SOPHISTICATED IRRIGATION TECHNOLOGY AND BIOTECHNOLOGY ADOPTION: IMPACTS ON GROUND WATER CONSERVATION

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A county-wide dynamic optimization model is used to evaluate the potential contributions associated with the adoption of sophisticated irrigation system technology and anticipated biotechnological advances in crop production on ground water conservation. The results indicate that adoption of these technologies could contribute significantly to ground water conservation efforts.

Key words: biotechnology; sophisticated irrigation technology; ground water conservation.

Irrigated agriculture in the U.S. critically depends on ground water supplies. About two-thirds of all irrigated acreage in the U.S. utilizes ground water supplies. Of fourteen million acres irrigated in areas where ground water aquifers are declining four million are located in Texas (National Research Council). The majority of this Texas acreage is located in the Texas High Plains (THP), where the Ogallala Aquifer is the main source of irrigation water.

The aquifer's saturated thickness in the THP, the interval between the water table and the bottom of the aquifer, ranges from 0 to 300 feet. Over the last three decades, the saturated thickness of the aquifer has significantly decreased as a result of continued overdraft. Moreover, pumping lift, the distance between the surface and the water table, is expected to continually increase over time since sources of recharge are limited. It is estimated that 30 to 35 percent of the pre-development ground water resources in the THP have been already mined. Continued withdrawal from the aquifer at current rates will likely result in the eventual depletion of this resource.

Cotton, grain sorghum, wheat, and corn are the major agricultural crops produced in the THP. These four crops contribute $2.3 billion in revenues annually to the THP's economy. Irrigated agriculture generates approximately 70 percent of this revenue. Given the reliance of the THP on agriculture, this is an inter-generational issue that must be evaluated in terms of the long-run sustainability of agricultural activities. In particular, the adoption of sophisticated irrigation system technologies such as the Low Energy Precision Application (LEPA) irrigation system, can significantly increase the efficiency of water use and, thus, decrease the amount of water needed to produce a crop (Lyle &

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Bordovsky, 1981). For example, in the Texas High Plains conventional furrow irrigation has an associated water application efficiency of 60 to 65 percent, depending on soil type and other factors. That is, 35 to 40 percent of the irrigation water pumped from the aquifer is lost to evaporation, percolation or other factors, and only 60 to 65 percent is used by the crop. Low Energy Precision Application has been shown to have a water application efficiency, again depending on soil type and other factors, of 98 percent (Lyle & Bordovsky, 1983).

In addition to improvements in irrigation technology, biotechnology could significantly enhance the long-run sustainability of agricultural activities in the THP. Specifically, biotechnology could extend the economic life of the Ogallala Aquifer through the development of crop varieties with high tolerance to water stress or reduced water requirements for crop growth.

The objective of this study is to determine the impact of new crop production technologies on ground water use and conservation in the THP. Specific objectives include: (1) to determine the economic and ground water depletion implications associated with the adoption of sophisticated irrigation system technologies and anticipated biotechnological advances, and (2) to evaluate potential monetary tradeoffs from ground water conservation efforts in the THP. Hale County serves as the representative THP study area.

Methods And Procedures

A recently updated dynamic optimization model used by Terrell (1998) was modified for Hale County, and is used to determine optimal cropping patterns and evaluate the impacts of sophisticated irrigation system technology and biotechnology adoption on ground water use. Specifically, the model optimally allocates ground water resources over time to maximize net present value of returns (NPVR) to land, risk, and management given the ground water stock on a per acre basis. Net present value of returns is the discounted value of the sum of expected future net returns over a given period of time (i.e., a planning horizon).

Net returns in this study are calculated as total gross returns minus total cost of crop production, where the later consists of variable and fixed costs. Variable crop production costs include the cost of pumping ground water, investment and maintenance costs associated with the establishment and up-keep of irrigation systems. The crop enterprises included in the model are: irrigated and dryland cotton, irrigated and dryland grain sorghum, irrigated and dryland wheat, and irrigated corn.

To examine the effects of the adoption of production technologies on the ground water stock, differences in saturated thickness depletion and NPVR from alternative models are analyzed. The model includes two equations of motion in order to monitor saturated thickness and pumping lift through time, whose initial values are 105 and 190 feet, respectively. In addition to a total cropland constraint, two crop acreage constraints were also included in the model. The first, was a constraint on the transition of acreage among irrigation technology states (conventional furrow, LEPA, and dryland). The maximum level of acreage assumed to transit among irrigation technology states was set at 5 percent per year. The second acreage constraint controlled the degree of crop adjustment. This constraint did not allow more than a 15 percent shift among crops per year. A 2 percent discount rate and a twenty-five year planning horizon are assumed in the model.

Overall, four variants of the model were solved using the Generalized Algebraic Modeling System (Brooke, *et al.*, 1998). In addition, a BASELINE was simulated assuming current production technologies remain in place in Hale County. The four models solved consist of the following

scenarios: (1) biotechnology adoption only (scenario A); (2) sophisticated irrigation system technology adoption only (scenario B); (3) joint adoption of biotechnology and sophisticated irrigation system technology (scenario C); and (4) joint adoption of biotechnology and sophisticated irrigation system technology constrained at the NPVR of scenario B (scenario D). Scenario D was formulated as minimization problem to find the minimum level of ground water required to achieve the specified NPVR level.

The methods and procedures used to derive crop yield expectations from biotechnological advances are outlined by Middleton (1996), and were introduced in terms of expected THP's long-term yield increases. The expected percentage crop yield increases in the biotechnology adoption scenarios for irrigated and dryland cotton are 11.55 and 8.64 percent, respectively; for irrigated and dryland grain sorghum, 10.56 and 10.62 percent, respectively; for irrigated and dryland wheat, 13.39 and 15.67 percent, respectively; and for irrigated corn, 9.85 percent (Arabiyat, 1998).

Results And Conclusion

The BASELINE simulation indicates a NPVR of $2,188.77 per acre and the associated level of ground water use is 26.04 feet/acre. The results from scenarios B and C, when compared to those of the BASELINE simulation, indicate that it is optimal to significantly decrease conventional furrow irrigated acreage, moderately increase LEPA irrigated acreage, and significantly increase dryland acreage (for details on optimal cropping pattern allocations and other particulars of the results see Arabiyat (1998)). The optimal levels of NPVR and ground water use for scenarios A, B, and C are as follows. Scenario A achieves a NPVR $2,891.50 per acre and water use of 26.04 feet/acre; scenario B achieves a NPVR $2,953.35 per acre and water use of 17.87 feet/per acre; and scenario C achieves a NPVR $3,624.46 per acre and water use of 17.87 feet/acre. As indicated by these figures, sophisticated irrigation system technology adoption has a larger marginal impact on NPVR than biotechnology adoption. Also, note that biotechnology adoption does not have a direct impact on ground water use, but sophisticated irrigation system technology adoption has a significant impact on water use, a reduction of 31.37 percent. Biotechnology adoption leads to a parallel shift of the production function (see figure 1) resulting in higher crop yields for the same level of water usage. It is important to point out, however, that the solutions associated with scenarios A, B, and C are not sustainable over time. That is, saturated thickness continually decreases over time under scenarios A, B, and C. For this reason, in approaching the potential contributions of biotechnology to ground water conservation, scenario D was formulated.

Specifically, in scenario D the model used in scenario C (joint adoption of production technologies) is constrained at scenario B's level of NPVR ($2,953.35 per acre). Scenario D is designed to find the minimum level of ground water required to achieve scenario B's level of NPVR. Thus, this scenario implicitly assumes that all the benefits from biotechnology adoption are "transformed" into ground water savings. That is, if the level of ground water conservation desired exceeds the level that could be achieved solely from adopting sophisticated irrigation systems, the optimal course of action is to adopt sophisticated irrigation system technology and then "transfer" the benefits of biotechnology adoption into additional ground water savings. The level of ground water use obtained under scenario D is 12.02 feet/acre, a reduction of 14.02 feet/acre or 53.84 percent from the BASELINE's level. Decomposing this reduction, 5.85 feet/acre and 8.17 feet/acre can be attributed to the adoption of biotechnology and sophisticated irrigation system technology, respectively. Of course, the associated level of NPVR under scenario D is less than for scenario C and has a value of $2,953.35 per acre, which is $671.11 per acre or 18.51 percent lower than scenario C's level. However, it is important to point out that scenario D is sustainable over time. In fact, under scenario D by year 17 the saturated

thickness stabilizes (i.e., no further decrease is experienced). A slight increase in saturated thickness from the lowest point in this scenario (approximately 2.4 percent) is experienced by the end of the 25 year planning horizon (for specific details on these findings see Arabiyat (1998)). The results from the BASELINE simulation and scenarios A to D are depicted in figure 1.

Figure 1. Net Present Value of Returns and Ground Water Use Levels – Simulation Results
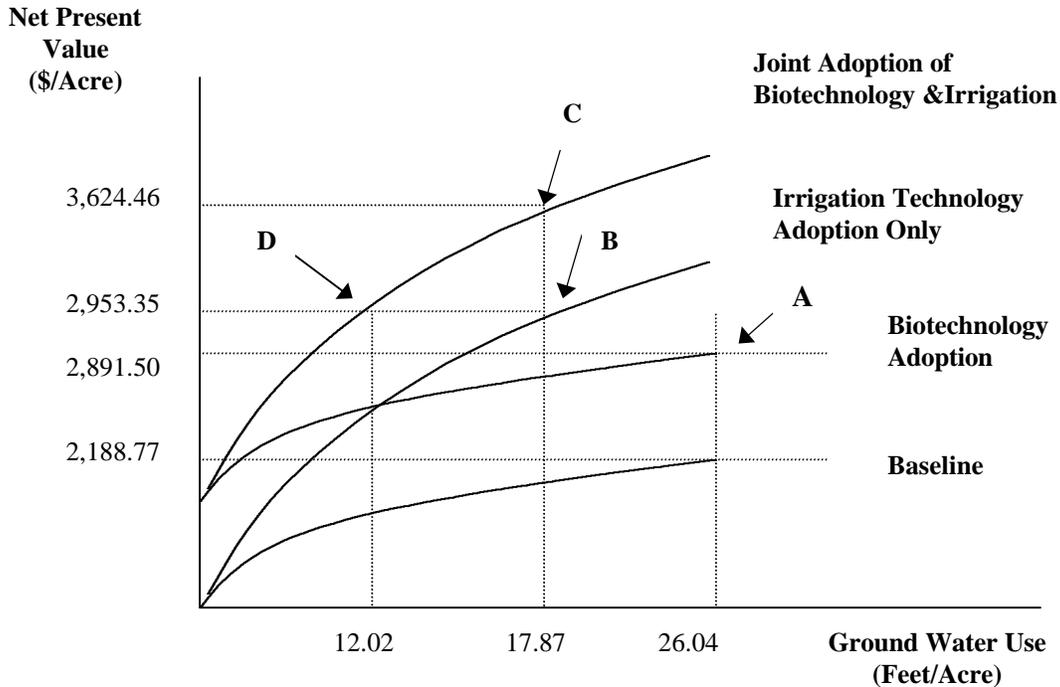
In conclusion, given the current conditions in the THP -- the widespread availability of sophisticated irrigation system technologies and the expected impacts of biotechnology in crop production -- it is optimal to adopt currently available sophisticated irrigation system technologies and, as soon as they become available, biotechnological advances. In the specific case of Hale County, joint adoption of these technologies increases NPVR from $2,188.77 to $3,624.46 per acre (a 65.59 percent increase), and reduces ground water use from 26.04 feet/acre to 17.87 feet/acre (a 31.37 percent reduction). Also, if it is desirable to maximize ground water savings from the joint adoption of these technologies, a trade-off of $671.11 NPVR per acre (or 18.51 percent) for an additional reduction of 22.46 percent in ground water use from the BASELINE level, would be expected. This latter solution is sustainable over time and would eliminate the overdraft of the aquifer in Hale County.

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