BENEFITS OF CONTROLLING SALINE WATER IN COLORADO

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ABSTRACT

The Arkansas River in Colorado is confronted with a salinity issue; the majority of this salinity problem is due to agricultural runoff caused by irrigation. Reducing applications of irrigation water through adoption of more technically efficient irrigation systems is one means of improving water quality in the Arkansas River basin. This research uses positive mathematical programming to model the cropping practices of the farms along the Arkansas River. It examines the affect of acreage and profit levels of these farms given the choice of changing their irrigation technologies.

INTRODUCTION

The Arkansas River in Colorado has a major salinity problem, a problem so severe that most of the river is on the Environmental Protection Agency's 303d list for violating the Clean Water Act. The Arkansas River starts in the Rocky Mountains in Leadville, Colorado and flows into the southeastern portion of Colorado forming the Lower Arkansas River Basin. The majority of this salinity problem is due to agricultural runoff caused by irrigation. Reducing applications of irrigation water through adoption of more technically efficient irrigation systems is one means of improving water quality in the Arkansas River Basin. A reduction in water application increases crop yield. However, while adoption of less water-intensive irrigation systems can enable irrigators to support an existing set of crops on reduced water applications, it may also allow irrigators to either expand acreage or to adopt different crops. As a result, while more technically efficient irrigation systems can potentially help improve water quality, it may also lead to changes in water consumption that make water quality problems worse. In addition, salinity increases leaching requirements, which is difficult to achieve with more technically efficient irrigation technology. The goal of this research is to analyze how cropping patterns and acreage levels change in response to adopting different types of irrigation technology in the Arkansas River Basin of Colorado.

LITERATURE REVIEW

There have been several articles written pertaining to salinization issues in crop irrigation that closely relates to the study at hand. Kan *et al.* (2002) wrote an article dealing with saline water used for irrigation in the San Joaquin Valley. Our study will deal with high salinity water in the Arkansas River Basin. The article used different water sources as their variable in the model. It did not adjust for a possible change in the crop type or an irrigation system. The study did conclude that an increase in salinity decreases on-farm profits (Kan *et al.,* 2002).

Dinar and Knapp (1991) studied the relationship between water quantity and soil salinity. They found that increases in water quantity applied to the crop decrease the soil salinity and the water concentration. In addition, they found that the soil salinity levels converge to a steady state over time. This article, as is our study, is trying to maximize profits via different levels of water applications. The experiment was performed in Arizona and primarily focused on alfalfa and cotton, where this paper will only focus on various crops including alfalfa for one time period (Dinar and Knapp, 1986).

The Westside Agricultural Drainage Economics (WADE) model used by Hatchett *et al.* (1991) is used to maximize on-farm revenues given various constraints, one of which is controlling the salinity level in the water. The model used in this article is similar to a model that will be used in the Arkansas River Basin research. However, the outcome from the Hatchett *et al.* (1991) article will differ from this paper's results due to differences in inputs. Also, the study took place in California and focused primarily on groundwater application, while our study is in Colorado and deals with surface water application. The differences between Colorado and California are discussed in more detail in a later portion of this paper.

Dinar and Zilberman (1991) also generated a model to maximize on-farm revenues. Their model differs from the WADE model in so much the WADE model holds the farmers' irrigation technologies constant while Dinar and Zilberman (1991) allow the irrigation technology to change in order to maximize profits. In addition, Dinar and Zilberman (1991) consider the environmental impacts such as differences in weather conditions. This research will focus on maximizing on-farm revenues, but will not take into consideration differences in weather conditions.

Another economic model to examine is the crop-water production function by Letey (1991). Letey (1991) develops a seasonal production function model and applies it to three different drainage scenarios: a high water table situation, water management during fallowing and management with subsurface drainage systems. The scenario that is applicable to the Arkansas River basin is the latter of the three. It focuses on water that is degraded by salts or other elements (Letey 1991). Letey (1991) examines previous studies and applies them to the crop-water production function. The study found that water markets are the most beneficial for farmers to obtain an improved irrigation technology to reduce the levels of pollution in the water. These results prove beneficial to the Arkansas River research because farms along the Arkansas River basin have the option of operating through a water bank, which is similar to a water market.

Another difference worth noting is the institutional differences in water delivery systems between Colorado and California and Arizona. California and Arizona typically operate under a water district, while Colorado and the Arkansas River Basin operates via private ditch companies. The water district acts as a public utility and is less likely to restrict water to the members of the district. Private ditch companies, however, are non-profit groups where all the members pool their water rights together and redistribute them via shares. Under a private ditch company water can be restricted relative to the shares. The ability to restrict water use is something that will need to be taken into consideration; however, it will not be considered in this paper.

The crops used in the previous articles vary from the crops found in production along the Arkansas River Basin. The crops in the lower Arkansas mainly consist of alfalfa hay, corn, wheat, beans and vegetables (Ward, 1996). The different crop types need to be considered when predicting results due to their different reaction to soil salinity and water application levels. In addition, this research is going to allow for changes in irrigation technologies across farms, as did Dinar and Zilberman (1991). In order to maximize profits along the Arkansas River, a modeling technique similar to Hatchett *et al.* (1991) will be implemented for the purpose of this research.

In order to improve water quality, runoff from crops needs to be reduced. This can be obtained by choosing the optimal combination of irrigation technology, crop mix and acreage levels across farms so that it reduces the amount of saline water returned to the system. Since each crop has different thresholds of soil salinity levels and water table depth levels, optimization over crops and irrigation technology must account for these constraints. The goal of this research is to find the optimal irrigation technology, water application rates, crop choice, and acreage levels while controlling for the soil salinity threshold and water table depth limits of alternative crops.

DATA AND METHODS

Data was collected on 3,284 farms along the Lower Arkansas River Valley located in Southeastern Colorado. The data was derived from an engineering model that reported acreage levels, crop mix, canal area, salinity level and water table depth for each farm. The crop mix for the area of study consisted of eight different types of crops: alfalfa, beans, corn, grass, melons, onions, sorghum and wheat. The canal companies included in the Lower Arkansas River Valley were Holbrook, Rocky Ford, Catlin, Otero, Rocky Ford Highline and Fort Lyon. The crop price and cost data was obtained from the Colorado Agricultural Statistics (Houk, 2003).

This research builds on a previously developed model of crop water quality and production for the Arkansas River Basin created at Colorado State University (Houk, 2003). This is a mathematical programming model coded in GAMS (General Algebraic Modeling System) that simulates crop production in the Arkansas River basin across alternative salinity and hydrologic states. This existing hydrologic/economic model is static in its acreage allocations, irrigation technology, and water applications, and this research extends this model to reflect a more dynamic production environment. This research updates the existing static hydrologic/economic model to allow for greater flexibility in cropping patterns and water applications while incorporating the ability to choose alternative irrigation systems. This integrated model moves beyond the current static hydrologic/economic model into a model that more accurately reflects both the physical hydrologic dynamics of the basin and the economic dynamics possible through changes in cropping patterns and irrigation technology. Extending the existing static model makes it possible to assess if adopting more technically efficient irrigation systems will improve water quality by reducing application rates, or if changes in cropping patterns resulting from changes in irrigation technology actually worsen water quality in the basin.

The previous model was integrated with a positive mathematical programming (PMP) model developed by Howitt (1995). Positive mathematical programming was used to replicate baseline cropping patterns. Positive mathematical programming involves three stages in its calculations. The first stage is the calibration run in which the acreage levels are calibrated and profit is calculated linearly. The second stage is an estimation of the parameters based on the calibration mathematical run. The second stage accurately models the baseline acreage that results in a nonlinear profit function. From the second stage, the data can easily be manipulated in order to evaluate certain policy changes. During the third stage the policy changes are implemented (Howitt, 1995). The effect of acreage and profit levels for each canal area based on varying irrigation technologies was examined. The irrigation technologies were based on the recharge rate back into the ground. The recharge rate is the percent of applied water that is not consumed and is returned to the system. Therefore, an increase in the recharge rate implies a decrease in efficiency of irrigation technology. Ten different scenarios of recharge rates ranging from 10% to 90% were evaluated. The sprinkler system, which is most commonly used in the Arkansas River Valley, recharges water at rates from 30% to 50%; therefore, its technology efficiency ranges from 50% to 70%. The other irrigation technology used along the Arkansas River Valley is the drip system, which recharges 10% to 20% of the applied water so it is 80% to 90% efficient (Texas, 2004).

The PMP model differs from Houk's (2003) model in so much that it allows for changes in crop coverage instead of just a change in crop mix. In addition, variable water application rates are accounted for. The PMP model was developed in GAMS. However, the limitations associated with the program, required a reduction in observations. Therefore, only fields with total acreage greater than 25 acres were the focus of this study. According to the Colorado Agriculture Statistics, farms with total acreage less than 25 acres are considered lifestyle farms. It is important to note that the total number of fields evaluated in the study were approximately 950 fields along the Lower Arkansas River Basin.

RESULTS

The static hydrologic economic model found that the costs outweighed the benefits of increasing irrigation efficiency. This model, however, did not allow for the option of choosing the optimal irrigation technology for each crop or for adjusting crop choices (Houk, 2003). While it did find an increase in agricultural productivity from reduced salinity in the Arkansas River Basin, the benefits possible when irrigators can adopt different irrigation systems in conjunction with different crops may be greater or less than current benefits estimates.

In order to examine the affects of changes in irrigation technologies along the Arkansas River Basin, total acres, total profit and profit per acre was evaluated for different irrigation technology efficiencies. While adoption of less water-intensive irrigation systems can enable irrigators to support an existing set of crops on reduced water applications, it may also allow irrigators to either expand acreage or to adopt different crops. However, as can be seen in Figure 1, an increase in irrigation technology efficiency decreases total acreage. As a farmer switches from a sprinkler to a drip irrigation system, for example, the decrease instead of increase their acreage. The argument for this is that the limited number of observations may not accurately model the true behavior of the farmers along the Arkansas River Basin. With more farms in the model, there is a chance that the results could be contrary to the results found in this study.

However, total profits by irrigation technology efficiency better model the on farm profits. Figure 2 displays the total profits by irrigation technology efficiency. As you increase the irrigation technology efficiency, the total profits decline. A decrease in profits coincides with economic theory because higher costs are taken into account. Increasing irrigation technology efficiency occurs by purchasing more efficient irrigation technology equipment, which increases your costs and therefore decreases your costs. Figure 3 portrays the decrease in profits per acre as irrigation technology efficiency increases. In addition, Table 1 breaks down the decrease in profits per acre across each canal area along the Arkansas River Basin. Initially, the purchase of more technically efficient irrigation systems will decrease your total profits and profits per acre because of the large cost associated with the purchase. However, over time the farmer will reach economies of scale and the increased irrigation technology will increase profits. This cannot be shown within the scope of this study. Further research needs to be conducted in order to see how profits change across time periods with a change in irrigation technology.

The high salinization in the Arkansas River Basin poses a threat to farmers that use the Arkansas River as a water source. In order to improve water quality in the basin, runoff from crops needs to be reduced. A farmer's goal is to maximize profits, however, acreage and water constraints need to be taken into account when producing crops. Positive mathematical programming was used in order to model the acreage levels and cropping patterns for farms along the Arkansas River. However, the constraint of the modeling program caused a reduction in the number of farms to be modeled that did not result in a true representation of acreage level of farms along the Arkansas River. However, declining profits levels with increasing irrigation technology efficiencies coincide with economic theory. In order to see how profits change across time periods and to achieve a better representation of field acreage levels, further research in this area needs to be conducted.

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FIGURE 1: TOTAL ACREAGE BY IRRIGATION TECHNOLOGY EFFICIENCY

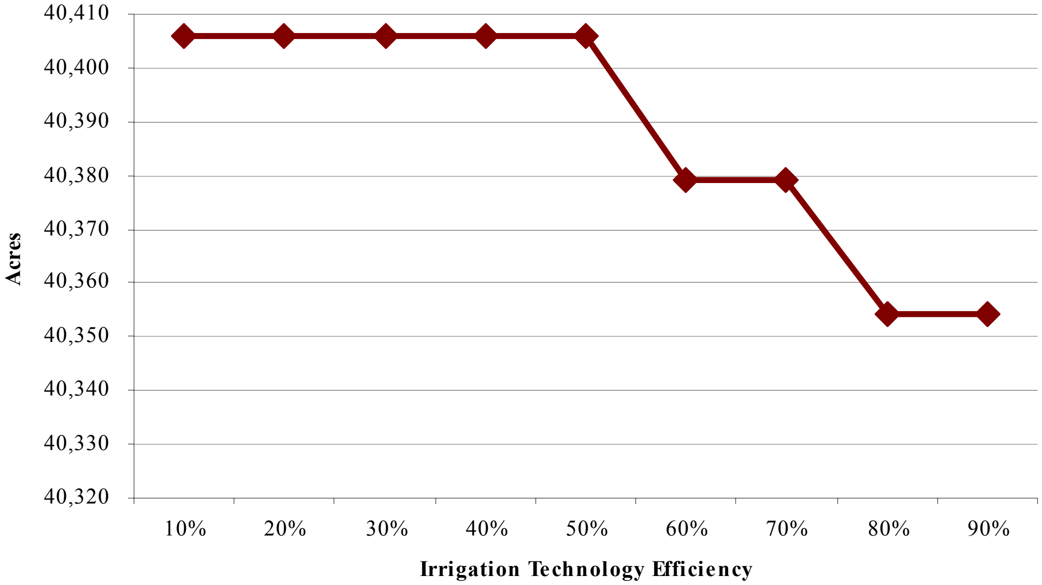

FIGURE 2: TOTAL PROFITS BY IRRIGATION TECHNOLOGY EFFICIENCY

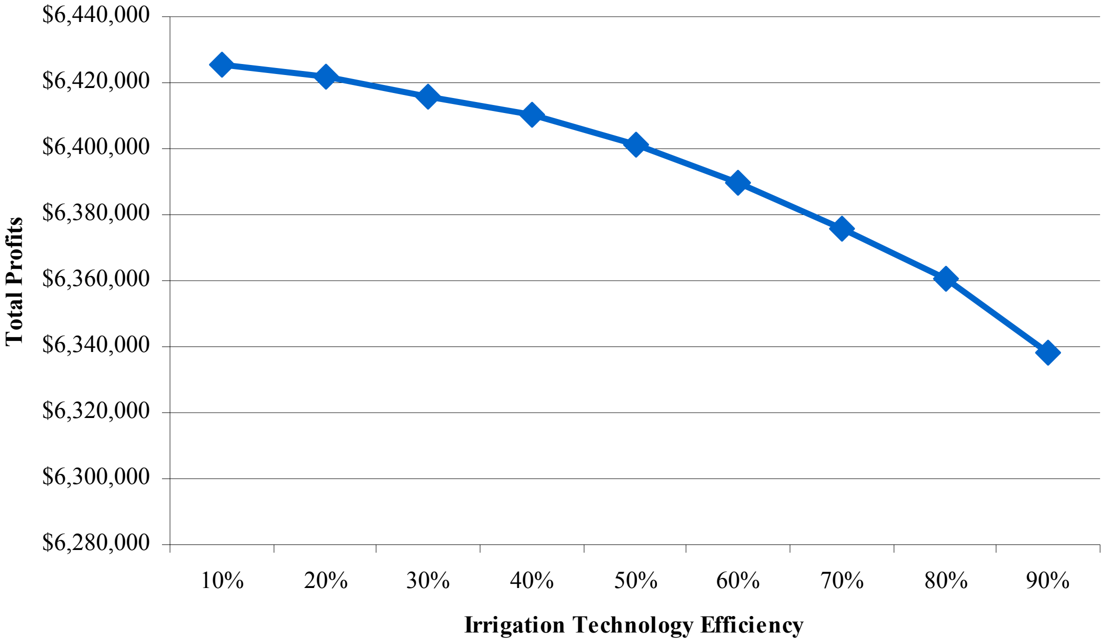

FIGURE 3: PROFITS PER ACRE BY IRRIGATION TECHNOLOGY EFFICIENCY

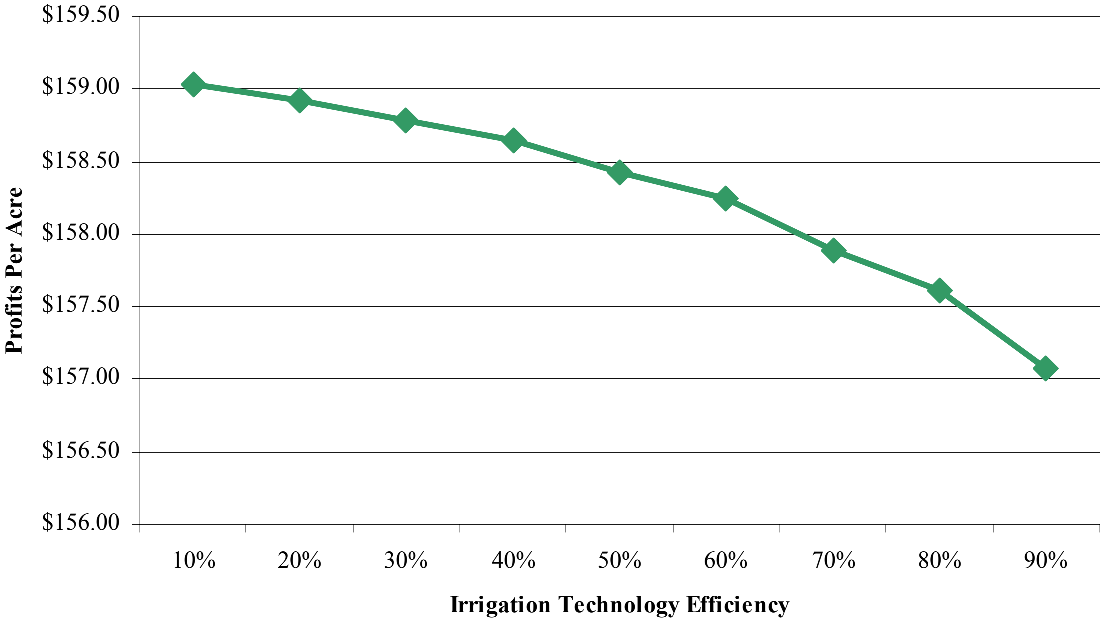

TABLE 1: PROFITS PER ACRE BY COMMAND AREA

Canal Area	90%	80%	70%	60%	50%	40%	30%	20%	10%
Holbrook	$136	$136	$136	$136	$135	$134	$134	$133	$132
Rocky Ford	$212	$212	$211	$211	$210	$209	$209	$208	$207
Catlin	$157	$157	$157	$156	$156	$156	$156	$156	$156
Otero	$68	$68	$68	$67	$67	$69	$69	$69	$67
RF Highline	$187	$187	$187	$187	$187	$187	$187	$187	$187
Fort Lyon	$143	$143	$143	$143	$143	$142	$142	$142	$142