ECONOMIC ANALYSIS OF SUBSURFACE DRIP IRRIGATION SYSTEM UNIFORMITY

C. Wilde, J. Johnson, J. P. Bordovsky

ABSTRACT. *As more subsurface drip irrigation (SDI) systems are being installed throughout the plains of Texas for cotton production, irrigators are concerned about the high cost of installation and the potential benefits of alternative designs. A field study was conducted at the Texas AgriLife Research facilities at Halfway, Texas, to document the agronomic impacts of distribution uniformities on cotton production over a six year period. Based on this study, a net present value analysis of SDI systems having different irrigation uniformities was conducted. The authors considered six scenarios that represent six treatments of the field study. The scenarios included three water distribution uniformities represented by flow variations of 5%, 15%, and 27%, with each irrigated at two levels, a base irrigation amount and 60% of the base irrigation amount. Net present values were calculated for each level of uniformity and irrigation level. At the lower irrigation level, the least uniform design provided a higher net present value. The length of the planning horizon affected NPV with the more uniform system having a better NPV at the longer planning horizon due to the cumulative effect of small improvements in net income over the longer time. In addition, the producer's risk aversion level affected their choice of design uniformities. A more risk averse producer preferred a more uniform design and was willing to pay a higher installation cost for a more uniform system. A less risk averse producer preferred a less uniform system design with a lower initial cost.*

Keywords. *Irrigation, Subsurface drip irrigation, Cotton irrigation, Irrigation uniformity, SDI.*

Agricultural producers are facing declining water supplies and are becoming increasingly aware of the need for conservation of limited natural resources. Producers are addressing these concerns by adopting new technology, such as subsurface drip irrigation (SDI). SDI is an efficient in-season water application method with the ability to provide consistently high yields for row crop production (Bosch et al., 1998; Phene, 1999). One of the biggest concerns to producers who are considering installing a SDI system is the high initial cost of the system (Henggeler, 1997; Camp, 1998). The design of a SDI system can have a major impact on the initial cost of investment with a direct relationship between level of uniformity and initial cost of the system. Producers who are currently discouraged from installing SDI systems due to high initial cost might consider SDI if these costs were reduced. One option to achieve this reduction is careful SDI design incorporating lower levels of water uniformity than those traditionally considered acceptable. Major consequences of reducing SDI system uniformity can include poor seed germination in dry years, increased difficulty in drip maintenance, reduced flexibility of alternative crops, and problems with future uniformity due to deterioration of the system and declining water supply. A key element in addressing the impact of alternative uniformity scenarios is an analysis to determine the financial benefits or consequences of lowering irrigation uniformity to reduce initial SDI costs.

Previous studies have considered subsurface and surface drip irrigation uniformity (Camp et al., 1997; Bordovsky and Porter, 2008), but little information is available that relates to net returns and investment analysis of SDI systems based on system uniformity. From a practical standpoint, uniformity represents the variation in emitter discharge among emitters within a lateral, a zone, or a field. One common measure of SDI system distribution uniformity is flow variation (Q_{var}). Flow variation is defined as the difference in maximum and minimum emitter flow rates within a zone or subunit divided by the maximum emitter flow rate of that zone or subunit.

In a study in the Texas High Plains, Bordovsky and Porter (2008) found no significant differences in cotton yield and value among SDI treatments having three different water distribution uniformities at either of two irrigation levels in 2001, 2003, 2004, 2005, or 2006 or for the 5-year average. The irrigation levels were a base irrigation amount (1.0BI) and 60% of base irrigation level (0.6BI). In their study, they found generally higher yields occurred at locations in the field of higher drip emitter discharge, even though yield variation did not uniformly change with changes in emitter flow along drip laterals. Some of the yield inconsistencies relative to emitter discharge were attributed to variations in slope, differences in soil texture, and variations in cotton plant population or growth caused by severe weather events during the test period. From an economic stand point, cotton producers in severely water deficit areas may be more concerned with total returns from a field rather than the yields for specific locations in a field. Yield and loan value data

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Submitted for review in February 2008 as manuscript number SW 7388; approved for publication by the Soil & Water Division of ASABE in February 2009.

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from the Bordovsky and Porter (2008) study were used for this economic analysis. Average yields and values over the test period at the 1.0BI level and flow variation treatments of 5%, 15%, and 27% were 1638 kg ha^{-1} with a loan value of \$1.194 kg^{-1}, 1643 kg ha^{-1} with a loan value of \$1.179 kg^{-1}, and 1608 kg ha^{-1} with a loan value of \$1.189 kg^{-1}, respectively. Yields and loan values at the 0.6BI level for flow variations of 5%, 15%, and 27% were 1603 kg ha^{-1} with a loan value of \$1.184 kg^{-1}, 1612 kg ha^{-1} with a loan value of \$1.185 kg^{-1}, and 1607 kg ha^{-1} with a loan value of \$1.194 kg^{-1}, respectively. The loan value represents the cotton lint price set by the USDA based on the quality characteristics of the lint.

The objective of this study was to compare the financial feasibility of different SDI system uniformities using net present value (NPV) and risk analysis. NPV investment analysis was used to evaluate three SDI systems each having different uniformities similar to those in the Bordovsky and Porter (2008) study, and specifically, how these SDI system uniformity levels affected NPV and the producer's decision based on risk preferences. This analysis will provide cotton producers in semi-arid regions additional investment information when choosing the design and uniformity of a SDI system for installation. Systems with designed flow variations of 5%, 15%, and 27% were studied. These flow variations represent a range of water distribution uniformities from very uniform to well outside the traditional range of uniformity used in cotton production in the Texas High Plains.

METHODS AND PROCEDURES

Calculation of NPV results in the value of future cash flows represented at a present value, for each of the systems and irrigation levels and is represented as:

$$NPV = -IC + \sum_{i=1}^{n}\left(\frac{ATCF_i}{(1+k)^i}\right) + \frac{TV_n}{(1+k)^n} \qquad (1)$$

where *IC* represents the initial investment cost of the SDI system for each design, *ATCF* represents the after-tax cash flow from cotton production in year *i*, *TV* represents the terminal value in year *n*, *k* represents the real discount rate, and *n* represents the number of years considered in the analysis (Barry, 2000). The value of *n* for this study is 7, 10, and 15 years which represent reasonable time horizons that a producer would consider for an investment such as a SDI system.

The *ATCF* was calculated as the gross margin after all variable costs (Lansford et al., 2004), including variable irrigation costs (Amosson et al., 2001) minus tax, assuming a 28% tax rate on income after depreciation for each year. *TV* is considered to be the additional value added to the land by the SDI system. Terminal value is calculated as the initial value of the investment minus accumulated depreciation calculated by the straight line deprecation method over 10 years. It is estimated that at the end of the 10-year depreciable life of the system the terminal value would be zero due to the uncertainty of future technology and the inability to remove drip laterals from the field. Terminal value would be positive at the end of the 7-year investment period because the investment payout period ends before the irrigation system is fully depreciated. Terminal value would be zero for the 10- and 15-year investment periods because these investment periods end after full depreciation of the irrigation system.

The real discount rate, *k*, equals 4.49% and is composed of the intermediate agricultural lending rate, 9.19% (Federal Reserve Bank-Dallas, 2006) adjusted for inflation by 4.50% using the inflation rate for other farm machinery in the Agricultural Prices report (USDA, 2006) and was calculated as (Bowlin et al., 1990):

$$k = \frac{(1+NR)}{(1+IR)} - 1 \qquad (2)$$

where *NR* represents the nominal interest rate and *IR* represents the inflation rate.

In this study, the NPV of several SDI systems with different uniformities were considered assuming that a water supply for the SDI system was already in place, therefore no installation cost of water supply was considered. Yield and loan rate data from the Bordovsky and Porter (2008) study conducted at the Texas AgriLife Research facility at Halfway, Texas, from 2001 through 2006 were averaged to provide gross revenue for determining ATCFs. The average was assumed to have an equal probability of occurring each year and was used as the basis for this analysis.

SDI systems with different flow variations at each of two irrigation levels were designed and analyzed. The target flow variations (Q_{var}) used in the hydraulic designs of these systems were 5%, 15%, and 27% and are represented as $Q_{var\text{-}5}$, $Q_{var\text{-}15}$, and $Q_{var\text{-}27}$, respectively. The designs were based on initial irrigation capacities of 6.7 and 4 mm/d (5 and 3 gpm/acre) representing the cotton irrigation levels of 1.0BI and 0.6BI of the earlier study. Although, somewhat drastic, to determine zone size and initial system costs of comparable High Plains SDI systems, an assumption was made that irrigation capacities (water well capacity) would decline to 25% of the initial irrigation capacity over a 20-year period. Therefore, SDI designs incorporated more zones in order to manage the declining water availability, thereby increasing the initial costs compared to systems where irrigation capacities were assumed to be constant. The six treatments were designated as $1.0Q_{var\text{-}5}$, $1.0Q_{var\text{-}15}$, $1.0Q_{var\text{-}27}$, $0.6Q_{var\text{-}5}$, $0.6Q_{var\text{-}15}$, and $0.6Q_{var\text{-}27}$.

The systems assumed a 804- × 804-m field with uniform downward slope of 0.25% parallel to drip laterals and crop rows. The cross slope was assumed to be zero. The SDI system water supply manifolds were located at the higher elevation with the filter station and controllers centered along the supply manifold line, at 402 m from the corners of the field. Additionally, the designs were based on 0.75-m row spacing with 1.5-m drip lateral spacing. The hydraulic design of both $Q_{var\text{-}5}$ treatments required dividing the field in half with two sets of laterals, one for the upper and the other for the lower half of the field each having drip laterals lengths of 402 m. The $Q_{var\text{-}15}$ and $Q_{var\text{-}27}$ treatments are designed with the SDI laterals running the entire length of the field, 804 m. Installation costs of the more uniform $Q_{var\text{-}5}$ treatments were increased due to additional material and labor required by supply and flush lines through the middle of these fields. The difference in installation costs between $Q_{var\text{-}15}$, and $Q_{var\text{-}27}$ designs are associated the increased cost of using larger diameter laterals, 25 mm, in the $Q_{var\text{-}15}$ design compared with 17-mm diameter laterals in the $Q_{var\text{-}27}$ design. The SDI system installation costs included pipe, filters, controllers, drip laterals, and installation, and were $2753, $2800, $2571, $2591, $2422, and $2441 per ha for the system designs $1.0Q_{var-5}$, $0.6Q_{var-5}$, $1.0Q_{var-15}$, $0.6Q_{var-15}$, $1.0Q_{var-27}$, and $0.6Q_{var-27}$, respectively (Funck, 2006).

Production risk can come from many sources and is important to consider in the decision-making process. The major source of risk comes from the variability in output caused by environmental conditions and management. Therefore, the relative magnitude of the standard deviations of yields and values are important to consider as they represent the variation of the different system designs. These variations in the production process over the life of the investment can have a substantial effect on the NPV. For this reason, a 10-year simulation analysis was conducted using Simetar© (Richardson et al., 2006) to determine the cumulative distribution functions (CDFs) for the NPVs of each system design under each irrigation level. Simetar© was also used to analyze stochastic dominance with respect to a function (SDRF) and stochastic efficiency with respect to a function (SERF). These analyses illustrate relative levels of risk by allowing the system designs to be ranked on the probability of a certain NPV occurring. Stochastic dominance and efficiency can be used to rank the systems based on a producer's level of absolute risk aversion (ARA) and can help explain the risk and potential outcomes with each system design. In this analysis, the yields and loan rates were considered to be the stochastic variables.

The CDF shows the probability (x-axis) of returns less than or equal to the associated return on the y-axis of the CDF graph. With the probability distributions, stochastic dominance can be used to determine efficient operating practices. An advantage of stochastic dominance is that complete information about a producer's utility function is not needed for analysis. Under first degree stochastic dominance, the CDF for the preferred choice has a probability of equal or greater returns than any other choice over the whole range of probabilities. There can be situations where the preferred choice is different at different probabilities, but a choice with second-degree stochastic dominance will have a greater value when integrated over the entire range of probabilities [i.e., area under the return function with respect to probability is greater than any other choice (Hardaker et al., 2004)].

In general, producers tend to be risk averse and try to minimize their production risk. Even in this general statement, some producers are more risk averse than others and level of risk aversion influences decisions. Stochastic efficiency with respect to a function (SERF) orders a set of risky choices by determining certainty equivalents (CE) for each choice based on a specified range of risk preferences. A CE represents a single value that a decision maker would assign to a distribution of possible returns. The CE for the same distribution of possible returns will be smaller for a decision maker who is more risk averse than another because they assume the guaranteed return from the distribution of possible returns is lower than a less risk averse decision maker would. The risk preferences are denoted by a producers risk aversion coefficient (ARAC). The ARAC values will vary for different decision makers, so there can be no fixed value for the relative risk of a group of decision makers. The larger the ARAC, the more risk averse a producer is. An ARAC of zero indicates that the producer is risk neutral while a negative ARAC would indicate the producer is risk preferring (Hardaker, et al. 2004). It is assumed that a producer would be risk averse and try to minimize their production risk.

RESULTS

The 10-year NPV analysis reveals differences between the two irrigation levels within the different system designs. All NPVs are positive meaning that all designs result in positive discounted after tax cash flows above the initial installation cost. Under the *1.0BI* level, the system design with Q_{var} of 15% resulted in the highest 10-year NPV compared to those Q_{var}'s of 27%, and 5% with a 10-year NPV of $3065 ha^{-1} as compared to $3030 and $3023 ha^{-1}, respectively (table 1). The positive 10-year NPVs represent the value of the future cash flows above the discount rate or required rate of return. Under 60% of the base irrigation level, the system design with the lowest irrigation uniformity ($0.6Q_{var-27}$) had the highest 10-year NPV of $3425 ha^{-1} compared to the $0.6Q_{var-15}$ and $0.6Q_{var-5}$ designs with 10-year NPV's of $3306 and $3076 ha^{-1}, respectively (table 1). When the two irrigation levels were evaluated, the *1.0BI* level resulted in lower 10-year NPVs across all flow variation designs. These results reflect the fact that the *1.0BI* and *0.6BI* levels had comparatively similar yields and revenues while the *1.0BI* level had higher variable irrigation costs due to the application of additional water resulting in lower cash flows and 10-year NPVs.

Seven- and 15-year NPVs were also evaluated for the different designs (table 1). Under the *0.6BI* level, the order of the systems based on their design did not change from the 10-year NPV when the time horizon of the NPV was changed. However, under the *1.0BI* level, the seven-year NPV differed from the 10-year NPV as the Q_{var-27} design resulted in the highest net present value. Additionally, when the 15-year NPV was evaluated, the Q_{var-5} design had the highest NPV. This change represents the extra time that is required for slightly higher ATCFs to accumulate to offset the higher initial installation cost. The time horizon of the NPV represents the planning horizon that the decision maker prefers to use and the length of the planning horizon can change the decision. Therefore, the choice must be specific to the decision maker's specific planning horizon. When the average returns for different designs are similar, many producers will choose the lower uniformity design because of reduced initial installation costs. However, there may be some increased risk with these lower uniformity designs.

All NPVs are positive indicating that the investment meets and exceeds the required return assumed in this study. Producers will experience a greater return on their

Table 1. Net present values across systems and irrigation rates.

	Q_{var-5} ($)	Q_{var-15} ($)	Q_{var-27} ($)
1.0BI			
7 year	1548	1625	1638
10 year	3023	3065	3030
15 year	5088	5080	4980
0.6BI			
7 year	1575	1800	1927
10 year	3076	3306	3425
15 year	5177	5415	5523

investment with the less uniform systems due to the lower initial cost, especially at irrigation levels that do not allow full irrigation.

The cumulative distribution functions (CDFs) of 10-year NPVs were used to identify the most preferred strategy at different levels of irrigation. Under the *1.0BI* level, the most uniform irrigation design (Q_{var-5}) exhibited an expected 10-year NPV distribution range from \$699 to \$5686 ha^{-1}, Q_{var-15} exhibited an expected 10-year NPV distribution range from \$807 to \$5781 ha^{-1}, and Q_{var-27} exhibited an expected 10-year NPV distribution range from \$212 to \$5993 ha^{-1}. When the *0.6BI* level was considered, the Q_{var-5} design exhibited an expected 10-year NPV distribution range from \$257 to \$6011 ha^{-1}, Q_{var-15} exhibited an expected 10-year NPV distribution range from \$1038 to \$5387 ha^{-1}, and Q_{var-27} exhibited an expected 10-year NPV distribution range from \$829 to \$6146 ha^{-1}.

When considering the CDF for the full base irrigation level (*1.0BI*), the Q_{var-15} design resulted in the smallest range in expected 10-year NPV and exhibited the highest minimum expected 10-year NPV. The Q_{var-15} design showed the smallest range in expected 10-year NPVs at the *0.6BI* level and the highest minimum expected 10-year NPV. Additionally, under the *1.0BI* level, the Q_{var-27} design displayed the highest maximum expected 10-year NPV. Under the *0.6 BI* level, the Q_{var-5} design displayed the highest maximum expected 10-year NPV.

At the *1.0BI* level, the Q_{var-15} design demonstrated second-degree stochastic dominance over the least uniform irrigation delivery (Q_{var-27}) and the most uniform irrigation delivery (Q_{var-5}). The Q_{var-27} design demonstrated second-degree stochastic dominance over the Q_{var-5} design. When the *0.6BI* level is considered, the Q_{var-27} design demonstrated second-degree stochastic dominance over designs with 15% and 5% flow variations. Additionally, Q_{var-15} demonstrated second-degree stochastic dominance over Q_{var-5}. When all treatments are considered together, the $0.6Q_{var-27}$ presented first-degree stochastic dominance over all the *1.0BI* level treatments.

The SERF analysis with absolute risk aversion coefficient (ARAC) bounds of 0.00 and 0.01 were used to evaluate a decision maker's preference for the 0.6 base irrigation level (fig. 1). The SERF analysis indicated that the Q_{var-15} and Q_{var-27} were the top ranked preferences at the 0.6 base irrigation level. The Q_{var-15} and Q_{var-27} for the 0.6 BI level switch ranking at an ARAC level of 0.0023 which illustrates that the more risk averse producer would prefer reducing the SDI flow variation from 27 to 15%. However, over this range of risk adversity ($0 < \text{ARAC} > 0.01$), producers would not prefer to further reduce Q_{var} to 5% for the 0.6BI level. Under the *1.0BI* level, Q_{var-15} was the preferred choice for all levels of risk (fig. 2). A more risk averse producer will be willing to pay a higher price for a more uniform system.

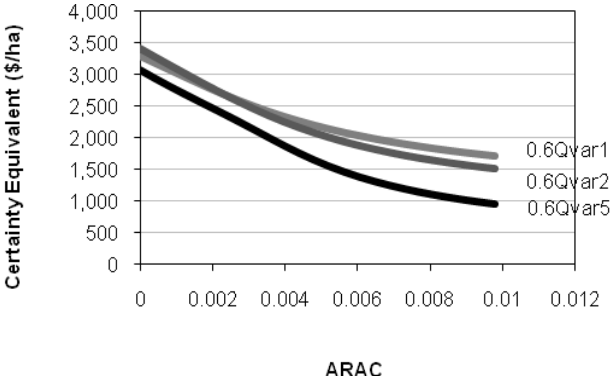

Figure 1. Stochastic efficiency with respect to a function (SERF) for 0.6 base irrigation level.

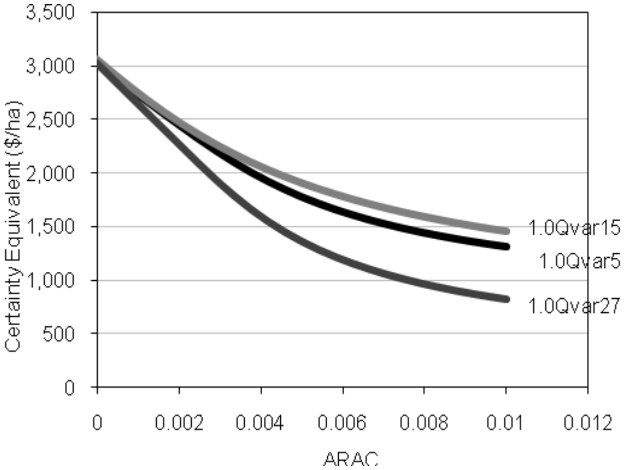

Figure 2. Stochastic efficiency with respect to a function (SERF) for full base irrigation level.

SUMMARY AND CONCLUSIONS

Under conditions of this study, cotton producers can obtain greater net present values with less uniform SDI systems when irrigation is limited under the semi-arid conditions of the Texas High Plains. In this study, limited irrigation was represented by irrigating to replace only 60% of the full irrigation amount. The net present value increased by 6%, 11%, and 22% for planning horizons of 15, 10, and 7 years, respectively, by using an SDI design with a flow variation of 27% rather than 5%. When irrigation is limited, it can be more profitable to accept a less costly and less uniform SDI design. Conversely, at the full irrigation level, there were some scenarios where a more uniform SDI distribution system increased the NPV. The greatest NPV for the 7-year time horizon at full irrigation was for the least uniform system, Q_{var-27} , while the greatest NPV for the 15-year time horizon was with the most uniform system, Q_{var-5}. This illustrates that as the time horizon increases, increased revenues due to greater uniformity can begin to overcome higher initial installation costs for the more uniform systems. Under the weather, crop production and economic conditions of this study, the reduced irrigation level, 0.6 BI, had approximately 2% to 13% greater NPVs than full irrigation with a 10-year planning horizon. The reduction in initial installation cost associated with a lower uniform system could help producers reduce the high cost of installing a SDI system for cotton production, making it a feasible choice when installing a new irrigation system. However, as producers become more risk averse they are more likely to choose a system with less flow variation and are more willing to pay the associated greater installation costs. The results show that even for risk averse producers with full irrigation capacity there is a point past which it is not economical to further increase SDI system uniformity.

The shape and size of the field can alter the costs of the SDI system design and make it an economically feasible alternative to furrow or center pivot irrigation. The assumption of decreasing irrigation capacities resulted in higher initial costs reducing NPVs than a system designed where irrigation capacity was assumed to be constant. Therefore, each case for SDI system design should to be considered on an individual basis as each scenario has its own unique results. This study only considered cotton grown on Pullman clay loam and Olton loam soils in Hale County, Texas. Further studies using other crops on different soil types are needed before any general recommendations to reduce SDI irrigation uniformity can be made.

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