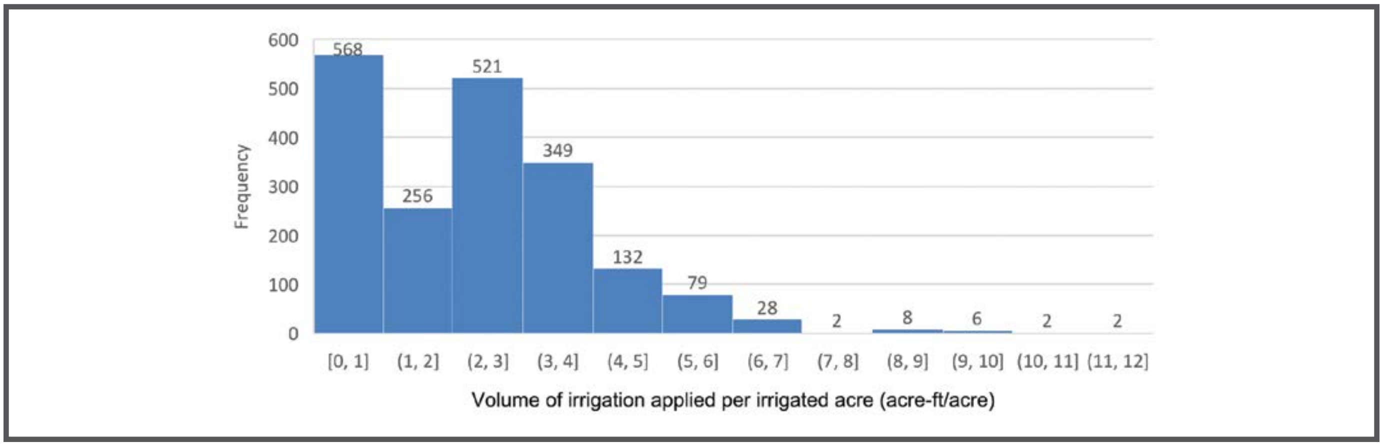


Figure 2. Distribution of the values of volume of irrigation water applied per irrigated acre

Source: Elaborated by authors, based on FRIS.
Note: Values on horizontal axis represent range of water per acre; values on top of bars represent number of farms in that category.

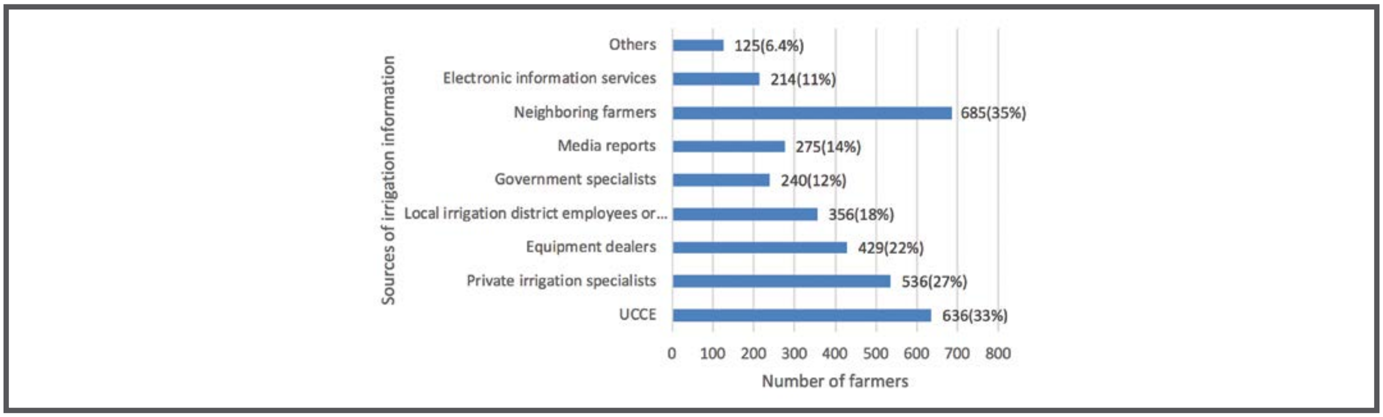


Figure 3. Farmer irrigation information sources by type and number (%) of users, 2003

Source: Elaborated by authors based on FRIS.
Note: Values on top of the bars represent the number (and percentage) of farms in that category.

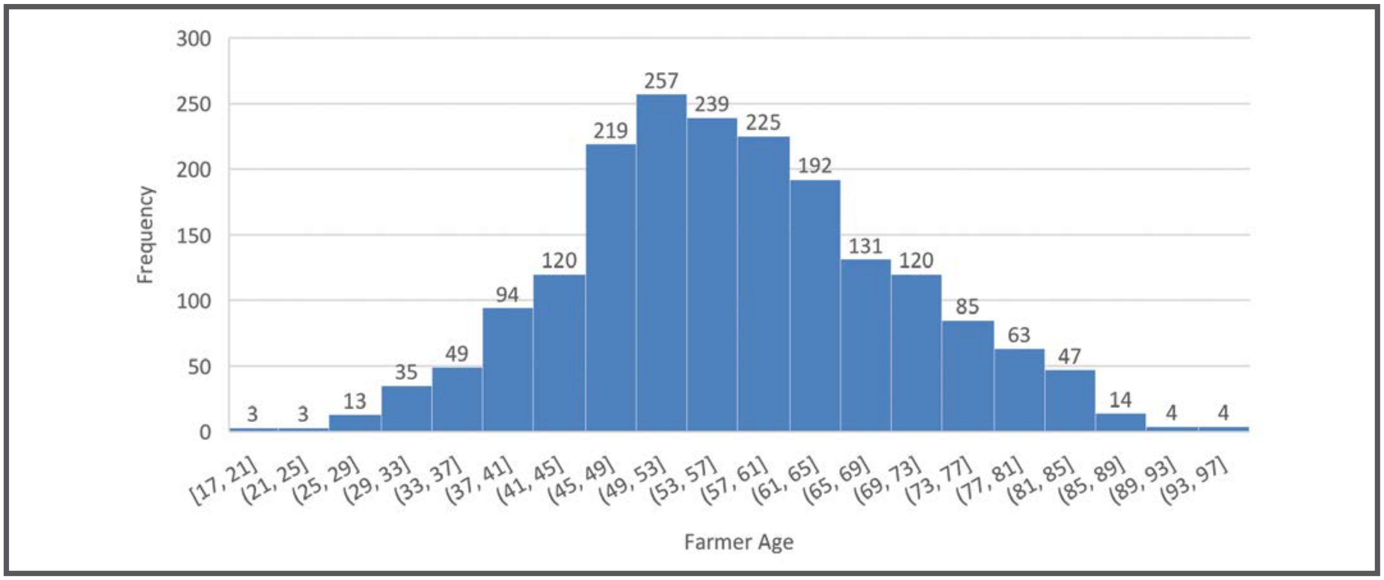


Figure 4. Frequency distribution of farmers by age

Source: Elaborated by authors, based on FRIS.
Note: Values on horizontal axis represent range of farmer's age. Values on top of bars represent number of farmers in that category.

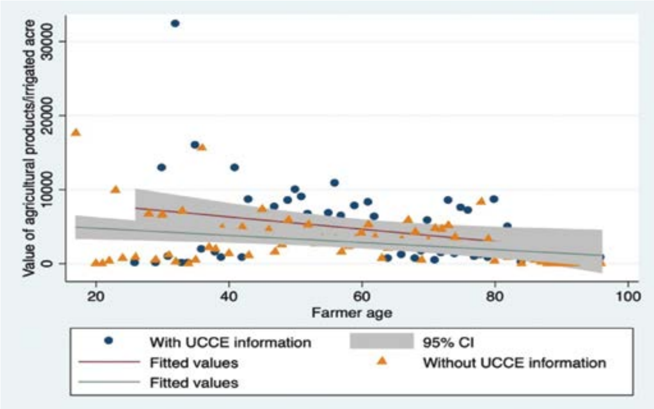


Figure 5. Mean value of agricultural output per irrigated acre for each farmer age, for users and non-users of UCCE irrigation knowledge

Note: Purple line represents fitted values of "with UCCE information," and light blue line represents fitted values of "without UCCE information."

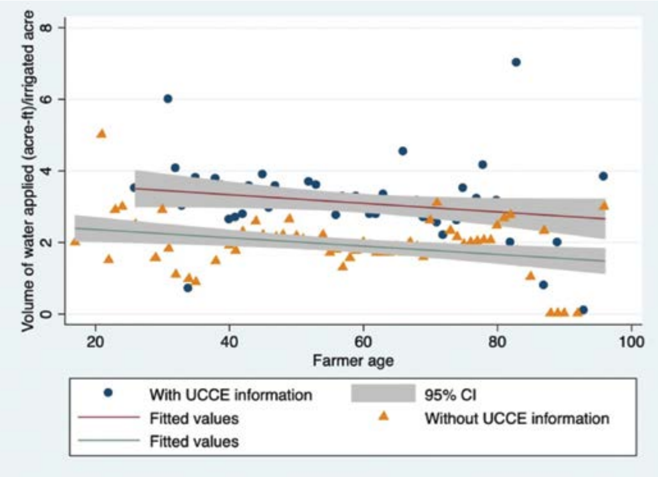


Figure 6. Mean value of irrigation water usage per irrigated acre for each farmer age, for users and non-users of UCCE irrigation knowledge

Note: Purple line represents fitted values of "with UCCE information," and light blue line represents fitted values of "without UCCE information."

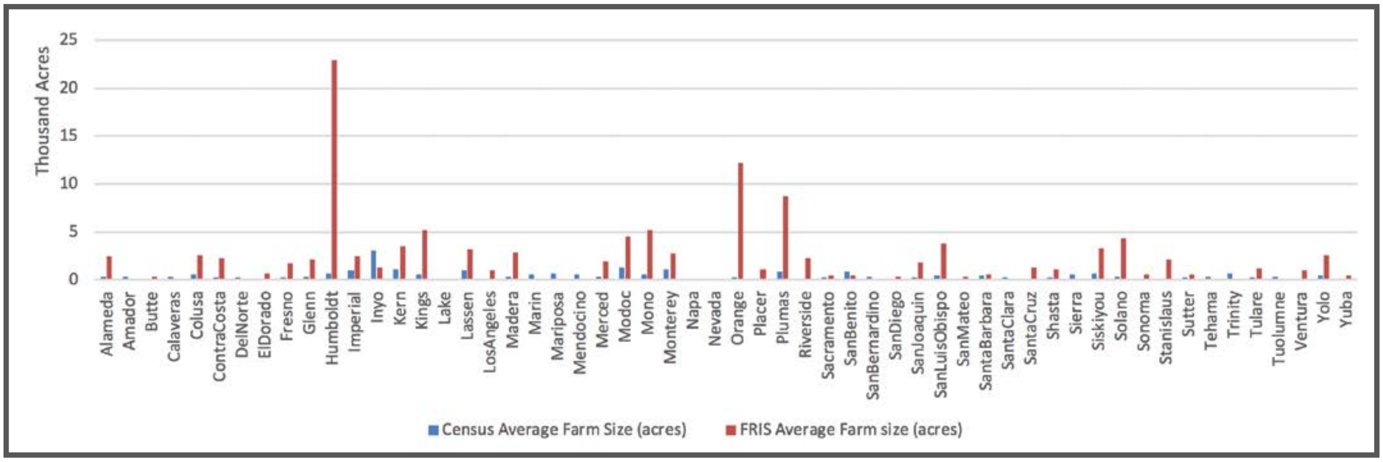
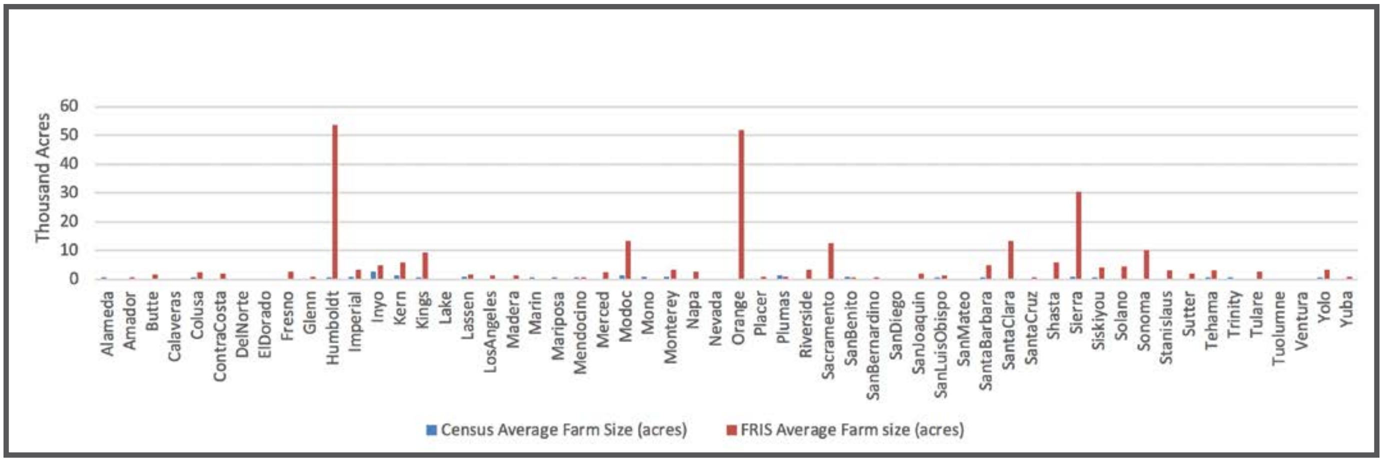


Figure A1. Panel (a). Average County Farm Size in 2003 — A comparison between Agricultural Census and FRIS



Panel (b). Average County Farm Size in 2008 — A comparison between Agricultural Census and FRIS