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Don E. Albrecht
Texas A&M University

Howard Ladewig
Texas A&M University

ADOPTION OF IRRIGATION TECHNOLOGY: THE EFFECTS OF PERSONAL, STRUCTURAL, AND ENVIRONMENTAL VARIABLES

Don E. Albrecht and Howard Ladewig
Department of Rural Sociology,
Texas A&M University

ABSTRACT During the past decade, there has been a growing interest in expanding the list of factors affecting the adoption and diffusion of agricultural technology. It has been suggested that most previous research efforts have been insensitive to contextual variables and institutional constraints. The physical environment has been suggested as one contextual variable that has been largely ignored in past adoption-diffusion research. The present study tested for the relative effects of a site-specific indicator of the physical environment (saturated thickness), as well as personal attributes and farm structural characteristics for the adoption of irrigation innovations in the Texas High Plains. The results revealed that saturated thickness is an important variable in understanding the adoption of the irrigation innovations considered. While a multivariate analysis revealed that farm size overall was the most important variable, the environmental factor was more important than traditional research variables selected for use in this study. It is concluded that the use of environmental variables does contribute to our knowledge of adoption of technology and should be included in studies of the diffusion of innovations.

Introduction

During the past half century, the development of improved agricultural technologies, and the eventual adoption of these technologies by farm operators, has led to extensive changes in agriculture and American society (Berardi and Geisler, 1984; Cochrane, 1979; Dillman and Hobbs, 1982; Hawley and Mazie, 1981; Summers, 1983). Adoption of yield-increasing and labor-saving technologies has enabled farmers to increase yields, expand operations, and increase efficiency ratios. Modern technology in agriculture also has reduced the need for human labor (Bertrand, 1978) and has resulted in farm production becoming increasingly concentrated on fewer and fewer farms (Paarlberg, 1980; Stockdale, 1982).

Because of the extensive implications of the adoption of agricultural technologies for American society, interest remains high in the adoption and diffusion of innovations in general, and farm technology in particular (Fliegel and van Es, 1983; Rogers, 1983). Unfortunately, current researchers face a similar problem to that faced by researchers of previous decades--all members of the population of potential adopters do not adopt simultaneously and some never adopt. This incomplete level of adoption prevails despite the theoretical and practical justification for the practices, despite the economic rationality for adoption, despite the thoroughness with which information is diffused through various media, and despite the length of time the practices have been advocated (Copp, 1956).

In attempting to identify factors affecting adoption, diffusion research focused on differences between adopters and nonadopters in terms of economic, social, psychological, and demographic characteristics (Brown, 1981). Numerous studies also examined differences in characteristics of the individual farm unit (Rogers, 1983). More recent research, however, indicates that while such differences may exist, these factors alone do not adequately explain differences in adoption (Crawford and Ward, 1974; Fliegel and van Es, 1983; Goss, 1979). Additional explanatory factors being recommended include the relationship between adoption and environmental conditions (Ashby, 1982; Dunlap and Martin, 1983) and between adoption and institutional constraints (Brown, 1981; Goss, 1979; Havens and Flinn, 1975; Hooks et al., 1983).

Researchers in developing countries have found these additional explanatory variables to be important in understanding the adoption and diffusion of agricultural technology (Ashby, 1982; Ashby and Coward, 1980; Gartrell and Gartrell, 1980). For example, after examining the adoption of "green revoluation" technologies in six low-income countries, Perrin and Winkelman (1976:893) made the following conclusion:

> The most pervasive explanation of why some farmers do not adopt new varieties and fertilizers while others do is that the expected increase in yield for some farmers is small or nil, while for others it is significant, due to differences (sometimes subtle) in soils, climate, water availability, or other biological factors.

However, the value of such factors for understanding adoption in a highly industrialized agricultural system has not been explicitly assessed in recent years. This is somewhat surprising since one of the few studies to examine the relationship between the physical environment and adoption (Gibbons, 1964) found that the rate of irrigation development in Texas counties was inversely related to the amount of rainfall in the county and to the cost of irrigation. In other words, farmers adopted irrigation as a farming practice in areas where it was needed most (low rainfall) if the costs were not excessive. He concluded that attempts to understand the diffusion of irrigation in Texas without considering such environmental conditions could be misleading.

The purpose of this paper is to apply an extended adoption model to the adoption of irrigation technology in the Texas High Plains--an area faced with diminishing water resources and an incomplete level of adoption of energy-efficient and water-efficient irrigation technology. This extended model includes some personal attributes and farm characteristics commonly used in previous adoption research efforts and some location-specific environmental factors. The paper continues with a brief overview of irrigation in the Texas High Plains and of recent innovations related to irrigation. Some variables assumed to be important in the adoption of irrigation innovations are then discussed. Finally, the relative strengths of the different variables in explaining adoption versus nonadoption are empirically assessed. Because of the importance of irrigation to agriculture on the High Plains (Green, 1973) and the contribution of agriculture to the general economy, knowledge of factors affecting the adoption of energy-efficient and water-efficient irrigation technology can provide a basis for increased understanding of the extent and direction of future changes of both the farm and nonfarm economy and population throughout the Great Plains (Fliegel and van Es, 1983).

Irrigation in the Texas High Plains

In recent decades, the Texas High Plains has become one of the most productive agricultural regions in the United States. Much of this increased productivity is a direct result of the conversion of millions of acres from dryland to irrigated agriculture, with the vast majority of the irrigation water being drawn from the extensive Ogallala aquifer (Bittinger and Green, 1980; Green, 1973). Irrigation development not only increased crop production (Casey et al., 1975), it also had major social and economic implications. As agriculture flourished, so did allied and secondary businesses (Bittinger and Green, 1980). In fact, it appears that irrigation development resulted in higher levels of agricultural employment and a greater likelihood of population retention in rural areas than otherwise would have been possible (Albrecht et al., 1984; Albrecht and Murdock, 1985; Gibbs, 1964; Green, 1973).

Much attention recently has been directed toward the fact that pumpage from the Ogallala aquifer is considerably greater than the estimated recharge (Supalla et al., 1982) and that in the long term, the aquifer will not support present levels of irrigation (Shelley, 1983; Williams and Banks, 1982). Pumpage from the Ogallala also faces a second major problem--rising energy costs (Pimentel and Pimentel, 1979). Since 1972, the price of natural gas, the predominant fuel used to power irrigation pumping plants, has increased by 900 percent (Allen, 1983) and has brought into question the economic feasibility of continued irrigation of High Plains agriculture. Not only is the cost of energy increasing, but as the water table declines, the amount of energy required to lift a unit of water increases.

The implications of reverting to dryland agriculture in the Texas High Plains could be extensive (Kromm and White, 1983; Supalla et al., 1982; Templer, 1983). A decline in the amount of irrigation in the Great Plains could result in reduced agricultural productivity, fewer and less productive farms, and a decline in both total and farm population (Albrecht and Murdock, 1985). Maintaining irrigation as a feasible alternative into the foreseeable future depends primarily on a large number of farm operators adopting more efficient irrigation techniques. Researchers have assumed that the use of these technologies will allow farmers to maintain current levels of crop production while reducing both the amount of water pumped and the energy used. Thus, the adoption of efficient irrigation techniques should benefit both the individual farmer and a High Plains society that depends on a productive agricultural economy.

Irrigation technology

Four improved irrigation techniques recommended to farmers include furrow diking, soil moisture detection, center-pivot sprinklers, and return pits.

Furrow diking: This irrigation technique involves placing dikes at specified intervals in the furrow to reduce water runoff (Clark, 1979). By holding the water in the furrow, more of it can be used by the plant. Furrow diking, therefore, not only conserves water, it also reduces energy costs since less pumping is required.

Soil moisture detection: Farmers typically schedule irrigation by watching their crops and applying water when they see signs of wilting or stress. However, using above-ground plant parts as moisture indicators is not efficient. By the time plants start to wilt from lack of water, yields have already diminished. Overwatering, on the other hand, also reduces yields and, in addition, drives up irrigation energy costs and reduces water supplies.

Irrigation can be fine tuned by detecting moisture levels in the root zone. Moisture-detecting devices facilitate more efficient irrigation scheduling and can reduce irrigation pumping by an estimated 20 to 50 percent (Svenson, 1983; Clark and Hiler, 1973).

Center-pivot sprinklers: Historically, much of the cropland irrigated in the High Plains has been furrow irrigated. In recent years, center-pivot sprinkler irrigation systems have increased in popularity because of their lower labor requirements, their adaptability to rolling terrain and sandy soils, and their higher application efficiency. Keese (1980) reports that sprinkler irrigation has an 80 percent water efficiency rating, compared with 60 percent for furrow irrigation. Thus, the use of center-pivots conserves both water and energy. A major drawback to the center-pivot system, however, is its high initial cost.

Return pits: Farmers in the High Plains who use furrow irrigation often have excessive water runoff from the lower end of the field. One conservation technique consists of digging a pit to catch the water runoff. This water can then be pumped from the pit and recycled over the crops, thus reducing the use of underground water (CAST, 1982).

Return pits also reduce energy costs because pumping water from a return pit is cheaper than pumping from an aquifer far below ground surface. Because this technique is applicable only to farmers using furrow irrigation, our return pit analysis will exclude farmers using only sprinkler irrigation systems.

Factors affecting adoption

The adoption of farm technology represents one of the most popular areas of rural sociology research, with literally thousands of research articles being published on this topic. Detailed theoretical discussions of the variables examined and their relationships to adoption can be obtained from the references cited and are not included here.

The purpose of this paper is to examine the importance of environmental variables in improving our understanding of factors affecting the adoption of water-efficient and energy-efficient irrigation technology. In the present analysis, five variables are used to explain the adoption of irrigation technology.

Education: The adoption of recommended and efficient farming practices requires certain managerial skills, many of which are gained through education (Abd-Ella et al., 1981). Past research generally has found education to be positively related to adoption (Ajaga, 1980; Beal and Sibley, 1967; Carlson et al., 1980; Nowak and Korsching, 1982; Rogers with Shoemaker, 1971). We hypothesize that education will be positively related to adoption of irrigation technologies.

Communication: The quality and quantity of communication with change agents has long been considered an important factor in the diffusion of innovations. Empirical research consistently has shown that persons who have more contact with change agents and who have more confidence in the information provided by change agents are more likely to adopt the innovation and to adopt it earlier than others (Rogers with Shoemaker, 1971; Fliegel, 1965). Thus, we expect a positive relationship between a change agent communication score and the adoption of irrigation technologies.

Farm size (acres): A larger farm size typically means that the farmer has more resources and thus, a greater risk-taking ability. A long line of adoption research consistently has found a positive relationship between farm size and the adoption of agricultural innovations (Abd-Ella et al., 1981; Beal and Sibley, 1967; Carlson et al., 1980; Hooks et al., 1983; Rogers with Shoemaker, 1971). We hypothesize a positive relationship between the adoption of irrigation technology and farm size.

Farm tenure: Tenure, or the farm operator's legal status relative to the land, has proven to be an important variable in understanding the adoption of agricultural innovations. Typically, owners are more innovative than renters (Lasley and Nolan, 1981; Nowak and Korsching, 1982). In many cases, renters lack the decision-making freedom to adopt innovations. Thus, we hypothesize that innovativeness will increase as the ratio of land owned to total land farmed increases.

Saturated thickness: This is the depth of the aquifer under the farm. Where the saturated thickness is shallow, the volume of water that can be pumped is less, smaller pumps must be used, and therefore the cost of lifting an acre-foot of water is increased. Thus, for farmers with low saturated thickness, irrigation is becoming economically less feasible. Under these circumstances, farmers are less likely to adopt irrigation innovations since the chances of recouping their investment are reduced. Accordingly, we hypothesize that farmers with a lower saturated thickness will be less likely to have adopted the irrigation innovations.

An argument could be made for expecting this relationship to be opposite of what is hypothesized. Farmers pumping water from areas where the aquifer is shallow may have a greater motivation to conserve their limited water resources. However, there are several reasons why we expect farmers with a larger saturated thickness to have adopted more of the efficient irrigation technologies. First, with energy expenses so high, the current profit margin for irrigation is quite small. In most cases, the value of added production from irrigation barely exceeds the irrigation costs (including energy, labor, and the initial cost of the system). Often, a long life expectancy is needed to justify an investment in a new technology, and there is not this assurance in a shallow water area. Second, all farmers in the region, regardless of their own groundwater situation, are aware of the problem of declining water tables and probably feel some need to conserve the water resources.

Methods

To test these hypotheses, data were collected using telephone interviews with a random sample of farmers in three counties (Parmer, Hockley, and Hale) in the Texas High Plains. These three counties were selected to provide a diversity in saturated thickness. Parmer County has a relatively plentiful groundwater supply, Hockley County a limited groundwater supply, and Hale County is intermediate.

A list of farmers producing crops in the three counties was obtained from agricultural agencies, and a proportionate random sample was drawn. Telephone interviews were conducted in early 1983, with a total of 394 farm operators being contacted. Of these, 338 interviews were successfully completed for a response rate of 86 percent. Of the 338 farmers interviewered, 307 currently irrigate and are used in the present analysis. A comparison of the characteristics of the interviewed farmers with the population of crop producing farmers in the three counties as reported in the 1982 Census of Agriculture reveals extensive similarities, supporting the contention that the sample is representative.

Measurement of variables

Dependent variables: The interviewed farmers were asked whether they had adopted each of the four irrigation technologies. Responses for each of these items were coded as either yes or no.

Independent variables: Education was the number of school years completed. Values on this variable ranged from less than a grade school education to two farmers who have Ph.D. degrees. The median educational level was high school graduate. A communication score was determined by asking respondents how helpful each of nine sources of information were in providing relevant information on irrigation technology.[1] Potential responses ranged from "of no help" (score of 1) to "extremely helpful" (score of 5). These nine items were then submitted to common factor analysis from which one factor emerged. The factor score generated by this procedure was then used in subsequent analysis. A higher score represents more trust in the information provided by the irrigation change agents.

Farm size was the total number of acres operated, both owned and rented. Values on this variable ranged from 25 acres to more than 7,000 acres, with an average of 1,035 acres. Farm tenure was the ratio of land owned to total land farmed. One-third of the farmers were full tenants, 15 percent were full owners, and the average farmer owned 33 percent of the acreage he farmed.

Saturated thickness was measured by asking farmers the depth of the aquifer under their farm.[2] Values on this variable ranged from less than 50 feet up to 250 feet. The average farmer had a saturated thickness of 91 feet.

Statistical analysis

Typically, farmer innovativeness is operationalized with a summated index of innovations a farmer has used (Ashby, 1982). Such a procedure ignores variations in the site suitability of the innovations for different biophysical resources. Thus, analysis in this study was conducted separately for each of the four irrigation innovations.

A t-test was used initially to test the hypotheses and to determine if adopters of each of the four irrigation

[1]The nine sources of information examined in this study included irrigation equipment dealers and representatives, county Extension agents, farm papers and magazines, lending agencies, other farmers, agricultural scientists, the Soil Conservation Service, private consultants, and High Plains Water Conservation District personnel.

[2]Results by county were as expected, indicating that farmers know the depth of the aquifer under their farms. Also as expected, farmers reported that their costs for pumping irrigation water increased as the saturated thickness declined.

technologies differ significantly from nonadopters on personal attributes (education and communication), farm characteristics (farm size and farm tenure), or the environmental factor (saturated thickness). Following this, a multiple logistic regression analysis was used to determine the relative importance of each predictor variable for each of the innovations studied. Logistic regression was used instead of standard regression techniques to avoid the estimation problems that result from the use of a dichotomous dependent variable (Harrell, 1980; Knoke and Burke, 1980; Nerlove and Press, 1973).

In using logistic regression, a chi-square statistic was computed for each individual variable and for each model to test the hypothesis that a parameter is zero. For this analysis, the chi-square for the model on each dependent variable is reported, as is the chi-square testing the significance of each individual predictor variable in the model. In addition, a D statistic measuring the fit of each model is reported. This D statistic is analogous to R-square in the normal setting. Individual D statistics, which are similar to partial R-squares, are also shown. Finally, the intercept and -2LogL for each model are presented (Harrell, 1980).

Findings

Table 1 presents the percentage of farm operators in the three county study area that have adopted each of the irrigation innovations. As shown in Table 1, only one of the innovations (furrow diking) has been adopted by a majority (52%) of the potential farm operators. A large minority (39%) of the farmers have adopted return pits, while only a small proportion have adopted center-pivot sprinklers (16%) or soil moisture detection (15%).

T-tests

Table 1 also compares adopters with nonadopters on each of the independent variables.

Personal attributes: It was hypothesized that those who were better educated and those who had more confidence in the information provided by change agents would be more likely to have adopted each of the irrigation innovations. A comparison of the means in Table 1 reveals limited support for the hypotheses. Only one statistically significant difference was found between adopters and nonadopters for both education and communication scores. As expected, the adopters of soil moisture detection had higher levels of education and also higher communication scores than nonadopters.

Farm characteristics: It was hypothesized that those with larger farms and those with a higher ratio of land owned to total land farmed would be more likely to adopt each of the irrigation-related innovations. For farm size, there was a statistically significant difference between adopters and nonadopters on all four innovations (Table 1).

Table 1

Table 1. Relationship between education, communication score, farm size, farm tenure, and saturated thickness and the adoption of irrigation innovations

Innovation	Percent adopted	Personalattributes		Farm characteristics		Environmental factor
		Education (years)	Communication score	Farm size (acres)	Farm tenure (%)	Saturated thickness (feet)
Furrow diking (N = 307)	52					
Adopters		12.5	.019	1,212	.31	83
Nonadopters		12.6	-.015	821*	.35	88
Soil moisture detection (N = 307)	15					
Adopters		13.4	.278	1,468	.28	93
Nonadopters		12.4*	-.047*	946*	.34	84*
Center-pivot sprinklers (N = 307)	16					
Adopters		12.6	-.089	1,298	.40	103
Nonadopters		12.6	.021	973*	.31*	82*
Return pits (N = 244)	39					
Adopters		12.7	.001	1,077	.33	96
Nonadopters		12.6	.069	921*	.33	71*

*Statistically different at the .05 level of significance.

As hypothesized, the adopters of each technique had larger farms than did the nonadopters. On the farm tenure variable, the only significant difference between the adopters and nonadopters was for center-pivot sprinklers. As expected, the ratio of land owned to total land farmed was greater for the adopters than for the nonadopters of center-pivot sprinklers.

Environmental factor: It was hypothesized that farmers with a greater saturated thickness would be more likely to have adopted the irrigation innovations. Of the four irrigation innovations, saturated thickness was significantly related to the adoption of three--soil moisture detection, center-pivot sprinklers, and return pits. As expected, the adopters of the irrigation technologies had a significantly greater saturated thickness than nonadopters.

Multivariate analysis

Findings presented in Table 1 indicate that farm size and saturated thickness are the most important variables in understanding the adoption of irrigation innovations in the Texas High Plains. However, because tests of significant differences between means do not show the interrelationship of independent variables considered collectively, a multiple logistic regression analysis was conducted. The results of this analysis are shown in Table 2.

Furrow diking: When all independent variables are considered simultaneously, the results indicate that only farm size is significantly related to the adoption of furrow diking. The other variables do not significantly contribute additional information for understanding the adoption of furrow diking. The overall model chi-square was 21.12, and 18 percent of the variance was explained.

Soil moisture detection: For this analysis, three variables--farm size, the communication score, and saturated thickness--made a significant contribution. Education was significantly related to the adoption of soil moisture detection in the bivariate analysis but not in the multivariate analysis. The overall model chi-square was 21.28, and 23 percent of the variance in adoption was explained.

Center-pivot sprinklers: This analysis shows, as expected, that farm size and saturated thickness, followed by farm tenure, were the most important variables for discriminating between adopters and nonadopters. This finding was as expected, because the high initial investment in sprinkler systems may be prohibitive to farmers having small farms or limited amounts of water. The overall model chi-square was 19.00, and 20 percent of the variation in adoption was explained.

Return pits: In this case, only one of the five independent variables--saturated thickness--made a significant contribution to explaining the adoption of return pits. The overall model chi-square was 14.75, and 14 percent of the variance was explained.

Table 2. Logistic regression analysis of factors related to the adoption of irrigation techniques

Predictor Variables	Furrow diking Chi square (N = 307)	Furrow diking D	Soil moisture detection Chi square (N = 307)	Soil moisture detection D	Center-pivot sprinklers Chi square (N = 307)	Center-pivot sprinklers D	Return pits Chi square (N = 244)	Return pits D
Personal attributes								
Education	0.07	.00	1.92	.00	0.75	.00	0.30	.00
Communication score	0.01	.00	5.74*	.13	1.15	.00	0.00	.00
Farm characteristics								
Farm size	13.07*	.18	11.53*	.21	8.98*	.18	1.81	.00
Farm tenure	0.01	.00	0.05	.00	5.43*	.12	2.12	-.02
Environmental factor								
Saturated thickness	1.08	.00	4.53*	.11	6.64*	.14	10.71*	.19
D	.18		.23		.20		.14	
Model chi-square	21.12*		21.28*		19.00*		14.75*	
Intercept	-0.60		-4.70		-2.72		-2.86	
-2LogL	315.15		196.43		205.11		233.65	

*Statistically different at the .05 level of significance.

Summary and conclusions

During the past decade, researchers of technology transfer have extended their focus of research to include the physical environment. While research in developing countries has shown location-specific measures of the physical environment to be important in understanding the diffusion of agricultural technology, the importance of such measures in a highly industrialized agricultural system has not been explicitly assessed in recent years. In this study, a location-specific measure of the physical environment (saturated thickness), two personal characteristics (education and communication score) and two farm structure variables (farm size and farm tenure) were used to predict the adoption of four irrigation innovations in the Texas High Plains (furrow diking, soil moisture detection, center-pivot sprinklers, and return pits).

A multivariate logistic regression analysis revealed that farm size was the most important variable for furrow diking, soil moisture detection, and center-pivot sprinklers, while saturated thickness was the most discriminating variable for return pits. Personal attributes proved to be of little importance. Only in the case of soil moisture detection--the most recent and perhaps the most abstract innovation studied--did personal attributes play an importanct role. Our ability to explain adoption of irrigation innovations was significantly improved with the inclusion of an environmental factor.

The results of this study provide further evidence that the traditional adoption-diffusion model must be expanded to include structural and environmental variables. Decades of research and thousands of studies have shown that a farmer's attitudes, farm characteristics, and personal characteristics are important for understanding the diffusion of an innovation. However, this study, along with other recent research, indicates that it is also critical to examine the context within which the farmer operates. That a farmer has not adopted a particular technology does not necessarily indicate that the farmer is less·innovative. Rather, lack of adoption may reflect economic constraints or the unsuitability of an innovation, given the natural resource structure of a particular farm. Along with Dunlap and Martin (1983), we reiterate that it is time to introduce the environment into the study of adoption and diffusion of agricultural technology.

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