**Drip Irrigation in the Desert: Adoption, Implications, and Obstacles**
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## Introduction

Drip irrigation is often promoted as a technology that can conserve water, increase crop production, and improve crop quality. Nonagricultural water demand has increased in the western United States, and efforts to improve irrigation efficiency through new technologies have been undertaken in many areas. However, irrigation methods in most farming regions of New Mexico have not changed significantly since the irrigated lands were originally developed. Drip irrigation remains a rarity throughout the state, despite research results showing potential crop yield and quality improvements with use of the technology (Wierenga and Hendrickx 1985).

The possibility that drip irrigation technology could increase yields, reduce the incidence of crop diseases, and improve fruit quality has been identified as a critical research issue by New Mexico chile pepper growers, processors, and researchers. These individuals are part of an inter-disciplinary research and development partnership that is seeking to identify and implement ways to keep chile pepper production and processing profitable in New Mexico. Concern about the long-term viability of commercial chile pepper production has arisen due to increased global competition, new or continuing disease and pest problems, increased competition for land and water resources, and ongoing agricultural labor difficulties. Many industry members, researchers, and extension specialists, and other observers believe drip irrigation is a technology which can help the local chile pepper industry compete in the global market.

In 1999 and 2000, extensive on-farm data gathering has been conducted in southern New Mexico, in areas of concentrated chile pepper and other vegetable production. Throughout 1999, members of the inter-disciplinary and inter-industry research group expressed numerous hypotheses regarding the low incidence of drip irrigation technology usage among southern New Mexico vegetable producers. Thus, a survey of chile growers in the southern region was conducted in mid-1999. The objective of the survey was to assess commercial chile pepper producers' attitudes toward and knowledge of drip irrigation technology. The survey also sought to identify current users and potential future adopters of advanced irrigation technologies. The research reported here uses the grower survey data to predict current high-tech irrigation system usage, drip irrigation usage, and plans for future drip irrigation adoption by chile pepper producers. The objective of this research is to provide information useful to local extension personnel, other chile pepper researchers, and chile industry members who are participating in the research initiative described above. The research results also have ramifications for the existing irrigation systems.

**Drip Irrigation**

Drip irrigation is defined as the application of water through point or line sources (emitters) on or below the soil surface at a small operating pressure (Dasberg and Or 1999). The term "trickle" is often used interchangeable with "drip." Other related, but broader, terms are “microirrigation” and “low-flow” irrigation. Microirrigation and low-flow include water application by sprayers and other devices above the ground, which usually results in partial wetting of the soil surface, although not to the extent of sprinkler irrigation.

Some microirrigation concepts date back to as early as 1917 (Howell 2000). However, commercial applications of microirrigation became feasible only after the post-World War II developments in plastic materials. Early advances in drip technology took place primarily in Israel from the 1950s into the 1970s. Usage of drip irrigation in the United States grew throughout the 1970s, and continues to increase at the current time. In 1999, low-flow irrigation systems were in use on 4.6% of the 64 million acres of irrigated farmland in the United States (Irrigation Journal 2000). In the same year, sprinkler irrigation accounted for 48.5% of irrigated acreage, while gravity or surface techniques were used on 46.9% of irrigated lands. Although it remains a small percentage of total irrigated acreage, drip irrigation in the United States has increased 650% since 1982 (Dasberg and Or 1999; Irrigation Journal 2000).

When drip irrigation is compared with surface or sprinkler irrigation technologies, its field application efficiency can be as high as 90%, compared to 60-80% for sprinkler and 50-60% for surface irrigation (Dasberg and Or 1999). With frequent drip irrigations it is possible to maintain an optimal balance between soil water and aeration. With surface irrigation, the soil may become saturated during irrigation, resulting in an inadequate supply of oxygen to the root zone. Plant growth and yield can thus be enhanced through the use of drip irrigation.

Drip technology also improves irrigation efficiency by reducing evaporation from the soil surface, reducing or eliminating runoff and deep percolation, and eliminating the need to drastically over-irrigate some parts of the field to compensate for uneven water application (Schwankl 1997). The application or injection of fertilizers and other chemicals can also be optimized through the use of drip irrigation, weed growth can be reduced, and salinity problems can be mediated. Relative to highly pressurized sprinkler irrigation systems, drip irrigation may require less energy. Drip irrigation systems also are very adaptable to difficult soil and terrain conditions.

Because plant foliage is kept dry during irrigations, the incubation and development of many plant pathogens is reduced with drip technology. Pathogen movement through fields via water flowing over the soil surface can be eliminated through the use of a drip system. Sub-surface drip irrigation permits growers to irrigate while workers, trucks, and other equipment are in the fields for harvesting, particularly beneficial for hand-picked vegetable crops or alfalfa hay, where surface or sprinkler irrigations cannot be conducted during harvest. Furthermore, drip irrigation systems can be easily automated and can include a variety of devices that sense field conditions, and adjust irrigation regimes accordingly.

Sub-surface drip irrigation does require changes in tillage equipment, although tillage operations are usually reduced by half when drip rather than surface irrigation is practiced (Johnson 2000). Soil compaction in fields is thus reduced, and operating costs are also lower as a result of reduced labor, fuel, and other machinery costs.

Although its benefits are numerous, drip irrigation is not without disadvantages. Drip systems require consistent maintenance and monitoring. Emitters can become clogged, and leaks can develop as a result of mechanical or animal damage. Salts can accumulate near the root zone as a result of inadequate flushing at the wetting front (Dasberg and Or 1999). Seeds may not germinate in fields where drip irrigation cannot be supplemented by surface or sprinkler irrigation early in the growing season. Microclimate control is reduced as a result of drip irrigation, while surface or sprinkler irrigation can lower air temperature around growing plants and thus reduce water stress and transpiration. Sprinkling can also provide frost protection. Finally, drip irrigation technology is expensive to install (costs range from $1000 - $3000 per acre), and requires high technical skills for proper design, maintenance, and optimum efficiency.

Drip irrigation clearly offers many advantages. Furthermore, many of the disadvantages described above can be compensated for through the use of a carefully designed and managed drip system (Schwankl 1997). Yet, with the exception of a few states, U.S. farmers' adoption of the technology has been minimal. In 1999, 88.2% of total irrigated area in Hawaii was under drip irrigation. In the same year, Michigan had 11.2% of irrigated lands using drip, while California and Florida had 6.6% and 5.2% of their irrigated acreage under drip, respectively (Irrigation Journal 2000). In most of the United States, drip technology is used on an extremely small fraction of irrigated lands. Examples include the arid states of Arizona (1.3%) and New Mexico (0.77%).

In the latter state, chile peppers (the state's signature vegetable crop) is under extreme pressure from so many forces that its immediate and long-term survival as an industry is in doubt. Thus, many university researchers, cooperative extension personnel, and industry members have identified drip irrigation as a change in the existing production system that would assist the industry. Many of these same people have asked why the adoption of drip irrigation technology in New Mexico has lagged behind virtually every other state in the country. Numerous competing hypotheses abound.

**Adoption and Diffusion of Agricultural Technologies**

Farmers' adoption of technologies, and the diffusion of those technologies throughout the agricultural population has been a central research issue in rural sociology and agricultural economics since the 1940s. Adoption-diffusion (A-D) research was summarized in a series of books by Rogers (1962, 1983 and 1995). Research in the field has examined A-D issues both in the United States and abroad, with extensive studies of agricultural technologies in developing countries. The study of adoption and diffusion of agricultural technologies in the United States began with a study of the spread of hybrid corn seed to Iowa growers (Ryan and Gross 1943). Sociologists were the leaders of A-D research throughout the 1950s, with the field of economics becoming dominant in the 1960s (Ruttan 1996). Griliches' (1957, 1958) study of the diffusion of hybrid corn in the 1950s is the landmark A-D research using economic analysis.

In the 1980s and 1990s, empirical economic studies of the adoption and diffusion of innovations were expanded to farmers' adoption or rejection of conservation and other environmentally oriented technologies. Farmers' soil conservation decisions were evaluated by Norris and Batie (1987) in a Tobit modeling framework. Farmers' willingness to participate in the Water Quality Incentives Program in the Cornbelt was modeled using binomial logistic regression analysis by Kraft, Lant and Gillman (1996). Logistic regression was also applied by Thomas, Ladewig and McIntosh (1990) in their study of the adoption of integrated pest management practices among Texas cotton growers. Probit procedures were used to examine the adoption of nitrogen testing by Nebraska farmers (Bosch, Cook and Fuglie 1995).

The adoption of advanced or water conserving irrigation technologies by farmers also has been a subject of research. Caswell and Zilberman (1985) applied a multinomial logit framework to predict irrigation technology choice (drip, sprinkler, or surface) as a function of water cost differentials, farm location, water source, and crops grown by perennial crop growers in the San Joaquin Valley of California. Higher water costs, the use of groundwater, the production of nuts, and location were found to increase the likelihood of using drip and sprinkler irrigation.

Caswell and Zilberman (1986) also examined the effects of well depth and land quality on a farmer's choice of irrigation system using a production function approach. Their findings indicated that the adoption of "modern" irrigation technologies (e.g., drip or sprinkler systems) was more likely in locations with relatively low land quality and expensive water (i.e., deep wells), while traditional surface irrigation technologies are more likely used in locations with heavy, leveled soils and cheap water.

Lichtenberg (1989) studied the diffusion of center pivot technology in the northern High Plains using a multinomial logit regression model of county-level cropland allocations of seven major crops. He found that the adoption of center pivot technology had induced significant changes in cropping patterns, and that land quality-augmenting technologies like center pivot irrigation will tend to be adopted especially rapidly on lower qualities of land.

The adoption and diffusion of drip irrigation technology in Hawaii was examined by Shrestha and Gopalakrishnan (1993). They stated that in Hawaii's sugar industry, the choice of drip was originally motivated by concern for water conservation, then changed to desires for yield increases, as growers became more experienced with drip technology. The Shrestha and Gopalakrishnan probit model was formulated such that choice of drip technology was a function of expected differentials in water use and yields, plant cycle, plantation location, soil types, temperatures, and field gradients. The authors concluded that use of drip technology in Hawaii is likely to expand onto marginal sugar-producing lands as well as increase yields on higher quality soils.

Lynne, Casey, Hodges and Rahmani (1995) researched a variety of competing theories to explain the adoption of water saving technology by Florida strawberry farmers. The authors developed attitudinal scales from data for a sample of farmers, and developed Tobit models to examine the competing theories of micro-irrigation technology adoption. They concluded that both Planned Behavior Theory and Derived Demand Theory explain strawberry farmers' irrigation technology investment behavior.

**Methods**

***The Data.*** A two-part questionnaire designed to assess chile pepper producers' attitudes toward and knowledge of drip irrigation technology was developed in 1999. Part I consisted of 57 attitudinal or knowledge statements, with possible responses ranging from *strongly disagree* (scored as 1) to *strongly agree* (scored as 5), including *undecided* (equal to 3). Part II consisted of questions dealing with demographic, crop production, and other characteristics of the survey respondent. The content of the questionnaire was designed using input from members of the inter-disciplinary and inter-industry chile pepper research group (which included numerous commercial chile pepper growers). The literature summarized above was also consulted during the process of instrument development.

A list of New Mexico chile pepper producers was obtained from the U.S. Department of Agriculture (USDA). As of 1998, USDA records indicated there were 447 pepper producers in the state. Of this total, 329 (73.6%) were producing less than 50 acres of chile peppers. Upon the recommendation of producers participating in the research project, the drip irrigation survey research was limited to growers with 50 or more acres of chile peppers. These growers were characterized as "commercial" producers. After adjustment for incomplete responses, undeliverable mailings and growers who sent back their survey packet with notes that they were no longer raising chile peppers, the final response rate to the survey was 53.1%, or 60 usable responses. All data are summarized and reported in a forthcoming New Mexico Agricultural Experiment Station Research Bulletin (Skaggs, Hillon and Phillips 2000).

***Modeling Techniques***. The purpose of qualitative choice models is to determine the probability an individual with a given set of attributes will make one choice rather than one or more alternative choices (Pindyck and Rubinfeld 1991). Choice models predict the likelihood that an individual, household, or firm will choose an option that will have some relationship to their attributes (i.e., demographics, socio-economic characteristics, or attitudes).

The binomial logit qualitative choice model is based on the cumulative logistic distribution and is specified as:

(1) $P_i = E(Y_i = 1^* X_i) = 1 / (1 + e^{-z_i})$,

where $Z_i = \beta_1 + \beta_2 X_i$, e is the base of natural logarithms (approx. equal to 2.718), $Y_i = 1$ for choice = 1 ("success") and $Y_i = 0$ for choice = 0 ("failure"). $P_i$ is the probability that an individual will make a certain choice when faced with two choices, given $X_i$ (individual attributes or characteristics) (Brown 1991).

Equation 1 above implies that:

(2) $1 - P_i = 1 / (1 + e^{z_i})$.

The odds ratio, or the probability of making one choice relative to the other is calculated by:

(3) $P_i / (1 - P_i) = (1 + e^{z_i}) / (1 + e^{-z_i}) = e^{z_i}$.

Therefore, if $P_i = 0.8$ then the odds ratio would be 4. This means that the odds are 4 to 1 in favor of the $i^{th}$ individual making the choice (e.g., buying a car versus not buying a car, or attending college versus not attending college). Taking the natural log of equation 3 will give the value of the logit ($L_i$) as illustrated in equation 4.

(4) $L_i = \ln [ P_i / (1 - P_i )] = \ln(e^{z_i}) = Z_i = \beta_1 + \beta_2 X_i + u_i$ ,

where $u_i$ is the stochastic disturbance term, and the regression or $\beta$ coefficients for the logit model are estimated using maximum likelihood techniques. A unique value for $P_i$ is found by taking the antilog of equation 4 and rearranging terms.

After the $\beta$ coefficients have been estimated, the probability a given individual will make a certain choice is calculated by substituting in specific values for the explanatory variables or attributes (i.e., income, age, education, etcetera). Probabilities are usually evaluated at the mean values of the explanatory variables (X's); and can also be evaluated at different, or representative values of the explanatory variables. The marginal effects of changes in explanatory variables can be analyzed by recalculating the probabilities when the variable takes different values with all other variables held constant (usually at their means) (Greene 1993).

When using logit models, the standard $R^2$ as a measure of the validity of the model has little meaning (Brown 1991). Alternative measures of goodness-of-fit used in this research were the likelihood ratio test with a $P^2$ statistic, hit-and-miss ratios, and McFadden pseudo-$R^2$. Goodness-of-fit was also evaluated by comparing the actual mean probabilities for the sample to the predicted mean probabilities generated by the model.

The hit-and-miss ratio compares the number of accurate and inaccurate outcomes predicted by the model to the actual outcomes for individuals in the sample. The McFadden pseudo-$R^2$ measurement is defined as:

(5) McFadden pseudo-$R^2 = 1 - ( LL_f / LL_c )$ ,

where $LL_f$ is the log of the likelihood function from the fitted model (unrestricted) and $LL_c$ is the log of the likelihood function containing only the constant (restricted). The standard t-test was also used to determine if the individual \$ coefficients were significantly different from zero.

The likelihood ratio test is the validity test most frequently used for qualitative choice models. Its null hypothesis holds that a model with only the intercept is better than the fitted model including explanatory variables. The test statistic follows a $P^2$ distribution with k degrees of freedom, where k is the number of independent variables in the model. The likelihood ratio test is calculated by:

(6) $D = -2( LL_c - LL_f )$.

If D exceeds the table value at the chosen level of significance, the null hypothesis is rejected in favor of the alternative hypothesis. It can then be concluded that the fitted model explains the dependent variable better than the model containing only the intercept.

***Hypotheses and Variable Selection.*** Variables were tested and selected for inclusion in the models reported below based on several factors. First, the A-D literature summarized above was consulted. Based on review of previous research, variables such as grower age, grower education, farm size, farm tenure, contact with cooperative extension personnel, off-farm employment, and net farm income were hypothesized to be variables that could help predict growers' use of high technology irrigation systems, drip irrigation systems, or intentions to install or expand drip irrigation on their farms.

Farmers participating with the inter-disciplinary and inter-industry research group expressed many hypotheses as to why chile pepper producers either do or do not use drip irrigation technology. They stated that growers fear losing water rights as a result of using water conserving technology, that growers are hesitant to adopt drip due to the cost, and that they are unwilling to invest the necessary time and effort to learn to operate and maintain a high technology irrigation system. The participating growers also believed that many of their colleagues think there are too many intractable technical problems with drip irrigation, and that many farms are too small to justify the large per acre investments necessary for state-of-the-art drip irrigation systems. The opinion was also expressed that farmers in southern New Mexico have already made so many investments in their current flood/furrow irrigation systems that they are unwilling to abandon those investments for the latest flashy technology. These investments include on-farm concrete ditch lining, which has been promoted extensively by USDA agencies in the region.

During the time the survey research was being designed (1999), the New Mexico chile pepper industry was experiencing widespread, weather-related crop failure that led to dramatic decreases in local crop production. Most growers are also aware of continuing growth in imports of fresh chile peppers from northern Mexico, and the likelihood their industry will probably soon lose access to pesticides for which no substitutes are currently available. Many commercial-sized growers in the region were also subject to extensive monitoring by U.S. Department of Labor officials during the 1998 and 1999, and experienced continuing difficulties in obtaining field labor. Disputes over surface water resources are ongoing in the state, and will most likely intensify in the near future.

Given these factors, many people in the research groups, and especially growers, have expressed pessimism about the future of the New Mexico chile pepper industry, and thus questioned why most growers would be interested in making large irrigation system investments. This pessimism was also manifested in some grower unhappiness with the role New Mexico State University (NMSU) has played in the chile pepper industry for the past several years. These chile pepper producer comments were incorporated into survey questions, with the survey responses tested for use as explanatory variables in the models reported below.

An additional hypothesis which was applied during variable testing and selection concerned the location of the chile pepper producers who responded to the survey. Forty-five percent of the respondents were located in the western production region, located in southern New Mexico's boot-heel region. Farms in this area are irrigated exclusively with groundwater, for which there is no significant source of recharge. Therefore, it would be expected that growers in this region would have a strong incentive to make investments in drip irrigation technology, so as to maximize their application efficiency (and thus prolong their eventual extinction). There is no urbanization or farmland conversion pressure in this region. Arid, desert soils characterize the region.

The central production region consists of the area surrounding the Rio Grande, and consists primarily of high quality, river basin farmlands within the Elephant Butte Irrigation District. Flood/furrow irrigation using surface water is the principal means of irrigation, although most large farms are able to pump groundwater when necessary. There is extensive urbanization pressure and farmland conversion throughout this production region, which is one of the fastest growing counties in the United States. The quantity and quality of water resources in the area are a continuous source of contention between Texas and New Mexico; the U.S. and Mexico; agricultural users, municipal/industrial users, and environmentalists. The hydrology of the area is extremely complex.

The eastern production region is irrigated by both the Pecos River and groundwater, and includes the Carlsbad Irrigation District. The Pecos River has been subject to extensive litigation between Texas and New Mexico in past years, with New Mexico currently subject to stringently monitored interstate delivery obligations. The area is experiencing low to moderate population growth and farmland conversion. State and federal agencies have also recently begun leasing Pecos River water rights from farmers for the purpose of maintaining instream flows, and deliveries into Texas.

During the model development phase, it was hypothesized that production region would be a useful variable in predicting use of high technology or drip irrigation systems, and farmers' likelihood of using drip technology in the future. Regional differences exist primarily due to variations in irrigation water sources, soil types, urbanization pressure, and overall outlook for production agriculture in the area.

**Findings**

Three predictive models were developed using the data and methods described above. The dependent variable for Model 1 was whether or not the grower was a current drip or sprinkler system user ($Y_i = 1$ if yes). The dependent variable for Model 2 was $Y_i = 1$ if the grower was a current drip irrigation user, while the dependent variable for Model 3 was $Y_i = 1$ if the grower indicated they were likely to install a drip irrigation system on their farm in the next five years (either for the first time, or adding onto an existing system). Numerous explanatory variables were tested during the development of the three models. Explanatory factors selected for inclusion in the models reported here were chosen based on estimated coefficients' levels of significance, and overall predictive abilities or model validity.

The model results, including estimated coefficients, significance levels, and variable means are presented in Table 1. Table 2 shows measurements of model validity, and Table 3 presents the probabilities of outcomes for each model at mean explanatory variable values, and different levels of the explanatory variables.

***Model 1.*** The growers were divided into two groups: those that currently use only surface or flood irrigation methods (65%), and those currently using drip and/or sprinkler systems on their farms (35%). This stratification split the growers into high-and low-tech irrigators. The results for Model 1 (Table 1) indicate that as age increases, the probability a grower will be a high-tech irrigator decreases. The probability of currently using drip or sprinkler technology increases with farm size, and is reduced for growers who report producing other vegetables in addition to chile peppers (i.e., lettuce, cabbage, pumpkins, watermelon). As a grower's level of on-farm concrete ditch lining increases, the likelihood of using drip or sprinkler irrigation decreases. With respect to attitudes, grower optimism regarding the future of chile production in New Mexico is related to an increasing probability of high-tech irrigation, as is a positive attitude toward NMSU's assistance to the state's chile producers. Also, growers located in the eastern and central production chile production regions have a lower probability of being drip or sprinkler irrigators than growers in the western production region.

***Model 2.*** The sample of growers was also divided into two groups based on whether they were currently using a drip irrigation system (17%) or not using drip (83%). Similar to Model 1, Model 2 results show that the probability of being a drip irrigator decreases as grower age increases, and that larger farms are more likely to currently have drip irrigation systems (Table 2). The grower belief that water rights could be lost if less irrigation water were used did not decrease the probability of drip irrigation (as had been expected), but rather increased the probability of drip use. A positive grower attitude toward NMSU increases the probability of drip irrigation usage, while the probability of drip technology is again found to be lower for growers in the eastern and central production regions.

***Model 3.*** As a dependent variable, Model 3 uses a survey question that asked producers to speculate about their future drip irrigation plans. Growers were divided into two groups, either likely (51%) or unlikely (49%) to install a new system (or expand an existing system). Grower age was found to be negatively related to future drip irrigation plans (Table 3). On-farm concrete ditch lining increases the probability a grower will express positive drip irrigation plans. Larger farmers show a greater likelihood of future installation or expansion of drip technology, as do growers for whom chile peppers are a more important crop (e.g., chile acres as a share of total acres farmed). Future drip irrigation plans are less positive for growers in the eastern and western production regions, relative to central region growers.

With respect to the hit-or-miss ratio, Model 1 correctly predicted 78.3% of the respondents' use or non-use of high-tech irrigation systems, while Model 2 produced accurate predictions 88.3% of the time. Model 3 was the weakest with respect to predictive accuracy, correctly hitting 73.3% of the time. Model 2 tended to underpredict the incidence of drip irrigation systems. Seventeen percent of the survey respondents currently use drip systems on their farms; Model 2 was able to predict only a 6% level of usage. The predicted mean probability of high-tech irrigation from Model 1 was also lower than the actual responses (at 30%, rather than 35%). These results indicate that both models are lacking one or more explanatory variables that are closely linked to the adoption of either drip or sprinkler irrigation. However, even with this obvious weakness, the hit-or-miss ratios of both Model 1 and Model 2 were relatively high.

The accuracy of Model 3 was high across the entire group of respondents, with predicted mean probabilities only one point away from actual responses. However, the percentage of accurate predictions was lowest for this model (at 73.3%). This indicates that while the model is quite robust in predicting future drip irrigation plans for the overall group, approximately a fourth of the respondents were not predicted correctly. However, these errors tended to cancel each other out.

Table 3 expands on the directions of effect for each model's explanatory variables, by showing calculated probabilities over a range of variables. This information provides a sensitivity analysis of the models' results. The effects of grower age and total acres farmed are demonstrated in this table. Older growers have much lower probabilities of current use of either drip or sprinkler irrigation, and are also the least likely to have plans to installing a drip system in the next five years. Growers who are 35 years of age or younger have at least a 75% probability of stating they are likely to install a system. The largest farms have the highest probabilities of planned drip irrigation adoption. Probabilities calculated for Model 3 show that the largest growers have an almost 100% probability of future drip irrigation plans. Concrete ditch lining has the hypothesized negative effect on actual usage of advanced irrigation technologies. However, the likelihood of installing drip irrigation in the future increases as the percentage of lined on-farm ditches increases. The explanatory variable reflecting a grower's intensity of chile pepper production (relative to total farmed acres) shows a strong trend toward future drip irrigation plans for individuals most dependent on the chile pepper crop.

Chile pepper growers who do not also produce other vegetable crops have a 37% probability of being a current high-tech irrigator. Growers who are optimistic about the future of New Mexico chile production have a 43% probability of being a current high-tech irrigator. Growers who have the most positive attitudes toward NMSU have an almost 50% probability of being high-tech irrigators, and an 18% chance of using drip irrigation. For producers with negative attitudes toward the university, the likelihood they will be drip irrigators is extremely small (2%), but somewhat higher that they will fall into the category of high-tech irrigators (16%).

The belief that water rights will be lost as a result of using drip irrigation does not have the effect hypothesized by members of the research group. The probability of being a current drip irrigation user is highest for individuals who believe they *could* lose water rights.

The inclusion of dummy variables for two of the three regions was tested in each model. Results were unacceptable, and thus regions were grouped together in the final models, with appropriate dummy variable coding. The western region of the state currently has the highest incidence of overall high-tech irrigation (i.e., drip or sprinkler), likely due to the exclusive use of groundwater. This situation is reflected in both Model 1 and Model 2, where western region growers are shown to have significantly higher probabilities of current sprinkler and/or drip system use.

In Model 3, the growers were grouped differently by region in order to identify a significant location effect. Central region growers have a 69% likelihood of drip irrigation plans within a five-year planning horizon. This effect may be a result of the recent intensive efforts by NMSU research and extension personnel, various USDA agencies, and the inter-industry research group to publicize and promote drip irrigation as a remedy for the local industry. Although these efforts are not confined to the central region, they are most visible there (largely due to the location of the university). Also, it may be that the confluence of forces working against the chile pepper industry in the Rio Grande area has provoked growers to seriously consider their future production options.

**Conclusions and Implications**

From the beginning of survey instrument design, and through the econometric analysis reported here, the primary objective of this research has been to provide information useful to chile pepper research, extension, and industry. Numerous members of the inter-disciplinary and inter-industry group have expressed puzzlement over local farmers' continued reliance on flood/furrow irrigation practices. Initial hypotheses revolved around irrigation system costs, water rights, farmer lack of information and pessimism. The logistic regression modeling effort reported here attempted to test these and other hypotheses using survey data obtained from the larger chile pepper producers in the state. The independent variables tested and rejected for inclusion in the final models had very weak explanatory powers. With respect to the variables included in the final models, the findings supported some of the research group hypotheses, but rejected others.

The independent variables included in the final models, and reported here tended to confirm findings of previous A-D research (i.e., grower age and farm size). Results of this research are also consistent with the conclusions of Caswell and Zilberman (1986), Lichtenberg (1989), and Shrestha and Gopalakrishnan (1993), who found that advanced irrigation technologies tend to be adopted first in areas with relatively low land quality and expensive water (particularly deep groundwater). These results show that growers in eastern New Mexico have higher probabilities of currently using sprinkler or drip irrigation systems. For Eastern New Mexico chile pepper producers, drip irrigation likely has the role of land-quality augmentation found by previous researchers.

These results provide new information to research, extension, and industry. But they also raise questions about the "fallacy of composition." This problem arises when there is an inverse relationship between the pursuit of individual goals and group results (Knutson, Penn, and Flinchbaugh 1998). Individual farmers and landowners may decide to invest in drip irrigation based on their assessment that benefits will outweigh costs for their own farming operations. And, as shown in the model results above, approximately 50% of the growers indicated they are likely to install drip irrigation within five years. The likelihood of drip irrigation adoption is very high for growers with some attitudes and attributes. However, growers' future on-farm irrigation investment decisions in the Rio Grande and Pecos River basins have the potential to negatively impact the overall hydrologic systems in those regions.

This issue has been recognized and described at length by other authors (Seckler 1996; Burke and Adams 1999). An on-farm water conservation measure may create on-farm water savings and increase on-farm water use efficiency, but the savings created may also reduce return flows that are obligated for downstream users. This difference has been defined as "wet" versus "dry" water savings (Seckler 1996). "Wet" water savings result in real gains in efficiency and real water savings, as in when water use by phreatophytes[1] is reduced through removal of the plants. Alternatively, "dry" water savings occur when drainage water or deep percolation is reduced. Water is thus saved by an upstream user, but water availability is decreased for downstream users who had previously made use of the return flows (King 2000).

The Rio Grande and the Pecos River have interstate and international delivery obligations. On-farm irrigation technology decisions in both irrigated areas can thus

[1] A deep-rooted plant that draws its water from the water table or other permanent ground supply.

affect water use and conservation on a larger scale. The impacts of widespread adoption of drip irrigation technology in New Mexico should therefore be examined from both on-farm and larger hydrologic perspectives. While drip irrigation offers many significant advantages over flood/furrow irrigation at the individual farm level, multi-user irrigation systems may not fare well as a result of widespread, or even moderate, adoption of drip irrigation.

Although drip irrigation has the reputation of reducing on-farm water use, this phenomenon would not necessarily be true for irrigated crop production in Southern New Mexico. Most surface irrigation as it is currently conducted in the state is deficit in nature. Deficit irrigation creates plant stress, which makes crops more susceptible to diseases, insects, and environmental damage. Deficit irrigation practices and consequent production problems result in reduced yields, however they also contribute to relative high on-farm application efficiencies. Drip irrigation could actually increase consumptive use of water in the region because plants grown under drip systems are never allowed to go into water deficit stress. Yields could increase significantly as a result of this effect, the reduction in diseases, insects, and environmental damage, and the fine-tuning of fertilizer applications. With no net reduction in crop acreage (in New Mexico's central and eastern production regions), farmers' adoption of "water saving " technologies could both increase water use and reduce downstream flows.

The future of drip irrigation in the chile pepper producing regions of New Mexico is a complicated issue. Research and extension personnel, whose primary clients are farmers, tend to believe that they must promote the technology to the industry because of its demonstrated on-farm benefits. Individuals who are knowledgeable about the hydrologic systems and water issues in the Rio Grande and Pecos River production regions are more circumspect about "advanced" irrigation technologies. They tend to view irrigation efficiency in a system-wide, rather than on-farm, context. Thus, the results of this research could very well be used to promote two very different agendas.

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## Table 1. Model Results and Variable Means.

| | | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|---|
| | | Is grower currently irrigating with a drip or sprinkler system? Yes = 1 No = 0 | | Is grower currently irrigating with a drip system? Yes = 1 No = 0 | | How likely is grower to install a drip irrigation system on their farm in the next 5 years? Very likely or somewhat likely = 1 Not likely or very unlikely = 0 | |
| **Independent Variable** | **Mean** | **Estimated Coefficient** | **P-value** | **Estimated Coefficient** | **P-value** | **Estimated Coefficient** | **P-value** |
| Intercept | --- | 1.60 | 0.41 | 2.67 | 0.26 | -0.81 | 0.70 |
| Grower age (years) | 51.9 | -0.05 | 0.14 | -0.12 | 0.04 | -.06 | 0.04 |
| Total acres farmed by grower | 870.6 | .0015 | 0.05 | .0009 | 0.07 | .0016 | 0.02 |
| Grower produces vegetables other than chile peppers (Yes = 1, No = 0) | 0.15 | -2.20 | 0.11 | | | | |
| Grower located in central or eastern region (Yes = 1, western region = 0) | 0.55 | -1.02 | 0.15 | -2.18 | 0.03 | | |
| Percent on-farm ditches concrete-lined | 59.7 | -.021 | 0.04 | | | .019 | 0.05 |
| Grower optimistic about future of NM chile production (Yes = 1, No = 0) | 0.42 | 1.01 | 0.14 | | | | |
| Grower believes NMSU has been effective in assisting chile producers (Yes = 1, No = 0) | 0.48 | 1.62 | 0.03 | 2.27 | 0.05 | | |
| Grower believes water rights will be lost if they use less irrigation water (Yes = 1, No = 0) | 0.18 | | | 1.56 | 0.17 | | |
| Grower located in eastern or western region (Yes = 1, central region = 0) | 0.67 | | | | | -1.11 | 0.67 |
| Chile pepper acres as percentage of total farmed acres | 0.23 | | | | | 10.49 | 0.01 |

**Table 2. Measurements of Model Validity (n = 60).**

| | Percentage of accurate predictions (Hit-or-miss ratio) | Actual Responses from Survey Results (%) | Predicted Mean Probabilities from Model Results (%) | Log of the Likelihood Function | Restricted Log of the Likelihood Function | ?$^2$ | McFadden pseudo-$R^2$ |
|---|---|---|---|---|---|---|---|
| **Model 1** | | | | | | | |
| Grower uses drip or sprinkler irrigation system | 78.3 | 35 | 30 | -27.73 | -38.85 | 22.24 | .29 |
| Grower uses only surface irrigation | | 65 | 70 | | | | |
| **Model 2** | | | | | | | |
| Grower currently uses a drip irrigation system | 88.3 | 17 | 6 | -17.79 | -27.03 | 18.48 | .34 |
| Grower uses surface and/or sprinkler irrigation | | 83 | 94 | | | | |
| **Model 3** | | | | | | | |
| Grower is likely to install a drip system in the next 5 years | 73.3 | 50 | 51 | -30.65 | -41.59 | 21.88 | .26 |
| Grower unlikely to install a drip system in the next 5 years | | 50 | 49 | | | | |

## Table 3. Probabilities Calculated for Different Explanatory Variable Values.

| | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| | Yes – Current Drip or Sprinkler Irrigator | No – Current Drip or Sprinkler Irrigator | Yes – Current Drip Irrigator | No – Current Drip Irrigator | Likely to install drip irrigation within 5 years | Unlikely to install drip irrigation within 5 years |
| Mean Attribute Values: | .30 | .70 | .06 | .94 | .51 | .49 |
| Grower Age: | | | | | | |
| 25 | .61 | .39 | .63 | .37 | .85 | .15 |
| 35 | .49 | .51 | .34 | .66 | .75 | .25 |
| 45 | .37 | .63 | .13 | .87 | .62 | .38 |
| 55 | .27 | .73 | .04 | .96 | .46 | .54 |
| 65 | .18 | .82 | .01 | .99 | .31 | .69 |
| 75 | .12 | .88 | .00 | 1.00 | .19 | .81 |
| Total Acres Farmed: | | | | | | |
| 100 | .15 | .85 | .03 | .97 | .23 | .77 |
| 250 | .17 | .83 | .04 | .96 | .28 | .72 |
| 500 | .22 | .78 | .05 | .95 | .37 | .63 |
| 750 | .27 | .73 | .06 | .94 | .46 | .54 |
| 1000 | .33 | .67 | .07 | .93 | .56 | .44 |
| 1500 | .46 | .54 | .10 | .90 | .74 | .26 |
| 2000 | .61 | .39 | .15 | .85 | .86 | .14 |
| 2500 | .73 | .27 | .21 | .79 | .93 | .07 |
| 3000 | .83 | .17 | .29 | .71 | .97 | .03 |
| Grower produces vegetables other than chile peppers. | | | | | | |
| Yes | .06 | .94 | | | | |
| No | .37 | .63 | | | | |
| Grower is located in central or eastern region. | .21 | .79 | .02 | .98 | | |
| Grower is located in western region. | .42 | .58 | .18 | .82 | | |
| Percentage of on-farm ditches that are concrete-lined: | | | | | | |
| 10% | .54 | .46 | | | .29 | .71 |
| 25% | .46 | .54 | | | .35 | .65 |
| 50% | .34 | .66 | | | .46 | .54 |
| 75% | .23 | .77 | | | .58 | .42 |
| 100% | .15 | .85 | | | .69 | .31 |
| Grower is optimistic about the future of NM chile production. | | | | | | |
| Yes | .43 | .57 | | | | |
| No | .22 | .78 | | | | |
| Grower believes NMSU has been effective in assisting chile producers. | | | | | | |
| Yes | .49 | .51 | .18 | .82 | | |
| No | .16 | .84 | .02 | .98 | | |
| Grower believes water rights will be lost if they use less irrigation water. | | | | | | |
| Yes | | | .19 | .81 | | |
| No | | | .05 | .95 | | |
| Grower located in eastern or western region. | | | | | .42 | .58 |
| Grower located in central region. | | | | | .69 | .31 |
| Chile pepper acres as a percentage of total farmed acres: | | | | | | |
| 10% | | | | | .21 | .79 |
| 25% | | | | | .56 | .44 |
| 50% | | | | | .95 | .05 |
| 75% | | | | | .99 | .00 |