Comparison of Decision Rules for Subsurface Drip Irrigation Practices Using a Nonlinear Mathematical Programming Model

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Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meetings, Little Rock, Arkansas, February 5-9, 2005

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Abstract: A comparison of decision rules has been made for case studies of corn production using subsurface drip irrigation under three agricultural management practices (no irrigation, uniform irrigation, and variable rate irrigation). The uniform irrigation strategy appeared to perform the best than the other two management practices under different risk scenarios.

Key words: corn production, mathematical programming, profitability, risk management, subsurface drip irrigation, variable rate irrigation.

Introduction

The quantity of water available for irrigation will generally decline in areas where water conservation is critical, as competition for water resources with municipalities and industry increases. Subsurface drip irrigation (SDI) technology uses water resources very economically and delivers water and nutrients to desired locations at the time and frequency of applications needed for optimal plant growth. Due to its burial depth, SDI has a longer life span than surface or shallow buried drip. It can provide good and reliable performance for 10-20 years if properly designed, installed, and managed (Camp et al., 2000). Besides, producers may have the opportunity to optimize spatial water management through variable rate technologies by management zone according to crop, soil types, and soil depth. O'Brien et al. (1998) indicated that SDI systems are feasible for some field crops and field arrangements using current levels of variable rate technology and the management of SDI systems is not necessarily more difficult to manage than other irrigation systems. Therefore, the variable rate technology in precision agriculture for corn production using SDI may provide producers an alternative to traditional irrigation practices.

To convert to SDI, producers from other irrigation systems or other agricultural practices might be faced with economic uncertainty about whether. While variable rate irrigation as opposed to uniform rate irrigation or no irrigation at all might be desirable to establish, producers may face the question of the best practice to use. The level of farm receipts, fixed investment costs involved, and the decision of how to manage subsurface drip irrigation might be some of the difficulties faced by corn producers. Variable rate application farming incorporates remote sensing, geographic information system (GIS), global positioning system (GPS), and process control. Information drawn from the GIS allows for the control processes such as fertilizer application, seeding rates, and herbicide application. As precise data regarding the optimal level of input use are desirable on a fine scale, at some point the fixed costs associated with this precision may not justify the additional costs. Therefore, suitable guidance of how to manage subsurface drip irrigation and inputs may present a great opportunity to assist producers in achieving the goal of profit maximization in response to risk management.

One of the primary responsibilities of a producer is to make decisions based on the goals and mission of the farm business subject to the constraints faced (Boehlje and Eidman, 1984). The goals are many and variable, but a producer frequently attempts to maximize profit as a means of achieving utility or satisfaction. The decision making under uncertainty is a process that leads to the selection of various optima to minimize costs or maximize profits. This in turn leads to a set of rules that enable the producer to determine the actions that will enable him to achieve his goals. The determination of actions that could potentially be undertaken in a production process must be defined so that they include all feasible acts. Each action undertaken will result in an economic consequence that depends on the state of nature of the production responses. In general, a producer's decision-making is derived from the economic consequences of the actions taken or being considered. The relevant method that will enable corn producers to optimize profits in response to risk management practices has been developed. While this method will be primarily used to assist corn crop producers, the techniques developed can be extended to other locations and other crops of similar nature. It is hoped that the techniques will present a challenge and opportunities for producers to optimize corn profitability in response to risk management practices.

Background

Managing spatial information variability that uses high technology such as geographic information system (GIS) and global positioning system (GPS) is one of the many challenges faced by precision agriculture users. Site-specific management is limited, among other things, by the cost of obtaining and utilizing information about a given field such as yield, soil fertility, soil type, and variable rate applications. In addition, the software tools to manage the data can be complex and cumbersome to use. Therefore, as with any other management procedure, the economic viability of precision agriculture might be one of the central problems for producers to consider its adoption.

The profitability results are mixed in the area of Precision agriculture, depending on the crop, inputs, agricultural practices, and prevailing conditions of the area. In terms of enhancing profitability, prior research has shown that the value of precision agricultural practices with respect to risk management can be even greater. In some cases, while available site-specific management technologies are profitable, studies done by Lowenberg-DeBoer (1996) suggest that in the production of bulk commodities like corn, soybeans, and wheat they often fail to cover all additional costs. This low profitability in bulk commodities might be due to more management problems rather than to technology. Lowenberg-DeBoer mentioned that the profitability of site-specific management is greater in higher value crops, such as vegetables, potatoes, and seed. When Watkins et al. (1998) performed analysis of farm and environmental economics of VRT application of nitrogen fertilizers in seed potatoes production in Idaho, the profits decreased relative to a conventional fertilizer application strategy.

Research in the area of variable rate technology has included analysis of such components as nitrogen management (Thrikawala et al., 1999; Babcock and Pautsch, 1998), lime application (Bongiovanni and Lowenberg-DeBoer, 1998) and spatial break-even variability assessment (English, Roberts, and Mahajanashetti, 1998). Babcock and Pautsch conducted a study on the profitability of VRT nitrogen fertilization relative to a uniform application in 12 randomly selected Iowa counties. The results indicated that the economic and environmental impacts of moving from URT to VRT depended heavily on the inherent yield variability in fields. There was a slight increase in returns above fertilizer costs.

A review of the economics of precision agriculture by Lowenberg-DeBoer and Swinton (1997) found that economic feasibility is dependent upon several factors including many components of the underlying economic, agronomic, and engineering environment. While the primary responsibility, among others, is to make decisions based on the goals and mission of the farm business, farm manager cannot control all these factors. The uncontrollable events, such as weather, market fluctuations, and government intervention, introduce a great deal of uncertainty into the decision process.

There are errors associated with all components of VRT, including errors related to GPS, heterogeneity of fertilizer composition, application overlaps and gaps (Fulton et al., 1999), topographic relief, and the response lags when changing application rates. None of these errors are independent. Additional errors result from the inadequacies of application equipment to deliver the desired amount of nutrient(s) when considering spatial shifts in the desired amounts under VRT. Calculating these error measures and making decisions depends on the ability to gather accurate farm information. This information can then be used to by producers to make decisions on a spatial or temporal basis, such as calculating the various levels of risk across a field.

Subsurface drip irrigation (SDI) is one of other areas worthy of attention. A SDI has been a part of agricultural irrigation in the USA for about four decades but interest has increased rapidly during the last two decades primarily due to increased pressure to conserve water resources and the availability of reliable system components. ASAE (1999) defined a SDI as an application of water below the soil surface through emitters, with controlled discharge rates. A SDI is a very precise irrigation method, both in the delivery of water and nutrients to desired locations and the timing and frequency of applications for optimal plant growth (Camp et al., 2000). The SDI system can potentially have higher irrigation efficiency and irrigation uniformity while at the same time reducing irrigation labor.

Lamm et al. (2002) and O'Brien et al. (1998) from Kansas State University conducted studies on economic comparison of SDI and center pivots (CV) for various field sizes. The results were mixed. The CP systems indicated to have an advantage over SDI for large field sizes. SDI systems indicated that they can generate more gross revenue by having a higher percentage of irrigated acres in a given field, however, the much lower cost and assumed longer life for CP systems offset the higher SDI revenue advantage. Results from research in Kansas indicate that daily SDI application of water (even <0.254 cm) doubled corn yields during extremely dry periods. Crop yields with SDI are equal to or better than yields with other irrigation methods, including surface drip methods. Water requirements are equal to or lower than surface drip, and fertilizer requirements are sometimes lower than for other irrigation methods. In that aspect, it can be said that the future of SDI appears to be promising especially in areas where water conservation is important or water quality is poor.

This article will assist in the establishment of a fundamental framework that will permit analysis of profitability of corn production using mathematical programming model. The model formulation will permit the appropriate economic analysis to be conducted for comparison of optimum corn production techniques. Additionally, the techniques include the economic assessment of another very important question: What is the optimal profit under no irrigation practice, uniform irrigation practice or variable rate irrigation practices? Optimal profit determination can be handled with this model for any corn production practice that producers will use.

Objectives

The main focus of this research is to assist corn producers by providing procedures and information that will assist them in making sustainable decisions concerning how to optimize profits and risk management. Using input and corn prices from previous studies, profit optimization model will be developed for a representative Henderson producer. The optimization model will account for the producer's attitude towards risk. While this work will be primarily used to assist corn crop producers, the techniques developed here will be suitable for other locations and other crops of similar nature.

Hence, the main goal of this proposed research is to enable crop producers using or considering subsurface drip irrigation technology to increase profitability and manage risk. This goal can be achieved by providing procedures and information that assist in determining the profitability while considering the economic and environmental health of the farm.

The specific objectives are to:

1) Compare and contrast the economic performance of no irrigation practice and subsurface drip irrigation practices (uniform irrigation and variable rate irrigation), and

2) Ascertain the relative performance of alternative irrigation practices upon risk faced by producers.

Model Development

We use mathematical programming to develop an economic model representing the economic decision framework of a Kentucky corn producer considering SDI. The objective function of this model will be to maximize risk adjusted net farm returns above selected relevant costs in a typical expected value-variance framework. Decision variables include corn production under various irrigation strategies, corn sales, net returns by weather state of nature (year), mean net returns. Constraints include limited land, limited weekly suitable field days, relevant accounting equations and requirements for irrigation or variable rate irrigation equipment investment when engaging in those corresponding practices.

Biophysical simulation models are used to estimate yield results from the production system being considered. Biophysical simulation is used because of its ability to provide the underlying yield response functions needed for the primary case example under a wide range of production practices and for a host of weather conditions under a constant level of agricultural technology. While agronomic field trials or similar data are preferable, such were not available with this breadth of information that will allow a rich and diverse series of production strategies to be embodied into the example portrayed. The use of biophysical simulation in this instance therefore enables the agronomic experimental design to manifest a broad spectrum of production practice alternatives for corn production.

Weekly corn planting from March 29 through May 24 is modeled for nine planting dates. Early, medium and late maturity classes are included for corn as well as low, medium and high plant populations of 49,400; 59,280 and 69,160 plants per ha respectively. Irrigation was included for three levels as well as for no irrigation. The low, medium and high level of irrigation called for applying water to field capacity in the event of the soil water reaching 75%, 50% and 25% of capacity respectively. The CORNF model (Stapper and Arkin, 1980) is used in simulating corn yields for these 288 (9 planting dates times 3 maturity classes times 3 plant populations times 4 irrigation levels) production strategies.

In the biophysical simulation models, a representative medium depth silt loam soil type was utilized that also needed daily weather data. These meteorological data are from Henderson for 1978 through 2003 that provided twenty-five seasons of estimated yield data. The exception on the use of Henderson weather data was the need for solar radiation that required the use of Evansville, Indiana as a location. Overall, the yield responses appear reasonable.

To estimate the number of days suitable for fieldwork, a suitable field days simulation model was used. This model relies upon historical weather data and soil water simulation under a modified procedure discussed by Dillon, Mueller and Shearer, 2001. The vector of the field days available appeared as the weekly right-hand side values in the mathematical programming model; the average weekly days available for Henderson County were 5.5 days per week with a standard deviation of 2.6.

The labor requirements per week, input prices and input requirements per acre were taken from representative Tennessee no-till enterprise budgets (Gerloff and Maxey, 1998). The 2000-2002 Kentucky average season corn price was used ($0.0878/kg, Kentucky Agricultural Statistics 2002-2003). A hauling charge of $0.0059/kg. was subtracted. Irrigation operating and ownership costs were adapted from O’Brien et al. (1998) assuming a 20 year useful life and zero salvage value, 8% interest rate and 0.75% insurance rate. Variable rate irrigation ownership costs were estimated at 5.75% more per land area by comparing different irrigation capacities.

Results and Discussion

We analyzed the base case scenario of corn production practices under risk-neutral and risk-averse scenarios. The results for optimum profit and production strategies selected for the base case are shown in Table 1. The risk-neutral optimal solution for non-irrigated farm provided mean profit above selected variable costs of $32,733.70 and a coefficient of variation (CV) of 82.43 percent compared to risk-averse scenario that provided mean profit of $28,234.04 and a CV of 75.22 percent. The expected corn yield under risk-neutral was higher than the risk-averse scenario with 5710 kg/ha resulting in a mean profit of only 33.76 percent of the optimal. The risk-averse scenario displayed an expected yield of 5498 kg/ha with mean profit of only 29.12 percent of the profit maximizing level. However, under risk-neutral with no irrigation, a producer has a chance of getting a negative minimum profit (i.e. a loss) while a risk-averse producer will have a positive minimum profit of above $2000 at any production practice.

In response to risk-neutral producer under uniform irrigation practice, the average profit is $96,945.91 and a CV of 20.40 percent compared to risk-averse producer's average profit of 96,373.15 and a CV of 18.49 percent. The expected corn yield and optimum mean profit under risk-neutral producer were slightly higher at 11,085 kg/ha and 100 percent respectively, compared to risk-averse producer with expected corn yield of 11,058 kg/ha and an optimum mean profit of 99.41 percent. As with the non-irrigated farm, the risk-averse producer has a greater chance of getting higher minimum profit due to risk reduction management practices undertaken than the risk-neutral producer.

Variable rate irrigation under risk-neutral scenario brings higher average profit and a CV at $95,011.91 and 20.81 percent respectively, compared to risk-averse scenario with average profit of $94,439.15 and a CV of 18.87 percent, similar with the other two agricultural practices. Expected corn yield and optimum mean profit for risk-neutral producers are slightly higher at 11,085 kg/ha and 98.01 percent respectively, compared to risk-averse producers with expected yield of 11,058 kg/ha and an optimum mean profit of 97.41 percent. However, the expected minimum profit is higher for risk-averse scenario due to risk reduction considerations than the risk-neutral. In general, the expected yield for all strategies in this study is lower than the yield estimated by Lamm et al. (2002) at 13,169 kg/ha. Notably the yields for a given risk attitude under uniform or variable rate irrigation are the same as variable rate irrigation was not used even if available. This may reflect an inadequate depth of irrigation strategies modeled to permit the benefits of variable rate irrigation to be realized.

These results indicate that the no irrigation practice has the lowest yield and profitability and the highest coefficient of variation under both risk scenarios compared to uniform and variable rate irrigations. In general, uniform irrigation practice performed better under both risk scenarios than the corresponding risk scenarios in variable rate irrigation, contrary to the expectation. Higher profits with uniform irrigation strategy probably resulted from lower production costs. Subsurface drip irrigation has the potential to improve both the profitability of the farm and to lessen environmental damages of agriculture. However, its financial performance will depend on the attributes of the farm's soils and other resources, the inherent variability in production for these resources, and previous management decisions. If the costs of SDI systems should decrease relative to other irrigation systems, SDI could become economically viable for most crops. The contention is that subsurface drip irrigation provides a workable uniform rate irrigation leading to higher yield and higher market returns for producers. The estimation suggests that this approach has potential for sizable profits for producers. The yield obtained is a reasonable estimate compared to various yields estimated from other research studies.

Average input usage may not vary greatly between uniform and variable rate technology across the fields. For example, the quantity of water usage was the same for both practices. While corn quality from different production practice may vary slightly in terms of moisture contents, their sale prices are not differentiated. As such, corn yield and price changes generally will not affect the choice of SDI practice for the range of corn yield and prices considered. The underlying production response function will, of course, have substantial impact on the potential results.

Summary and Conclusions

In this research, we analyzed the profitability of non-irrigated farm relative to uniform and variable rate irrigation in deep and shallow soil type fields in Henderson County. Generally, uniform irrigation strategy appeared to be economically better than variable rate irrigation. While risk management has been long considered to be an important component of the agricultural producer's decision-making environment, the current economic and financial environment creates a special need to focus upon this aspect in whole farm planning. Risk management is a complicated undertaking with several basic categories of risk sources to be considered, including production, marketing or price, and institutional and financial risk. In turn, there are many sources of risk within each of these categories including, for example, the fluctuation of yields and the risk of days unsuitable for fieldwork as a result of weather.

We employed a mathematical programming model of a Henderson representative corn farm confronted with a decision to adopt an irrigation strategy, including status quo no irrigation strategy. Comparison of key economic variables under no irrigation with uniform irrigation and variable irrigation rates using subsurface drip irrigation has been performed. The results indicate that uniform irrigation using subsurface drip irrigation to be an optimal strategy for profit maximization.

This study has important implication for the use of subsurface drip irrigation. While variable rate irrigation has the potential to improve profitability and yield, it did not result in higher profits than uniform irrigation. This type of investigation inherently has limitations. Corn yield differences between uniform and variable rate irrigation may not be the same with less or more favorable growing conditions. Uncertainties are many and difficult to account for all of them in evaluating the relative profitability of production strategies. Therefore, future studies should attempt at a more comprehensive treatment of such uncertainties. Also there is a need to further investigate the costs and benefits of variable rate irrigation relative to uniform irrigation. Further efforts are needed in the design and development of efficient, low-cost variable rate irrigation system.

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Table 1. Key economic indicators under alternative irrigation strategies and risk preferences

Particulars	No irrigation		Uniform irrigation		Variable rate irrigation	
	Risk Neutral	Risk averse	Risk neutral	Risk Averse	Risk Neutral	Risk averse
Average profit ($)	32,733.70	28,234.04	96,945.91	96,373.15	95,011.91	94,439.15
CV (%)	82.43	75.22	20.40	18.49	20.81	18.87
Min. profit ($)	-5,231.00	2,069.39	49,932.36	60,303.28	47,998.36	58,369.28
Perc. Opt (%)	33.76	29.12	100.00	99.41	98.01	97.41
Irrg. Avg. (cm)	0.00	0.00	19.43	19.30	19.43	19.30
Yield avg. (kg/ha)	5710.37	5498.41	11,085.25	11,058.28	11,085.25	11,058.28