Economic Analysis of Variable Rate Applications of Irrigation Water in Corn Production

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INTRODUCTION

Traditionally, producers treated the entire field as if it were a homogeneous unit, even though there were variations in soil types, soil fertility, and yield potentials. They applied average rates of inputs over the entire field. As a result, some areas were under applied while others were over applied, resulting in lower profits and chemical and nutrient losses to surface and ground water.

Precision agriculture is a knowledge-based system that enables producers to apply precise amounts of fertilizers, pesticides, water, seeds, or other production inputs to specific areas where and when plants need them for optimal growth. It is a promising group of technologies that could theoretically increase crop productivity and profitability, reduce chemical use, and decrease environmental degradation.

Variable rate technology (VRT) is probably the best-developed part of precision agriculture (Searcy, 1994; National Research Council, 1997). Many VRT products are presently available to producers via equipment dealers (Lu, et al., 1997). According to a Purdue University survey of agricultural chemical dealers, 13 percent of respondents used controller-driven VRT for applying fertilizers (Akridge and Whipker, 1997).

Since precision agriculture is still in an early stage of adoption, few economic analyses have been published. Lowenberg-DeBoer and Swinton (1995) reviewed the profitability of precision agriculture and found most of the studies focused on fertilizer applications, especially potash and phosphate. The reason for this is that abundant literature is available on relationships among fertilizer, soil nutrients, and yields, and fertilizer costs form a large portion of the total costs. The results of their review showed that of the 11 studies reviewed, only two studies showed potential profitability.

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Since the Lowenberg-DeBoer and Swinton's review, several other economic studies have been reported in conferences. In the Third International Conference on Precision Agriculture held in 1996, 12 economic papers were presented. Again, much of the interest then focused on the benefits and costs of fertilizer applications. Seven out of 12 papers presented involved fertilizer applications. As with the Lowenberg-DeBoer and Swinton review, the results of economic analyses were mixed.

There have been only two economics articles published in the international Journal of Precision Agriculture since its inception in 1999. Wang (2000) evaluated economic and environmental effects of variable rate nitrogen and lime application for claypan fields in north central Missouri. He compared VRT rates for two different uniform N applications, URT–N1 and URT-N2. URT-N1 was based on topsoil depth within claypan fields, and URT-N2 was based on a typical N rate for corn production in the area. The results indicate that VRT was more profitable than URT-N1 in all four fields and URT-N2 in two of the four fields.

Bongiovanni and Lowenberg-Deboer (2000) evaluated the profitability of variable rate lime application in Indiana. Three VRT strategies: agronomic recommendation, economic decision rule, and information strategy, were compared with the uniform application for the whole field. The agronomic recommendation strategy used the agronomic recommendation rules, the economic decision strategy used the economic rule that profit is maximized when the marginal product is equal to the marginal cost, and the information strategy used site-specific information to determine the economically optimal uniform rate of lime. Results indicated that all three VRT application strategies were more profitable than the uniform application strategy and, among the three VRT application strategies, the economic strategy increased the highest average annual return over the uniform application, followed by the information and agronomic strategies.

Watkins, et al. (1998) used the EPIC (Environmental Policy Integrated Climate) simulation model to estimate seed potato yield over a 30-year period for four different ranges within a field. The simulated yields were used to evaluate the long-term profitability and nitrogen losses for VRT and uniform nitrogen applications while considering nitrogen carryover effects. A dynamic optimization model was used to determine optimal steady-state nitrogen levels for each range and for the entire field. Average nitrogen losses and economic returns were evaluated for both VRT and uniform nitrogen applications. They found that the VRT nitrogen application was not profitable when compared to uniform application. Nitrogen loss from the field was about equal for both VRT and uniform applications.

There are very few studies analyzing the profitability of VRT application of irrigation water. In a follow-up study, Watkins, et al. (2002) evaluated profitability and environmental outcomes associated with VRT applications of nitrogen and irrigation water in seed potato production in Idaho. Again, the EPIC crop growth model was used to simulate seed potato yields and nitrogen losses for four different ranges under both uniform and VRT water applications. A dynamic optimization model was used to determine optimal levels of nitrogen for each range under each irrigation scenario.

Average nitrogen losses and economic returns were evaluated for all management strategies. Results indicated that VRT nitrogen application was, again, not profitable and there was little to no reduction in nitrogen losses when compared to uniform applications. VRT application of irrigation water produced the greatest economic return and the greatest reduction in nitrogen loss regardless of which nitrogen management strategy was employed. These results indicate that VRT water management may be more important than VRT nitrogen management for some fields in irrigated agriculture.

This paper evaluates the economic feasibility of VRT applications of irrigation water in corn production in South Carolina.

MATERIALS AND METHODS

Source of Data

The data were obtained from an experiment conducted at the site-specific center pivot irrigation facility in Florence, SC, USA, during the 1999-2001 corn growing seasons. Corn ('Pioneer 3163') was planted with a 6-row planter that had in-row subsoilers to a depth of 40 cm. Row spacing was 0.76 m, and the final plant populations in the three years ranged from about 64,000 to 66,000 plants/ha. Conventional surface tillage culture was used. Irrigation and N treatments were imposed using a commercial, three-span center pivot irrigation system that had been modified to provide site-specific water and fertilizer applications. The experimental design used 4x2 factorial randomized complete blocks (RCBs) where sufficient area existed within soil map unit boundaries as delineated by USDA-NRCS on a 1:1200 scale. Where insufficient area was available, randomized incomplete blocks (RICBs) were used. The plot sizes were nominally 9.1 m x 9.1 m at the outer boundaries and 6 m x 6 m in the central control area. On larger soil map areas, multiple RCBs were imposed. The number of RCB blocks was 39, of RICB, 19, resulting in a total of 396 plots. Each plot was irrigated according to a specific irrigation strategy. All irrigation applications were controlled by a computer interfaced with the commercial pivot control panel and a PLC control system to operate valves. Treatments were imposed continually on the same plots, so yield responses reflect the cumulative effects of water or nutrient excesses or deficits. Each year, a 6.1-m length of two rows near the center of each plot was harvested using a plot combine. The harvested grain was weighed, corrected to 15.5% moisture, and the yield was expressed per unit ground area. A detailed description of this experiment is described in Camp, et al. (2003).

Net returns, defined as total returns minus total variable costs, were used to measure profitability. The variable costs include costs of seeds, fertilizers, lime, herbicides, insecticides, irrigation, drying and hauling, operation of tractors and machinery, labor, and interest on operating capital. The cost data were obtained from the enterprise budget of the Clemson Extension Service, Clemson University (2002), and modified for each irrigation strategy. The irrigation cost was estimated at $4/acre-inch, or about 40 cents/ha-mm. The costs for drying and hauling were estimated at $9.80/Mg. The other variable costs are the same for all strategies. The price of corn was obtained from USDA Agricultural Statistics (2002). The average prices of $80/Mg for corn and 40 cents/ha-mm for irrigation water were used in this analysis.

A corn response function for water, or water production function, for each of the 396 plots was estimated and used to determine the optimal amount of irrigation water and yields under yield-maximizing and profit-maximizing strategies. The estimated plot production functions (total of 396) were used to compute net returns for each plot under the different strategies.

Irrigation Water Application Strategies

For this study, we compared economic returns and irrigation efficiency of VRT and uniform applications. The profit-maximizing and yield-maximizing strategies were used for both application methods. For uniform applications, the optimal amounts of irrigation water used in VRT applications were assumed to be used uniformly in the field. Two other strategies, Irr 100 and Irr ET, also were used for comparison. The six strategies are as follows:

1. VRT applications
    a. Profit-maximizing
    b. Yield-maximizing
2. Uniform applications
    a. Profit-maximizing
    b. Yield-maximizing
    c. Irr 100
    d. Irr ET

For each plot, the amount of irrigation water that maximizes yield and profit was obtained from the estimated production function for each plot. The amount of irrigation water that maximizes yield can be obtained by equating the marginal physical product (MPP), or the slope of the production function, to zero, and that for maximizing profit can be obtained by equating the MPP to the ratio of the price of water to the price of corn. Unless irrigation water is free, the yield-maximizing irrigation amount will not give maximum profit. In general, the higher the water/corn price ratio, the more profitable the profit-maximizing strategy than the yield-maximizing strategy.

Irr 100 is for the design and normal practice (keeping tensiometers in the NkA soil above a constant reading). Irr 100 is constant for each year, as it was the 100% treatment. Irr ET was the irrigation amount that would have replaced ET (evapotranspiration) exactly. Irr ET was estimated from the ASCE Etr guidelines with crop coefficient for corn (Allen, et al., 1998; Walter, et al., 2000). The Irr ET yield was computed from production functions assuming the amount of water exactly equated with computed Etr. Had our Irr 100 been perfect, Irr 100 would have been equal to Irr ET. Differences indicate sub-optimal operation of the pivot. Irr ET and Irr 100 amounts are constant over the field, but the corresponding yields vary in space because the production functions vary.

Since we assume that the average profit-maximization amount of irrigation water is applied to all plots in the field under uniform application, the total amount of irrigation water per hectare for both VRT and uniform applications are the same. By using this assumption, there is no saving in irrigation water for using VRT applications. Consequently, the benefit of VRT application must be derived solely from increased yields.

Estimation of Production Functions

To determine the optimal amounts of irrigation water that maximize yields or profits, we need to estimate a corn response function to water, or production function. Several algebraic functional forms have been used as production functions (Griffin, 1984). Many studies indicated that the quadratic function is most appropriate for crop production functions (Barrett and Skogerboe, 1978; Hexem and Heady, 1978; Musick et al.,1976; Watkins, et al., 1998). In a previous study (Lu, et al., 2003), several forms of production functions, including quadratic, squared root, and double-log polynomial functions, were estimated with ordinary least squares, and the results confirmed that the quadratic equation was the most appropriate for the particular set of data used in this study.

The following form of production function was estimated using ordinary least squares:

$$\mathrm{Y} = \alpha + \beta W + \gamma W^2$$

where α, β, and γ are coefficients to be estimated. A production function for each of the 396 plots for the years 1999, 2000, and 2001 was estimated and used to determine the amount of irrigation water that maximizes yield and net return.

RESULTS AND DISCUSSIONS

Estimated irrigation amount, corn yield, and net return

The optimal amount of irrigation water, yields, and net returns under VRT and uniform applications using variable strategies are presented in Table 1. The results indicate that the VRT applications yielded larger net returns than the uniform applications, using either yield-maximizing or profit-maximizing strategies. Of the two VRT application strategies, the profit-maximizing strategy conserved more irrigation water and produced slightly larger net returns than the yield-maximizing strategy. For example, in 2001, the profit-maximizing strategy used 155 ha-mm/ha of irrigation water to produce 12.16 Mg/ha of corn and yielded \$486/ha of net returns, while the yield-maximizing strategy used 206 ha-mm/ha of irrigation water to produce 12.40 Mg /ha of corn, but yielded \$482/ha of net returns.

The difference in net returns would be higher if the price of irrigation water were higher relative to the price of corn (Lu, et al., 2003). For uniform applications, the profit-maximizing strategy produced larger net returns than all other strategies. Again, in 2001, the profit-maximizing strategy produced $477/ha net return, while the yield-maximizing, Irr 100, and Irr ET strategies produced net returns of $463/ha, $438/ha, and 417/ha, respectively.

Table 1. Estimated irrigation amount, corn yield, and net return per hectare for VRT and uniform applications.

Application	Strategy	1999			2000			2001		
		Water	Yield	Net return	Water	Yield	Net return	Water	Yield	Net return
		ha-mm	Mg	$	ha-mm	Mg	$	ha-mm	Mg	$
Variable rate	Profit-max	247	10.61	340.11	236	11.05	375.37	155	12.16	486.08
	Yield-max	282	10.80	339.37	256	11.11	372.07	206	12.40	482.26
Uniform	Profit-max	247	10.41	326.17	236	10.78	356.40	155	12.04	477.31
	Yield-max	282	10.58	324.44	256	10.85	353.27	206	12.14	463.72
	Irr 100	218	10.20	314.89	203	10.51	340.04	200	12.14	437.95
	Irr ET	253	10.46	322.88	212	10.60	346.24	240	12.07	417.48

However, VRT applications require different equipment and control systems. To adopt VRT of irrigation water, producers have to make additional capital investment for this new technology. Thus, before VRT can be widely adopted by producers, the system must be proved profitable. The benefits of reduced irrigation water cost plus the value of increased yields or quality of products must be greater than the additional costs associated with VRT. The differences in net returns for VRT and uniform applications range from $8.77/ha in 2001 to $18.97/ha in 2000 if the profit-maximizing strategy is used, and from $14.93/ha in 1999 to $18.88/ha in 2000 if the yield-maximizing strategy is used. If growers use the profit-maximizing strategies, the breakeven point for the costs of additional equipment is about $9.00/ha. That is, the additional cost of new equipment and controls must not exceed $9.00/ha.

Changes in relative prices of corn and irrigation water will also change the benefits of VRT. Often, VRT will result in savings of irrigation water and higher yields, but in this analysis, we assumed that the average amount of irrigation water used in uniform applications is the same as for the profit-maximizing strategy. Therefore, there is no savings in irrigation water and changes in the price of water will have no effect on the difference between VRT and uniform applications. However, increases in corn price will make VRT much more profitable than the uniform application. For example, in 2001, if the price of corn increased from $80/Mg to $90/Mg and the price of irrigation water remained the same, the breakeven cost for new equipment and control would increase from $8.77/ha to $16.17/ha.

Costs of VRT equipment and control

At the time this experiment was initiated, the VRT equipment and control were not commercially available. The three-span center pivot irrigation system was modified to provide site-specific water and fertilizer applications. The VRT equipment and control used in this experiment include the control system and the water delivery system. The control system includes the PC/PLC (computer and programmable logic controller) and associated hardware, remote PLC units, LCD display, transmitters, electronic components, conduit, fittings and enclosures. The water delivery system includes PVC pipe and fittings, solenoids, filters, low pressure drains, pressure regulators, rubber hose and quick connectors, nozzles, drop pipes, etc. The total cost for the control system was $19,480 and the water delivery system was $ $29,900 in 1999 for a total of about $50,000. Thus, the VRT system used in the experiment is too expensive to be profitable.

Site-specific irrigation equipment and controls designed and used for research are different from commercially produced equipment and controls in several respects. In order to achieve research objectives, the research equipment was designed to make precision irrigation applications on areas smaller than those required in practice and required greater precision both spatially and in volume applied. For example, each of the 3-tower systems used in this experiment can irrigate only 14 acres (5.67 hectares) as compared to many commercial systems that can irrigate 130 acres (52.65 heactares). In most cases, commercial equipment is not available; hence, standard, commercial equipment must be modified or new equipment designed and constructed for the research project. Further, when commercial VRT application hardware and controls are not available, the application hardware and control system must be assembled from available commercial components to achieve the desired application. Often these components may be oversized or have reserve capacity because of limited size availability and to ensure consistent performance under unknown operating conditions. All of these factors combine to make research equipment less compact, require more parts that are often connected in an inefficient manner, and more expensive per unit area. Consequently, research equipment and controls are seldom suitable for commercial uses, the cost is almost always greater than that of commercial equipment and controls designed for the purpose, and should not be used for economic evaluations.

It has been estimated that a commercial system costs about $110/acre (a cluster upgrade for about $56/acre and variable rate for $54/acre) or $271.60/ha (Harting, 2003). Assume that the average useful life of the system is 15 years and there is no salvation value at the end of its useful life. By using the capital recovery method (Boehlje and Eidman, 1984) at 6% interest, we estimated that the annualized additional cost for VRT is $27.97/ha, which exceeds the breakeven point of using the VRT applications. Thus, at present, VRT is probably not profitable for corn in the Southeast USA compared with uniform applications. However, VRT costs are decreasing with further research and refinement of the system, and new commercial equipment and controls designed for site-specific applications are becoming more cost effective. Furthermore, the costs of these equipment and control systems will decline when VRT is widely adopted and these equipment and control systems are mass-produced commercially

SUMMERY AND CONCLUSIONS

This paper compared the net returns from VRT with uniform applications of irrigation in corn production under different strategies. The data were obtained form an experiment conducted at the site-specific center pivot irrigation facility at Florence, SC, USA, during the 1999-2001 corn growing seasons. Two VRT strategies (profit-maximizing and yield-maximizing) were compared with four uniform application strategies (profit-maximizing, yield-maximizing, Irr 100, and Irr ET).. For each year, a water production function was estimated for each of the 396 plots using the ordinary least squares. The estimated production functions were used to determine the amount of irrigation water that maximizes yield or profit.

The results indicate that the VRT applications yielded larger net returns than the uniform applications, using either yield-maximizing or profit-maximizing strategies. Of the two VRT application strategies, the profit-maximizing strategy conserved more irrigation water and produced larger net returns than the yield-maximizing strategy. The difference in net returns could be higher if the price of irrigation water is higher relative to the price of corn. Among the uniform applications, the profit-maximizing strategy produced larger net returns than either yield-maximizing, Irr 100, or Irr ET strategies.

However, for VRT is to be widely adopted by producers, the benefits of reduced irrigation water cost plus the value of increased yield or quality of products must outweigh additional costs for different equipment and controls required for the VRT application. Because the VRT system used in this experiment was built for research purposes that required additional details and resolution, the costs were much higher than those would have been used for commercial growers. Thus, the VRT system built for the experiment is not profitable for corn in the Southeast USA.

Even for the estimated current cost of a retro-fitted commercial system, the additional costs of VRT equipment and control system exceed the value of increased yield. Thus, at present, the VRT application of irrigation water is not profitable compared with uniform applications. However, VRT costs are decreasing with further research refinement of equipment and control systems and with these systems mass-produced commercially when VRT is widely adopted by producers.

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