Multicrop Production Decisions and Economic Irrigation Water Use Efficiency: Effects of Water Costs, Pressure Irrigation Adoption and Climatic Determinants

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Abstract

In an irrigated multicrop production system, farmers make decisions on land allocated to each crop, and irrigation water application, which determines crop yield and irrigation water use efficiency. Focusing on production decisions on multiple irrigated crops, this study analyzes effects of multiple factors on farmers' decision making and economic irrigation water use efficiency (EIWUE). To better deal with the farm-level data embedded in states, the multilevel models (MLMs) are employed, and it permits the incorporation of state-level variables in addition to the farm-level factors. The results show higher costs of surface water are not effective in reducing water use for both corn and soybeans, while groundwater prices show a net effect of water conservation at the farm-level. Adoption of pressure irrigation systems could reduce soybean water use and increase soybean yield. Higher EIWUE can be achieved with adoption of enhanced irrigation systems on both corn and soybean farms. High temperature promotes more efficient water use and higher yield, and high precipitation is correlated with lower water application and higher crop yield. Intraclass correlation coefficients (ICC) suggest a moderate variability in water demand and EIWUE is accounted by the state-level factors, with an ICC value greater than 0.10.

Key words: climate variability, economic irrigation water use efficiency, multicrop production, pressure irrigation systems, water costs

JEL Codes: Q15, Q25, Q55

1. Introduction

In many countries, agricultural production relies heavily on water resources. Most of the cropland needs irrigation, and some traditionally rain-fed agriculture systems have seen growing irrigation to increase production and mitigate climate risks. Accounting for more than 80% of total water withdrawals, irrigated agriculture needs to contribute an increasing share of food production to meet the growing demands of a rising population. Faced with the dramatic impacts of climate change, many arid and semiarid areas are suffering from severe water shortages, for instance, the Western U.S. (EPA, 2014) and Northwestern China (Jin et al., 2015). At the same time, some areas that were not facing water deficiency are experiencing more droughts, for instance, the Midwestern U.S. (Zhang and Lin, 2016; Zhang, Lin, and Sassenrath, 2015), thus increasing the stress on current water resources. In addition, in many areas, the water demand from other sectors is expected to grow faster. Though a large proportion of water demand could be satisfied through new investments in water supply and irrigation systems, and expansion of water supply could be met with some non-traditional sources, the shrinking water availability increases both economic and environmental costs of developing new water supplies (Murray, Foster, and Prentice, 2012; Schaible and Aillery, 2012; Wanders and Wada, 2015). Therefore, investments in water systems and developing new water sources to meet growing demands will not be a sufficient solution.

As a more practical path to achieve sustainability of water resources, water can be saved in current uses through increasing irrigation water use efficiency (total yield per unit of land divided by irrigation water applied) in agricultural production (George, Shende, and Raghuwanshi, 2000). The traditional flood (also called furrow or gravity) irrigation systems have been reported to lose 50-70% of the water applied as soil evaporation, seepage, deep drainage, etc. (Batchelor, Lovell, and Murata, 1996; Dalton, Raine, and Broadfoot, 2001). Potential improvements in irrigation water use efficiency can be realized through adopting enhanced pressure irrigation systems.

Most of the studies on irrigation water use efficiency are conducted at the field level based on experiments (Gheysari et al., 2015; Qin et al., 2016). Two foci of field experiments include comparison of irrigation water use efficiency at different water application levels and utilizing various irrigation methods, and interaction and compatibility of improved irrigation systems and other farm best management practices (film or straw mulching, irrigation scheduling, etc.) (Ibragimov et al., 2007; Kang et al., 2012; Schneider and Howell, 2001). Previous studies on irrigation water use efficiency (IWUE) typically use experimental data in one field, collected over multiple years. Due to lack of available farm-level data, an evaluation of crop IWUE in multiple fields is impossible mainly because of limited research funding, heterogeneity of experimental fields, and diversity of cropping systems and farming structures. As a matter of fact, at the farm level, producers usually grow two or more crops on their farms. In addition to making adoption decisions regarding different irrigation systems, farmers also need to make decisions on land allocation and irrigation water application for each crop they choose to plant. These decisions can determine whether water is used efficiently or not.

The farm-level irrigation production decisions to improve crop irrigation water use efficiency in a multicrop system are understudied, in particular across regions with different cropping patterns and climatic conditions (Olen, Wu, and Langpap, 2016). In addition, production decisions in irrigated agriculture may be affected by other factors like water sources, input costs, farming area, etc. Analysis of irrigation decisions and crop irrigation water use efficiency, as affected by these and other factors, could help farmers and policy makers adapt to potential climate risks, better manage irrigation water application and achieve sustainable use of limited water resources. Furthermore, given the heterogeneity of farms and states, multi-level models (MLMs) can be readily utilized to deal with the hierarchical nature of the farm-level data, and to extract the percentage of variability in each response accounted for by farm- and state-level factors. The multilevel model has been applied in social science research (e.g., Dolisca et al. (2009) and Guerin, Crete, and Mercier (2001)). However, MLMs have never been used to analyze crop production or farm irrigation decisions. Given the FRIS data structure, i.e., farms are embedded in states, we explore the applicability of the MLMs to multiple equations relating to production decisions in irrigated multicrop agriculture.

Therefore, the objective of this paper is to better understand production decisions for irrigated agriculture and economic irrigation water use efficiency of major crops in U.S., as well as the effects of water costs, adoption of pressure irrigation systems and climatic determinants in a multicrop production system.

Specifically, this study aims to answer the following fundamental questions:

1) Are enhanced irrigation systems conserving water and more efficient than the traditional systems under diverse farm conditions?

2) How does climate variability affect production decisions in irrigated agriculture?

3) What are the major influential factors and how are the production decisions affected by these factors at the farm and state levels?

The layout of the analyses in this paper is presented in figure 1. Focusing on irrigated farms in a multicrop production system, four equations on land allocation, water demand, crop supply, and economic irrigation water use efficiency are estimated using multilevel models. Intensive and extensive margins of water use to water price and energy costs are calculated. Intraclass correlation coefficients (ICC) as defined later are calculated to find out the proportion of variability in each response is accounted for by each level. Econometric results from the multilevel models are provided to show the effects of exogenous variables on each response variable.

[Insert figure 1 about here]

2. Literature review

2.1. Crop water use efficiency

In general, water management includes issues relating to five sub-systems existing on most irrigated farms: supply systems, on-farm storage systems, on-farm distribution systems, application systems and recycling systems (Dalton et al., 2001). In a report on the Australian cotton industry, Dalton et al. (2001) defined water use efficiency at the farm level focusing on three dimensions: agronomic efficiency, economic efficiency, and volumetric efficiency. The agronomic water use efficiency includes a gross production water use index (yield/total water applied), an irrigation water use index (yield/irrigation water applied), a marginal irrigation water use index (marginal yield due to irrigation/irrigation water applied), and a crop water use index (yield/evapotranspiration). The economic water use efficiency includes a gross production economic water use index (total value/total water applied), an economic irrigation water use index (value/irrigation water applied), a marginal economic irrigation water use index (value due to irrigation/irrigation water applied), and a crop economic water use index (value/evapotranspiration). The volumetric water use efficiency includes overall project efficiency, conveyance efficiency, distribution efficiency, and field application efficiency, which emphasize irrigation uniformity to avoid over- and under-irrigation issues (reducing the water use efficiency and yield, respectively). Moreover, Pereira (1999) discussed various measurements for both distribution uniformity and application efficiency in various irrigation systems.

From a multi-disciplinary perspective, Nair, Johnson, and Wang (2013) reviewed the efficiency of irrigation water use. Among all the measures of WUE, agronomists defined it as yield per unit area divided by the water used to produce the yield. The yield can be grain yield or total aboveground biomass depending on the use of the crop produced, and the water can refer to crop evapotranspiration, soil water balance, or precipitation plus irrigation. However, from an economist's perspective, the efficient level of irrigation water occurs "when the marginal revenue (price of the crop produced in a perfectly competitive market) is equal to the price of water)" (Nair et al., 2013: p.359). The water application level at Stage II in the classical production function was identified as the economically efficient water use amount. Stage II ranges from point where marginal product equals average product, i.e., $w/p = Y/X$ $(MPP = APP)$ with w the water cost, p the output price, Y the output quantity, and X the input quantity, to the yield maximizing point, where $dY/dX = w/p = 0$ (i.e., $MPP = 0$). Other research proposed an operating profit water use index to evaluate water use efficiency, which is defined as: $(\text{gross return} - \text{variable costs} - \text{overhead costs})/\text{total water used}$ (Harris, 2007).

Comparing WUE measures from the perspectives of agronomists and economists, a major difference is whether to consider output price. For example, the economic irrigation water use index (value of crop or grains/irrigation water applied) is the product of the irrigation water use index (yield/ irrigation water applied) and the crop price. Because producers are price takers in a competitive market, different farmers growing the same crop will sell it for the same price in the same market. Thus, exogenous variables affecting economic irrigation efficiency and agronomic irrigation efficiency will have the same effects in terms of the signs and significance levels, though the magnitude will be different proportionally. To make analyses easier and follow the mainstream of decision-making on land allocation and water use to maximize the expected profit as formulated in the model section below, this study uses the economic measure of irrigation water use efficiency (EIWUE) (crop value/irrigation water use) incorporating state-average crop prices in the econometric estimation.

Various approaches to have been explored conserve irrigation water use, such as developing new irrigation techniques (e.g., Tanwar et al. (2014)), increasing investment in irrigation infrastructure such as canals, wells and drip systems (e.g., Kang et al. (2012)), and designing water conservation policies (e.g., Bozzola and Swanson (2014)). Water-conserving irrigation systems have been proposed and applied to various crops in many farming areas around the world. For instance, in eastern Australia (Sadras and Rodriguez, 2010), arid and semi-arid areas in China (e.g., Fan, Wang, and Nan (2014) and Kang et al. (2012)), and southern and southeastern U.S. (Salazar et al., 2012; Schneider and Howell, 2001; Vories et al., 2009). Examples include pressure (or pressurized) irrigation systems (versus gravity irrigation methods), including linear move, center pivot, sprinkler and drip irrigation methods. Field experiments with sprinkler and drip irrigation and their comparison with traditional flood or furrow irrigation have been conducted on various crops worldwide (e.g., Dağdelen et al. (2009), Ibragimov et al. (2007), Liu et al. (2010), Salvador et al. (2011), and Usman et al. (2010)). As a result, a substantial quantity of water could be conserved by enhanced irrigation systems and crop irrigation water use efficiency can be improved.

3. Hypotheses

In this section, factors affecting farmers' adoption behaviors and irrigation decisions are reviewed, and hypotheses are constructed. Farmers' irrigation decisions are hypothesized to be a function of expected profit, costs, perceived barriers, information availability, farm and farmer characteristics, and their environmental attitudes and perceptions of climate variability.

Literature reviews of agricultural production and economics show that many changes in socioeconomic, agronomic, technical, and institutional aspects can have considerable positive/negative effects on water use, crop yield and crop water use efficiencies, and thus diverse effects on the profitability of crop production. Farm management practices including controlling the amount and timing of irrigation water, fertilizer/manure use, mulching and tillage can affect farm returns and profits (Abd El-Wahed and Ali, 2013). Through analyzing various measurement of water use efficiency, Pereira (1999) recommended combining improved irrigation methods and scheduling strategies to achieve higher performance. Pressure irrigation systems are thus expected to decrease water application and increase efficiency.

Based on field-level measurements, Canone et al. (2015) assessed surface irrigation efficiency in Italy. The results from both simulated scenarios and monitored irrigation events highlighted the necessary strategies to improve irrigation efficiencies through reducing the flow rates and increasing the duration of irrigation events. Thus, we hypothesize more water availability from various sources and more wells decrease crop water use efficiency.

In addition, diverse effects of physical factors on farm yield and profits have been reported based on farm-level studies. For instance, with carrot farmer interviews in Pakistan, Ahmad, Hassan, and Bakhsh (2005) found that farm-level yield and profitability were affected by many factors including expenditures on facility and labor investments regarding application of fertilizer, irrigation and weeding. In a similar study, Dahmardeh and Asasi (2014) evaluated the effects of costs of fertilizer, seeds and water on the profitability of corn farms as well as the effects of income sources. Thus, the facility expenses and labor payment at the farm level are hypothesized to have positive effects on water application and crop yield, but a negative effect on water use efficiency.

Farmers face many barriers and challenges when making irrigation and production decisions. Using data on 17 western states from the USDA Farm and Ranch Irrigation Survey (FRIS), Schaible, Kim, and Aillery (2010) studied dynamic adjustment of farmers' irrigation decision and pointed out some major barriers impacting the adoption of enhanced irrigation technologies. The most important barriers were related to investment cost and financing issues. Greater sharing of costs by government or landlords for installation of advanced irrigation techniques can improve their adoption rates especially for beginning farmers with limited resources and social disadvantages (Schaible and Aillery, 2012). Moreover, uncertainty about future water availability and farming status could influence farmers' willingness to adopt. Hence, uncertainties regarding potential costs and future benefits will limit adoption of water conservation practices, and thus discourage farmers to use water more efficiently (Rogers, 2003; Sunding and Zilberman, 2001).

Information availability and its sources can affect farm irrigation decisions (Prokopy et al., 2008). On the one hand, limited information can be an obstacle to using water efficiently. Rodriguez et al. (2009) pointed out that lack of information on irrigation, crop management, effectiveness of practices and government programs could be common obstacles for resource-limited farmers when facing the uncertainty of changing to something unknown. On the other hand, effective information can facilitate optimal irrigation decisions by farmers. Frisvold and Deva (2012) studied water information used by irrigators and the relationship of information acquisition and irrigation management. Their study indicated that appropriate information use could benefit irrigation management and crop production for farmers with varying acreage. Thus, more information on how to conserve water and use water more efficiently is expected to decrease water use, increase crop yield, and improve irrigation efficiency (Pannell et al., 2006; Rogers, 2003).

Regional variables could capture differences in climate, water institutions, and supporting infrastructure (Negri, Gollehon, and Aillery, 2005) as well as farming systems. More generally, which irrigation decisions are appropriate will vary spatially. For example, western states tend to have concentrated irrigation acreage and their irrigation institutions are well established (Negri et al., 2005). Eastern and southern states receive moderate amounts of rainfall to support agriculture and do not rely as heavily on irrigation. Thus, we hypothesize that compared with those in the high plains states, more farmers in western states will irrigate more, while farmers in midwestern and southern states will irrigate less.

Furthermore, farmers are also motivated to respond facing varying weather conditions. Climate conditions can influence farm yield and revenue, and irrigation can be considered as a strategy to mitigate the adverse effects and increase profits (Kresovic et al., 2014). Specifically, awareness of climate change (e.g., drought and heat waves) could motivate farmers to prepare for and take actions to adapt to future risks to production (Jin et al., 2015; Li, Ting, and Rasaily, 2010). Olen et al. (2016) found farmers were more likely to apply advanced water-saving irrigation systems to mitigate and adapt to various weather and climate impacts including frost, heat, drought, etc. Therefore, farmers are hypothesized to irrigate more and decrease irrigation water use efficiency if they perceive and experience less precipitation, higher temperature or more losses due to droughts in the future. This is proxied by changes of weather conditions in 2011, 2012 and 2013.

4. Methods

In this section, we introduce a model of profit maximization by Moore, Gollehon, and Carey (1994b), and then turn to the maximization of economic irrigation water use efficiency to deal with market failure in water management. In multicrop irrigated agriculture, producers make decisions on land allocation to each crop, and amount of water for irrigation[1]. Choosing from common crops, a typical producer may plant two or more crops on a farm. Then decisions on the land allocation and water supply can be made to maximize the expected total profit.

Following a multicrop production model by Moore et al. (1994b), the expected profit functions of the multicrop system and specific crop i can be represented by $\Pi(\boldsymbol{p}, \boldsymbol{r}, b, N; \boldsymbol{x})$ and $\pi_i(p_i, \boldsymbol{r}, b, n_i; \boldsymbol{x})$, respectively. $\boldsymbol{p}$ is a vector of crop prices; p_i is the price of crop i,

[1] Producers also need to choose which type of irrigation system(s) to adopt, and this has been examined by much research, for instance, Olen et al. (2016).

$i = 1, \dots, m$; $\boldsymbol{r}$ is a vector of variable input prices excluding water prices; b is the water prices; N is the total farming area as a constraint; n_i is the land allocation for crop i; $\boldsymbol{x}$ represents other exogenous variables including land characteristics, water sources, adoption of various irrigation systems, climate perceptions, etc. Each crop-specific profit function π_i is assumed to be convex and homogenous of degree one in output prices, water price, and other prices of variable inputs, nondecreasing in output price and land allocation, and nonincreasing in water prices and other variable input prices.

We extend the model of Moore et al. (1994b) by adding crop irrigation water use efficiency. A single producer makes production and irrigation decisions to maximize profits. While to achieve sustainability of the water resource, the total profit function of the whole society needs to consider the marginal user cost and higher pumping cost externality of extracting water by every farmer. Thus, in addition to the decision-making on conserving water use and increasing crop yield, the way to achieve higher crop irrigation water use efficiency should be explored. Following the discussion on indicators of water use performance and productivity by Pereira, Cordery, and Iacovides (2012), the following definition can be used to calculate the farm-level crop-specific economics irrigation water use efficiency.

$$EIWUE = \frac{\text{Crop yield} \cdot P}{\text{Total irrigation water appied}} \tag{1}$$

where EIWUE is economic irrigation water use efficiency, crop yield is the marketable grain yield, *P* is average crop price in each state, and irrigation water application is measured based on all irrigation water sources: well, on- and off-farm surface water. The greater the EIWUE value[2], the higher the efficiency due to irrigation water application.

To analyze the effects, EIWUE can be a function of the exogenous variables affecting

[2] The calculation of EIWUE (and IWUE) just considers irrigation water applied, while excluding rainfall amounts, but the state-level variation is controlled in the MLMs presented below.

both yield and water demand.

$$EIWUE_i = h_i(\boldsymbol{p}, \boldsymbol{r}, b, N; \boldsymbol{x}) \qquad i = 1, \ldots, m \tag{2}$$

In addition, the farm-level water demand can be decomposed to analyze the role of water price on production decisions regarding each crop (Moore et al., 1994b). The crop-specific water demand can be decomposed into extensive margin of water use (an indirect effect on water use due to land allocation change) and intensive margin of water use (a direct effect on water use due to water demand).

The farm-level total water demand (W) equals the sum of water demands for each crop grown on the farm with the optimal land allocation (Moore, Gollehon, and Carey, 1994a; Moore et al., 1994b):

$$W = \sum_{i=1}^{m} w_i(p_i, \boldsymbol{r}, b, n_i^*(\boldsymbol{p}, \boldsymbol{r}, b, N; \boldsymbol{x}); \boldsymbol{x}) \qquad i = 1, \ldots, m \tag{3}$$

Taking the derivative of the equation with respect to water price gives:

$$\frac{\partial W}{\partial \mathrm{b}} = \sum_{i=1}^{m} \left(\frac{\partial w_i}{\partial \mathrm{b}} + \frac{\partial w_i}{\partial n_i^*} \ \frac{\partial n_i^*}{\partial \mathrm{b}} \right) \tag{4}$$

where $\frac{\partial w_i}{\partial \mathrm{b}}$ is the intensive margin, and $\frac{\partial w_i}{\partial n_i^*} \ \frac{\partial n_i^*}{\partial \mathrm{b}}$ is the extensive margin. The total effect can be obtained by summing the effects on all the crops. The intensive margin will decrease in price, and $\frac{\partial w_i}{\partial \mathrm{b}}$ should have a negative sign for each crop. The sign of the intensive margin depends on $\frac{\partial n_i^*}{\partial \mathrm{b}}$. The total farm-level effect on water use should be negative, which indicates decreasing water demand as water price increases.

4.1. Multilevel models

Multilevel models have the advantage of examining individual farms embedded within states and assess the variation at both farm- and state-levels. The multilevel regression model is commonly viewed as a hierarchical regression model (Hox, 1995). A multilevel linear modeling technique is utilized to analyze the effects of influential factors on land allocation, water application, crop yield, and EIWUE.

For the research questions, we have *N* individual crop-specific farms ($i = 1, \dots, N_j$) in *J* states ($j = 1, \dots, J$). The X_{ij} represent a set of independent variables at the farm level, and a series of state-level independent variables are represented by Z_j. The model estimation includes two steps. For the first step, a separate regression equation can be specified in each state to predict the effects of the independent variables on the dependent variables.

$$\boldsymbol{Y_{ij}} = \beta_{0j} + \boldsymbol{\beta_{1j}} \boldsymbol{X_{1ij}} \tag{5}$$

For the second step, the intercepts, β_{0j}'s are considered parameters varying across states as a function of a grand mean (γ_{00}) and a random term (u_{0j}). The β_{1j}'s are assumed constant across states and are presented as a function of fixed parameters (γ_{10}).

$$\boldsymbol{\beta_{0j}} = \gamma_{00} + \gamma_{\boldsymbol{01}} \boldsymbol{Z_j} + u_{0j} \tag{6a}$$

and

$$\boldsymbol{\beta_{1j}} = \boldsymbol{\gamma_{10}} + u_{1j} \tag{6b}$$

Combining eq. 5, 6a and 6b, we have:

$$\boldsymbol{Y_{ij}} = \gamma_{00} + (\boldsymbol{\gamma_{10}} + u_{1j}) \boldsymbol{X_{ij}} + \gamma_{\boldsymbol{01}} \boldsymbol{Z_j} + u_{0j} \tag{7}$$

The model is called a random-intercept and random-slope model, as the key feature is that not only the intercept parameter in the Level-1 model, β_{0j}, is assumed to vary at Level-2 (state) (Raudenbush and Bryk, 2002), but the slope is also random with an error term u_{1j}. The γ_{01} coefficient captures the effects of the state-level variables (Z_j) on the β_{0j}'s, whereas γ_{10} predicts the constant parameter, β_{1j}, (with errors).

The data were analyzed using the SAS package in the USDA data lab in St. Louis, Missouri, with official permission.

5. Data and variables

This study uses a national dataset from the USDA 2013 Farm and Ranch Irrigation Survey (FRIS). Null models for all equations of 17 crops are estimated to calculate the intraclass correlation coefficient (ICC). However, only models in further steps on land allocation, water demand, crop supply, and EIWUE are estimated and presented in this paper focusing on corn and soybeans as they have the most observations but different distribution patterns across the five regions (specified below).

The lower 48 states are grouped into five regions according to USDA National Agricultural Statistics Services (NASS)[3], including Western, Plains, Midwestern, Southern, and Atlantic states[4]. The descriptive statistics of the corn and soybean farms[5] are presented in table 1. Of the 19,272 irrigated farms, 6,030 farms grow corn for grain with an average area of 357 acres, and 3,933 farms grow soybeans with an average area of 341 acres. For corn farms, the mean water application is 1.11 acre-feet/acre; mean yield is 190 bu/acre; and EIWUE is 1311 dollars/acre-foot on average. For soybean farms, the mean water application, yield, and EIWUE are 0.81 acre-feet/acre, 55 bu/acre, and 1221 dollar/acre-foot, respectively.

[Insert table 1 about here]

The independent variables are at two levels. At the farm level, the explanatory variables are related with water sources, costs on surface water and energy, expenditures on irrigation equipment, labor payment, farm characteristics including farming area, number of wells, irrigation systems, as well as barriers for improvements and information sources. Variables related to water sources, federal assistance, barriers and information sources are dummy variables (Yes=1, No=0), and all other independent variables are continuous.

At the state level, in addition to the dummies variables related to the five regions, six

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[3] A map can be found on the USDA NASS website: https://www.nass.usda.gov/Charts_and_Maps/Farm_Production_Expenditures/reg_map_c.php

[4] Ideally, analyses on all the production decisions (i.e., 4 equations regarding all crops (17 crops) can be conducted at the region level (i.e., 5 regions). Given the huge amount of work and the focus of this paper, such analyses are beyond the scope.

[5] The crop-specific analyses just focus on farms that are at least partially irrigated, while excluding non-irrigated farms.

explanatory variables on state-wide weather conditions are included using the data from NOAA. The variables are state average precipitation changes in 2011, 2012 and 2013, and temperature changes in 2011, 2012 and 2013.

6. Results

6.1. Descriptive statistics

The summary statistics of the farm-level independent variables are presented in table 2. Four water sources are investigated including groundwater only, on- and off- farm surface water only, and two or more water sources (Yes=1, No=0). For corn and soybean farms, about 71% and 81% use groundwater only, respectively, while water from on- or off-farm surface sources only account for about 4% of farms (about 11% corn farms only use off-farm surface water). About 12% of farms get water from two or more sources.

[Insert table 2 about here]

Water costs are measured by the payment for off-farm surface water and energy expenses for pumping groundwater. The average cost for off-farm surface water is 6.89 and 4.22 dollars/acre-foot for corn and soybean farms, respectively. The average energy expenses are 47.05 and 35.60 dollars/acre for corn and soybean farms. The average facility expenses and labor payments are 37.61 and 5.24 dollars/acre for corn, and 25.13 and 1.45 dollars/acre for soybeans.

Regarding the farm characteristics, the average number of wells used to irrigate corn and soybeans are 5.76 and 7.37, respectively. The mean areas of total land are 1,879 and 1,665 acres/farm for corn and soybeans, and the percentage of owned land is 50% and 45%. For irrigation systems, about 20% corn farms use gravity systems and 29% of soybean farms use gravity systems, while those using pressure irrigation account for 80% and 71%, respectively. About 20% of the corn farmers received federal assistance to improve irrigation and/or drainage systems, compared to 22% for soybean farms.

Regarding the barriers to implementing improvements for the reduction of energy costs or water use, nine barriers are investigated in the national survey. Major ones include: investigating improvement is not a priority at this time (17% for corn farmers and 14% for soybean farmers), limitation of physical field or crop conditions (11% for corn farmers and 10% for soybean farmers), not enough to recover implementation costs (17% for corn farmers and 20% for soybean farmers), cannot finance improvements (12% for corn farmers and 14% for soybean farmers), and landlords will not share improvement costs (12% for corn farmers and 14% for soybean farmers).

For the eight sources of irrigation information, the top ones are extension agents (33% for corn farmers and 40% for soybean farmers), private irrigation specialists (35% for corn farmers and 37% for soybean farmers), irrigation equipment dealers (31% for both corn and soybean farmers), neighboring farmers (23% for both corn and soybean farmers), e-information services (19% for both), and government specialists (15% for both).

Regarding location, this study includes more farms in the Plains states, 55% for corn and 53% for soybeans. Farms in the Midwest and South account for 16% and 11% for corn, and 18% and 24% for soybeans, and fewer farms in the Midwest and South.

The state-wide average weather related variables are presented in table 1 for the 43 states planting corn. Compared with the 1981-2010 average precipitation, the changes for 2011, 2012 and 2013 are 1.51, -3.66, and 1.74 inches, respectively. Compared with the 1981-2010 average temperature, the changes for 2011, 2012 and 2013 are 0.54, 2.47 and -0.50 ℉. While in 2013, the year covered by the survey, it's more favorable for agricultural production as far as the rainfall.

The summary statistics of dependent variables are also presented in table 2. Among the 4761 irrigated farms planting corn in 2013, about 84% had adopted pressure irrigation systems, and 39% had adopted at least one of the four scientific irrigation scheduling practices. There are 3491 soybean farms with 70% adopting pressure irrigation, and 36% adopting scientific scheduling practices.

[Insert table 3 about here]

6.2. Decomposition of farm-level water demand

To decompose the effect of water cost on farm-level water demand, the extensive and intensive margins are provided in table 3. This paper takes corn and soybeans as examples[6]. The estimated coefficients on crop acreage and water costs in the water demand equation suggest: a change in water use given a change in land use ($\frac{\partial w_i}{\partial n_i}$), and a marginal change in water use given a change in water cost ($\frac{\partial w_i}{\partial \mathrm{b}}$). The estimated coefficients on water cost in the land allocation equation represent a change in land use given a change in water cost ($\frac{\partial n_i}{\partial b}$). The intensive margin can be obtained with $\frac{\partial w_i}{\partial \mathrm{b}}$ while adjusting for the estimated probability the crop is grown. The extensive margin can be calculated using $\frac{\partial w_i}{\partial n_i}\frac{\partial n_i}{\partial b}$. Summing the intensive and extensive margins for each crop gives the total effect of a change in water cost. Further summing the effects on all crops gives the total effect on a typical farm growing both crops.

Margins on both on-surface water costs and energy costs are calculated. Only water from on-surface sources is priced and investigated in the survey. Energy expenses on groundwater pumping is considered as a proxy of water price for groundwater. The results show only $\frac{\partial n_i}{\partial b}$ decreases in energy expenses for soybeans, and other values of $\frac{\partial n_i}{\partial b}$ and $\frac{\partial w_i}{\partial \mathrm{b}}$ are positive, which is contradictory to expectations. This indicates an increase in water prices also increases water use. This is probably true in practice when adoption of enhanced irrigation

6 Ideally, equations on water demand and land allocation for each crop can be estimated to obtain both extensive and intensive margins for each crop, and then the aggregate effect can be calculated for a typical farm growing all crops. Equations on production decisions can also be estimated for each region to calculate the aggregate effect for a typical farm growing all crops in each region. Similar reasons are followed here as noted in footnote 4.

systems increase acreage under irrigation and thus increase the amount of irrigation water, as reported in Kansas (Pfeiffer and Lin, 2014). A numerical illustration can help understand the effects of water prices. A 1 dollar increase in groundwater costs (energy expenses) ($\Delta b = \$1$) would lead to a decrease of 0.109 acre-feet of water application per acre of soybeans, and an increase of 0.0737 acre-feet of water per acre of corn. In a multicrop system, a typical farm growing both corn and soybeans would decrease water demand by -10.87 acre-feet. These results show water use is highly inelastic in water cost (Moore et al., 1994b). While this may be different for regions/states with varying availability of water resources, an in-depth analysis of regional or state effect of water costs on water use can be helpful.

[Insert table 3 about here]

6.3. Intraclass correlation coefficients

The first step in conducting a multilevel model is to calculate the ICC which shows how much of the variability in one response variable is accounted for by the level 2. The intraclass correlation coefficients (ICC) for crop-specific multilevel models are presented in table 4. To better understand these values, for example, the ICC for the water demand equation of corn is 0.2102, which suggests about 21% of the variability in water application decisions is accounted for by the factors at the state level, leaving 79% of the variability to be accounted for by the farm-level factors. A moderate variability in water demand and EIWUE is accounted by the state-level factors, with an ICC value greater than 0.10. However, more variability of land allocation and crop supply is accounted for by farm-level factors. In the following sections, results for each estimated equation are presented for corn and soybeans jointly to facilitate the comparison of the effects on the two crops.

[Insert table 4 about here]

6.4. Land allocation equation

The estimated coefficients from MLMs for land allocation of corn and soybeans are presented in table 5 and table 6. The results show compared with groundwater use, water from on-, off-farm surface and more sources shows a positive effect on land allocation to corn planting. While water from more sources increases the planting of both crops.

Surface water price doesn't affect land allocation, which is consistent with expectation as the decision on how much land allocated to grow a crop is made mainly depending on the expected crop price and input costs with little consideration of water price. While energy expenses as a proxy of groundwater price increase corn planting and decrease soybean planting. Higher facility expenses increase the corn planting.

[Insert table 5 and table 6 about here]

Regarding farm characteristics, more wells on a farm increase the planting of both crops. Larger areas of cropland increase the land allocation for both crops. Federal assistance on farm irrigation and drainage management has a negative effect on soybean planting. Unfortunately, land tenure and adoption of pressure irrigation systems don't have a significant effect on land allocation for both crops.

Regarding barriers to improvements, uncertainty about future water availability has a negative effect on corn planting, and not enough to recover implementation costs has a positive effect. For soybean, landlords will not share improvements costs has a negative effect on soybean planting, while investigating improvement is not a priority shows a positive effect. While positive effects are unexpected, a comparison of the negative effects on the two crops indicate corn farmers are more concerned with future uncertainties, and soybean farmers with share of improvement costs.

Information from extension agents and neighboring farmers decreases the planting of corn, and soybean planting is also negative affected by the information from extension agents. While information from private irrigation specialists increases the planting of corn. These findings indicate the effectiveness of extension programs in promoting the growing of water-conserving crops.

At the state-level, the precipitation change in 2013 is negatively associated with corn planting. Both the precipitation change and temperature change are positively associated with soybean acreage. These findings suggest that given climate variability, less water available for crop production probably promotes farmers growing more water-conserving crops (in this case, soybeans), and vice versa. Compared with Plains farmers, those in Midwestern, Southern and Atlantic states are more likely to plant corn. While, farmers in the Southern states are less likely to plant soybeans.

6.5. Water application equation

The parameter estimates for water application equations of corn and soybeans are presented in table 7 and table 8. The results show compared with groundwater use only, the water use from two or more sources has a positive effect on water application of corn. High surface water cost, energy expenses and labor payment are positively associated with water application on corn. And the energy expenses are also positively associated with water application on soybeans. The positive effects of water prices and energy expenses are unexpected, but this may indicate the ineffectiveness of higher water price on water conservation. A positive effect of labor payment may suggest that these factors are complements; more labor use facilitates more irrigation, or producers who need more irrigation to maximize profits use more labor.

[Insert table 7 and table 8 about here]

Regarding farm characteristics, results show more wells are positively associated with water application on soybean farms, which is consistent with the hypothesis as mentioned above that more wells provide farmers more and easier access to water. Large farming area has a positive association with the average water application on corn farms. Adoption of pressure irrigation systems reduces irrigation water application for soybean farms, which is consistent with the hypothesis that the enhanced pressure irrigation systems reduce water use.

Barriers showing a negative effect on water application on corn farms include limitation of physical field or crop conditions, uncertainty about future water availability, and will increase management time or cost. For soybeans, barriers with a negative effect are landlords will not share improvements costs, uncertainty about future water availability, and will not be farming long enough. These negative effects are in line with expectations. However, further investigations are needed on variables showing a positive effect.

Information from extension agents, private irrigation specialists, and neighboring farmers has a negative effect on the water use of both corn and soybeans, and irrigation equipment dealers, and media reports also show a negative effect on soybean water use. However, information from E-information services has a positive effect. These findings indicate certain groups can be more effective in conserving water use.

The state-level variables on climate variability show a very consistent pattern on both corn and soybean water use. Compared with the average precipitation in 1981-2010, more precipitation in 2012 and 2013 leads to less irrigation water application on corn and soybean farms. Compared with the average temperature in 1981-2010, the higher temperature in 2012 and 2013 is negatively associated with the water application of both corn and soybeans in 2013. This indicate water use is related with both climate perception based on early experience and current water availability. Compared to the farmers in the Plains, those in the West use more water for both crops, which is consistent with the expectation.

6.6. Crop supply equation

The MLMs results for crop supply equations of corn and soybeans are presented in table 9 and table 10. The results show compared with groundwater use only, water from off-farm sources has a positive effect on soybean yield. Unfortunately, none of the cost variables is significantly for both crop yields.

For farm characteristics, more wells used on soybean farms increase the yield. Larger area of farming land has a positive effect on corn yield, which indicates economics of scale on corn production. Larger percentage of land owned decreases the yield for both crops. The adoption of pressure irrigation systems shows a positive effect on soybean yield, indicating soybean yield is increased under enhanced irrigation systems.

Barriers showing a negative effect on yields of both crops include limitation of physical field or crop conditions, and lack of financing to make improvements. This suggests crop yield is more related to physical limitation.

Irrigation information from extension agents, and private irrigation specialists show a positive effect on both corn and soybean yield. E-information services only show a positive effect on corn yield, and information from media reports and neighboring farmers have a positive effect on soybean yield. However, information showing a negative effect include government specialists (on corn yield), and irrigation equipment dealers and local irrigation district employee (on soybean yield).

Regarding state-level variables, precipitation change in 2012 and temperature changes in 2012 and 2013 show a positive effect on soybean yield. Given the results from the water application regressions, it seems that farmers who have access to irrigation were able to fully off-set the effects of weather variability. Compared with Plains states, farms in the West have a lower soybean yield.

[Insert table 9 and table 10 about here]

6.7. Economic irrigation water use efficiency equation

The parameter estimates for EIWUE equations of corn and soybeans are presented in table 11 and table 12, respectively. The results show irrigation using water from on-farm surface only and multiple sources has a negative effect on corn EIWUE, compared to groundwater only. Higher water prices decrease EIWUE of corn, and higher energy expenses also decrease EIWUE of both crops. Combining with the results on water use and yield, these findings suggest higher efficiency cannot be achieved through increasing water prices. Higher labor payment also decreases EIWUE of corn.

Regarding farm characteristics, number of wells shows a negative effect on both corn and soybean EIWUE. This indicates fewer wells available on a farm can encourage an efficient use of irrigation water. Adoption of pressure irrigation increases water use efficiency of both crops, indicating the effectiveness of achieving higher irrigation water use efficiency with the application of enhanced irrigation systems, and this is consistent with the results of water application and crop yield.

Similarly, irrigation efficiency is limited by factors related to risk of reduced yield or poorer quality crop (on soybeans), limitation of physical field or crop conditions (on soybeans), cannot finance improvements (on corn), and will not be farming long enough (on corn). These findings can be true if water application is limited by poor water distribution systems and or farmers are resource-limited.

Effects of information sources are consistent for the two crops. Media reports show a positive effect, and variables showing a negative effect include local irrigation district employee, and government specialists.

Regarding the state-level variables on climate variability, for soybean farms, compared with the average precipitation, more precipitation in 2011 and 2012 are positively associated with higher irrigation water use efficiency in 2013. The precipitation change in 2013 is positively associated with water use efficiency of both crops. The temperature change in 2011 decrease EIWUE of corn, and the temperature changes in 2013 increase EIWUE of both crops. These findings suggest that higher temperatures in the growing season promote farmers to use water more efficiently, while perceptions of precipitation if more effective to increase EIWUE than perceptions of temperature. Compared with farms in the Plains, soybean farms in the West have a lower EIWUE, while corn farms have a higher EIWUE.

[Insert table 11 and table 12 about here]

7. Discussion and conclusions

Using the USDA 2013 FRIS data, this paper analyzes farmers' production decisions relating to irrigated agriculture in a multicrop production system. To study the role of water costs, the farm-level water demand is decomposed into crop-specific demands. For each crop, the total effect can be obtained by summing intensive and extensive margins of water use. With the aggregate effect at the farm level, we can quantify the effect of a one unit increase in water price. Furthermore, effects of exogenous variables are analyzed using a multilevel approach. Four equations regarding land allocation, water demand, crop supply, and economic irrigation water use efficiency are formulated using two-level models.

A fundamental finding from the decomposition of farm-level water demand illustrates higher costs of surface water are not effective to reduce water use for both corn and soybeans through both intensive and extensive margins. While a proxy of groundwater price has a negative effect on soybean water use. This finding is a surprise, but is empirically supported by some evidence. Similar to the mixed effects of water price found by Moore et al. (1994b), water cost is ineffective in conserving water use once producers have made decisions on crop production. Pfeiffer and Lin (2014) found polices to conserve water use may not be effective.

In addition, results from MLMs allow us to make certain the relative importance of farm- and state-level factors, and the estimation outcomes present effects of those exogenous variables at both levels. Adoption of pressure irrigation systems could reduce soybean water use and increase soybean yield. Higher EIWUE due to enhanced irrigation methods can also be achieved on both corn and soybean farms.

The findings from MLMs show the state-level variables on climate variability have fairly consistent effects. High temperature promotes more efficient water use and higher yield. High precipitation is correlated with low water application and higher crop yield. Droughts due to less rainfall or high temperature and their perceptions increase farmers' awareness of potential production risks not only during droughts, but in subsequent years (Peck and Adams, 2010). As a result, farmers can be motivated to change the land allocation for different crops and irrigate more to mitigate adverse effects of climate variability. Contrary to Olen et al. (2016), we find the irrigation water use is more responsive to precipitation than to temperature. Given the nonlinear impacts of climatic factors, farmers' responses in adapting to climate risks depend on the cropping patterns.

This study also leaves some opportunities for future research. Aggregate effect is estimated for a typical farm growing corn and soybeans taking roughly half of the average farming area. Equations on more crops can be estimated to provide a more complete estimate of the effect of water price, and regional equations can be estimated to account for structural differences across regions. Ideally, elasticity with respect to water price can be estimated to quantify price effect from a different and equally important perspective. Though MLMs are supposed to deal with multiple estimation problems, more investigations are needed especially on potential sample selection problems.

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Table 1. Summary statistics of crop-specific dependent variables and state-level weather-related independent variables.

Variable	Description (Unit)	N	Mean	Std Dev	CV	Min	Max
Crop-specific dependent variables							
Corn							
Land allocation	Average farming area (acre)	6030	356.84	1426.66	4.00		
Water application	Average water application (acre-foot)	6030	1.11	1.97	1.77		
Crop yield	Average yield of all farms (bu/acre)	6030	190.29	87.19	0.46		
EIWUE	Average economic irrigation water use efficiency ($/acre-foot)	6030	1310.99	3199.15	2.44		
Soybeans							
Land allocation	Average area of all farms (acre)	3933	340.79	1195.10	3.51		
Water application	Average water application of all farms (acre-feet)	3933	0.81	1.13	1.40		
Crop yield	Average yield of all farms (bu/acre)	3933	54.76	27.89	0.51		
EIWUE	Average economic irrigation water use efficiency ($/acre-foot)	3933	1220.55	2352.57	1.93		
***State-wide average weather-related* variables**							
PrecipChange2011	Precipitation in 2011 — Average precipitation in 1981-2010 (inch)	43	1.51	8.26	5.46	-15.87	17.61
PrecipChange2012	Precipitation in 2012 — Average precipitation in 1981-2010 (inch)	43	-3.66	4.74	1.29	-12.21	10.30
PrecipChange2013	Precipitation in 2013 — Average precipitation in 1981-2010 (inch)	43	1.74	5.36	3.08	-15.19	14.26
TempChange2011	Temperature in 2011 — Average temperature in 1981-2010 (F)	43	0.54	1.09	2.03	-2.70	2.10
TempChange2012	Temperature in 2012 — Average temperature in 1981-2010 (F)	43	2.47	1.11	0.45	-1.70	4.00
TempChange2013	Temperature in 2013 — Average temperature in 1981-2010 (F)	43	-0.50	0.75	1.48	-2.20	0.90

Table 2. Summary statistics of farm-level independent variables and region dummies.

	Corn (N=6030)		Soybean (N=3933)	
Variables	**Mean**	**Std Dev**	**Mean**	**Std Dev**
Water sources				
Groundwater only (base)	0.713	1.124	0.808	0.926
On-farm surface water only	0.058	0.579	0.045	0.488
Off-farm surface water only	0.105	0.762	0.031	0.406
Two or more water sources	0.124	0.819	0.116	0.752
Costs				
Cost for off-farm surface water ($/acre-foot)	6.891	113.473	4.215	47.154
Energy expenses ($/acre)	47.047	184.994	35.602	62.841
Facility expenses ($/acre)	37.605	367.721	25.131	293.385
Labor payment ($/acre)	5.237	197.950	1.454	25.398
Farm characteristics				
# of wells used	5.755	23.632	7.365	23.585
Total acre	1879	13497	1665	5238
% of owned land	0.497	0.937	0.448	0.852
Pressure irrigation	0.799	0.996	0.708	1.070
Gravity irrigation	0.201	0.996	0.292	1.070
Federal assistance	0.202	0.998	0.219	0.973
Barriers to improvements				
Investigating improvement is not a priority	0.165	0.921	0.140	0.816
Risk of reduced yield or poorer quality crop	0.089	0.708	0.071	0.605
Limitation of physical field or crop conditions	0.110	0.776	0.104	0.718
Not enough to recover implementation costs	0.172	0.937	0.195	0.932
Cannot finance improvements	0.129	0.834	0.114	0.748
Landlords will not share improvement costs	0.119	0.805	0.137	0.808
Uncertainty about future water availability	0.110	0.776	0.080	0.637
Will not be farming long enough	0.075	0.656	0.059	0.554
Will increase management time or cost	0.079	0.671	0.065	0.579
Information Sources				
Extension agents	0.330	1.169	0.401	1.153
Private irrigation specialists	0.354	1.188	0.366	1.133
Irrigation equipment dealers	0.310	1.150	0.308	1.086
Local irrigation district employee	0.082	0.683	0.059	0.555
Government specialists	0.153	0.895	0.146	0.831
Media reports	0.118	0.802	0.122	0.769
Neighboring farmers	0.231	1.047	0.231	0.991
E-information services	0.188	0.972	0.191	0.925

Regions				
West	0.139	0.859	0.005	0.171
Plains (base)	0.554	1.235	0.532	1.174
Midwest	0.160	0.912	0.182	0.908
South	0.113	0.787	0.242	1.008
Atlantic	0.033	0.445	0.038	0.450

All variables have been weighted using weights provided within the FRIS data.

Table 3. Crop-specific extensive and intensive margins to surface water cost and energy expenses.

	dw/dn	dn/db	dw/db	Share of crop-specific farms	Extensive margin	Intensive margin	Total effect (acre-feet per acre)	Total effect-farm (acre-feet per farm)
Surface water cost								
Corn	1.0266	0.1766	0.0030	0.3129	0.0567	0.0009	0.0577	20.5769
Soybeans	1.0040	0.0816	0.0006	0.2041	0.0167	0.0001	0.0168	5.7396
Farm total								26.3165
Energy expenses								
Corn	1.0266	0.2282	0.0012	0.3129	0.0733	0.0004	0.0737	26.2881
Soybeans	1.0040	-0.5334	0.0012	0.2041	-0.1093	0.0002	-0.1090	-37.1606
Farm total								-10.8725

As defined by Moore et al. (1994b), $\frac{\partial w_i}{\partial n_i}$ is the estimated coefficient on crop acreage in the water demand equations, where w_i is the acre-feet of irrigation water on crop i and n_i is acres of growing crop i. $\frac{\partial n_i}{\partial b}$ is the estimated coefficient on water price in the land allocation equations, with b the water price. $\frac{\partial w_i}{\partial \mathrm{b}}$ is the estimated coefficients on water price in the water demand equation. The calculation of both intensive and extension margin should be adjusted by the share of the crop planted.

Table 4. Intraclass correlation coefficients (ICC) for null models of each crop-specific multilevel model.

State-level variation	Land allocation	Water demand	Crop supply	EIWUE
Corn	0.0068	0.2102	0.0270	0.1501
Soybeans	0.0291	0.1365	0.0277	0.1763

EIWUE: economics irrigation water use efficiency.

Table 5. Results of multilevel models for land allocation for CORN farms.

	Model 1: Random intercept only		Model 2: M1+fixed Level 1		Model 3: M2+random Level 1		Model 4: M3+fixed Level 2	
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Fixed Effects								
Intercept	303.480***	22.498	-567.590***	41.889	-468.850***	34.956	-533.020***	55.823
Water sources								
On-farm surface water only			93.510***	25.390	78.811***	22.808	78.808***	23.286
Off-farm surface water only			139.460***	23.516	143.170***	20.822	151.370***	22.352
Two or more water sources			103.450***	17.356	80.487***	15.701	85.086***	15.758
Costs								
Cost for off-farm surface water($/acre-foot)			0.216*	0.130	0.235**	0.113	0.177	0.116
Energy expenses ($/acre)			0.199**	0.080	0.207***	0.072	0.228***	0.073
Facility expenses ($/acre)			0.207***	0.040	0.160***	0.035	0.170***	0.036
Labor payment ($/acre)			0.069	0.070	0.047	0.062	0.034	0.063
Farm characteristics								
# of wells used			37.133***	0.678	38.793***	3.992	38.663***	4.081
LN(total acre)			93.438***	5.304	82.817***	4.969	81.107***	4.816
% of owned land			-33.288**	15.807	-17.249	15.132	-20.374	14.257
Pressure irrigation			43.682***	16.853	13.824	15.015	21.763	15.337
Federal assistance			-38.624***	14.432	-41.438***	13.031	-26.108	16.153
Barriers to improvements								
Investigating improvement is not a priority			-19.349	15.295	-10.244	13.784	-10.970	13.782
Risk of reduced yield or poorer quality crop			10.387	21.869	2.736	19.686	-0.682	19.700

Limitation of physical field or crop conditions	-25.796	19.828	-28.051	17.873	-27.543	17.893
Not enough to recover implementation costs	29.944*	15.726	30.023**	14.196	29.853**	14.160
Cannot finance improvements	-29.817*	17.092	-21.547	15.417	-22.241	15.403
Landlords will not share improvement costs	1.104	18.674	-9.473	16.856	-9.536	16.863
Uncertainty about future water availability	-26.540	19.146	-33.740**	17.257	-35.165**	17.261
Will not be farming long enough	26.760	22.286	3.447	20.059	3.877	20.056
Will increase management time or cost	-2.610	22.334	-0.373	20.131	3.408	20.145
Information sources						
Extension agents	-38.202***	13.019	-28.021**	11.717	-29.179**	11.727
Private irrigation specialists	41.348***	12.482	24.310**	11.238	23.782**	11.218
Irrigation equipment dealers	1.819	13.075	-3.827	11.778	-3.008	11.816
Local irrigation district employee	-20.099	22.038	2.309	19.883	-2.399	19.916
Government specialists	-26.349	17.226	-6.763	15.568	-5.252	15.564
Media reports	2.848	18.503	-0.378	16.674	-0.350	16.675
Neighboring farmers	-22.567	14.148	-29.198**	12.748	-27.456**	12.756
E-information services	23.000	15.261	13.241	13.752	12.732	13.760
State-level variables						
PrecipChange2011					-2.820	1.936

PrecipChange2012							-3.283	2.405
PrecipChange2013							-7.201**	2.715
TempChange2011							2.116	16.396
TempChange2012							-0.811	12.082
TempChange2013							1.927	18.476
West							45.578	34.692
Midwest							64.791*	33.045
South							131.760***	41.441
Atlantic							119.730**	55.951
Error Variance								
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Intercept	13704***	4152	7466***	2107	<.0001***	<.0001	<.0001***	<.0001
Residual	1982591***	36208	1058238***	19320	859702***	15768	858667***	15746
Fit Statistics								
N	6030		6030		6030		6030	
-2 Log Likelihood	98287		94502		93319		93300	
AIC	98293		94566		93389		93378	
AICC	98293		94566		93389		93379	
BIC	98298		94622		93451		93446	

Significance levels: * 10%; ** 5%; *** 1%.

Table 6. Results of multilevel models for land allocation for SOYBEAN farms.

	Model 1: Random intercept only		Model 2: M1+fixed Level 1		Model 3: M2+random Level 1		Model 4: M3+fixed Level 2	
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Fixed Effects								
Intercept	251.560***	36.365	-559.860***	49.189	-488.890***	70.552	12.756	241.400
Water sources								
On-farm surface water only			53.993**	26.139	29.337	24.599	29.948	24.573
Off-farm surface water only			84.522**	35.078	55.902*	32.696	49.960	32.727
Two or more water sources			82.163***	17.063	66.167**	18.512	71.824**	20.262
Costs								
Cost for off-farm surface water($/acre-foot)			0.154	0.323	0.059	0.301	0.082	0.302
Energy expenses ($/acre)			-1.034***	0.202	-0.541*	0.260	-0.533*	0.253
Facility expenses ($/acre)			-0.002	0.041	0.009	0.037	0.009	0.037
Labor payment ($/acre)			0.001	0.472	0.204	0.427	0.168	0.428
Farm characteristics								
# of wells used			26.798***	0.644	18.112***	2.587	18.199***	2.566
LN(total acre)			104.310***	6.176	93.807***	10.859	92.613***	10.983
% of owned land			-38.648**	15.518	-17.687	14.232	-17.387	14.205
Pressure irrigation			-5.626	14.232	6.627	22.892	5.519	22.995
Federal assistance			-28.991**	13.303	-24.863**	12.092	-25.000**	12.067
Barriers to improvements								
Investigating improvement is not a priority			39.375***	15.101	24.635*	13.697	23.756*	13.675
Risk of reduced yield or poorer quality crop			-7.174	21.826	-1.054	19.718	1.521	19.659

Limitation of physical field or crop conditions	-21.666	18.698	-20.495	16.979	-19.917	16.972
Not enough to recover implementation costs	1.015	14.419	-1.521	13.206	-2.248	13.184
Cannot finance improvements	-13.699	17.191	-1.988	15.583	-1.889	15.567
Landlords will not share improvement costs	-27.246*	16.473	-29.687**	14.930	-29.516**	14.914
Uncertainty about future water availability	-40.029*	20.772	-29.033	18.991	-28.533	18.987
Will not be farming long enough	8.091	22.843	16.063	20.735	13.336	20.680
Will increase management time or cost	0.895	22.199	4.858	20.089	4.782	20.079
Information source						
Extension agents	-5.977	11.381	-19.407*	10.398	-18.427*	10.380
Private irrigation specialists	3.464	11.464	8.654	10.440	8.490	10.429
Irrigation equipment dealers	4.104	12.228	-4.019	11.097	-4.227	11.089
Local irrigation district employee	29.577	23.722	23.857	21.660	23.229	21.612
Government specialists	13.728	15.598	4.769	14.130	4.839	14.125
Media reports	0.108	16.763	-1.229	15.189	-0.632	15.178
Neighboring farmers	-21.697*	12.978	-18.505	11.698	-17.951	11.690
E-information services	-9.579	14.137	12.719	12.828	11.728	12.817
State-level variables						
PrecipChange2011					-8.475	6.350
PrecipChange2012					16.053	9.861
PrecipChange2013					30.293**	11.885

TempChange2011							11.812	80.683
TempChange2012							-28.899	73.028
TempChange2013							134.110*	75.466
West							-276.61	217.030
Midwest							-94.133	141.990
South							-994.360***	163.420
Atlantic							-343.38	216.110
Error Variance								
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Intercept	33062***	9046	12197***	3563	54283***	20602	<.0001***	<.0001
Residual	1101143***	24905	537987***	12169	433603***	9931	433053***	9882
Fit Statistics								
N	3933		3933		3933		3933	
-2 Log Likelihood	61977		59154		58453		58421	
AIC	61983		59218		58527		58513	
AICC	61983		59218		58528		58514	
BIC	61988		59269		58587		58571	

Significance levels: * 10%; ** 5%; *** 1%.

Table 7. Results of multilevel models for mean water application for CORN farms.

	Model 1: Random intercept only		**Model 2: M1+fixed Level 1**		**Model 3: M2+random Level 1**		**Model 4: M3+fixed Level 2**	
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Fixed Effects								
Intercept	1.076***	0.123	0.870***	0.129	1.027***	0.154	1.041***	0.328
Water sources								
On-farm surface water only			-0.015	0.038	-0.024	0.070	-0.037	0.069
Off-farm surface water only			0.132***	0.036	-0.045	0.080	-0.075	0.083
Two or more water sources			0.075***	0.025	0.106**	0.041	0.106**	0.044
Costs								
Cost for off-farm surface water($/acre-foot)			0.000	0.000	0.003**	0.001	0.003**	0.001
Energy expenses ($/acre)			0.001***	0.000	0.001*	0.001	0.001*	0.001
Facility expenses ($/acre)			0.000***	0.000	0.000	0.000	0.000	0.000
Labor payment ($/acre)			0.001***	0.000	0.003**	0.001	0.002**	0.001
Farm characteristics								
# of wells used			0.001	0.001	0.003*	0.001	0.002	0.001
LN(total acre)			0.033***	0.008	0.023	0.017	0.026*	0.015
% of owned land			0.020	0.023	-0.012	0.048	-0.003	0.049
Pressure irrigation			-0.090***	0.025	-0.196	0.119	-0.057	0.107
Federal assistance			-0.003	0.021	0.023	0.032	0.029	0.033
Barriers to improvements								
Investigating improvement is not a priority			0.067***	0.022	0.053***	0.021	0.056***	0.020
Risk of reduced yield or poorer quality crop			0.046	0.032	0.061**	0.029	0.064**	0.029

Limitation of physical field or crop conditions	-0.083***	0.029	-0.094***	0.026	-0.094***	0.026
Not enough to recover implementation costs	0.015	0.023	0.004	0.021	0.001	0.021
Cannot finance improvements	0.093***	0.025	0.134***	0.023	0.139***	0.023
Landlords will not share improvement costs	0.008	0.027	-0.015	0.025	-0.012	0.025
Uncertainty about future water availability	-0.060**	0.028	-0.071***	0.026	-0.074***	0.026
Will not be farming long enough	-0.014	0.032	0.060**	0.030	0.055*	0.030
Will increase management time or cost	-0.052	0.032	-0.074**	0.030	-0.077***	0.030
Information source						
Extension agents	-0.094***	0.019	-0.063***	0.017	-0.062***	0.017
Private irrigation specialists	-0.040**	0.018	-0.042**	0.017	-0.040**	0.017
Irrigation equipment dealers	0.060***	0.019	0.056***	0.018	0.055***	0.018
Local irrigation district employee	0.117***	0.032	0.103***	0.030	0.098***	0.030
Government specialists	0.012	0.025	0.039*	0.023	0.038	0.023
Media reports	-0.040	0.027	-0.010	0.025	-0.009	0.025
Neighboring farmers	-0.059***	0.021	-0.069***	0.019	-0.069***	0.019
E-information services	0.070***	0.022	0.062***	0.020	0.060***	0.020
State-level variables						
PrecipChange2011					-0.043***	0.015
PrecipChange2012					-0.064***	0.019
PrecipChange2013					-0.079***	0.022

	Estimate	Std Err	Estimate	Std Err	Estimate	Std Err	Estimate	Std Err
TempChange2011							0.050	0.109
TempChange2012							-0.330***	0.095
TempChange2013							-0.335	0.146
West							0.961**	0.204
Midwest							0.180***	0.262
South							-0.101	0.276
Atlantic							0.591	0.437
Error Variance								
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Intercept	0.619***	0.141	0.554***	0.127	0.536***	0.167	<.0001***	<0.0001
Residual	2.325***	0.042	2.228***	0.041	1.761***	0.033	1.766***	0.033
Fit Statistics								
N	6030		6030		6030		6030	
-2 Log Likelihood	16071		15812		14788		14730	
AIC	16077		15876		14874		14834	
AICC	16077		15876		14875		14835	
BIC	16082		15932		14950		14926	

Significance levels: * 10%; ** 5%; *** 1%.

Table 8. Results of multilevel models for mean water application for SOYBEAN farms.

	Model 1: Random intercept only		Model 2: M1+fixed Level 1		Model 3: M2+random Level 1		Model 4: M3+fixed Level 2	
	Estimate	*Std Err*	*Estimate*	*Std Err*	*Estimate*	*Std Err*	*Estimate*	*Std Err*
Fixed Effects								
Intercept	0.712***	0.073	0.691***	0.089	0.842***	0.093	1.151***	0.227
Water sources								
On-farm surface water only			0.151***	0.036	0.018	0.079	0.015	0.078
Off-farm surface water only			0.075	0.049	0.022	0.052	-0.015	0.055
Two or more water sources			0.034	0.023	0.040	0.033	0.039	0.036
Costs								
Cost for off-farm surface water($/acre-foot)			0.001***	0.000	0.001	0.000	0.001	0.000
Energy expenses ($/acre)			0.001	0.000	0.001**	0.001	0.001**	0.001
Facility expenses ($/acre)			0.000	0.000	0.000	0.000	0.000	0.000
Labor payment ($/acre)			-0.002***	0.001	-0.001	0.002	-0.001	0.002
Farm characteristics								
# of wells used			0.001	0.001	0.003**	0.001	0.002*	0.001
LN(total acre)			0.027***	0.008	0.001	0.013	0.004	0.010
% of owned land			-0.007	0.021	-0.034	0.032	-0.024	0.035
Pressure irrigation			-0.214***	0.020	-0.162**	0.058	-0.174***	0.044
Federal assistance			0.033*	0.018	0.047*	0.025	0.046*	0.025
Barriers to improvements								
Investigating improvement is not a priority			0.016	0.021	0.007	0.020	0.006	0.020
Risk of reduced yield or poorer quality crop			0.056*	0.030	0.078***	0.028	0.079***	0.028

Limitation of physical field or crop conditions	0.003	0.026	0.037	0.025	0.039	0.025
Not enough to recover implementation costs	0.037*	0.020	-0.007	0.019	-0.004	0.019
Cannot finance improvements	0.016	0.023	0.026	0.022	0.027	0.022
Landlords will not share improvement costs	-0.058***	0.022	-0.059***	0.022	-0.060***	0.022
Uncertainty about future water availability	-0.099***	0.028	-0.086***	0.028	-0.084***	0.028
Will not be farming long enough	-0.049	0.031	-0.064**	0.030	-0.068**	0.030
Will increase management time or cost	-0.019	0.030	-0.014	0.029	-0.014	0.029
Information source						
Extension agents	-0.062***	0.016	-0.042***	0.015	-0.041***	0.015
Private irrigation specialists	-0.058***	0.016	-0.041***	0.015	-0.042***	0.015
Irrigation equipment dealers	-0.040**	0.017	-0.044***	0.016	-0.044***	0.016
Local irrigation district employee	0.052	0.032	0.024	0.031	0.024	0.031
Government specialists	0.037*	0.021	0.055***	0.020	0.054***	0.020
Media reports	-0.058**	0.023	-0.037*	0.022	-0.042*	0.022
Neighboring farmers	-0.038**	0.018	-0.040**	0.017	-0.037**	0.017
E-information services	0.051***	0.019	0.038**	0.018	0.037**	0.019
State-level variables						
PrecipChange2011					-0.008	0.006
PrecipChange2012					-0.018*	0.009
PrecipChange2013					-0.036***	0.011

TempChange2011							0.111	0.072
TempChange2012							-0.152**	0.067
TempChange2013							-0.135*	0.071
West							0.809***	0.192
Midwest							-0.160	0.122
South							-0.131	0.149
Atlantic							-0.227	0.195
Error Variance								
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Intercept	0.171***	0.053	0.137***	0.044	0.054	0.044	<.0001***	<.0001
Residual	1.083***	0.025	1.000***	0.023	0.884***	0.020	0.886***	0.020
Fit Statistics								
N	3933		3933		3933		3933	
-2 Log Likelihood	7622		7305		6949		6892	
AIC	7628		7369		7033		6994	
AICC	7628		7369		7033		6995	
BIC	7633		7420		7100		7076	

Significance levels: * 10%; ** 5%; *** 1%.

Table 9. Results of multilevel models for mean yield on CORN farms.

	Model 1: Random intercept only		**Model 2: M1+fixed Level 1**		**Model 3: M2+random Level 1**		**Model 4: M3+fixed Level 2**	
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Fixed Effects								
Intercept	184.170***	2.330	180.110***	3.749	170.640***	5.663	159.780***	22.366
Water sources								
On-farm surface water only			-15.384***	2.008	-6.250	3.806	-6.410	3.823
Off-farm surface water only			-11.424***	1.895	-2.491	3.621	-2.328	3.640
Two or more water sources			-5.704***	1.357	1.022	2.660	1.011	2.681
Costs								
Cost for off-farm surface water($/acre-foot)			0.008	0.010	0.007	0.012	0.005	0.013
Energy expenses ($/acre)			0.003	0.006	0.001	0.025	0.000	0.025
Facility expenses ($/acre)			-0.012***	0.003	0.003	0.007	0.003	0.007
Labor payment ($/acre)			-0.002	0.006	0.013	0.021	0.016	0.022
Farm characteristics								
# of wells used			0.033	0.053	0.023	0.081	0.020	0.082
LN(total acre)			0.986**	0.417	1.883***	0.651	1.980***	0.656
% of owned land			-6.216***	1.236	-5.739***	2.112	-5.814***	2.129
Pressure irrigation			6.099***	1.345	3.688	3.693	3.956	3.790
Federal assistance			2.426**	1.126	1.865	1.894	1.824	1.887
Barriers to improvements								
Investigating improvement is not a priority			-1.290	1.194	-1.595	1.150	-1.614	1.151

Risk of reduced yield or poorer quality crop	10.405***	1.707	10.903***	1.636	10.875***	1.636
Limitation of physical field or crop conditions	-4.097***	1.547	-3.824***	1.485	-3.803***	1.485
Not enough to recover implementation costs	-0.120	1.227	-0.881	1.187	-0.888	1.187
Cannot finance improvements	-6.445***	1.334	-6.888***	1.298	-6.858***	1.298
Landlords will not share improvement costs	-2.276	1.457	-0.981	1.390	-0.976	1.390
Uncertainty about future water availability	-0.971	1.496	-2.046	1.441	-2.009	1.441
Will not be farming long enough	-0.016	1.740	0.969	1.682	0.955	1.682
Will increase management time or cost	0.010	1.743	-0.717	1.679	-0.777	1.679
Information source						
Extension agents	3.523***	1.018	4.069***	0.976	4.107***	0.977
Private irrigation specialists	4.120***	0.976	3.520***	0.940	3.528***	0.940
Irrigation equipment dealers	-1.745*	1.022	-0.970	0.988	-1.009	0.988
Local irrigation district employee	-0.303	1.722	-1.048	1.676	-1.044	1.677
Government specialists	-5.552***	1.345	-3.708***	1.310	-3.724***	1.310
Media reports	1.575	1.445	2.096	1.380	2.022	1.381
Neighboring farmers	-1.044	1.105	-0.552	1.066	-0.522	1.066
E-information services	3.319***	1.191	2.553**	1.147	2.574***	1.147

State-level variables								
PrecipChange2011							0.780	0.802
PrecipChange2012							-1.145	1.225
PrecipChange2013							-1.679	1.234
TempChange2011							-11.005	8.570
TempChange2012							3.181	6.313
TempChange2013							3.242	9.373
West							-10.149	18.285
Midwest							9.455	16.155
South							25.860	19.538
Atlantic							17.813	23.744
Error Variance								
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Intercept	191***	52	174***	47	473***	189	326**	154
Residual	6887***	126	6434***	118	5635***	106	5636***	106
Fit Statistics								
N	6030		6030		6030		6030	
-2 Log Likelihood	64185		63775		63282		63275	
AIC	64191		63839		63368		63361	
AICC	64191		63839		63369		63362	
BIC	64197		63895		63444		63440	

Significance levels: * 10%; ** 5%; *** 1%.

Table 10. Results of multilevel models for mean yield on SOYBEAN farms.

	Model 1: Random intercept only		**Model 2: M1+fixed Level 1**		**Model 3: M2+random Level 1**		**Model 4: M3+fixed Level 2**	
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Fixed Effects								
Intercept	51.990***	0.852	47.767***	1.680	49.200***	2.023	51.233***	4.905
Water sources								
On-farm surface water only			-0.506	0.859	0.422	1.548	0.547	1.416
Off-farm surface water only			4.534***	1.151	5.186***	1.241	5.590***	1.210
Two or more water sources			1.444***	0.558	1.106	0.808	1.060	0.835
Costs								
Cost for off-farm surface water($/acre-foot)			-0.032***	0.011	-0.005	0.011	-0.001	0.011
Energy expenses ($/acre)			-0.011	0.007	0.001	0.014	0.000	0.014
Facility expenses ($/acre)			0.001	0.001	0.000	0.001	0.000	0.001
Labor payment ($/acre)			0.022	0.015	0.036	0.034	0.035	0.034
Farm characteristics								
# of wells used			0.139***	0.021	0.120***	0.035	0.130***	0.032
LN(total acre)			-0.287	0.202	-0.102	0.239	-0.262	0.203
% of owned land			-1.015**	0.508	-2.242**	1.010	-2.669**	1.028
Pressure irrigation			4.879***	0.467	2.052	1.296	2.401*	1.203
Federal assistance			1.002**	0.435	0.772	0.667	0.810	0.701
Barriers to improvements								
Investigating improvement is not a priority			0.403	0.494	-0.294	0.484	-0.241	0.484

Risk of reduced yield or poorer quality crop	-0.051	0.714	-0.240	0.695	-0.262	0.696
Limitation of physical field or crop conditions	-1.277**	0.612	-1.417**	0.601	-1.338**	0.602
Not enough to recover implementation costs	1.071**	0.472	1.435***	0.475	1.401***	0.475
Cannot finance improvements	-1.689***	0.562	-1.647***	0.551	-1.695***	0.552
Landlords will not share improvement costs	-1.096**	0.539	-0.611	0.529	-0.572	0.530
Uncertainty about future water availability	-1.438**	0.680	-0.930	0.677	-1.052	0.677
Will not be farming long enough	2.526***	0.747	2.713***	0.729	2.783	0.730
Will increase management time or cost	-0.113	0.726	-0.479	0.709	-0.462***	0.711
Information sources						
Extension agents	2.007***	0.372	1.829***	0.367	1.732***	0.368
Private irrigation specialists	1.722***	0.375	1.568***	0.371	1.555***	0.371
Irrigation equipment dealers	-0.600	0.400	-0.978**	0.394	-0.981**	0.394
Local irrigation district employee	0.098	0.776	-0.482	0.762	-0.327	0.761
Government specialists	0.067	0.510	-0.069	0.498	-0.083	0.500
Media reports	1.285**	0.549	1.224**	0.534	1.323**	0.537
Neighboring farmers	0.693*	0.425	0.918**	0.411	0.907**	0.413
E-information services	0.772*	0.463	0.556	0.453	0.563	0.454

State-level variables								
PrecipChange2011							0.045	0.117
PrecipChange2012							0.697***	0.171
PrecipChange2013							0.142	0.245
TempChange2011							-3.625***	1.388
TempChange2012							3.151**	1.488
TempChange2013							5.494***	1.439
West							-11.099***	4.055
Midwest							3.151	2.285
South							1.568	2.825
Atlantic							-1.050	4.153
Error Variance								
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Intercept	17.943***	5.807	19.890***	6.249	19.143***	9.372	<.0001***	<.0001
Residual	629.360***	14.251	575.210***	13.026	531.160***	12.307	534.360***	12.309
Fit Statistics								
N	3933		3933		3933		3933	
-2 Log Likelihood	32608		32259		32078		32059	
AIC	32614		32323		32162		32149	
AICC	32614		32323		32162		32150	
BIC	32619		32374		32229		32220	

Significance levels: * 10%; ** 5%; *** 1%.

Table 11. Results of multilevel models for economics irrigation water use efficiency (EIWUE) of CORN farms.

	Model 1: Random intercept only		Model 2: M1+fixed Level 1		Model 3: M2+random Level 1		Model 4: M3+fixed Level 2	
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Fixed Effects								
Intercept	1920.710***	182.270	2228.690***	201.950	1907.850***	197.900	1601.320***	341.430
Water sources								
On-farm surface water only			284.240***	68.502	528.900***	196.320	536.290***	196.380
Off-farm surface water only			163.000**	65.040	513.210	367.270	561.910	390.290
Two or more water sources			-34.817	45.944	-63.021	45.799	-49.571	45.746
Costs								
Cost for off-farm surface water($/acre-foot)			-0.491	0.347	-10.831*	6.444	-11.042*	6.483
Energy expenses ($/acre)			-1.264***	0.211	-3.152***	0.938	-3.339***	0.986
Facility expenses ($/acre)			-0.137	0.105	-0.430	0.400	-0.461	0.394
Labor payment ($/acre)			-0.802***	0.193	-0.494*	0.277	-0.519*	0.278
Farm characteristics								
# of wells used			-5.903***	1.803	-9.892***	2.637	-8.072***	2.181
LN(total acre)			-57.837***	14.247	-1.622	23.655	-17.208	17.449
% of owned land			-33.294	41.897	-2.715	67.490	-4.086	62.276
Pressure irrigation			212.810***	45.958	144.780*	70.034	141.810**	64.876
Federal assistance			64.142*	38.111	12.883	48.679	14.624	48.547
Barriers to improvements								
Investigating improvement is not a priority			-95.948**	40.433	-104.120***	38.537	-108.420***	38.485

Risk of reduced yield or poorer quality crop	-7.577	57.784	-13.755	54.740	-14.715	54.688
Limitation of physical field or crop conditions	-40.131	52.376	-26.627	49.597	-28.084	49.586
Not enough to recover implementation costs	-34.720	41.535	-56.299	39.584	-52.497	39.605
Cannot finance improvements	-151.960***	45.172	-206.260***	43.568	-206.720***	43.527
Landlords will not share improvement costs	-49.482	49.295	-9.108	46.403	-12.135	46.402
Uncertainty about future water availability	104.840**	50.633	106.590**	48.465	111.800**	48.486
Will not be farming long enough	-65.038	58.923	-94.172*	56.534	-98.065*	56.303
Will increase management time or cost	130.580**	59.016	179.420***	56.392	188.680***	56.305
Information sources						
Extension agents	7.256	34.497	-12.537	32.662	-15.285	32.670
Private irrigation specialists	-1.415	33.032	-15.023	31.364	-20.287	31.278
Irrigation equipment dealers	-46.253	34.617	-24.198	33.018	-21.818	33.008
Local irrigation district employee	-149.490***	58.298	-110.630**	56.266	-106.130**	56.215
Government specialists	-130.910***	45.542	-170.130***	43.843	-173.390***	43.837
Media reports	199.680***	48.923	170.730***	46.221	170.240***	46.276
Neighboring farmers	31.803	37.402	58.472*	35.660	54.146	35.616
E-information services	-61.057	40.328	-35.264	38.358	-35.648	38.361
State-level variables						
PrecipChange2011					7.837	12.116

PrecipChange2012							-2.929	17.994
PrecipChange2013							64.873***	18.850
TempChange2011							-330.240***	117.880
TempChange2012							45.172	96.719
TempChange2013							348.990**	131.810
West							-765.200***	259.830
Midwest							893.260***	224.720
South							717.640**	283.450
Atlantic							1734.600***	361.360
Error Variance								
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Intercept	1349132***	315840	1234794***	292676	736041***	257135	<.0001***	<.0001
Residual	7639249***	139655	7363930***	134627	6264332***	117426	6299184***	118144
Fit Statistics								
N	6030		6030		6030		6030	
-2 Log Likelihood	106536		106312		105721		105657	
AIC	106542		106376		105805		105759	
AICC	106542		106376		105805		105760	
BIC	106547		106432		105879		105849	

Significance levels: * 10%; ** 5%; *** 1%.

Table 12. Results of multilevel models for economics irrigation water use efficiency (EIWUE) of SOYBEAN farms.

	Model 1: Random intercept only		**Model 2: M1+fixed Level 1**		**Model 3: M2+random Level 1**		**Model 4: M3+fixed Level 2**	
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Fixed Effects								
Intercept	1768.550***	164.010	1751.090***	198.940	1814.070***	225.090	2381.410***	692.380
Water sources								
On-farm surface water only			17.919	71.708	28.057	95.000	22.336	94.799
Off-farm surface water only			142.940	96.472	166.270	297.100	248.880	289.240
Two or more water sources			-20.759	46.098	-131.790	124.290	-126.340	120.950
Costs								
Cost for off-farm surface water($/acre-foot)			-2.789***	0.874	-7.519	4.462	-6.737	4.378
Energy expenses ($/acre)			-2.508***	0.548	-3.271***	0.861	-3.189***	0.859
Facility expenses ($/acre)			0.036	0.110	0.103	0.560	0.172	0.550
Labor payment ($/acre)			3.693***	1.274	0.369	3.396	0.147	3.418
Farm characteristics								
# of wells used			-2.118	1.743	-4.611*	2.201	-4.342*	2.135
LN(total acre)			-31.183*	16.805	-19.908	22.291	-18.973	20.326
% of owned land			2.975	41.989	34.895	77.407	35.360	81.314
Pressure irrigation			221.650***	38.774	198.470**	74.680	206.590**	73.067
Federal assistance			33.668	35.954	-13.822	63.952	-12.277	62.920
Barriers to improvements								
Investigating improvement is not a priority			124.980***	40.828	106.500***	40.133	107.210 ***	40.140

Risk of reduced yield or poorer quality crop	-116.510**	58.982	-154.650***	57.873	-155.590***	57.861
Limitation of physical field or crop conditions	-92.433*	50.513	-121.590**	49.937	-124.660**	49.947
Not enough to recover implementation costs	-86.521**	38.954	-38.334	39.349	-37.805	39.363
Cannot finance improvements	-3.261	46.480	17.128	45.684	17.588	45.694
Landlords will not share improvement costs	16.654	44.477	6.790	43.883	8.707	43.887
Uncertainty about future water availability	88.545	56.228	71.141	57.527	73.290	57.502
Will not be farming long enough	41.026	61.701	62.919	60.427	64.175	60.414
Will increase management time or cost	36.033	59.938	23.831	59.676	23.363	59.680
Information sources						
Extension agents	54.725*	30.794	45.698	30.398	42.179	30.393
Private irrigation specialists	77.723**	31.006	29.558	30.794	29.727	30.785
Irrigation equipment dealers	19.191	33.093	7.559	32.882	6.813	32.874
Local irrigation district employee	-136.420**	64.231	-121.290*	64.163	-119.260*	64.125
Government specialists	-56.086	42.158	-89.588**	41.350	-89.006**	41.363
Media reports	192.190***	45.397	157.790***	44.378	160.840***	44.404
Neighboring farmers	82.817**	35.079	87.685***	34.301	84.640**	34.312
E-information services	39.641	38.288	60.271	37.552	60.764*	37.575

State-level variables								
PrecipChange2011							57.016***	14.839
PrecipChange2012							66.779**	25.763
PrecipChange2013							121.720***	30.980
TempChange2011							-41.801	195.770
TempChange2012							-91.935	215.370
TempChange2013							375.790*	198.710
West							-1404.190**	558.800
Midwest							484.590	313.720
South							-611.140	389.730
Atlantic							-413.260	471.070
Error Variance								
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Intercept	878725***	232619	830411***	222879	773961***	252791	98568*	68609
Residual	4106553***	93048	3917688***	88780	3601179***	84806	3607043***	84572
Fit Statistics								
N	3933		3933		3933		3933	
-2 Log Likelihood	67211		67026		66887		66842	
AIC	67217		67090		66975		66950	
AICC	67218		67091		66976		66952	
BIC	67222		67142		67046		67037	

Significance levels: * 10%; ** 5%; *** 1%.

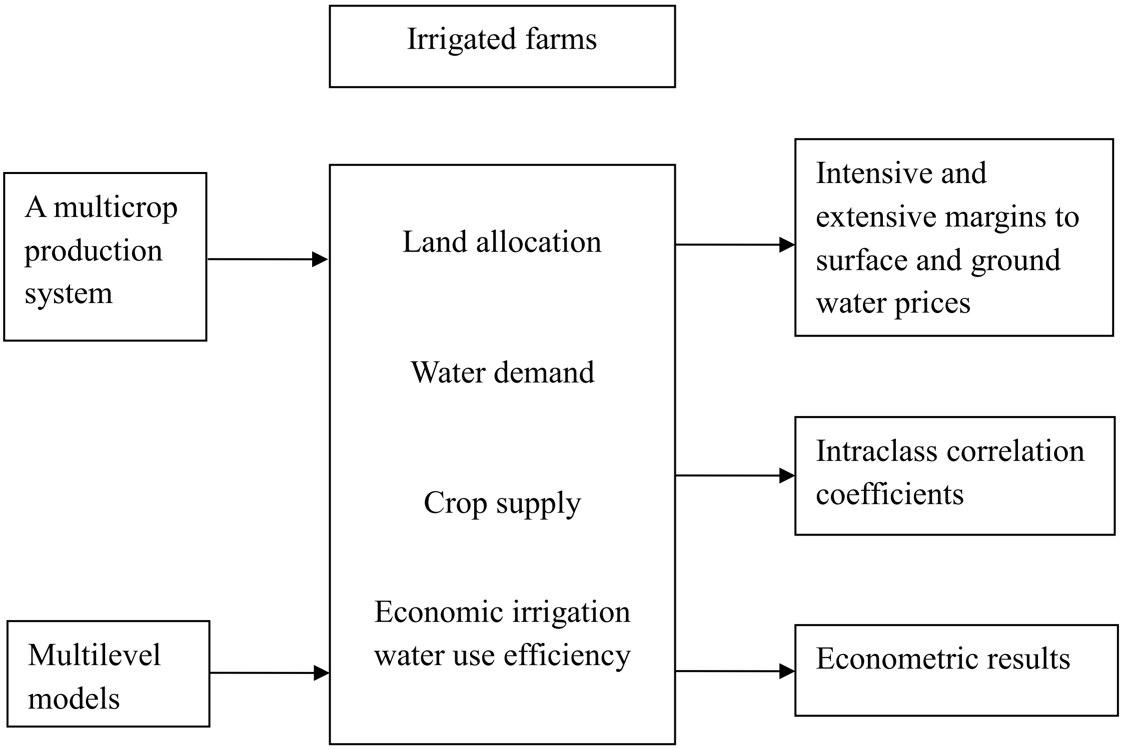

Figure 1. Layout of the analyses.