

FACTORS INFLUENCING IRRIGATION TECHNOLOGY AND WATER
MANAGEMENT IN GEORGIA

by

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(Under the Direction of JEFFERY MULLEN)

ABSTRACT

Improved irrigation technology and water management could increase water conservation. This study focused on factors impacting farmers' adoption of newer water irrigation technologies and water management practices in Georgia. A mail-out questionnaire was administered to irrigation farmers on comparative costs of irrigation systems and farm irrigation water management practices. Farmers were knowledgeable on current comparative costs of different irrigation systems. Important factors to farmers in purchasing irrigation systems were: water delivery efficiency, labor requirements and maintenance expense. Multivariate linear regression was used to estimate the degree to which certain factors influence irrigation water use. Results show higher pumping costs are accompanied by reduced irrigation water use. Inclusion of irrigation water management variables in the estimation of irrigation water use, improved the performance of the model.

INDEX WORDS: Irrigation technology, Water management variables, Comparative costs, Pumping costs, Georgia

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DEDICATION

To my mum and dad for their love and the resources they have invested in my life and education.

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My foremost thanks is to Jesus, My Lord, Savior and Redeemer. For in my times of discouragement, challenges and joy you were with me. Through it all, I have learnt to trust in Jesus and I have learnt to depend upon your word.

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CHAPTER 1

INTRODUCTION

The humid subtropical climate of Georgia has average monthly temperatures of between 92.2⁰ F and 32.6⁰ F, and annual average rainfall highs of 75 inches and lows of 40 inches. This climate supports an agricultural industry, which accounts for about 16 percent of the state's \$350 billion annual economic output (Georgia Farm Bureau, 1998). In 2000, broilers, cattle and calves, with cash revenues of about \$2.2 billion, were the major non-crop agricultural commodities produced in Georgia (USDA, 2001). The principal crops produced in 2000 were cotton, peanuts and tobacco. These three crops accounted for about \$0.93 billion in cash receipts for the state (USDA, 2001).

The method of cultivation of these principal crops, in addition to the diverse vegetables, fruits and tree crops produced in Georgia, has undergone a gradual transition from rain-dependent agriculture to supplemental irrigation farming. The trend can be attributed to increasing crop yield, soil conditions in the state, variability of climatic conditions in the region, the reliability of water supply provided by irrigation and reduced variation and uncertainty per acre of irrigated farms as compared to non-irrigated farms. This shift to supplemental irrigation has resulted in an increase in the total acreage of lands under irrigation systems.

In the early seventies, total acreage of irrigation systems in Georgia was estimated to be less than 200,000 acres (Hook, 2001). By 2000, Hook (2001) estimated that 20,200 agricultural withdrawal permits had been issued and Georgia had 1.4 million

acres of irrigation systems. Of this amount, the lower Flint River Basin in southwestern Georgia had a third of the overall water withdrawal permits in 2000. The same basin also provided drinking water and discharged water into the Flint River and its tributaries. The Georgia Environmental Protection Division (EPD) assessing the current year rate of water withdrawal in the Flint River basin has projected that the Flint River would likely dry up if remedial measures were ignored.

The Flint River Basin situation was worsened by drought conditions prevailing in the state from 1998 to 2002. The drought resulted in reduced instream flows, low water table levels and decreased replenishment of aquifers. The cumulative impact of drought and water withdrawals for irrigation, municipal and industrial purposes has caused salt-water intrusion into some underground water sources in Southeastern Georgia (Hook, 2001).

In 1988, the Georgia EPD, in an attempt to sustain the supply of fresh water for fish, wildlife, plant species, municipalities and industries, adopted interim measures to help restrict and regulate water use in certain localities in the state. Measures adopted included: an agricultural permit freeze, limiting daily amount of withdrawals, fining illegal drilling and site visitation of wells drilled before issuance of permits (Hook, 2001).

Moreover, the state's law presently stipulates that agricultural permits are only required for withdrawals that exceed 100,000 gallons per day, and permits must be given in perpetuity. In 2000, underground water withdrawals accounted for 67 percent of irrigation water use in Georgia (Fanning, 2003). However, in southwest Georgia, there is linkage in flow of water between ground and surface water sources. This implies that

increased withdrawal of water from underground water sources also reduces the total volume of water available for surface flows.

A related issue is that currently unused irrigated permits are never reported to EPD, since agricultural permits do not expire. This undermines the ability of EPD to determine the actual amount of water used by irrigation farmers. In addition, irrigation permits issued by EPD do not require farmers to measure or report water use on their farms. This has led to the situation where any difference between the actual amounts of water used per day on irrigated farms, as compared to the amount issued by EPD, cannot be assessed.

Increased demand of fresh water from population growth, the environment, municipalities and industries has also resulted in increased stress on surface and underground water resources. The problem is compounded by the tri-state water conflicts between Georgia, Alabama and Florida over fresh water allocation from the Alabama, Coosa, and Tallapoosa river basin and the Apalachicola, Flint and Chattahoochee river basin. The above issues highlight the need for water conservation in the state, especially in the agricultural sector, to meet present and future water consumption. The ability of the state to decrease or maintain present levels of water withdrawals will depend largely on the ability to maintain or reduce agricultural water use.

For agriculture, a possible solution is through improved irrigation technology and water management that help with water conservation. It is known that water saving irrigation technology can enable farmers to maintain or reduce water use on their farms without any negative impact on crop yields and profit. Evans et al. (1998) determined

that the replacement of 4,400 old sprinkler packages in Georgia with new and more efficient sprinklers would result in conservation of 4,181 million gallons of water annually. Additionally, they showed that the repair and furnishing of correctly operating end gun shutoffs for about 2,000 center pivot systems in Georgia would conserve an additional 2,851 million gallons of water annually.

This research gives credence to improved irrigation technology's potential in aiding water conservation in Georgia. The question, however, is: what factors inhibit farmers in Georgia from adopting these technologies? Some reasons attributed to this adoption include: high sunk cost of modern irrigation technologies, cost of technical expertise to manage and maintain these systems, inadequate profits from crops to repay initial investments, and high interest rates on loans from banks (Hook, 2001).

Statement of the Problem

Research in the southeastern U.S., especially Georgia, has been primarily on yield, agricultural water quality management and optimal water application rates for various crops. Research focused on factors impacting the adoption of irrigation technology and water management in Georgia has been limited.

Thus, to ensure efficient water use and better public understanding of water-saving irrigation technology, this research assesses the factors considered by farmers' in the selection of irrigation systems. In addition, irrigation water use is influenced by frequency of irrigation applications and amount of water applied to crops. After the selection of an irrigation system, this study therefore seeks to ascertain the factors influencing farmers' decisions on the timing of irrigation application and amount of water

applied to crops. There have also been various policy initiatives in Georgia towards water management and conservation. These policy initiatives include: EPD moratorium on permits, and acreage reduction auctions held in 2001 and 2002 to reduce farmers' irrigation acreage. It is therefore important to discuss the policy initiatives that arise from this research. It is hoped that the research will provide the needed information to help conserve water and thereby, minimize water quality issues of irrigation, to the benefit of the state, local governments, municipalities, industries, and farmers.

Objectives

The purpose of this study is to assess irrigation farmers' perceptions of the relative advantages and disadvantages of various irrigation systems used in Georgia and factors taken into consideration by irrigation farmers in the management of their farms. The research also seeks to ascertain the specific water management practices used by irrigation farmers in Georgia and the reasons behind their adoption. Specifically, the objectives of the study are:

1. To elicit the views of farmers on the relative merits and demerits of various irrigation systems;
2. To ascertain the factors influencing farmers' decisions on timing and application rates of irrigation water;
3. To discuss the policy implications of the findings of the research to enable the state to put water to its best use.

Proposed Methodology

To achieve the first objective mentioned, a survey, with a sample drawn from the Agricultural Water Pumping Program, would be administered to irrigation farmers to ascertain their perceptions on: difficulty of use, installation expenses, maintenance expenses, labor requirements, energy use and application efficiency of various irrigation systems. Additionally, farmers' views on crop yield and quality of harvested crops for various irrigation systems, as well as preferred irrigation systems, will be acquired through the survey statistics.

For the second objective, the survey statistics and an econometric model are used for the analysis. Data for the econometric model analysis will be from: farmers' response on factors influencing irrigation water application, secondary data from the Agricultural Water Pumping Program and calculations by Alvarez-Gonzalez (2002) on pumping costs and Blaney-Criddle index of evapotranspiration (using information obtained from the Agricultural Water Pumping Program). Lastly, the main of the discussions on policy implications of the study will be obtained through the findings of the econometric model, which will be used to address the third objective of this study.

Organization of the Study

The thesis is composed of five chapters. Chapter 2 provides information on theoretical and empirical literature pertaining to irrigation technology and water management. Chapter 3 gives the survey methodology, general survey description and statistics. Chapter 4 entails the methodology, theoretical and empirical model, hypothesized signs of the predicted coefficient variables posited to affect irrigation water

use, and the results and its interpretation. The study ends in Chapter 5 with summary of the study, policy implications, limitations, conclusions, and suggestions for further research.

CHAPTER 2

LITERATURE REVIEW

This chapter is divided into two sections: empirical and theoretical literature. The theoretical aspect provides insight into some of the economic underpinnings of irrigation technology and water management strategies. The empirical section gives information on past research findings on irrigation technology and water management.

Theoretical Literature

Economic theory serves as the basis upon which empirical models are built. This section looks at the concept of efficiency and production as adapted to water management and irrigation systems.

Efficiency in Irrigation Water Management

There are different terminologies used in describing efficiency in irrigation water management. Amongst these are: application efficiency, storage efficiency and irrigation efficiency.

Application efficiency refers to the fraction of applied water used by crops. It is measured by assessing the water stored in the soil root zone as a fraction of water delivered to farms. Variations in application efficiency amongst different irrigation systems are due to: design, maintenance and management of irrigation systems, soil characteristics, water availability and climatic conditions. Application efficiency,

however, fails to consider uniformity and adequacy of irrigation water applied on farms (Wang et al., 1996).

Storage efficiency, on the other hand, looks at the effectiveness of crop yield by measuring the adequacy of wetting in the crop root zone. It is the fraction of water stored in the soil root zone to water needed in the crop root zone. Storage efficiency does not account for water losses beyond the root zone (Wang et al., 1996).

Irrigation efficiency is measured by assessing the fraction of net crop evapotranspiration to the volume of water diverted (Wichelns, 2002). Irrigation efficiency is maximized when deep percolation and surface runoffs on farms are minimized.

There is, however, a difference between the above efficiency concepts and economic efficiency. The main difference between them is that while economic efficiency is a criterion, the others are ratio measures. Economic efficiency considers economic indicators such as input prices, output prices and yield of crops, which help determine whether higher irrigation efficiencies necessarily translate into greater net economic output (Wichelns, 2002).

Additionally, economic efficiency indicates the parameters that maximize net benefits given resource availability. There is also a differentiation between economic efficiency at the farm level and the public sector. At the farm level, farmers optimize their inputs where the incremental benefits accrued equate incremental costs. Therefore, farmers would always choose crops that maximize their profits relative to their water resources and land availability.

The public sector optimizes water use by looking at the present value of net benefits over time, and also accounts for opportunity costs and externalities (Wichelns, 2002). Opportunity costs in the allocation of water resources indicate the alternative potential uses of irrigation water, which includes non-agricultural activity. Externalities entail the off-farm benefits or costs of irrigation and drainage on other farms or public and private lands.

However, the three criteria necessary for economic efficiency are technical, allocative and scale efficiency. A farm is said to be technically efficient when, given a certain set of inputs, maximum attainable output is obtained, or when selected level of output is obtained at minimum cost. In figure 2.1, all points on the crop-water production function are technically efficient. Point F on the production function is therefore technologically efficient, with K unattainable and P inefficient.

The production possibility frontier (PPF) could also be used to explain the concept of technical efficiency. The PPF shows the trade-off between various combinations of crops that can be produced on farms given farmers' variable inputs and technology. All points on the PPF are technologically efficient, with those above unattainable, and those below, inefficient. In figure 2.2, point F on the PPF is technically efficient. However, point P indicates under utilization of resources and point K is unattainable because of inadequate resources and technological means.

The curvature of the PPF also shows the concept of opportunity cost and decreasing incremental returns from crop output. This implies that, if a decision is made to increase the output of one commodity, it will result in incremental amounts of

reallocation of variable inputs from the production of another commodity and a decrease in output for that commodity (Wichelns et al., 2002).

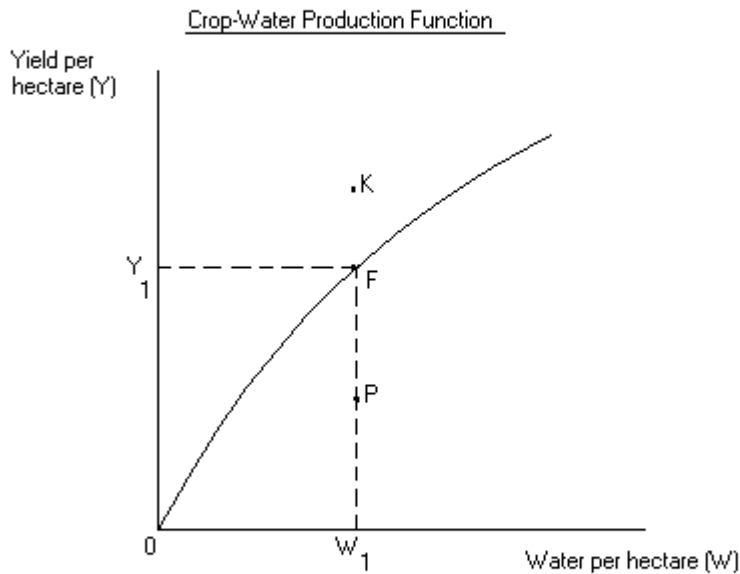


Figure 2.1 (Wichelns,2002)

Allocative efficiency indicates the least cost combination of resources to attain a particular output. Given a certain set of resources, farmers will equate the ratios of the output prices to the rate at which the output of one product must be reduced in order to increase the output of another product. In figure 2.2, allocative efficiency is established where the budget line is tangential to the PPF at point F. At point F, the farmer is both allocative and technologically efficient. Given that the farmer produces peanuts and

maize, OP_1 of peanuts and OM_1 of maize is produced at this least cost combination point.

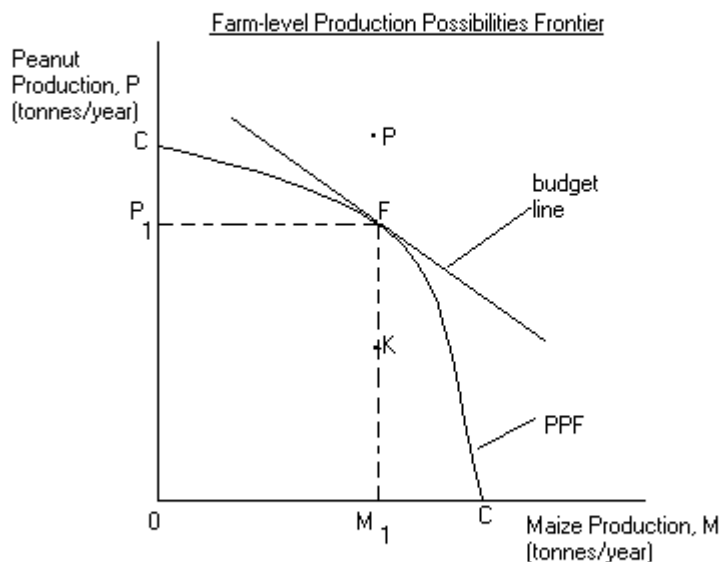


Figure 2.2 (Wichelns, 2002)

Scale efficiency is attained when the output price equates the marginal cost of production. It implies that farmers' willingness to pay for an additional unit of output must equate farmers' cost of producing this additional unit of output. Hence, if output price of maize were greater than marginal cost of production, farmers will reallocate more resources to the production of maize and decrease production of peanuts if it has a higher output price in comparison to its production cost.

Economic efficiency would thus be attained in figure 2.2 if at point F, technical, allocative and scale efficiency are the same. However, in the long-run, problems like salinization of farmlands as a result of poor drainage can lead to the shifting of the PPF inwards. This is illustrated in figure 2.3, where the PPF shifts inwards from CC to C_1C_1 , which results in reduction of peanuts produced from OP_1 to OP_2 , with output of maize remaining the same at OM_1 . It should also be noted that technological innovations and increased resources would result in the shift of the PPF outwards, increasing output of commodities produced.

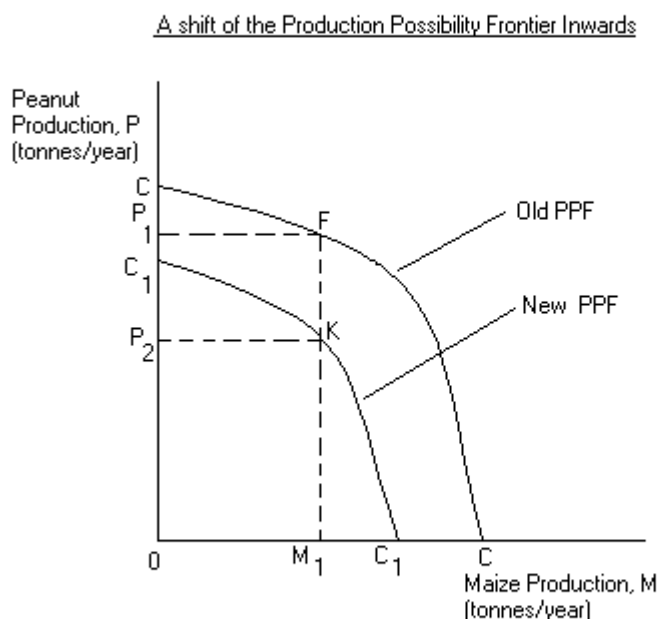
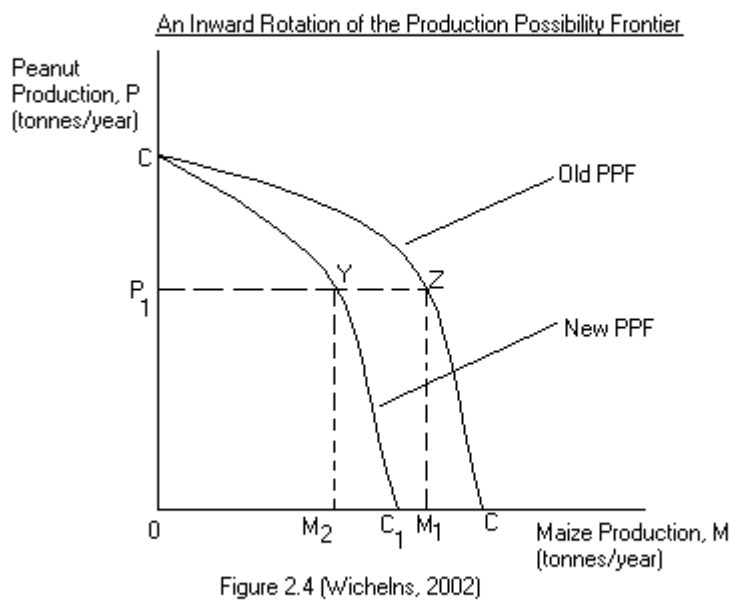


Figure 2.3 (Wichelns, 2002)

Upstream farming could create an externality to downstream farmers, if it reduces the maximum attainable crop returns downstream due to saline waters for

example. This is illustrated in figure 2.4, where, due to the negative externality, the PPF rotates inwards. The inward rotation indicates that at any given level of peanut production, lesser amounts of maize can now be produced.

In figure 2.4, it is now seen that at the same level of peanut production OP_1 , the output of maize now decreases from OM_1 to OM_2 . On the other hand, positive externalities would result in the rotation of the PPF outwards, increasing output of crops produced.



In conclusion, economic efficiency helps determine inefficiencies in the allocation of private and public resources in farming. Therefore, private and public agencies in

their planning and decision-making processes must ensure optimal allocation of water resources for irrigation agriculture.

Irrigation Technology and Water Management

The analysis for irrigation technology and water management was adapted from Caswell and Zilberman (1986). In the analysis, effective water refers to the actual percentage of irrigation water consumed by crops. To enhance the development of the production function used in the analysis, irrigation choices were blended with the natural characteristics of the irrigation system.

Given constant returns to scale, y and e in the production function represents, respectively, the yield per acre and effective water per acre. The production function $y = f(e)$ relates the concavity between y and e . Assuming two types of pressurized irrigation systems, center-pivot (old) and low energy precision application - LEPA (improved), land quality denoted by q , is assumed to differ within the range $0 < q \leq 1$. With j denoting the type of irrigation system, a_j , applied water per acre using technology j , $h_j(q)$, irrigation efficiency of technology j on land quality q , 1, old irrigation system and 2, improved irrigation system, the effective water used by the crop is given as:

$$e = h_j(q)a_j \tag{2.1}$$

Assuming LEPA had a higher efficiency as compared to the center pivot, then, $h_2(q) \geq h_1(q)$. Additionally, the proportionate benefits obtained in irrigation effectiveness as a result of the adoption of LEPA to the old irrigation system $[h_2(q) \geq h_1(q) / h_1(q)]$ are smaller at higher land qualities. Given c_j as annualized technology's fixed cost per acre,

it is projected that $c_2 > c_1$. With p denoting the output price, $R(q)$, the rental rate of land quality, M the pumping cost of applied water, the maximum profits under technology j , Π_j , can be obtained by solving the following equation:

$$\Pi_j = \text{Max}[Pf[ajh_j(q)] - Maj - c_j - R(q)] \quad \text{where } j = 1,2 \quad (2.2)$$

Profit maximization for the two irrigation systems is determined by comparing the profits after optimal water use. LEPA would be used if $\Pi_2 \geq \Pi_1$ and $\Pi_2 \geq 0$. Center pivot would be used if $\Pi_1 > \Pi_2$ and $\Pi_1 \geq 0$. Optimal water application with technology j is established when the marginal productivity of applied water equates the price of applied water (in this case, water pumping cost), which is

$$Pf'h_j(q) = M \quad (2.3)$$

Equation 2.3 shows that value of the marginal product of applied water is a product of output price, marginal product of effective water, and irrigation efficiency. $M / h_j(q)$ is the price of effective water and equation 2.3 could be modified as:

$$Pf' = M / h_j(q) \quad (2.4)$$

Equation 2.4 indicates that the old and improved technologies have the same production functions and maximization of profits occurs when the marginal product of effective water equates its price. Assuming LEPA possesses the lower effective water price, it will possess the better efficiency as compared to the old technology. LEPA will, therefore, have a higher yield ($y_2 > y_1$). LEPA will also possess the better irrigation efficiency, since it utilizes water more efficiently ($e_2 > e_1$). The analysis is further consolidated with figure 2.5. The effective irrigation marginal product in figure 2.5 is given by PK, which indicates a positive and declining marginal product, the economic phase of production.

Optimal Effective Water Choices for Old and Improved Irrigation Technologies

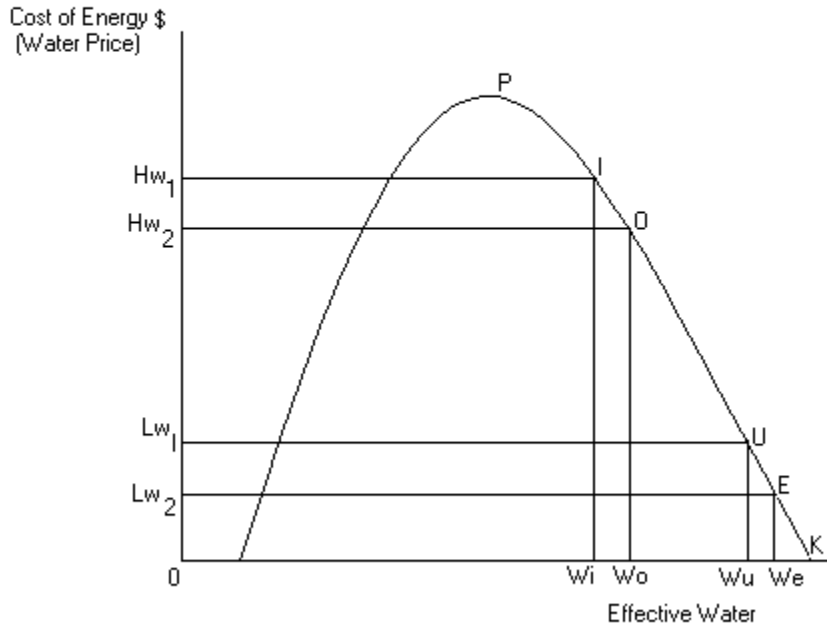


Figure 2.5 (Casewell and Zilberman, 1986)

Given a hypothetical situation that the efficiency of LEPA is double that of center pivot sprinkler, we can have two prices for applied water for both technologies, a high one, H_w , and a low one, L_w . Profit-maximizing outputs for the high and low prices of applied water for center pivot are respectively given by I and U. For LEPA, O and E respectively represent the high and low prices of applied water.

In figure 2.5, point K represents the maximum yield. When the price of water is low, $0W_e - 0W_u$ gives the small difference between the two technologies systems. This indicates that a change of technology from center pivot to LEPA when the price of water is low would have little impact on yield, but would have substantial impact on water savings when one considers the water applied. On the other hand, a change from

center pivot to LEPA due to increases in price of applied water results in substantial increases in both yield and effective water use ($OW_o - OW_i$). Additionally, a reduction in the fixed cost of LEPA and increases in energy cost and output price would increase the adoption of improved irrigation technology resulting in increases in yield and water savings.

Summary

The basis for economic analysis of water management and irrigation technology was outlined in this section. Economic efficiency criterion was used to discuss the necessity for water management for irrigation farming.

The analysis focused on how technical, allocative and scale efficiency helps determine the output produced by farmers given various crop alternatives and technology. The PPF was used to explain the concepts of opportunity cost and externalities in the optimal allocation of public and private resources.

The economic analysis also looked at how irrigation technology impacts on water applied on farms, water savings, and crop yields. The analysis combined irrigation choice decisions with the natural features of irrigation systems.

Empirical Literature

The empirical section gives information on past research findings on irrigation and water management. The section is comprised of three parts. It presents research findings entailing factors affecting adoption of irrigation technology and its returns, study

results of irrigation water management and research related to environmental impacts of irrigation.

Adoption of Irrigation Technology and Its Returns

Irrigation technology systems are generally adopted to enhance distribution and supply of irrigation water on farmlands. That is, irrigation systems are chosen to maintain or increase crop yields, or reduce uncertainty of yields, or both.

Caswell and Zilberman (1985) reviewed the behavior patterns of fruit growers in the Central Valley of California in the adoption of furrow, sprinkler and drip irrigation technologies. The study determined farmers' adoption behaviors by applying a multinomial logit model to the land shares of each of the irrigation systems. Their investigations revealed that local differences in regions played a more significant role in the adoption of drip irrigation as compared to sprinkler. Caswell and Zilberman also affirmed that water-price policies could increase the adoption of improved irrigation technologies, which would subsequently impact positively on water savings.

Nieswiadomy (1988) used a dual cost function to estimate Allen's partial elasticity of substitution for water, labor, and center pivot, furrow and wheel row irrigation systems. These agricultural inputs were used to produce cotton and grain sorghum in the Texas High Plains between the years of 1970 and 1980. Nieswiadomy found lower energy requirements for furrow systems as compared to wheel rows and center pivot irrigation systems. He also observed that farmers reduced their water applications as pumping costs increased during the study period. This research, however, did not

evaluate the effects of price and tax changes, the impacts of fertilizers, chemicals and other capital inputs on the ratios of marginal products of inputs used in the study.

Lichtenberg (1989) analyzed the intricacies of relationships between land quality, crop choice and technological innovation between the years of 1966 and 1980 in western Nebraska. He estimated the county cropland allocations for the seven major crops grown in the area using a multinomial logit regression model. Results showed that cropping patterns in the region were positively influenced by the introduction of center pivots and land quality augmenting technologies. The research also indicated that land quality influenced the types of crops cultivated in the region and played an important role in crops acreage allocation.

Caswell et al. (1990) identified that output prices influenced technology choice through determination of limits where water prices and drainage charges would be profitable. The authors found that without a sufficiently high output price, drip and sprinkler technology, with high savings in water cost and drainage fees, would not be adopted, since they had a very high sunk cost.

Farm data of citrus growers in Israel were used by Dinar and Yaron (1990) to ascertain the effects of input price and quality, scarcity of inputs, environmental conditions, human capital and water price on the adoption of improved irrigation technologies. Dinar and Yaron realized human capital, management and economies of scale of production influenced the speed and level of adoption of improved irrigation technologies in Israel. The researchers also realized that adoption of irrigation technology for the growth of citrus were significant in areas with high evaporation rates, low quality land, high water prices and low amounts of irrigation water allocation. Policy

analysis indicated that water prices and quota rates could be used to facilitate the adoption of modern irrigation technology in Israel.

National cross-sectional farm-level data on land quality and cross-sectional variations on water and labor cost, climate, topography and soil features was used to estimate the determinants of irrigation technology choice by Negri and Brooks (1990) using a discrete choice model. The analysis focused on only two water-saving technologies, sprinkler and gravity irrigation systems. It also considered groundwater applications of irrigation water and combinations with surface water applications. Findings from the research indicated that soil slope, texture and quality were more significant in the selection probabilities for irrigation technology, as compared to climatic factors. Negri and Brooks also noticed that higher pumping costs of groundwater, increased adoption of water-saving technologies. Additionally, pumping costs played a minimal role in the adoption of sprinklers, but was moderately significant for tailwater recovery pits (a gravity system). They also observed that farms with access to surface waters and large irrigated acreage were more inclined to adopt gravity systems. Gravity systems also tended to be more labor intensive than sprinkler irrigation systems. Policy analysis showed that water-pricing policies that do not consider other factors impacting on irrigation technology choice would be ineffective in analyzing the adoption of sprinkler irrigation systems. Negri and Brooks realized the need for further research that incorporates cropping patterns, adoption of advanced irrigation technologies and efficient water management practices.

Wilchens et al. (1997) investigated the factors influencing the use of sprinklers for initial irrigation events and the later use of surface irrigation methods for cotton and

tomatoes on the west side of California's San Joaquin Valley. Data collected indicated that the above sequence of irrigation farming served to increase the yields of farmers. They also observed that since water supply in the region was limited as compared to available land area, water saved through pre-irrigation with sprinklers, were used to irrigate other farms.

Amossen et al. (2001) examined the economics of irrigation systems used in Texas. Amongst other issues, the study focused on each system's potential benefits for improving water application efficiency and reducing field operations, the effects of economies of size on center pivots, and the potential use of chemigation for an irrigation system. Results from their analysis showed center pivot offered more benefits in application efficiency and reduction in field operations as compared to furrow irrigation. This to them compensates for center pivot's additional operational costs. Moreover, the researchers showed that advanced irrigation technologies provided opportunities in lowering pumping costs, increasing savings from chemigation and reducing field operations. They therefore realized that improved irrigation systems would be better suited for crops with higher water needs (particularly in areas with deep pumping lifts).

Carey and Zilberman (2002) adapted the option value theory to develop a stochastic dynamic model. The model was used to assess how water markets influenced farmland decisions on the adoption of improved water-saving irrigation technologies. The analysis was also done while considering the uncertainties of future water supplies and prices, and the quasi-irreversibility of irrigation technology investments. Policy analysis indicated that the net present value (NPV) investment rule was biased towards early investment in improved irrigation technology. The bias results

from the inability of the NPV investment rule to account for uncertainty and irreversibility in the decision-making process of farms. The analysis also showed that farms with relatively abundant water supplies were likely to be early adopters of improved irrigation technology when water markets are introduced, whereas those with scarce water supplies would be late adopters. Policy analysis indicated that, because of uncertainty, irreversibility and the option to wait, farmers were likely to ensure that expected benefits of investments outweighed costs by a potentially large hurdle rate before they would invest in modern irrigation technology.

The above empirical literature on factors affecting irrigation technology and its' returns indicated farmers generally adopted irrigation technologies to maximize profits, and minimize their cost. Additionally, major factors influencing farmers' decisions in the adoption of modern irrigation technology include: tax policies, water prices, water quota rates, land characteristics, and pumping costs.

Water Management

Water management strategies in the agricultural perspective can be viewed as the technological methods and innovative inventions, which enhance crop production and optimal water use and allocation that lead to water conservation. Smittle et al. (1990) studied the yield and water use responses of sweet potatoes to diverse irrigation regimes. The authors discovered that marketable yields and water use increased when sweet potatoes were cultivated on Tifton loamy soils as compared to Bonifay sand. They also showed that irrigation applications produced the highest yields of U.S. #1 sweet potato, when soil depth water tensions and pressure were respectively 25

centimeters (cm) and 25 kilopascals (kPa). In addition, during storage root development, soil water pressure of 100kPa did not affect the yield of sweet potatoes.

The excessive soil water of the Pelham loamy sandy soils in the Flatwoods of South Georgia reduced crop root growth and crop production. Shirmohammadi et al. (1991) therefore developed guidelines and technical information, which enabled the use of controlled drainage sub-irrigation systems for crop production in the region. Analyses of blueberry production in the Flatwoods showed that the application of drainage, without supplemental irrigation, would result in crop stress. Crop stress occurred because of inadequate soil water for crop growth after drainage. The authors also concluded that drain-tiles spacing of 15-20 meters and depths of 91-99 centimeters and appropriate management of weir elevations would be vital for the total performance of the installed drainage sub-irrigation system.

Increasing amounts of irrigation water and fertilizer were applied to sweet potato by Thompson et al. (1992) to determine the maximum irrigation depth yield for sweet potato. Their research indicated that yield and quality of sweet potatoes were affected by irrigation water levels. Specifically, yields of sweet potatoes increased with higher amounts of irrigation water until total water application of 76 percent of pan evaporation was attained. Thereafter, yields decreased at an increasing rate with applied irrigation water on both loamy sand and silt loam soils. Moreover, they concluded that over-application of water was more likely in silt loam than in loamy soils.

Scheierling and Cardon (1997) demonstrated the importance of economically optimal allocation of irrigated water with a model proposed by van Genuchten–Hanks. The model applied timing effects to determine the relationship between irrigation water

application and crop yield. The research found that, given a certain number of irrigations, crop yields varied depending on the timing of irrigation events. Moreover, any additional irrigation event with optimal timing affected crop yields. For it was realized that crop yield increased at diminishing rates, as the number of irrigation events increased. Policy analysis indicated the number of irrigations and the amount of water applied could be reduced over a certain range without negative impacts on evapotranspiration and crop yield.

Omezzine and Zaibet (1998) discussed the importance of irrigation efficiency and water allocation efficiency as relevant indices of water use performance with field data from Oman. The explanatory variables of irrigated crops used in the estimation of the production function were: irrigation schedule, water quantity and soil characteristics. They affirmed that both irrigation water and soil quality had positive significant effects on crop yield. However, a negative relationship existed between irrigation frequency and crop yield. The latter result to them seems to indicate that frequent irrigation of crops does not necessarily translate to increases in crop yield. Irrigation efficiency results showed farmers were operating below planned water requirement and had lower-than-maximum technical output levels. Measurement of allocation efficiency pointed out that farmers were not operating efficiently due to excess or under use of water.

Juan et al. (1999) maximized the gross returns from farming production in the sub-humid Alava province of Spain. In their analysis, they considered the water availability for crops presently not in production. The authors realized that half of the farming area in the irrigation district could be used for dry land farming and the rest for irrigation due to the low crop water requirement in this semi-arid region. This to them will

enable farmers to economically optimize crop alternatives in relation to water availability.

Yazar et al. (1999) used hand-held infrared thermometers to evaluate the crop water stress index for alternate low energy precision application (LEPA) irrigated corn. They also assessed the water use efficiency of corn using the corn water stress index (CWSI). CWSI was shown to respond positively to irrigation differences, even in years with above normal rainfall in a semi-arid region. However, the CWSI could not easily differentiate between small irrigation differences. The authors also observed that LEPA irrigated corn water use efficiency declined as CWSI increased, but for small to modest CWSI values, irrigation water use efficiency remained largely unaffected by water deficits.

Panigrahi et al. (2001) investigated potato tuber yield water use efficiency for irrigation scheduling and plant furrow treatments under deficit water supply conditions. They discovered that water use efficiency at different irrigation levels had little impact on potato tuber yield. However, plant furrow treatment had a positive impact on yield. Additionally, the best yield obtained under furrow treatment was as a result of maximum foliage coverage from higher amounts of crop evapotranspiration.

Reca et al. (2001) demonstrated the suitability of non-linear optimization techniques for water allocation planning in drought conditions in southern Spain. Research analysis showed that consideration of only the internal demands of the irrigation districts caused lower irrigation efficiency and high volumes of water allocations, which had low economic benefits per unit of water used. Inversely, consideration of a hypothetical proposed water market, in which water can be

transferred to alternative uses at a fixed price, resulted in a lower consumption of water in the irrigation districts.

Pereira et al. (2002) examined irrigation management under water scarcity conditions. They realized that uniform application of irrigation water was especially important in areas where water quality was low, because it enhances efficiency of water application with less negative effects on the environment. Furthermore, the authors realized it was more profitable to optimize return per unit of water than land in water scarce areas. They also showed that maximization of return per unit of water was influenced by level of fertilizer applications on farms, sowing dates, and amount of rainfall.

Research on water management has shown that uniformity of water distribution, quantity of water applied, number of irrigations, irrigation frequency and water availability impact crop yields. Additionally, optimal water use and application would vary depending on the irrigation system, crop type and soil characteristics. Lastly, farmers would maximize profits considering water and land availability.

Environmental Impacts of Irrigation Systems

The use of irrigation systems could have negative and positive impacts on the environment. For example, runoffs and deep percolation from farms containing saline waters, pesticides, chemicals and fungicides create problems to underground and surface water sources. Positive impacts obtained from irrigation systems include land conservation and flood prevention.

A dynamic programming model was adopted by Dinar and Knapp (1986) to estimate the optimal water application rates of cotton and alfalfa under saline conditions. The data used for the response functions were obtained from two field experiments in southern Arizona and Lost Hills, California. The analysis showed yield for cotton and alfalfa increasing with increases in water quantity and quality, and decreasing with increases in initial soil salinity. Soil salinity at the end of the growing season as a function of initial soil salinity increased with decreasing water quantity, and decreased with decreasing initial soil salinity and water concentrations.

Knapp et al. (1990) explored the means of disposing drainage effluent from deep percolation in irrigated areas with high water tables. They confirmed that a combination of modern irrigation systems and reduced water applications could postpone drainage cost and water build-up in farmlands. Additionally, they observed that improved irrigation systems and reduced water applications could be alternated with periods of water application with traditional irrigation systems. They realized this would help reduce the need for installation of drainage systems used to lower water table levels.

Posnikoff and Knapp (1994) researched the lessening of source control costs and optimal policies for reducing excessive deep percolation in the San Joaquin Valley of California. They affirmed that deep percolation was reduced, but at an increased cost to farmers, through the introduction of relatively more efficient technology. This enhanced uniform distribution of water over the field by reducing applied depth for a given irrigation system. Furthermore, they observed that the response in crop acreage to increases in deep percolation emission costs was in direct contrast to economic views that farmers will move to different crops in response to water policy reforms like

higher prices or reduced allocations. This deviation was attributed to: annual variation of profitability of most crops, insignificant variations in deep percolation flows, marketing contracts, crop acreage limitations caused by land quality, and risk and marketing considerations.

Wu et al. (1994) used a dynamic model to analyze the effects of farmers' irrigation investment and crop choice decisions on different soils and their effects on water quality. Results showed cultivation of grain sorghum with improved furrow was the most profitable method on both Richfield clay loam and Dalhart fine sandy loam soils. However, it was projected that per acre income and irrigated land will decrease, due to increasing production costs and relatively stable output prices. Additionally, they observed that nitrogen use tax neither reduced water use nor enhanced the adoption of modern irrigation technologies. In the implementation of water use limits, the authors cautioned against excessive restrictions on irrigation water use, as it might actually discourage adoption of modern technologies.

Annandale et al. (1999) employed a simple dynamic soil water-salt balance-generic crop growth model to determine the long-term effects of gypsiferous mine water on soil and water resources in South Africa. They discovered that use of annual high frequency irrigation with a leaching fraction in water was effective and economical in lessening the effects of gypsiferous mine water. In addition, the use of large volumes of gypsiferous water did not cause irreparable damage to soil resources.

Kim et al. (1999) analyzed the private and socio-economic benefits of government subsidized irrigation technology investments and their effects on groundwater contamination. From the social perspective, they realized it would be

economically efficient and environmentally beneficial for the government to share the cost of adoption of center-pivot irrigation systems. Moreover, human health and ecological benefits could justify a government share of more than \$22.55 per hectare per year.

Sun et al. (2000) using adoption assessment, biophysical simulation and mathematical programming, assessed the possibilities for voluntary adoption of specific best management practices alternatives to reduce nitrogen water pollution at the Gum Creek Watershed, in the Coastal Plain of Georgia. Results from the study indicated that supplemental irrigation management could enhance farmers' expected net revenues with little impact on the soil and nitrogen runoff in the Gum Creek Watershed. They also observed that farmers' reduction of soil and nitrogen runoff on their farms would reduce significantly their net revenues if the government lowers its payments in the cost-sharing pilot program. In the above scenario, they realized that most farmers would opt out of the program. The program would thus be ineffective without statutory ramifications. In summary, they stated that despite the fact that the findings of the research was site-specific due to market price, soil type, costs and farmers' attitudes, the analytical framework was adaptable in other agricultural areas.

Valiant (2000) looked at the possibilities of improving crop yield returns and water quality levels in the Arkansas River Valley of Colorado. He concluded that irrigation of crops on saline soils with ground water was risky, regardless of the irrigation method. However, Valiant suggested that the cultivation of salt tolerant forage crops like alfalfa, barley, sorghum and wheat, with higher quality river water, would improve yields.

Chen et al. (2002) studied the capabilities of micro-sprinkler irrigation (MI) and surface flood irrigation (FI) systems to reduce preferential flow and Bromide tracer leaching in shrink/swell soils used in the cultivation of pear orchard. Using equal amounts of applied irrigation, the authors discovered FI had greater water amounts reaching the passive capillary samplers installed at 1.2m soil-depths. FI also increased the loss of Bromide tracer in the soil as compared to MI. Despite the merits of FI in leaching soluble salts from shrink soils, they recommended the adoption of MI where groundwater was sensitive to contaminant loading and preferential flow channels extended beyond root depth.

Research on environmental impacts of irrigation systems seems to indicate that implementation of appropriate tax or subsidy policies helps in the adoption of improved irrigation technology, which serves to reduce the adverse effects of irrigation on the environment. However, adoption of improved irrigation technology will always be at higher fixed cost to farmers. Therefore, the local, state and federal governments could establish policies to augment the increases in cost entailed in the adoption of improved irrigation technology.

Summary

The review of selected empirical literature examined past studies on the factors affecting the adoption of irrigation technology and its returns, irrigation water management strategies and the environmental impacts of irrigation. Generally, farmers minimized the cost of producing their crops and/or optimized yields and/or profits. Moreover, crop type, irrigation systems and soil characteristics influenced the optimal

water application rates on farms. The research findings also showed that adoption of water saving irrigation technology increased the sunk cost of farmers.

Furthermore, the review of empirical literature has shown that there is a concentration of research on irrigation technology adoption and water management west of the Mississippi river. Research in the southeastern U.S., especially Georgia, has been primarily on yield, agricultural water quality management and optimal water application rates for various crops. Additionally, research focused on factors impacting the adoption of irrigation technology and water management in Georgia remains scant at best. The remainders of this research would describe and give the general statistics for the survey, look at the econometric model, research results and policy implications.

CHAPTER 3

SURVEY AND DESCRIPTIVE STATISTICS

The chapter comprises the survey methodology, survey description and provides statistics of responses from respondents. The methodology shows how the survey sample was obtained. The survey description gives you the general trend and details of the survey, and additionally, provides the statistics obtained from respondents.

Survey Methodology

The survey sample was adapted from the Agricultural Water Pumping Program instituted in 1998 to determine the actual agricultural water use of farmers in Georgia. Using the Agricultural Water Pumping Program sample data was advantageous as it provided the means of comparing farmers' questionnaire responses with their historical water use data.

The sample data for the Agricultural Water Pumping Program survey incorporated 2 percent of the agricultural water withdrawal permits in the state. The statistical representation for the project consisted of surface and underground water withdrawals, as well as crop type. The smallest sample unit used, counties, was supposed to have a minimal irrigation permit number of 50. However, to enhance representation of all counties in the state, counties with less than 50 permits were lumped into one group and 2 percent was chosen for monitoring. Despite these provisions, regional representation of agricultural permits especially in North-Georgia

was still small. This was compensated for through additional site selection in the region, which ensured at least one site was monitored (Evans et al., 1998).

Sites selection for potential monitoring was obtained through random statistical sampling selection. At least 6 percent of the total agricultural withdrawal permits was selected for potential monitoring. Selection of this initial sample size was necessary as participation in the program was voluntary. In the final statistical selection, a voluntary participation rate of 67 percent of sampled agricultural permit holders were obtained. However, some sites earmarked for the program were not used because of the complex nature of some irrigation water delivery systems and the inability of monitors to measure accurately the actual water used on some sites. In other instances, the surveyors realized that the irrigation withdrawal permit were no longer in use.

Currently, 407 agricultural irrigation permits are being monitored. Forty five percent of these monitored areas derive their water from underground water sources, which is proportional to the ground water withdrawal percentage in the permit database. Overall, 38,330 acres were monitored for the program. However, in reality, actual monitoring is done on 580 individual field sites and 44 other sites where water is pumped from a well or from other sources into a pond.

General Survey Description

The main sections of the survey are: irrigation systems used by farmers, comparative costs of irrigation systems, yield and quality related differences, irrigation system preferences, water management timing and quantity issues, variable rate irrigation, crop yield and demography. Additionally, responses for comparative costs of

irrigation systems were compared with present empirical literature to assess whether they are consistent.

Likert scale, relative rankings, open-ended, contingency and dichotomous questions were used to construct the survey. Likert scale questions asked respondents to express their perceptions or feelings about a statement using a discrete scale. The number at one end of the scale could denote least important and at the other, most important. Relative ranking questions used in the survey employed an ordered scale in obtaining farmers opinions. Open-ended questions in the survey left blank spaces for respondents to provide their answers. Dichotomous questions provided respondents with two possible sets of responses (yes or no). Finally, contingency questions were asked to determine if a respondent had an opinion about an issue, before asking a subsequent one.

Approximately 400 questionnaires were mailed and 40 usable ones were received. A follow up mail-out of 137 of the questionnaires had 17 usable responses. Five questionnaires were returned unfilled due to renting of farms and the death of an irrigation farmer. Overall, 57 usable questionnaires were used for the analysis. A sample of the questionnaire is attached as Appendix A.

Irrigation Systems Used by Farmers

Standard center pivot is a self-propelled lateral system supported from wheeled towers spaced from 100 to 170 feet apart. The towers are self-propelled so that the sprinkler rotates around a pivot point located at the center of the irrigated area. Traveling gun is a high volume, high-pressure system. Water application rate of the

traveling gun is determined by the travel speed of the system. It may be operated in a stationary position for a desired time and then moved to a new location. Low energy precision application (LEPA) is a center pivot system, which uses drop tubes and very low-pressure nozzles (each with a pressure regulator) positioned on or close to the field surface, to distribute water into blocked furrows.

Drip/micro irrigation refers to irrigation methods where water is delivered directly to small areas adjacent to individual plants through emitters placed along a water delivery line. Generally, drip irrigation refers to systems, which use low flow rate emitters from which water drips onto the soil. Micro-sprinklers on the other hand, have rotating parts with emitters that throw water horizontally and vertically (Definitions of irrigation systems obtained directly from Burt et al., 1999).

Respondents were asked to state the crop(s) they cultivated during the 2002 growing season. Additionally, growers indicated if they have had any experience with standard center pivot, LEPA, traveling gun, micro-sprinkler and drip tape (or other systems). Farmers also identified the irrigation systems (standard center pivot, LEPA, traveling gun, micro-sprinkler and drip tape) they thought were appropriate for their crop(s) and which system(s) they actually used in irrigating crop(s) during the 2002 growing season. Lastly, farmers explained why other system(s) identified by them as appropriate for their crop(s) were presently not being used.

Crops grown by respondents were diverse. Major crops grown were peanuts, cotton, corn, pecan and tobacco. Other crops grown by respondents were berries, fruits, vegetables, sweet corn, sod, grass, hay, silage, oat, wheat, ornamentals, millet and watermelon. Pertaining to experience with irrigation systems, table 3.1 indicates that

most respondents have had much more experience with standard center pivot, traveling gun and drip tape as compared to LEPA and micro-sprinkler. Additionally, most farmers thought standard center pivot, traveling gun, LEPA and drip tape were appropriate for their crops in comparison to micro-sprinkler. For the 2002 growing season, most farmers used standard center pivot, traveling gun and drip tape to irrigate crops. The specific crops grown with irrigation systems were excluded from the statistics given, since most respondents had multiple irrigation systems (used) in growing more than two crops.

Comparative Costs

The On-farm irrigation committee of the Environmental and Water Resources Institute assembled a team of water specialists and irrigation engineers (Burt et al., 1999) who prepared a manual on the relative merits and demerits of different irrigation methods. Their report, which corresponds to some aspects of this study, is used to assess farmers' responses on comparative costs of various irrigation systems. In this study, the comparative costs of irrigation systems are visualized through their difficulty of use, installation expenses, maintenance expenses, labor requirements, energy use and application efficiency.

Difficulty of Use

Burt et al. (1999) used two categories to assess the difficulty of use of irrigation systems. The first, day-to-day maintenance of equipments was grouped into simple, medium, master, complex and very complex categories.

Table 3.1: Farmers' Response on Irrigation Systems They Have Had Experience With, Thought Were Appropriate for Crops and Actually Used for the 2002 Growing Season¹

Irrigation system	Experience With	System(s) Appropriate For	Actual System Used
	System	Crop(s) Grown	During 2002 growing Season
	Number	Number	Number
Standard Center Pivot	46	49	48
LEPA Center Pivot	4	21	4
Traveling Gun	27	37	39
Micro-Sprinkler	3	7	6
Drip Tape	14	19	20

¹Figures do not correspond with actual number of questionnaires received due to unanswered and multiple responses received from respondents

The other, relative management time and labor needed to operate, maintain and manage these irrigation systems, had a Likert scale, with 1 indicating minimal effort and 10, maximum effort. Burt et al. (1999), gives the least to most difficult to use of these irrigation systems as: standard center pivot, LEPA, traveling gun, micro-sprinkler and drip tape.

The questionnaire asked farmers' the degree of difficulty in using standard center pivot, LEPA, traveling gun, micro-sprinkler and drip tape. Farmers' used a Likert scale, with values between 1 and 10 (with 1 representing not difficult and 10, very difficult), to grade the degree of difficulty in using these irrigation systems.

Table 3.2 indicates that respondents thought the least difficult irrigation system to use was center pivot, followed respectively by LEPA, micro-sprinkler, drip tape and travel gun. Opinions given by Burt et al. (1999) and that of farmers on relative difficulty of use of the irrigation systems were quite consistent. The only difference was farmers ranking traveling gun as the most difficult system to use, while Burt et al. (1999) thought it less difficult to use, as compared to micro-sprinkler and drip tape.

Installation Expense

Kerry Harrison (Extension Engineer, UGA) states that site-specific features on farms make it difficult to readily assess installation costs of irrigation systems. He estimates traveling gun initial installation cost to be generally less expensive for smaller acres as compared to the four other irrigation systems. However, as acreage increases, standard center pivot and LEPA installation costs are less expensive as compared to traveling gun. Additionally, he reiterated that the initial installation costs for micro-sprinkler and

drip irrigation systems are usually more expensive than other irrigation systems. Table 3.3 shows that for increasing installation costs of irrigation system, farmers had: travel gun, standard center pivot, LEPA, micro-sprinkler and drip tape. Kerry Harrison and growers' opinions on these irrigation systems are therefore quite consistent.

Maintenance Expense

Burt et al. (1999) gives the typical economic life of standard center pivot, LEPA and traveling gun to be 15 years. The maintenance of these irrigation systems which was measured as a percentage of capital costs, were respectively, 5%, 6% and 6%. The researchers assessed orchard drip tape and micro-sprinkler to have an economic life between 6 to 15 years, and maintenance expenses to be equivalent to 6% of capital costs. Additionally, they estimated capital costs (measured in 1995 US dollars per acre) for drip tape and micro-sprinkler to be more expensive compared to costs for standard center pivot, LEPA, and traveling gun. Table 3.3 shows that respondents ranked maintenance expenses as lowest for standard center pivot, followed respectively by travel gun, LEPA, micro-sprinkler and drip tape. Farmers' perception therefore corresponds with empirical data.

Labor Requirement

Burt et al. (1999) estimated labor requirements for sprinkler and drip/micro irrigation systems through pre- and post-season man-hours per hectare as well as, per irrigation man-hours per hectare. In increasing order of labor requirements intensity, they had center pivot, LEPA, drip tape, micro-sprinkler and traveling gun.

Table 3.2: Ranking of Responses on Difficulty of Use of Irrigation Systems

Irrigation Systems	Percentage Ranking ¹										Mean Rank	Sample Rank
	1	2	3	4	5	6	7	8	9	10 ²		
Standard center pivot	40	41	9	4	0	2	0	0	0	4	2.15	1
LEPA center pivot	25	36	10	13	3	0	0	5	3	5	3.08	2
Traveling gun	0	2	6	8	23	8	11	20	2	20	6.71	5
Micro-sprinkler	10	13	13	0	13	10	24	10	0	7	5.13	3
Drip tape	14	9	9	2	11	5	9	11	14	16	5.87	4

¹Where 1 means using irrigation system is not at all difficult and 10 means very difficult (according to farmers experience and/or perceptions). ²Vertical summation of percentages do not sum to 100, because some respondents did not rank some systems.

Table 3.3: Ranking of Responses on Installation and Maintenance Expenses of Irrigation Systems

Comparative costs of Irrigation Systems	Percentage Ranking ¹					Mean	Sample
	1	2	3	4	5 ²	Rank	Rank
Installation Expenses							
Standard Center Pivot	33.33	27.45	17.65	13.73	7.84	2.35	2
LEPA Center Pivot	2.27	31.82	29.55	18.18	18.18	3.18	3
Traveling Gun	47.06	23.53	17.65	5.88	5.88	2.00	1
Micro-Sprinkler	10.00	20.00	15.00	47.50	7.50	3.22	4
Drip Tape	19.55	8.51	12.77	8.51	51.06	3.63	5
Maintenance Expenses							
Standard Center Pivot	38.89	44.44	5.56	11.11	0.00	1.89	1
LEPA Center Pivot	8.89	33.33	44.44	2.22	11.11	2.73	3
Traveling Gun	36.54	13.46	25.00	13.46	11.54	2.50	2
Micro-Sprinkler	5.00	15.00	12.50	57.50	10.00	3.53	4
Drip Tape	21.74	4.35	15.22	13.04	45.65	3.56	5

¹Where 1 means irrigation system has the least cost, 2 means possesses the second least cost and so on. ²Vertical summation of percentages do not sum to 100, because some respondents did not rank some systems.

Table 3.4: Ranking of Responses on Labor Requirements and Energy Use of Irrigation Systems

Comparative costs of Irrigation Systems	Percentage Ranking ¹					Mean Rank	Sample Rank
	1	2	3	4	5 ²		
Labor Requirements							
Standard Center Pivot	77.78	9.26	5.56	5.56	1.85	1.44	1
LEPA Center Pivot	10.87	67.39	13.04	8.70	0.00	2.20	2
Traveling Gun	11.54	15.38	23.08	50.00	0.00	4.12	5
Micro-Sprinkler	12.02	12.20	39.02	37.71	4.88	3.07	3
Drip Tape	25.53	2.13	17.02	29.79	25.53	3.27	4
Energy Use							
Standard Center Pivot	20.75	15.09	22.64	28.30	13.21	2.98	4
LEPA Center Pivot	6.98	32.56	25.58	30.23	4.65	2.93	3
Traveling Gun	7.84	13.73	17.65	9.80	50.98	3.82	5
Micro-Sprinkler	10.00	45.00	25.00	15.00	5.00	2.60	2
Drip Tape	76.09	8.70	4.35	10.87	0.00	1.65	1

¹Where 1 means irrigation system has least requirement, 2 means possesses the second least requirement and so on. ²Vertical summation of percentages do not sum to 100, because some respondents did not rank some systems.

In the survey, labor requirements were categorized into ten. One showed low labor requirement and 10, high labor requirement. Table 3.4 gives labor requirements (from least to highest) for the irrigation systems as: standard center pivot, LEPA, micro-sprinkler, drip tape and traveling gun. Burt et al. (1999) however ranks labor requirements for micro-sprinkler relatively higher as compared to drip tape.

Energy Use

Burt et al. (1999) used kilopascals to estimate energy costs for sprinklers, drip tape and micro irrigation systems. In terms of increasing energy costs, they had LEPA, drip tape, micro sprinkler, standard center pivot and traveling gun. In their estimations, they acknowledged that energy costs varied regionally. Additionally, they stated that irrigation energy costs is influenced by gravity pressure, which makes it difficult to provide actual energy costs. In terms of decreasing energy use, respondents had: traveling gun, standard center pivot, LEPA, micro-sprinkler, and drip tape. Farmers' thus perceived the energy costs for LEPA to be relatively higher than that for drip tape and micro-sprinkler. This perception differed from Burt et al. (1999), who had energy costs of LEPA to be least expensive.

Application Efficiency

Burt et al. (1999) looked at the application efficiency of irrigation systems through distributional uniformity, needed duration of irrigations as compared to actual duration and losses in terms of evapotranspiration and runoff. Distributional uniformity, in this context measured the uniformity of irrigation water distribution to plants in a field.

Table 3.5: Ranking of Responses on Application Efficiency of Irrigation Systems

Irrigation Systems	Percentage Ranking ¹										Mean Rank	Sample Rank
	1	2	3	4	5	6	7	8	9	10 ²		
Standard center pivot	4	6	0	12	20	6	20	22	6	4	6.15	4
LEPA center pivot	0	0	2	9	4	9	11	40	16	9	7.44	3
Travel gun	10	11	15	13	31	10	6	2	0	2	4.19	5
Micro-sprinkler	0	0	0	5	10	12	10	27	31	5	7.59	2
Drip tape	4	0	0	2	0	0	4	6	29	55	8.98	1

¹Where 1 means low application efficiency and 10, high application efficiency (according to farmers' perceptions and/or experience). ²Vertical summation of percentages do not sum to 100, because some respondents did not rank some systems.

The researchers had in decreasing application efficiency, drip tape, micro-sprinkler, LEPA, center pivot and then traveling gun. Table 3.5 indicates that farmers' thought drip tape possessed the highest application efficiency, followed respectively by micro-sprinkler, LEPA, standard center pivot and travel gun. Farmers' responses agree with Burt et al. (1999).

Yield-Related Differences

A contingency question was used to determine if farmers believed some irrigation systems produce higher yields compared to others. Seventy three percent of respondents believed some irrigation systems produced higher yields as compared to others. Farmers then used a relative scale (1 for system producing highest yield for crop(s), 2 for the second best and so on) in ranking the irrigation systems. Farmers' responses, shown in table 3.6, shows travel gun as producing the lowest yield, followed respectively (in terms of increasing yields) by micro-sprinkler, standard center pivot, LEPA and drip tape.

Additionally, growers were asked if changing irrigation system(s) affected consistency of crop yield across years and across fields. Those who adjudged consistency of crop yields could be affected, further relatively ranked (1 as system which produces highest consistency for crop(s), 2 as the second best and so on) the irrigation systems. Respondents were evenly split on the issue whether irrigation systems change affected yield across years. Fifty one percent of respondents thought yield across fields were not affected by an irrigation system change. Tables 3.7 show respondents rankings for yield across fields and years. In decreasing consistency of

yields for both across fields and years, respondents had drip irrigation, LEPA, standard center pivot, micro-sprinkler and travel gun.

Quality Related Differences

Irrigators were asked whether some irrigation systems produced higher quality of harvested crop(s) compared to others. Farmers who judged that some irrigation systems produced higher quality crop(s) used a Likert scale (1 representing low quality harvested crop and 10, high quality harvested crop) to grade the quality of harvested crop(s) produced. Sixty three percent of respondents stated that some irrigation systems produced higher quality crop(s) compared to other system(s). Table 3.8 shows that respondents attributed highest quality of yield produced to drip tape, followed respectively in decreasing order by LEPA, micro-sprinkler, standard center pivot and travel gun.

Irrigators were also asked if changing an irrigation system(s) affects consistency of crop product quality across years and across fields. Irrigators who had affirmative answers used relative rankings (1 indicating the system producing the best consistent variation and 2, system producing the second most consistent variation and so on) to grade consistency of crop product quality among the irrigation systems. A majority of respondents had the opinion that changes in irrigation systems do not substantially impact product quality across fields and years. Respectively, 48% and 41% of respondents saw changes in product quality across fields and across years with irrigation system(s) change.

Table 3.6: Ranking of Responses on Average Crop Yield of Irrigation Systems

Irrigation System	Percentage Rank of Crop Yield ¹					Mean	Sample
	1	2	3	4	5 ²	Rank	Rank
Standard Center Pivot	21.05	28.95	23.68	23.68	2.63	2.58	3
LEPA Center Pivot	25.00	31.25	31.25	9.38	3.13	2.34	2
Traveling Gun	0.00	13.16	26.32	15.79	44.74	3.92	5
Micro-Sprinkler	10.75	39.29	17.86	28.57	3.57	2.75	4
Drip Tape	70.59	8.82	2.94	2.94	14.71	1.82	1

¹Where 1 means irrigation system produces the highest yields, 2 the second highest yields and so on, according to farmers' perceptions and/or experience. ²Vertical summation of percentages do not sum to 100, because some respondents did not rank some systems.

Table 3.7: Ranking of Responses on Consistency of Crop Yield of Irrigation

Systems							
Irrigation Systems	Percentage Ranking for Consistency of Yield ¹					Mean Rank	Sample Rank
	1	2	3	4	5 ²		
Across Years							
Standard Center Pivot	32.14	28.57	14.29	25.00	0.00	2.32	3
LEPA Center Pivot	26.09	30.43	39.13	0.00	4.35	2.26	2
Traveling Gun	0.00	18.52	22.22	11.11	48.15	3.89	5
Micro-Sprinkler	18.18	27.27	18.18	31.82	4.55	2.77	4
Drip Tape	70.83	8.33	0.00	8.33	12.50	1.83	1
Across Fields							
Standard Center Pivot	23.33	40.00	13.33	20.00	3.33	2.40	3
LEPA Center Pivot	40.00	20.00	32.00	8.00	0.00	2.08	2
Traveling Gun	0.00	14.29	21.43	3.57	60.71	4.11	5
Micro-Sprinkler	9.09	31.82	18.18	36.36	4.55	2.95	4
Drip Tape	70.83	4.17	12.50	12.50	0.00	1.67	1

¹Where 1 means irrigation system has the most consistent yield, 2 the second most consistent yield and so on, according to farmers' perceptions and/or experience.

²Vertical summation of percentages do not sum to 100, because some respondents did not rank some systems.

Table 3.8: Ranking of Responses on Quality of Harvested Crop of Irrigation Systems

Irrigation Systems	Percentage Ranking ¹										Mean Rank	Sample Rank
	1	2	3	4	5	6	7	8	9	10 ²		
Standard center pivot	3	3	3	6	21	23	26	0	6	9	6.94	4
LEPA center pivot	0	0	0	0	7	14	22	22	25	10	7.75	2
Travel gun	6	3	9	15	27	31	6	0	0	3	4.88	5
Micro-sprinkler	4	0	0	8	4	0	25	29	17	13	7.42	3
Drip tape	7	0	0	0	0	3	3	18	24	45	8.55	1

¹Where 1 means irrigation system has the lowest product quality and 10, highest product quality according to farmers perceptions. ²Vertical summation of percentages do not sum to 100, because some respondents did not rank some systems.

Table 3.9: Ranking of Responses on Consistency of Product Quality of Irrigation

Irrigation Systems	Percentage Ranking for Consistency of Product Quality ¹					Mean Rank	Sample Rank
	1	2	3	4	5 ²		
	Across Years						
Standard Center Pivot	21.43	35.71	21.43	17.86	3.57	2.46	3
LEPA Center Pivot	26.09	26.09	34.78	13.04	0.00	2.35	2
Traveling Gun	0.00	7.69	11.54	26.92	53.85	4.27	5
Micro-Sprinkler	5.26	36.84	15.79	26.32	15.79	3.11	4
Drip Tape	68.18	9.09	13.64	9.09	0.00	1.64	1
	Across Fields						
Standard Center Pivot	20.83	33.33	25.00	16.67	4.17	2.50	3
LEPA Center Pivot	31.58	21.05	26.32	21.05	0.00	2.37	2
Traveling Gun	0.00	17.39	13.04	17.39	52.17	4.04	5
Micro-Sprinkler	11.76	41.18	11.76	23.53	11.76	2.82	4
Drip Tape	77.78	0.00	11.11	11.11	0.00	1.56	1

¹Where 1 means irrigation system has the most consistent product quality, 2 means possesses the second most consistent product quality and so on, according to farmers perceptions. ²Vertical summation of percentages do not sum to 100, because some respondents did not rank some systems.

Table 3.9 shows a consensus among respondents (who thought product quality changes) that drip tape produces the highest consistency in product quality across fields and across years. Drip tape was followed respectively (in decreasing product quality across fields and years) by LEPA, standard center pivot, micro-sprinkler, and travel gun.

Irrigation System Preferences

The survey sought farmers' preferred irrigation system(s). Additionally, an open-ended question asked why they preferred that particular system. Farmers who were not using their preferred irrigation system(s) were further asked whether they intended to use the system in the future, and if yes, when? None of the respondents chose travel gun as their preferred irrigation system. Thirty-three percent of respondents preferred only LEPA or in conjunction with drip tape, overhead, solid set and center pivot irrigation systems. Respectively, 30% of respondents' preferred only drip tape or in association with LEPA, 22% preferred standard center pivot or in addition to lateral move or LEPA irrigation systems, and 5% of respondents each preferred only micro-sprinkler and the new valley irrigation system technology.

Farmers based their choice of these irrigation system(s) on efficiency, easiness to use, water conservation and labor requirements. Open-ended questions showed that respondents preferred drip tape because of uniform application of water on fields. Open-ended responses obtained from farmers also suggested that the prevalent reason why farmers were not adopting or using their preferred irrigation system was due to cost. Moreover, farmers wanted to use their preferred irrigation system in the future when affordable.

Growers also used the Likert scale (scale ranging from 1 to 10, representing not important to very important respectively) to rate how important purchase price, amortization period, difficulty of use, installation expense, maintenance expense, labor requirement, energy use, water delivery efficiency and other considerations (to be specified by farmers) were important to them in choosing an irrigation system. Table 3.10 shows that respondents thought all the factors listed as important in choosing an irrigation system. This might suggest that the survey question was unable to properly segment farmers' considerations in the selection of an irrigation system. On the other hand, it could imply all the factors are truly important to them. Overall, farmers thought water delivery efficiency of an irrigation system was the most important consideration in the selection of an irrigation system.

Irrigation Timing

The specific irrigation schedule technique adopted by farmers in irrigating crop(s) and any additional information needed for 2003 growing season was enquired. In addition, plant and soil conditions relevant to farmers in decisions on when to apply water to crop(s) and source of their technical advice was solicited. Farmers also used the Likert scale to rate (on a scale of 1 to 10, with 1 representing not important and 10, very important) the degree of importance of recent temperatures, temperature forecasts, saw others irrigate, evapotranspiration, recent rainfall, rainfall forecasts, soil conditions, plant conditions, days after planting, days since last irrigation, advice of others and labor availability and other management considerations (to be specified by farmers) on when to apply water to crop(s).

Table 3.10: Rank of Factors in Choosing an Irrigation System

Factor	Percentage Ranking ¹										Mean Rank	Sample Rank
	1	2	3	4	5	6	7	8	9	10 ²		
Purchase Price	0	0	2	0	4	4	4	23	21	43	8.77	5
Amortization period	4	0	4	6	11	11	9	23	11	21	7.19	7
Difficulty of use	0	2	0	0	2	4	11	14	21	46	8.80	4
Installation expense	0	0	0	4	2	2	7	20	21	45	8.80	4
Maintenance expense	0	0	2	0	2	2	2	27	25	41	8.88	3
Labor needs ³	0	2	2	2	0	0	4	11	32	48	8.98	2
Energy use	0	2	2	2	2	0	9	21	23	39	8.61	6
Water delivery efficiency	0	0	0	0	0	2	2	12	25	59	9.38	1

¹Where 1 means not important and 10 means very important to farmers. ²Vertical summation of percentages do not sum to 100, because some respondents did not rank some factors. ³Labor needs was labeled as labor requirements in the survey.

Table 3.11: Rank of Factors in Deciding When to Apply Water on Crop(s)

Factor	Percentage Ranking ¹										Mean Rank	Sample Rank
	1	2	3	4	5	6	7	8	9	10 ²		
Saw others irrigate	47	15	11	6	7	4	6	0	2	4	2.83	12
Recent temperature	2	0	4	6	17	9	15	22	15	11	7.00	6
Temperature forecasts	4	0	0	11	19	15	11	22	11	7	6.59	8
Evapo-transpiration	0	0	0	6	8	8	12	21	17	29	8.02	5
Recent rainfall	0	0	0	0	2	4	4	7	24	59	9.26	2
Rainfall forecasts	9	2	4	7	6	13	11	13	11	24	6.81	7
Soil conditions	0	0	0	2	6	4	6	13	28	43	8.76	3
Plant conditions	0	0	0	0	2	0	2	15	20	61	9.35	1
Days after planting	9	8	6	4	9	4	12	12	13	23	6.54	9
Days since last irrigation	0	2	4	4	6	7	7	15	24	31	8.04	4
Advice of others	24	4	19	6	17	9	9	9	4	0	4.20	10
Labor Avail ³	33	13	11	4	9	13	6	2	4	6	3.74	11

¹Where 1 means not important and 10, very important according to farmers perceptions.

²Vertical summation of percentages do not sum to 100, because some farmers did not rank some factors. ³Labor Avail shows Labor Availability.

Farmers listed the soil conditions that help determine timing of water applications as: soil moisture, soil type and topography. For plant conditions, irrigators had stress, stage of growth, and fruiting. Irrigators source of advice were obtained from personal experience, extension personnel, irrigation engineers, weathermen, and consultants. Table 3.11 summarizes respondents' ranking of factors influencing decisions on timing of water applications. The first four relevant factors farmers assessed as critical in determining timing of water applications on farms were: plant conditions, recent rainfall, soil conditions and days since last irrigation.

Irrigation Application Amounts

Respondents were asked the specific soil and plant conditions important to them in determining the amount of water to apply on crop(s) and the source of their technical advice. Respondents also answered a dichotomous question on whether they varied amount of water applied on crop(s) during the cropping season. Lastly, farmers rated the degree of importance (on a scale of 1 to 10, with 1 representing not important and 10, very important) of recent temperatures, temperature forecasts, saw others irrigate, recent rainfall amount, rainfall forecasts, soil conditions, plant conditions, days after planting, days since last irrigation, advice of others, labor availability and other management considerations (to be specified by the farmers) in determining how much water to apply on crop(s).

The specific soil conditions influencing farmers' decisions on the amount of water to apply on crops were soil moisture, soil water holding capacity, soil type, slope and topography. Respondents listed the following plant conditions as influencing decisions

on amount of water to apply on crops: stress, stage of maturity and crop yield. Farmers also stated they relied on personal experience, county agents, consultants and extension publications in determining water application amounts. All respondents (but one) said they varied water application amounts during the cropping season. From table 3.12, irrigators identified recent rainfalls, plant conditions, soil conditions and days since last irrigation as the most important factors in deciding the amount of water to apply on crop(s).

Variable Rate Irrigation

Respondents were asked if they have heard of variable rate irrigation. Additionally, growers were asked whether variable rate was used during the 2002 growing season, or they had plans to use it in the future. Farmers who planned to use variable rate irrigation were asked to specify the time frame. Respondents, who had no plans on using the system, were asked to specify their reason(s). Finally, two open-ended questions were used to inquire the merits and demerits of variable rate irrigation.

Sixty three percent of respondents stated having heard of variable rate irrigation. Twenty percent of this percentage used variable rate irrigation during the 2002-growing season. Fifty two percent of respondents (who have heard of variable rate irrigation) had expectations of using it in the future as at when it is affordable. Most respondents stated the advantages of variable rate irrigation as water conservation, addressing of variability in fields, and plant management. The only disadvantage of variable rate irrigation mentioned by respondents was the cost.

Table 3.12: Rank of Factors in Deciding Water Application Amounts

Factor	Percentage Ranking ¹										Mean Rank	Sample Rank
	1	2	3	4	5	6	7	8	9	10 ²		
Saw others irrigate	47	11	17	8	8	0	0	0	0	6	2.68	11
Recent temperature	0	0	2	6	11	8	17	28	15	13	7.43	5
Temperature forecasts	2	0	2	4	17	8	21	19	21	8	7.11	6
Recent rainfall	0	0	0	0	2	2	4	19	21	53	9.13	1
Rainfall forecasts	8	2	4	2	9	15	11	15	17	17	6.91	7
Soil conditions	0	0	2	0	2	0	11	19	30	36	8.75	3
Plant conditions	2	0	0	0	2	2	4	4	40	47	9.07	2
Days after planting	10	8	4	6	10	0	13	17	10	24	6.58	8
Days since last irrigation	2	2	2	4	6	9	15	19	19	23	7.64	4
Advice of others	27	10	15	4	17	12	4	8	2	2	3.88	9
Labor availability	36	4	11	9	9	8	6	8	4	6	2.96	10

¹Where 1 means not important and 10, very important according to farmers perceptions.

²Vertical summation of percentages do not sum to 100, because some respondents did not rank some factors.

Crop Yield

Farmers' were asked of the approximate yield per acre for crop(s) cultivated during 2001 and 2002 cropping season. Respondents also specified crop(s) no longer grown on farms and reason(s) why they stopped cultivating those crop(s). Responses received from respondents indicated that crop yield data for 2001 and 2002 growing season were well documented by farmers. Generally, yield variations between the two years for respondents', were insignificant. Eighteen percent of respondents claimed to have stopped irrigating some particular crop(s). Reasons for not cultivating those crops were generally not stated. However, some respondents attributed low crop prices, crop disease and current use of row cropping as reasons why they stopped cultivating some particular crop(s).

Demography

The questionnaire sought the following demographic factors from respondents: gender, age, years of farming, total acres of farm irrigated and not irrigated, total acres of farm irrigated during the 2002 growing season, whether farm was owned and/or rented, method of farm management, percentage of annual household income from farming, approximate yearly income and number of permanent and temporary hired farm workers. All respondents were males with an average age of 49. The oldest respondent was 83 years and the youngest was 25. The mean years of farming for respondents was 26 years. The range of years of farming varied from 5 to 65 years.

Total acreage farmed by respondents ranged from 30 to 5,000 acres with a mean of 1,196 acres. Total farm acres irrigated for the 2002-growing season by respondents

ranged from 30 to 3,000 acres. Sixty two percent of respondents totally owned their farms, 33% owned and rented farms, and 2% entirely rented their farms. Eighty two percent of respondents managed their own farms, 13% had hired farm managers and 4% managed their farms together with hired farm managers. Fifty nine percent of the respondents described their annual household income from farming to be greater than 75%. Nineteen percent described their annual household farm income as between 51% and 75%. Additionally, 28% of respondents described their approximate yearly farm income to be greater than \$500,000. Twenty seven percent of respondents approximated their yearly farm income within the range of \$100,000 and \$500,000, and nineteen percent said it was below \$50,000. Number of permanently hired farm workers by respondents ranged from 0 to 80, with a mean of 6. Finally, number of temporary hired farm workers by respondents ranged from 0 to 300.

Summary

The chapter presented the survey methodology, farmers' perceptions and statistics on irrigation systems, comparative costs, yield, product quality, irrigation timing and quantity issues and variable rate irrigation. Comparison between views of farmers on comparative costs of irrigation systems and empirical studies was analyzed.

Statistics obtained from respondents on installation expenses, maintenance expenses, labor requirements, application efficiency, energy use and difficulty of use of standard center pivot, LEPA center pivot, traveling gun, micro-sprinkler and drip tape were quite consistent with previous views. Most respondents thought some irrigation system(s) produced higher yield and quality of harvested crop(s) as compared to others.

Respondents' preferences for irrigation system were based on ability to conserve water, efficiency, labor requirements, and easiness to use. Important factors in purchasing irrigation systems to farmers were: water delivery efficiency, labor requirements and maintenance expense. Perceived important factors that influenced decisions on timing and application rates of irrigation water were: recent rainfall, plant conditions, soil conditions and days since last irrigation. The next chapter presents the econometric model.

CHAPTER 4

THE ECONOMETRIC MODEL

This chapter identifies, explains and evaluates the relevant economic variables that impact irrigation water use and irrigation water management decisions in Georgia. The multivariate linear regression model was used to assess the relationship between irrigation water use and farmers' water-related managerial considerations. The chapter also provides information on the conceptual and empirical model, model methodology, the hypothesized signs, summary statistics and interpretation of results.

Conceptual Multivariate Linear Regression Model

The multivariate linear regression fits a dependent variable (y) to a function of independent variables and parameters. The general linear regression model has the form:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_k X_{ki} + u_i \quad \text{for } i = 1, 2, \dots, n \quad (4.1)$$

where:

Y_i is the dependent variable

$\beta_0, \beta_1, \dots, \beta_k$ are the unknown parameters

$X_{1i}, X_{2i}, \dots, X_{ki}$ are the independent variables

u_i is the stochastic term

In equation 4.1, u is a random variable distributed with zero mean

$$E(u_i) = 0 \quad \text{for all } i \quad (4.2)$$

and constant variance

$$\text{Var}(u_i) = \sigma_u^2 \quad \text{for all } i. \quad (4.3)$$

Additionally, the errors of the random variable u , are independent for each of the X variables and are also independent of one another, such that

$$E(u_i u_j) = 0 \quad \text{for all } i \neq j. \quad (4.4)$$

Given that u has a random distribution, from equations 4.2 and 4.3, the normality assumption is given by

$$u \sim N(0, \sigma_u^2). \quad (4.5)$$

Generally, the least squares estimation used in linear regression chooses estimators so as to minimize the sum of squares of the difference between the actual and fitted values of the dependent variables, that is,

$$S = \sum (Y_i - \hat{Y}_i)^2 \quad \text{where } \hat{Y}_i = \hat{\beta}_0 + \hat{\beta}_1 X_{1i} + \dots + \hat{\beta}_k X_{ki} \quad (4.6)$$

It ought to be stated that explanatory variables can either be qualitative or quantitative. Dummy variables would be used to analyze some qualitative effects. Dummy variables are binary variables, possessing values of 0 or 1 used to analyze ordinal or unordered variables. Binary variables will be included in the linear regression to enable hypothesis testing of estimated coefficients and standard errors of explanatory variables.

Model Methodology

Previous research has estimated irrigation crop water use as influenced by soil type, seasonal temperature, seasonal rainfall, irrigation schedule, cost of energy, costs of inputs, output price, evapotranspiration, cost of water and type of irrigation system (Nieswiadomy, 1988; Scheierling and Cardon, 1997; Omezzine and Zaibet, 1998; and

Burt et al., 1999). Thus, the general model envisaged for the study from these empirical studies was:

$$RWUSE = f(STTP, TEMP, RAIN, IRRSY, IRSCH, ENGY, INCT, OUPX) \quad (4.7)$$

where:

RWUSE = irrigation water use

STTP = soil type

TEMP = seasonal temperature levels

RAIN = seasonal rainfall amounts

IRRSY = type of irrigation system

IRSCH = irrigation schedule

ENGY = pumping cost of water

INCT = cost of other inputs used for irrigation

OUPX = price of output

Nieswiadomy (1988) and Omezzine and Zaibet (1998) measured pumping costs as a function of expenditure on water extraction, which includes: labor, energy (electricity), maintenance of pumps and other equipments. Omezzine and Zaibet (1998) also measured irrigation water use through farmers' irrigation schedule (interval and period of irrigation) and irrigation application design. They additionally obtained data on price of output, soil quality and irrigation water supply through farmer interviews. Scheierling and Cardon (1997) measured precipitation by summing the mean daily effective rainfall values over the preceding irrigation period. Additionally, daily maximum and minimum temperatures were used as a function of evapotranspiration to determine crop yield (given the number of irrigations). Burt et al. (1999) estimated the application

efficiency of different types of irrigation systems by looking at the distributional uniformity of irrigation water on plants. All other things being equal, table 4.1 summarizes hypothesized signs between explanatory variables and the dependent variable.

The final model for the analysis, however, was influenced by Gonzalez-Alvarez (2002) thesis on 'The Response of Agricultural Water Use to Changes in Pumping Costs.' Gonzalez-Alvarez had pumping cost and a water requirement variable as the determinants of irrigation water use in his model (sample data derived from Agricultural Water Pumping Program). He used a four-step procedure from Roger and Alam (1999) to calculate the marginal cost of pumping water. The steps entailed calculating the total dynamic head of pumping plant pressure, fuel usage, amount of water to be pumped and total fuel cost. He used the following formulas to calculate the total dynamic head (TDH) in feet and fuel usage:

$$\text{TDH} = \text{psi} * 2.31 + \text{LIFT} \quad (4.8)$$

$$\text{Fuel usage} = \text{Fuel unit} * \text{TDH} \quad (4.9)$$

Psi in equation 4.8 is the pumping pressure in pounds per square inch (procedure for obtaining psi derived from Lamont Jr. et al., 2001) and LIFT, number of feet from the water table to the surface in feet. In equation 4.9, fuel unit is defined as amount of fuel needed to lift one acre-foot of water, per foot of lift. He estimated yearly total fuel cost by multiplying total fuel consumed and fuel unit prices (Gonzalez-Alvarez, 2002). In accordance with *a priori* expectations, he found the coefficient of pumping cost to be negative and significant. Moreover, Gonzalez-Alvarez used the Blaney-Criddle method (Doorenbos and Pruitt, 1984) to estimate crop water requirements.

**Table 4.1: Select Variables for Predicting Irrigation Water Use in Georgia and
Theory Predicted Signs**

Label	Variable	Expected Sign
Soil type	STTP _i	+/-
Temperature	TEMP	+
Rainfall	RAIN	-
Irrigation system type dummy	IRRSY	+/-
Farmers Irrigation schedule dummy	IRSCH	+/-
Pumping cost of water	ENGY	-
Cost of other inputs used for irrigation	INCT	+/-
Output price	OUPX	+

$$\text{Irrigation Demand} = \left[\left(\frac{\text{temperature} * \text{p - value}}{100} \right) * Kc \right] - \text{Precipitation} \quad (4.10)$$

where:

Temperature = Mean Daily or monthly temperature for the length of observation
in degrees Fahrenheit

P-value = Mean daily or monthly percentage of daytime hours for a given
latitude. The selected latitude for Georgia is 30°N.

Kc = Total crop factor

Precipitation = Total daily or monthly precipitation for the length of observation
in inches.

In this study, crop water requirements were calculated for the following crops: carrot, watermelon, cotton, field corn, peanut, pecan, tobacco, snap bean, sorghum, winter forage, silage, collard, pepper, summer squash, cucumber, and vegetables. Forage is a low-valued crop. Forage in this context, consists of winter forage and silage. To ascertain whether forage used less water as compared to the other high-valued crops in the Blaney-Criddle index of evapotranspiration, it was included in the model as a dummy variable. 1998 to 2002 were considered as drought years in Georgia. Dummy variables for the growing-seasons of 2000 and 2001 were included (with 1999 as the base year) in the model to determine the impact of drought on irrigation water use.

Output price was not included in the model because of inadequate variation in farmers' crop prices within the same locality. Costs of other inputs used for irrigation was also excluded in the model due to the unavailability of data. Additionally, irrigation system type was not in the final model since farmers survey responses on the type of

irrigation system used for irrigating crop(s) for the 2002 growing season, conflicted with data obtained from the Agricultural Water Pumping Program from 1999 to 2001.

Irrigation water use is, however, not dependent upon only pumping cost, crop water requirements, forage dummy and impact of drought in the years 2000 and 2001. Thus, the survey, amongst other objectives, determined the perceived importance of recent temperatures, temperature forecasts, observation of other farmers irrigating, recent rainfall amount, rainfall forecasts, soil conditions, plant conditions, and advice of others in farmers' decisions on how much water to apply on their crop(s). Some of these survey variables for water application amounts were used as proxies for farmers' perceptions and administration practices on irrigation water management.

There was little variation in responses for perceived importance of recent rainfalls on water application amounts. Thus, to obtain a measure for the perceived importance of rainfall in determining irrigation water use, perceived importance of rainfall forecasts was included in the model. Additionally, due to lack of variation in responses for plant conditions, irrigators' Likert scale responses for perceived importance of plant and soil conditions were summed together to form an agronomic variable. The agronomic variable created, was termed plant and soil conditions. Responses on perceived importance of days since last irrigation, and days after planting (in the survey), measured the perceived importance of irrigation scheduling to farmers. Hence, to obtain an index for irrigation schedule, the Likert scale responses for perceived importance of days since last irrigation and days after planting, were summed together.

Moreover, survey variable responses for timing of water application and the amounts of water applied seemed to be similar. Thus the t-test procedure was used to

assess whether the variable responses for timing of water application and the amounts of water applied, were statistically significant. To attain this goal, a farmer's perceived importance (Likert scale response) for timing of irrigation application (for each variable considered), was subtracted from that of perceived importance for water application amounts (for the same variable under consideration). The t-test procedure was then applied on the resultant figures. Table 4.2 summarizes the statistics obtained from the t-test procedure for all the variables considered. For the variables advice of others and days since last irrigation, table 4.2 shows them to be statistically significant at the 10% level.

The t-test results indicate that respondents generally apply the same techniques in determining the timing and quantity of water to be applied (with the exception of advice of others and days since last irrigation). The finding also shows that (with the exception of advice of others and days since last irrigation) substitution of an individual response for each variable applying to both timing of irrigation water application and quantity of water applied, would not significantly alter the analysis. This was actually done for two respondents who had no variable responses for water application amounts. Additionally, to further observe the impact of water management decision variables on irrigation water use in Georgia, two multivariate linear regression models were posited and estimated.

Empirical Multivariate Linear Regression Model

The first hypothesized model, equation 4.11, (consisting of secondary physical data) derives data from the Agricultural Water Pumping Program and calculations by

Gonzalez-Alvarez (2002). The second hypothesized model, equation 4.12, includes all variables in the first model and adds other water management variables; primary non-physical data. The hypothesized models are:

$$\text{USE} = \beta_{00} + \beta_{01}(\text{BLCD}) + \beta_{02}(\text{MCP}) + \beta_{03}(\text{FORG}) + \beta_{04}(\text{DUM0}) + \beta_{05}(\text{DUM1}) + \delta_t \quad (4.11)$$

$$\text{USE} = \beta_0 + \beta_1(\text{BLCD}) + \beta_2(\text{MCP}) + \beta_3(\text{FORG}) + \beta_4(\text{DUM0}) + \beta_5(\text{DUM1}) + \beta_6(\text{RRAF}) + \beta_7(\text{PTSL}) + \beta_8(\text{LTDY}) + \xi_{it} \quad (4.12)$$

where:

USE = irrigation water use in feet per acre

β_{00} = intercept term for equation 4.11

β_0 = intercept term for equation 4.12

$\beta_{01} \dots \beta_{05}$ = unknown parameters of explanatory variables for equation 4.11 to be estimated

$\beta_1 \dots \beta_8$ = unknown parameters of explanatory variables for equation 4.12 to be estimated

BLCD = Blaney-Criddle index of evapotranspiration in inches

MCP = pumping costs per unit of water in acre-feet

FORG = forage dummy

DUM0 = dummy for 2000 growing season

DUM1 = dummy for 2001 growing season

RRAF = perceived importance of forecasted rain on water application amounts

PTSL = perceived importance of soil and plant conditions on water application amounts

LTDY = perceived importance of irrigation schedule on water application amounts

δ_t & ξ_{it} = stochastic terms respectively for equation 4.11 and 4.12

Table 4.2: T-test Procedure to Assess Whether Responses Between Irrigation Application Amounts and Timing of Water Application are Statistically Significant

Variable	N	Mean	Std Dev	T value	Pr > t
Saw others irrigate	48	0.0833	1.8316	0.32	0.7540
Recent temperatures	48	-0.3330	2.1171	-1.09	0.2809
Temperature forecasts	48	-0.3330	1.7300	-1.33	0.1883
Recent rainfall amount	48	0.1667	1.2434	0.93	0.3578
Rainfall forecasts	48	-0.0210	1.2289	-0.12	0.9070
Soil conditions	48	-0.0630	1.4790	-0.29	0.7710
Plant conditions	48	0.2708	1.7472	1.07	0.2883
Days after planting	47	0	1.8997	0.00	1.0000
Days since last irrigation	48	0.6250	1.9638	2.21	0.0324
Advice of others	47	0.4468	1.5295	2.00	0.0511
Labor availability	48	-0.1880	1.2489	-1.04	0.3036

Data Description and Hypotheses for Linear Model

The Blaney-Criddle index of evapotranspiration (BLCD) is a measure of crop water requirements. All other things being equal, it is anticipated that a high water requirement would lead to higher irrigation water demand and vice versa. A positive relationship is thus envisaged between BLCD and irrigation water use.

Irrigation farmers seek to minimize irrigation pumping cost, which are contingent on horsepower rating of pumps and their power source. Higher pumping expenditures, without a corresponding increase in crop prices, reduce total net farm income. A negative relationship is therefore projected between irrigation water use and pumping costs per unit of water (MCP). Throughout this study, pumping cost is used as a proxy for water price, because there is no explicit per unit charge of water withdrawn. Additionally, pumping cost also serves as private opportunity cost of using irrigation water.

Forage (FORG) is a low-valued crop in comparison to most other crops. It is thus expected that farmers will apply minimal amounts of water on forage, and higher amounts on other higher-valued crops. All other things being equal, a negative relationship is therefore anticipated between FORG and irrigation water use. 1999 through 2001 were considered as drought years in Georgia. It is therefore projected that irrigation water use in 2000 and 2001, will relatively increase when compared to 1999, or irrigation water use will be at the same levels. A positive relationship will therefore exist between the explanatory variables DUM0, DUM1 and irrigation water use.

Farmers' responses for perceived importance of rainfall forecasts was used as an index for the forecasted rainfall variable (RRAF). Forecasted rain in an area

represents the projected amount of water to be received in the soil and thus water available to crops. Excess amounts of water in the soil can stunt the growth of some crops and impact crop yield. Farmers who depend on forecasted rains would thus augment irrigation with projected rains. It is therefore hypothesized that a negative relationship would exist between perceived importance of forecasted rainfall and irrigation water use.

The index for plant and soil conditions (PTSL) comprises the perceived importance of plant and soil conditions. Plant and soil conditions play an integral part in the growth of crops. Soil texture and structure dictates the water holding capacity of some soils and hence water requirements for a crop. Plant stress could result in wilting and stunted growth of crops, reducing crop quality. All other things being equal, during drought years, demand of water by plants and water holding capacity of soils would tend to increase. A positive relationship is therefore projected between the perceived importance of plant and soil conditions (PTSL) and irrigation water use, during drought periods.

The irrigation schedule index (LTDY) comprises the perceived importance of days since last irrigation and days after planting. Irrigation scheduling depends on soil type, feet of effective rainfall, net irrigation applied by irrigation system, feet of crop water use and estimated crop future use. Drought conditions, however, would likely reduce feet of effective rainfall, thus increasing irrigation water use. In drought periods, a positive relationship is projected between perceived importance of irrigation schedule (LTDY) and irrigation water use. In the model, ξ_{it} & δ_t capture any unexplained variation in the dependent variable (USE) not explained by the model.

Summary Statistics and Interpretation

Estimation of equation 4.11 was a replication and expansion of the study of Gonzalez-Alvarez (2002). He posited irrigation water use as a function of Blaney-Criddle index of evapotranspiration and pumping cost. For equation 4.11, irrigation water use is a function of the Blaney-Criddle index of evapotranspiration, water pumping cost, forage dummy, and dummies for the years 2000 and 2001. Table 4.1 shows estimated signs of equation 4.11 consistent with *a priori* expectations.

A positive relationship is shown between the Blaney-Criddle index of evapotranspiration and irrigation water use. One unit increase in the Blaney-Criddle index of evapotranspiration, with all other independent variables held constant causes a 0.01284 unit increase in irrigation water use. Table 4.2 shows BLCD with t-value of 1.77 as statistically significant at the 10% level.

Relation between irrigation water use and pumping cost was estimated to be negative. If pumping cost increased by a dollar, the irrigator decreased irrigation water use by 0.01083 acre-feet. The t-value of -2.09 was statistically significant at the 5% level. The model shows forage irrigation as insignificant in equation 4.11.

The parameter estimate of 0.31869 for DUM0 indicates that irrigation water use for 1999 and 2000 was different. The positive parameter estimate shows that irrigation water use increased in 2000 as compared to 1999. The conclusion is validated by the high t-ratio of 2.44, which was statistically significant at the 5% level. Dummy variable for 2001, DUM1, was not significant in the model.

The F-value of 6.24 for equation 4.11 and its associated p-value of 0.0001 indicate that at least one coefficient in the model is not zero. The R-square of 0.2105 for

the model suggests that 21.05% of variation in irrigation water use is explained by the independent variables in equation 4.11. The adjusted R-square for the estimation was 0.1768.

Estimated signs for BLCD and MCP were consistent with those of Gonzalez-Alvarez (2002). Additionally, Gonzalez-Alvarez had BLCD and MCP to be statistically significant at the 10% level. These variables were also found significant in this present estimation. However, it is worth noting that while Gonzalez-Alvarez had a total number of 707 observations, this study had 133. The low number of observations for the current study could be directly attributed to the number of questionnaires obtained from respondents.

Estimation of equation 4.11, however, excludes farmers' irrigation water management variables, which also influences irrigation water use on farms. These effects are captured in equation 4.12, with the addition of perceived importance of rainfall forecasts, plant and soil conditions and irrigation schedule to the original model, equation 4.11.

Table 4.3 shows all predicted signs of equation 4.12 as conforming to *a priori* expectations and table 4.4 gives the estimated coefficients of the variables. In equation 4.12, BLCD was found to be insignificant. There was a negative relationship between pumping costs and irrigation water use. An increase in water pumping cost by one dollar decreases irrigation water use by 0.01053 acre-feet. This relationship was statistically significant at the 5% level and also in conformity with the finding of Gonzalez-Alvarez (2002).

The relationship between the forage dummy and irrigation water use was negative. The result was statistically significant at the 10% level, with a p-value of 0.0998. This finding confirmed suspicions that farmers generally might apply less water to low valued crops, as compared to high valued ones. The parameter coefficient for the 2000 dummy variable, 0.28075, was highly significant at the 5% level. This shows that irrigation water use in 2000 was different from that of 1999. Irrigation water use in 2001, was however, statistically insignificant.

An inverse relationship existed between perceived importance of rainfall forecast and irrigation water use. The result was significant at the 1% level with a t-ratio of -3.07 . The results suggest that farmers who pay more attention to rainfall forecasts use less water.

The index for plant and soil conditions had a positive impact on irrigation water use. The t-ratio of 1.97 was statistically significant at the 10% level. The finding shows that irrigators, who consider agronomic factors such as plant and soil conditions, might be inclined to use more water. This is because (all other things being equal), there will be little water reserves in the soil, during drought periods.

Table 4.4 shows a positive relationship between perceived importance of irrigation schedule (LTDY) and irrigation water use. The relationship was significant at the 1% level with a p-value of 0.0008. This finding suggests that farmers who are mindful of the perceived importance of irrigation schedule would be more inclined to increase water use during drought conditions.

Overall, the F-value of 7.09 and associated p-value of 0.0001 shows that at least one coefficient in equation 4.12 is not zero. The R-square value of 0.3323 indicates that

approximately 33.23% of variation in irrigation water use is explained by the independent variables. The adjusted R-square for equation 4.12 was 0.2855.

In summary, all the models fared well as shown by the two F-tests. All estimated signs were as hypothesized. Some of the independent variables were insignificant, however, this is explained in the context of sample data and for reasons the model is unable to capture.

Table 4.3: Expected Signs for Some Factors Influencing Irrigation Water Use in Georgia, 1999-2001

Label	Variable	Expected Sign
Blaney-Criddle evapotranspiration in inches	BLCD	+
Pumping costs per unit of water in acre-feet	MCP	-
Forage dummy	FORG	-
Dummy for 2000 growing season	DUM0	+
Dummy for 2001 growing season	DUM1	+

Table 4.4: Parameter Estimates for Some Factors Influencing Irrigation Water Use in Georgia, 1999-2001

Variable	Parameter Estimate	Standard Error	T-ratio	P-value
Intercept	0.64141	0.14140	4.54	0.0001
Blaney-Criddle	0.01284	0.00727	1.77	0.0800
Pumping cost	-0.01083	0.00518	-2.09	0.0388
Forage dummy	-0.31849	0.20605	-1.55	0.1249
Dummy for 2000	0.31869	0.13045	2.44	0.0161
Dummy for 2001	0.07222	0.12349	0.58	0.5598

**Table 4.5: Expected Signs for Factors Influencing Irrigation Water Use in Georgia,
1999-2001**

Label	Variable	Expected Sign
Blaney-Criddle evapotranspiration in inches	BLCD	+
Pumping costs per unit of water in acre-feet	MCP	-
Forage dummy	FORG	-
Dummy for 2000 growing season	DUM0	+
Dummy for 2001 growing season	DUM1	+
Importance of rainfall forecasts on water application amounts	RRAF	-
Importance of plant and soil conditions on water application amounts	PTSL	+
Importance of Irrigation schedule on water application amounts	LTDY	+

Table 4.6: Parameter Estimates for Factors Influencing Irrigation Water Use in Georgia, 1999-2001

Variable	Parameter	Standard	T-ratio	P-value
	Estimate	Error		
Intercept	-0.50171	0.61485	-0.82	0.4162
Blaney-Criddle	0.00982	0.00687	1.43	0.1557
Pumping cost	-0.01053	0.00495	-2.13	0.0357
Forage dummy	-0.32623	0.19659	-1.66	0.0998
Dummy for 2000	0.28075	0.12185	2.30	0.0230
Dummy for 2001	0.02548	0.11569	0.22	0.8261
Rainfall forecasts	-0.16460	0.05360	-3.07	0.0027
Plant and soil	0.39424	0.20013	1.97	0.0513
Irrigation schedule	0.18475	0.05338	3.46	0.0008

CHAPTER 5

SUMMARY

This chapter summarizes the survey statistics and the research conducted. Summary and findings of the thesis is presented. This is followed by policy implications, limitations of the study, conclusion and suggestions for future research.

Summary and Findings of Thesis

This research attempted to elicit from irrigation farmers', factors influencing their decisions in adopting water-saving technologies. The study also sought the water management practices of irrigators on farms. To achieve these objectives, a mail-out questionnaire was administered to irrigation farmers.

Comparative costs statistics gathered from respondents on installation expenses, maintenance expenses, labor requirements, energy use and difficulty of use of standard center pivot, LEPA center pivot, traveling gun, micro-sprinkler and drip tape were generally consistent with previous empirical views. Additionally, farmers' assessments of the application efficiency of the above five irrigation systems conformed to previous research. This finding suggests that most farmers in Georgia were knowledgeable on current comparative costs of different irrigation systems.

Furthermore, most respondents thought some irrigation systems produced higher yield and quality of harvested crop(s) as compared to others. However, respondents were statistically evenly split on the issues of whether irrigation system change affects

yield and quality of harvested crop(s) across years and across fields. Generally, respondents' preferences for irrigation systems were based on efficiency, labor requirements, easiness to use, and ability to conserve water. The most important factors to farmers in purchasing irrigation systems were: water delivery efficiency, labor requirements and maintenance expense.

Specifically, respondents listed soil moisture, soil type, topography, wilting, stage of growth and fruiting as the plant and soil conditions important to them when it comes to timing of water applications on crops. For irrigation application amounts, respondents held these additional factors relevant: soil holding capacity, slope and crop yield. Respondents generally relied on extension personnel, county agents, consultants, extension publications, irrigation engineers, weathermen and own personal experience to meet their daily irrigational management.

Of the 63% of respondents who have heard of variable rate irrigation, only half of them expected to use it in the future due to financial constraints. Most respondents rightly stated the advantages of variable rate irrigation as water conservation and ability to address variability in fields.

Multivariate linear regression was employed to estimate the relationship between irrigation water use and the hypothesized variables. Variables used in estimating irrigation water use were based on economic theory and past research. The empirical analysis data were obtained from the Agricultural Water Pumping Program and a questionnaire administered to farmers participating in this program. The findings of the empirical estimation may be briefly summarized as follows:

- 1) Inclusion of irrigation water management variables in the estimation of irrigation water use, improves the performance of the model.
- 2) The Blaney-Criddle index of evapotranspiration was shown to have a positive relationship with irrigation water use for the first model.
- 3) Forage production, which is a low-valued crop, was shown to have a negative relationship with irrigation water use in the second model.
- 4) Irrigation water use in 2000 was shown to be significantly higher than in 1999. This can be attributed to relative drought conditions prevailing in the state during this period.
- 5) Higher pumping costs were accompanied by reduced irrigation water use for both models.
- 6) A negative relationship existed between the index for perceived importance of rainfall forecast and irrigation water use. This shows that farmers who pay more attention to rainfall forecasts might use less irrigation water.
- 7) A positive relationship pertained between the index for perceived importance of plant and soil conditions and irrigation water use. It indicates that irrigators who are mindful of agronomic variables such as plant and soil conditions are more likely to increase irrigation water use during drought years.
- 8) A positive relationship existed between the index for perceived importance of irrigation schedule and irrigation water use. This result

suggests that farmers with higher-valued crops pay attention to crop quality and yield during drought years.

Policy Implications

Discussions on irrigation and water management for Georgia have captured the attention of academicians, policy makers and extension agents especially after the recent drought in the state. The policy implications of this study are, therefore, a contribution towards a cost-effective and workable plan for irrigation water management in Georgia.

A close examination of the regression estimates for the two models demonstrates that farmers' irrigation water use is best determined if farmers' irrigation management practices are taken into consideration in addition to other variables. The significance of forage irrigation in the second model seems to indicate that farmers apply less water to lower-valued crop(s) during drought periods because of the opportunity cost of irrigation water use.

The significance of the 2000 dummy variable (estimated coefficient) indicates that irrigation water use was higher in 2000 as compared to 1999. Dummy variable for 2001 was not significant as compared to 1999. Nevertheless, it should be noted that the latter was also a drought year. Therefore, it can be deduced that, the marginal irrigation water use for farmers in 2001, as compared to 1999, was not significant.

The Blaney-Criddle index of evapotranspiration was found to increase irrigation water use in the first model. This suggests that the index, which incorporates temperature, rainfall and crop factor, can explain irrigation decisions on irrigation water

use. However, it was relatively insignificant for the second model. This shows that the consideration of variables influencing farmers' perceptions on water application rates, partially reduces the Blaney-Criddle index of evapotranspiration explanatory power on farm irrigation water management decisions.

Pumping cost was found to be important in determining irrigation water use for both models. This finding seems to suggest that irrigation farmers would decrease irrigation water use, if pumping costs rise significantly. This may also indicate that significant increases in pumping costs would lead to irrigation farmers investing in energy and/or water-efficient irrigation technology, which, all other things being equal, will reduce irrigation water use.

Rainfall forecast was relevant to farmers in the study. This suggests farmers might rely on forecasted rains to lessen operational costs, labor and probably pumping cost involved in irrigating their farms. Thus, local government officials and extension personnel could encourage irrigation farmers to postpone irrigation of farms if reliable rainfall forecasts could be obtained.

Soil and plant conditions were found to increase irrigation water use in drought years. Notwithstanding the fact that these were drought years, there is need for research into high-quality drought-resistant varieties of crops, which farmers should be encouraged to adopt. In addition, water-reducing agronomic techniques and irrigation technologies should be introduced to farmers. Education of irrigation farmers on future repercussions, such as irrigation water purchase, if current water use continues unchecked would be critical for the success of these programs.

The finding that perceived importance of irrigation scheduling increased irrigation water use is quite troubling. This is because a good irrigation schedule program is thought to reduce water use, relative to not using such programs. The drought years contributed to the increased water use with irrigation schedule. Additionally, the positive sign between irrigation water use and irrigation schedule could be due to obsolete irrigation equipment as shown by Evans et al. (1998). Education through extension engineers and personnel, as well as the right financial incentives from the state, could play a critical role in encouraging irrigation farmers in replacing obsolete irrigation equipments and systems. It is hoped that these suggestions would facilitate and help reduce overall irrigation water use in Georgia.

Conclusions, Limitations and Suggestions for Further Research

Incorporating farmers' irrigation water management variables into our model, we find that pumping cost, forage irrigation, drought conditions, and perceived importance of rainfall forecasts, plant and soil conditions and irrigation schedule, influence irrigation water use in Georgia. Respondents' survey responses also highlight farmers' increasing awareness, willingness and preference for improved irrigation technology that conserves irrigation water use when affordable.

The primary limitation of this research was the low questionnaire response from respondents. This was partially due to insufficient finances to adequately compensate farmers, send questionnaires to all respondents who did not respond the first time and undertake follow ups. This data limitation resulted in the need to combine the questionnaire data with that of the Agricultural Water Pumping Program.

The low questionnaire response did not allow the study to consider the relationship between the adoption of specific irrigation systems and impacts on irrigation water use, employing the logistic model. The logistic model was critical in determining the relationship between adoption of improved irrigation technology and ability to reduce irrigation water use.

Additionally, the research did not consider potential benefits to the environment from increased conservation of water through decreased irrigation water use. Decreased erosion of top soils, chemicals, pesticides, and fungicides into underground and surface water sources, are potential benefits to be obtained as improved irrigation technologies are adopted.

The issue of additional costs with increase in irrigation efficiency was not dealt with in this research. Higher costs are generally associated with increasing irrigation water savings. Hence, the willingness and ability of farmers to pay ought to be assessed before policies are implemented. Failure to take this into account might lead to increasing cost, which will cause the divestiture of most farms to the detriment of the state.

Repeating this research with a much more comprehensive data could be of much interest in the future. Additionally, comparing the effects of adoption of improved irrigation system on irrigation water use could be analyzed in a future study. The issue of adoption of improved water-saving irrigation systems and effects on crop yield and product quality would be of much interest to farmers, academicians and planners. It is hoped that these future research topics would ensure a wealth of information pertaining to irrigation water management in Georgia.

This study has shown that farmer' perceptions of irrigation water management and irrigation technology is essential in farm irrigation water policy decisions. The research therefore affirms the relevancy of farmers' irrigation water management practices in determining irrigation water use in Georgia.

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APPENDIX A
QUESTIONNAIRE

Dear Georgia Producer,

On behalf of the Department of Agricultural and Applied Economics and the Department of Biological and Agricultural Engineering at the University of Georgia, we would like to request your assistance in evaluating irrigation technology used in the state. The attached survey is designed to gather information on what producers, like yourself, consider to be the advantages and disadvantages of different irrigation systems. This information will help guide the development of future irrigation research projects in Georgia, and help in the design of extension materials and programs related to irrigated agriculture. In an effort to make our research and extension activities increasingly relevant to the community we serve, we are asking for your assistance.

We would like to assure you that all of your responses will be strictly confidential – your name will not be associated with your responses. Participation in this project is completely voluntary.

We recognize your time is valuable. We also recognize the value of your expertise, experience, and opinions regarding irrigation in Georgia. As a token of our appreciation for taking the time to fill out and return the survey, we have included a University of Georgia decal – it is not much, but budgets are tight these days. We have also included an addressed return envelope with the postage paid. Please use it to return your completed survey at your earliest possible convenience.

Once again, thank you for your assistance. ¹

Sincerely,

Jeff Mullen and Augustus Matekole, Department of Ag. & Applied Economics;
Dan Thomas, Department of Biological and Agricultural Engineering

¹ Additional questions or comments regarding your rights participant, should be addressed to Chris A. Joseph, Ph.D. Human Subjects Office, UGA, 606A Boyd Graduate Studies Research Center, Athens, GA 30602-7411; Tel. (706) 542-3199; email: IRA@uga.edu

1. What crops did you irrigate in 2002?

Please use Table 1 to answer questions 2 through 5.

2. Please consider the irrigation systems listed in COLUMN 1. Which of these systems do you have experience with? Please mark an X next to each irrigation system with which you have experience.
3. Please consider the irrigation systems listed in COLUMN 1. Which of these systems are appropriate for irrigating the crops you grow? Please mark an X next to each irrigation system that is appropriate for your crops.
4. Which system did you use to irrigate your crop(s) during the 2002-growing season? Please mark an X in the row of the irrigation system you used.
5. Why don't you use the other irrigation systems identified in COLUMN 1 to irrigate your crop(s)? Please respond for each irrigation system you do not use.

Table 1: Questions 2, 3, 4 and 5

IRRIGATION SYSTEM	Question #2 Experience	Question #3 Appropriate Systems	Question #4 System Used	Question #5 Why don't you use the system?
Standard Center Pivot				
LEPA Center Pivot ²				
Traveling Gun or Big Gun				
Micro-Sprinkler				
Drip Tape or Drip Tubing				
Other System?				

² LEPA is an adaptation of center pivot (or lateral-move) systems that uses drop tubes extending down from pipelines to apply water at low pressure below the canopy, usually only a few inches above the ground.

6. Different irrigation systems may be more difficult to use than others. Based on your perception or experience, please consider, overall, how difficult each of the following irrigation systems is to use. On a scale of 1 to 10, with one being not at all difficult and 10 being very difficult, please rate each system with respect to how difficult you feel they are to use.

<u>System</u>	<u>Not</u> <u>Difficult</u>									<u>Very</u> <u>Difficult</u>
Standard Center Pivot	1	2	3	4	5	6	7	8	9	10
LEPA Center Pivot	1	2	3	4	5	6	7	8	9	10
Traveling Gun	1	2	3	4	5	6	7	8	9	10
Micro-Sprinkler	1	2	3	4	5	6	7	8	9	10
Drip Tape/Tubing	1	2	3	4	5	6	7	8	9	10

Installation Expenses

7. Different irrigation systems may have different costs of installation. Based on your perception or experience, please rank from 1 to 5 each of the following irrigation systems with respect to how expensive they are to install. Place a 1 next to the system you believe is the least expensive to install, place a 2 beside the system you believe has the second lowest installation expense, and so on.

<u>Irrigation System</u>	<u>Rank</u>
Standard Center Pivot	_____
LEPA Center Pivot	_____
Traveling Gun	_____
Micro-Sprinkler	_____
Drip Tape / Tubing	_____

Maintenance Expenses

8. Different irrigation systems may have different maintenance expenses. Based on your perception or experience, please rank from 1 to 5 each of the following irrigation systems with respect to how expensive you believe they are to maintain. Place a 1 next to the system you believe is the least expensive to maintain, place a 2 beside the system you believe has the second lowest maintenance expense, and so on.

<u>Irrigation System</u>	<u>Rank</u>
Standard Center Pivot	_____
LEPA Center Pivot	_____
Traveling Gun	_____
Micro-Sprinkler	_____
Drip Tape / Tubing	_____

Labor Requirements

9. Different irrigation systems may require different amounts of labor to operate. Based on your perception or experience, please rank from 1 to 5 each of the following irrigation systems with respect to how much labor they require to operate. Place a 1 next to the system you believe requires the least labor, place a 2 beside the system you believe has the second lowest labor requirement, and so on.

<u>Irrigation System</u>	<u>Rank</u>
Standard Center Pivot	_____
LEPA Center Pivot	_____
Traveling Gun	_____
Micro-Sprinkler	_____
Drip Tape / Tubing	_____

Energy Use

10. Different irrigation systems require different amounts of energy to apply an acre-inch of water. Based on your perception or experience, please rank from 1 to 5 each of the following irrigation systems with respect to how much energy they require to apply an acre-inch of water. Place a 1 next to the system you believe require the least energy, place a 2 beside the system you believe has the second lowest energy requirement, and so on.

<u>Irrigation System</u>	<u>Rank</u>
Standard Center Pivot	_____
LEPA Center Pivot	_____
Traveling Gun	_____
Micro-Sprinkler	_____
Drip Tape / Tubing	_____

Application Efficiency

11. One measure of an irrigation system's performance is application efficiency. By application efficiency we mean the percentage of water applied that is available to the plant's roots for uptake. Please consider how well you believe each irrigation system performs with respect to application efficiency. On a scale of 1 to 10, with 1 being low application efficiency and 10 being high application efficiency, please rate each system.

<u>System</u>	<u>Low Efficiency</u> _____ <u>High Efficiency</u>									
Standard Center Pivot	1	2	3	4	5	6	7	8	9	10
LEPA Center Pivot	1	2	3	4	5	6	7	8	9	10
Traveling Gun	1	2	3	4	5	6	7	8	9	10
Micro-Sprinkler	1	2	3	4	5	6	7	8	9	10
Drip Tape/Tubing	1	2	3	4	5	6	7	8	9	10

Crop Yield

12. For the crops you irrigate, do you believe some irrigation systems produce a higher yield than other irrigation systems?

_____ Yes (Please answer question 13)

_____ No (Please go to question 14)

13. Please rank from 1 to 5 each of the following irrigation systems with respect to the average yield they produce for the crops you grow. Place a 1 next to the system you believe produces the highest yields, place a 2 beside the system you believe produces the second highest yields, and so on.

<u>Irrigation System</u>	<u>Rank</u>
Standard Center Pivot	_____
LEPA Center Pivot	_____
Traveling Gun	_____
Micro-Sprinkler	_____
Drip Tape / Tubing	_____

14. Yields often vary from year to year. Do you believe changing your irrigation system would change the consistency of yield from year to year for your crops?

_____ Yes (Please answer question 15)

_____ No (Please go to question 16)

15. Please rank from 1 to 5 each of the following irrigation systems with respect to the consistency of yield from year to year. Place a 1 next to the system you believe produces the most consistent yearly yield, place a 2 beside the system you believe produces the second most consistent yearly yield, and so on.

<u>Irrigation System</u>	<u>Rank</u>
Standard Center Pivot	_____
LEPA Center Pivot	_____
Traveling Gun	_____
Micro-Sprinkler	_____
Drip Tape / Tubing	_____

16. Do you believe changing your irrigation system would change the consistency of yield across fields for your crops?

_____ Yes (Please answer question 17)

_____ No (Please go to question 18)

17. Please rank from 1 to 5 each of the following irrigation systems with respect to the consistency of yield across fields for the crops you grow. Place a 1 next to the system you believe produces the most consistent yield across fields, place a 2 beside the system you believe produces the second most consistent yield across fields, and so on.

<u>Irrigation System</u>	<u>Rank</u>
Standard Center Pivot	_____
LEPA Center Pivot	_____
Traveling Gun	_____
Micro-Sprinkler	_____
Drip Tape / Tubing	_____

Quality of Harvested Crop

18. For the crops you irrigate, do you believe some irrigation systems produce a higher quality crop than other irrigation systems?

_____ Yes (Please answer question 19)

_____ No (Please go to question 20)

19. On a scale of 1 to 10, with 1 being low quality and 10 being high quality, please rate each system with respect to the quality of yield you feel they produce for your irrigated crops.

<u>System</u>	<u>Low Quality</u> _____ <u>High Quality</u>									
Standard Center Pivot	1	2	3	4	5	6	7	8	9	10
LEPA Center Pivot	1	2	3	4	5	6	7	8	9	10
Traveling Gun	1	2	3	4	5	6	7	8	9	10
Micro-Sprinkler	1	2	3	4	5	6	7	8	9	10
Drip Tape/Tubing	1	2	3	4	5	6	7	8	9	10

20. Do believe changing your irrigation system would change the consistency in product quality across years for your crops?

_____ Yes (Please answer question 21)

_____ No (Please go to question 22)

21. Please rank from 1 to 5 each of the following irrigation systems with respect to the yearly variation in product quality for the crops you grow. Place a 1 next to the system you believe produces the most consistency in product quality, place a 2 beside the system you believe produces the second most consistent yearly variation in product quality, and so on.

<u>Irrigation System</u>	<u>Rank</u>
Standard Center Pivot	_____
LEPA Center Pivot	_____
Traveling Gun	_____
Micro-Sprinkler	_____
Drip Tape / Tubing	_____

22. Do you believe changing your irrigation system would change the consistency in product quality across fields for your crops?

_____ Yes (Please answer question 23)

_____ No (Please go to question 24)

23. Please rank from 1 to 5 each of the following irrigation systems with respect to the variation in product quality across fields for the crops you grow. Place a 1 next to the system you believe produces the most consistent product quality across fields, place a 2 beside the system you believe produces the second most consistent product quality across fields, and so on.

<u>Irrigation System</u>	<u>Rank</u>
Standard Center Pivot	_____
LEPA Center Pivot	_____
Traveling Gun	_____
Micro-Sprinkler	_____
Drip Tape / Tubing	_____

Your Preferred Irrigation System

24. If you could choose any irrigation system to apply water to your irrigated crops, which one would you choose?

25. Why would you choose this irrigation system?

26. If you are not using your preferred irrigation system now, why don't you use it?

27. If you are not using your preferred irrigation system now, do you expect to use it in the future?

Yes

No

If yes, when? _____

28. If you were to choose an irrigation system for your farm, how important would each of the following factors be to your choice? On a scale of 1 to 10, with one being not at all important and 10 being very important, please rate the importance of each of the following factors would be to your choice of irrigation system.

<u>Factor</u>	<u>Not Important</u>									<u>Very Important</u>
Purchase Price	1	2	3	4	5	6	7	8	9	10
Amortization Period	1	2	3	4	5	6	7	8	9	10
Difficulty of Use	1	2	3	4	5	6	7	8	9	10
Installation Expense	1	2	3	4	5	6	7	8	9	10
Maintenance Expense	1	2	3	4	5	6	7	8	9	10
Labor Requirement	1	2	3	4	5	6	7	8	9	10
Energy Use	1	2	3	4	5	6	7	8	9	10
Water Delivery Efficiency	1	2	3	4	5	6	7	8	9	10
Other Considerations	1	2	3	4	5	6	7	8	9	10

Please Specify _____

Irrigation Timing

Questions 29 through 33 refer to factors that may influence your decisions regarding the timing of water application.

29. What specific irrigation scheduling technique did you use this year for each of your crops?

30. What additional information would you need for irrigation scheduling for each of your crops in 2003 growing season?

31. What soil conditions are important to you in deciding when to apply water to your crop(s)?

32. What plant conditions are important to you in deciding when to apply water to your crop(s)?

33. Whose advice is important to you in deciding when to apply water to your crops? (Please rank them)

Irrigation Application Amounts

Questions 35 through 38 refer to factors that may influence your decisions regarding the amount of water to apply to your crops.

35. What soil conditions are important to you in deciding the amount of water to apply to your crop(s)?

36. What plant conditions are important to you in deciding the amount of water to apply to your crop(s)?

37. Whose advice is important to you in deciding the amount of water to apply to your crop(s)? (Please rank them)

38. Do you change the amount of water you apply during the cropping season?

_____ Yes

_____ No

39. On a scale of 1 to 10, with 1 being not important and 10 being very important, please rate the importance of each of the following factors with respect to your decision of how much water to apply to your crops.

<u>Factor</u>	<u>Not Important</u>									<u>Very Important</u>
	1	2	3	4	5	6	7	8	9	10
Saw Others Irrigate	1	2	3	4	5	6	7	8	9	10
Recent Temperature	1	2	3	4	5	6	7	8	9	10
Temperature Forecasts	1	2	3	4	5	6	7	8	9	10
Recent Rainfall Amount	1	2	3	4	5	6	7	8	9	10
Rainfall Forecasts	1	2	3	4	5	6	7	8	9	10
Soil Conditions	1	2	3	4	5	6	7	8	9	10
Plant Conditions	1	2	3	4	5	6	7	8	9	10
Days After Planting	1	2	3	4	5	6	7	8	9	10
Days Since Last Irrigation	1	2	3	4	5	6	7	8	9	10
Advice of Others	1	2	3	4	5	6	7	8	9	10
Labor Availability	1	2	3	4	5	6	7	8	9	10
Other Management Considerations	1	2	3	4	5	6	7	8	9	10

Please Specify _____

40. Have you heard of variable rate irrigation?

_____ Yes (Please answer question 41)

_____ No (Please go to question 45)

41. Did you use variable rate irrigation during the 2002 growing season?

_____ Yes

_____ No

42. Do you plan to use variable rate irrigation in the future?

_____ Yes When? _____

_____ No Why Not? _____

43. What do you feel are the main advantages of variable rate irrigation?

44. What do you feel are the main disadvantages of variable rate irrigation?

Please provide the following information to facilitate our analysis of the survey. As with all of your responses in this questionnaire, your answers are strictly confidential.

50. Your gender: Male
 Female
51. Your age: _____
52. How many years have you been farming? _____
53. How many total acres do you currently farm? _____
54. How many total acres of your farm did you irrigate during the 2002 growing season? _____
55. Do you own or rent your farm?
 Own Rent
56. How do you manage your farm?
 Self management of farm
 Hired farm manager
57. What percentage of your annual household income is from farming?
 Under 10%
 Between 10% and 25%
 Between 26% and 50%
 Between 51% and 75%
 Greater than 75%
58. Which of the following best describes your approximate yearly farm income?
 Under \$50,000
 Between \$50,000 and \$99,999
 Between \$100,000 and \$199,999
 Between \$200,000 and \$499,999
 Greater than \$500,000
59. Number of permanent hired farm workers _____
60. Number of temporary hired farm workers at peak need _____

Thank you for taking the time to complete the survey. Your assistance is greatly appreciated. Please use the space below for any comments or suggestions you might have.