Assessing the Benefits Of On-Farm Reservoirs and Tail-Water Recovery Systems

Jennie Popp, Eric Wailes, Ken Young, Jim Smartt

Department of Agricultural Economics and Agribusiness
University of Arkansas
Fayetteville, AR 72701

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Denver, Colorado, August 1-4, 2004

Abstract

This paper uses the Modified Arkansas Off-stream Reservoir Analysis (MARORA) model to examine the impacts of on-farm reservoirs and tail-water recovery systems in conjunction with other best management practices on profitability, and water use for rice-soybean farming operations. Results suggest that under limited water availability conditions, reservoirs and tail-water recovery systems can improve profitability and reduce ground water dependence. Additionally, while reservoirs may not be profitable under plentiful ground water conditions, cost-sharing opportunities may make them a viable means of addressing environmental concerns.

Introduction

For nearly a century, agricultural producers in the Grand Prairie region of eastern Arkansas have produced rice, the most heavily irrigated crop produced in the state. Ground water from the Alluvial Aquifer in eastern Arkansas is used to irrigate about four million acres of crops, primarily rice, soybeans and cotton (Scott et al.). In recent years, this ground water has also been used to keep fields flooded for duck hunting. With increased aquifer exploitation, the water table has declined, forcing owners to lower their pumps and/or drill additional wells to maintain the irrigation level. For rice production, increased attention has been given in recent years to better utilize both the remaining ground water and rainfall with greater use of on-farm reservoirs, tail-water recovery and the adoption of water-conserving cultural practices.

Less than 45 feet of saturated thickness remain in the Alluvial Aquifer in the older, more developed irrigated areas of eastern Arkansas such as the Grand Prairie (Scott et al.). Average annual natural recharge in the region is less than 1.5 inches because of the relatively impermeable clay cap overlaying the aquifer (Scott et al.). Remedies to supply additional water are limited. Thus far, artificial recharge has not proven to be economically feasible (Smith and Griffis, Fitzpatrick, White, et al.). Proposals to supply new external surface water sources for irrigation in the region including diversions from major rivers such as the White River have been strongly contested to date because of economic and environmental concerns (U.S. Army Corps of Engineers). Furthermore, recent emphasis has been placed on row crop agriculture to minimize the potential for water quality degradation in nearby streams caused by agricultural runoff.

Researchers at the University of Arkansas have developed a simulation model to study the use of on-farm reservoirs and tail-water recovery systems in the management of rice and soybean production in Eastern Arkansas (Smartt et al.). This model, the Modified Arkansas Off-Stream Reservoir Analysis (or MARORA) model, is a farm level irrigation management and investment simulation framework that evaluates the economics of ground and surface water supplies for Arkansas rice and soybean farms under various farm resource conditions The model can be used to provide an analysis of the economics of on-farm reservoirs in conjunction with other best management practices (BMPs) that can protect ground water availability, sustain irrigated agricultural production and perhaps improve surface water quality in the Arkansas Delta.

The purpose of this paper is to apply the MARORA model to evaluate the use of on-farm reservoirs/ tail-water recovery systems in conjunction with other BMPs with respect to: 1) economic costs and returns and. Additionally application of MARORA in addressing environmental concerns, particularly sediment movement off farm, will be discussed.

Background and Literature Review

Water Quantity and Quality Concerns

All of eastern Arkansas is underlain by the deep water Sparta Aquifer and the more shallow water Mississippi River Valley Alluvial Aquifer. However the Sparta has limited irrigation use due to high pumping costs. The Mississippi River Alluvial Aquifer has developed cones of depression due to excessive pumping. The current irrigation system relies on ground water sources that are not sustainable in the long-run (Czarnecki, Hays and Terry).

To reduce the dependence on ground water use, some proposals such as the White River Diversion Project have called for large scale stream diversion of surface water for irrigation purposes (USACE). The White River Diversion Project has been challenged by environmentalists that are concerned about ecosystem damage associated with large scale water withdrawal which can exacerbate sedimentation problems already evident in the region.

Best Management Practices for Irrigated Rice and Soybean Production

Farms can decrease water needs for rice and soybean production by increasing irrigation efficiency with approved BMPs. Some of these BMPs include shorter season rice varieties, land leveling, irrigation pipelines, on-farm reservoirs and tail-water recovery systems. Shorter season rice varieties reduce the amount of time the field needs to be flooded. Some varieties can reduce flood time by 5 to 20 days. Irrigation pipelines can increase irrigation efficiency by roughly 10% compared to open canals by reducing evaporation and seepage losses (Tacker). Land leveling eliminates high spots in a field, which decreases the irrigation flood depth requirement and allows better drainage. As a result, irrigation is approximately 10 to 20% more efficient because less water is needed to flood the field (Tacker).

There are many factors that can influence the decision to construct a reservoir and/or tail-water recovery system. Major factors include construction costs, water availability, crop mix, environmental concerns, farm size and length of production period. Reservoir construction does not represent a negligible expense. The cost of moving the soil alone has been estimated up to $1.00 per cubic yard (Farmer Panel) and valuable cropland is sacrificed for reservoir construction. The wide variety of economic, resource and production conditions that any given producer may face suggests that the decision to adopt or not adopt these management practices is not an easy one. The MARORA model has been developed to assist in this type of decision making.

The MARORA Model

Previous research with MARORA has estimated the net economic benefits of supplementing ground water with surface water sources, using on-farm reservoirs, and tail-water recovery systems (Wailes et al., 1999, 2002). The MARORA simulation model evaluates daily weather data to predict the crop yield response, irrigation demand, reservoir use and water balance, well use and well yield, and associated pumping costs in each growing season. Major changes in the irrigation system include construction of on-farm reservoirs to supplement well use and access to surface water sources such as bayous and canals. These modifications are evaluated over a 30-year period to determine the impact on the discounted net present value of annual net farm income over the projected period.

Methodology

This analysis uses the MARORA model to evaluate the impacts of on-farm reservoirs and tail-water recovery systems in conjunction with other BMPs with respect to economic returns and water use. Two baseline models were developed. The Adequate Ground Water scenario assumes a 50 ft initial saturated thickness and a 0.5 ft annual decline in the water level. The Limited Ground Water scenario assumes a 30 ft initial saturated thickness and a 1.0 ft annual decline in the water level. These assumptions represent two general cases in Eastern Arkansas. Both baseline models include the following assumptions. (1) Weather and silt loam soil conditions are used that are representative of Stuttgart, Arkansas, one of the largest rice producing areas of the state. (2) A reservoir is assumed to service a 320 acre field, and the construction of a reservoir would result in the reduction of the available crop land in the field by the amount of area occupied by the reservoir. (3) A reservoir is filled once in the spring from surface water and field runoff and tail-water is returned throughout the crop growing season. (4)

As rice and soybeans are grown in a 1 to 1 rotation, the model field is comprised of 50% rice and 50% soybeans in the first year of the simulation. The ability to maintain that rotation in future years can be impacted by weather and water availability. (5) The maximum annual soybean and rice yields are 50 bushels per acre and 160 bushels per acre, respectively. These are conservative estimates based on 10-year averages in Stuttgart, Arkansas. (6) Water recovery efficiency is 80%, based on relift pump and temporary on field storage availability (Fooks). (7) Baseline irrigation efficiency with no water conservation improvements is 50% for rice and 45% for soybeans (Tacker). (8) Production costs reflect those in the 2002 University of Arkansas Crop Production Budgets (Windham and Laferty, 2002a, 2002b, 2002c). (9) The discount rate used to calculate net present value of costs and returns is 8%. (10) Crop prices are adjusted to reflect price plus government payments. (11) Laser leveling was priced at $300 an acre. (12) Excavation costs for reservoir construction were priced at $1.00 per cubic yard. (13) Underground piping was priced at $50.00 an acre. (14) Cost share opportunities do not exist. (15) The projection period is 30 years.

Using these assumptions, the two baseline models are run to determine if an on-farm reservoir is an economically efficient management practice for rice and soybean production on the 320 acre field under adequate and limited ground water situations. Economic returns and water use are monitored for the baselines. Next, in the event that a reservoir is deemed profitable, impacts of on-farm reservoir and tail-water recovery systems in conjunction with other BMPs are examined. These BMPs include shorter season rice varieties which result in removal of flood waters 5, 10, 15, or 20 days earlier than full season rice; improvements to irrigation efficiency by adding underground pipe only; and improvements to irrigation efficiency by adding underground pipe and laser leveling the field. Underground pipe is expected to increase irrigation efficiency by 10% (such that rice/soybean irrigation efficiency increases from 50/45 to 50/55, respectively), whereas laser leveling can increase irrigation efficiency by 10 to 20% (Tacker).

Results

Baseline Scenarios

Rice and soybean production was first simulated using the Adequate Ground Water and Limited Ground Water baseline characteristics. Results of these simulations are found in Table 1. The reservoir and tail-water recovery system was not profitable in the Adequate Ground Water scenario. However, sensitivity analysis suggests that the reservoir does become profitable when a 75% cost share opportunity exists.

In this Adequate Ground Water scenario, the manager of a 320 acre field earned an average annual return of $63,277 over the 30-year period. Water usage was relatively high - 39.9 acre inches and 26.2 acre inches for rice and soybeans, respectively - and contributed to average annual production of 160 bushels per acre of rice and 50 bushels per acre of soybeans. As reservoirs are not profitable in this Adequate Ground Water scenario, no further analyses of the impacts of reservoirs and BMPs were conducted.

Reservoir construction for the Limited Ground Water scenario was profitable. A 620 acre foot reservoir and tail-water recovery system was constructed that removed 70.66 acres from the available cropping acreage. In utilizing the reservoir, a manager could use on average 38.9 acre-inches of water on rice and 25.4 acre inches on soybeans. The remaining 249 acres of cropland averaged 49.5 bushels per acre annually for soybeans and 156 bushels per acre for rice, which are nearly as good as the yields in the Adequate Ground Water scenario. Average annual returns were reduced from the Adequate Ground Water situation to $49,280.

As reservoirs were found to be profitable in the case where a Limited Ground Water situation exists, impacts of reservoirs along with other BMPs were examined to determine whether the addition of other BMPs impacted the reservoir size, economic returns and water use.

BMP Analysis

Simulations were run next to determine the impact of a reduction in the rice growing season Four scenarios were run assuming a five, ten, fifteen and twenty day reduction in the needed growing season. Results are presented in Table 2. Results from the Limited Ground Water baseline scenario are also presented again for comparative purposes. This study found that compared to the baseline scenario, the reduction in the growing season by 5 to 20 days can increase average annual income by as much as $2,393 to $6,606, reduce needed reservoir size by a range of 40 to 100 acre feet, and reduce total annual water needs per acre by roughly 2 to 7 inches.

Increases in irrigation efficiencies over the baseline level were examined three ways: 1) 10% from added underground pipe, 2) 10% from pipe and 10% from laser leveling and 3) 10% from pipe and 20% from laser leveling. These three scenarios represent an increase in irrigation efficiencies for rice/soybeans from 50/45 to 60/55, 70/65 and 80/75, respectively. As expected, results suggest that the greater the irrigation efficiency, the smaller the needed reservoir size. Actual reservoir sizes fell from 620 acre feet in the baseline scenario to 560 acre feet with the addition of underground pipe, and finally to only 440 acre feet when irrigation efficiency increased to 80/75 for rice/soybeans with underground pipe and laser leveling. While each additional water conservation practice did result in additional water savings, as shown in Table 3, these savings accrued at a diminishing rate.

Under the assumed limited ground water supply conditions, reservoirs and tail-water recovery systems may become a profitable way to manage scarce water conditions. When reservoirs are used in conjunction with other BMPs such as shorter season rice varieties, laser leveling, and underground pipe, profits may increase further while water needs are reduced.

Other environmental considerations

While the use of a reservoir and tail-water recovery system may not be economical for a relatively adequate water situation, environmental concerns in the region suggest the possibility of other benefits of reservoir and tail-water recovery systems. As noted, the reservoirs store rainwater, groundwater, and surface water until water is needed on the field. Tail-water recovery systems capture runoff water as it is leaving the field so that it can be recycled throughout the production system. Therefore, reservoirs and tail-water recovery systems may produce an added benefit by reducing the amount of runoff sediment, nutrients and pesticides that leave a farm. This is especially important as sedimentation is the number one problem affecting surface waters in Eastern Arkansas and is also the focus of the Total Maximum Daily Load (TMDL) discussions in the state. Efforts are underway to amend the MARORA model to account for sediment, nutrient and pesticide runoff. Preliminary analysis suggests that these systems are capable of collecting 80 percent of the potential sediment loss from a field. Depending upon the soil and management practices used, this could reduce sediment loss by up to 12,000 tons over a thirty year period on a 320 acre field. The addition of these sedimentation reduction benefits, and the possibility for cost share opportunities through EQIP and other state and federal programs may expand the desirability of reservoirs and tail-water recovery systems in the Arkansas delta.

Summary and Conclusion

This research was conducted to determine the impacts of reservoirs and tail-water recovery systems in conjunction with other BMPs on annual returns and water use under two assumed ground water situations. An Adequate Ground Water scenario was developed that assumed an initial saturated thickness of 50 ft and an annual decline rate of 0.5 ft. Results suggest that reservoir construction under these ground water conditions is not profitable. Under the assumed Limited Ground Water supply conditions, reservoirs and tail-water recovery systems may become a profitable way to manage scarce water conditions. When used in conjunction with other BMPs such as shorter season rice varieties, laser leveling, and underground pipe, profits may increase further while water needs are reduced.

Evidence from this study supports the use of on farm reservoirs and tail-water recovery systems as an effective and profitable method of supplying needed irrigation water. In addition, these systems might provide an additional benefit by controlling the amount of sediment, nutrient and pesticides that leaves the farm. On-farm and modeling research continues at the University of Arkansas to better understand the relationships between agricultural management practices, sediment, nutrient and pesticide movement and the potential for reservoir and tail-water recovery systems to effectively reduce the potential for environmental degradation in the region.

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Table 1. Results of Adequate and Limited Ground Water Baseline Scenarios

Ground Water Situation	Optimal Reservoir Size	Average Annual Income	Average Annual Water Use Rice	Average Annual Water Use Soybeans
	acre/ft.	$	in.	in.
Adequate	0	63,227	39.9	26.2
Limited	620	49,280	38.9	25.4

Table 2. Impacts of Short Season Varieties and On-farm Reservoirs and Tail-water Recovery Systems, for "Limited Ground Water" Situation

Rice Season Shortened By	Optimal Reservoir Size	Average Annual Income	Average Annual Water Use Rice	Average Annual Water Use Soybeans
	acre/ft.	$	in.	in.
Limited Ground Water baseline	*620*	*49,280*	*38.9*	*25.4*
5 days	580	51,673	37.1	25.3
10 days	580	53,376	35.5	25.5
15 days	540	54,672	33.4	25.0
20 days	520	55,886	31.7	25.2

Table 3. Impacts of Irrigation Efficiencies and On-farm Reservoirs and Tail-water Recovery Systems, for "Limited Ground Water" Situation

Increase in Irrigation Efficiency (Improvements to rice yields)	Optimal Reservoir Size	Average Annual Income	Average Annual Water Use Rice	Average Annual Water Use Soybeans
	acre/ft.	$	in.	in.
Limited ground water baseline	*620*	*49,280*	*38.9*	*25.4*
10% - pipe only	560	51,202	32.8	20.8
20% pipe and leveling	460	51,946	28.0	17.0
30% pipe and leveling	440	54,808	24.7	14.9