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Energy Efficiency versus Economic Efficiency of Pollution Abatement in an Irrigated Farming Area of the Pacific Northwest

by

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ABSTRACT

The national goals of a cleaner environment and energy conservation are in conflict in many areas. This paper examines the energy requirements of abating pollution from irrigation return flows. It is shown, for the area studied, that pollution control practices need not increase the energy requirements of a particular farm. However, some energy intensive practices such as sprinkler systems may be chosen by farmers for reasons other than effective pollution abatement.

Introduction

There are two national goals which create potential conflicts for agricultural policy makers--the desire to improve environmental quality, and the need to conserve energy. Frequently, it is suggested that attempts to abate agricultural pollution will result in a more energy intensive production agriculture. This paper examines the energy requirements of abating pollution from irrigation return flows in the Pacific Northwest. Alternative solutions or control practices to meet environmental quality standards are examined for economic efficiency and energy requirements.

Problem Setting

Water diverted for irrigation from surface or ground waters is frequently altered in its quality. Water returning to surface bodies contains higher levels of salinity, nitrates, sediment, coliform, and other pollutants that are derived from irrigation. These pollutants result in reduced water quality for the receiving waters.

The study area for this analysis consists of Jerome and Twin Falls Counties in the Magic Valley of south central Idaho. The major soil textures of the region are silt loams and sandy loams with a terrain that is level to rolling. Irrigation is predominantly by gravity flow furrow methods. The major crops include alfalfa, wheat, pasture, dry beans, and potatoes.

This paper will focus upon two parameters of water quality as affected by irrigation return flows. The first is sediment which is picked up by runoff waters. Sediment losses can also be a proxy for a number of other pollutants such as phosphates, coliforms, and temperature changes that result from surface runoff and exposure. The other element of concern in this analysis is nitrates obtained by water percolating through the soil profile. Nitrates derive primarily from fertilizers and natural soil nitrogen. Nitrates may also be considered as a proxy for any dissolved chemicals or minerals obtained as the water moves through the soil profile.

Control Practices

Several control practices may be considered as viable alternatives for abating sediment or nitrogen pollution. In general, the control practices fall into two classifications. The first involves better management of the current furrow irrigation system, physical alteration of the existing system, or conversion to sprinkler irrigation. The second type of solution involves the use of devices that retain sediment removed from the field by surface runoff. Each of these general types of control practices may alternately affect either the amount of runoff or deep percolation water flowing from an irrigated field. Control practices considered in this analysis are described below.

Present Furrow

The benchmark for comparison of results considered in this analysis is the present furrow irrigation system practiced in the Magic Valley. Using this system, farmers frequently over-irrigate because of an abundance of water. Water is substituted for labor and capital, resulting in excessive runoff and deep percolation. These practices result in large sediment and nitrogen losses from the farm.

Improved Furrow

The improved furrow system makes no changes in physical facilities of the typical farm in the Magic Valley, but uses optimum irrigation scheduling, length of set, and stream size. These factors are measures of the management input for irrigation. Irrigations are scheduled to meet crop needs through the use of a computerized scheduling service. The irrigator adjusts the length of time for a given irrigation to the field needs and adjusts furrow stream size to minimize runoff and deep percolation losses. It was assumed that total labor inputs for irrigation did not increase under this irrigation system. The cost of the scheduling service served as a proxy for the increased costs of improved management.

Cut-Back Furrow

The cut-back furrow system employs additional labor with the present furrow system to reduce the size of the irrigation stream once water has advanced to the bottom of the field. In so doing, runoff losses are reduced. A relatively large stream is initially used to achieve a short furrow advance time. As a result, the uniformity of water application is improved and deep percolation losses at the top of the field are reduced.

Pump-Back Furrow

The pump-back furrow system collects runoff water with ponds at the bottom of the field. This water is then pumped back to the top of the field or the farm head ditch. Although field runoff occurs, no pollutants are allowed to leave the farm through surface runoff. The collection ponds also serve as sediment ponds from which eroded sediment can be redistributed to nearby croplands. Deep percolation losses are unaffected by the pump-back system.

Gated Pipe Furrow

The gated pipe furrow system combines features of the improved furrow and the cut-back irrigation systems. Irrigation scheduling and length of set are controlled through automated means. Stream size is automatically reduced when the stream reaches the end of the furrow to reduce runoff and deep percolation.

Multi-Set Furrow

The multi-set furrow system combines features of the improved furrow system with a shorter furrow length. Irrigation scheduling and length of set are automatically controlled to match crop needs. The shorter length of run is utilized to reduce furrow advance time and the potential for runoff from the surface. These changes lead to increased uniformity of water application and decreased deep percolation.

Side-Roll Sprinkler System

The side-roll sprinkler system is an alternative to current furrow irrigation methods. Crop water requirements determine the irrigation schedule and length of set, both of which are automatically controlled. The sprinkler system eliminates surface runoff and hence, sediment losses from the field. This system also reduces deep percolation and nitrogen losses.

Sediment Retention Devices

Two additional control practices were considered as means of retaining sediment losses on the farm for redistribution on fields. The first is a strip of grass or grain across the end of a field to filter sediment from surface runoff. The filter strip is a relatively inexpensive control practice, but also ineffective in the complete abatement of sediment pollution.

A second sediment retention device considered was the sediment pond. In this case, a pond is placed in the path of the irrigation return flow system on the farm for collection of sediment. The surface runoff passes through the pond reducing the flow velocity and depositing sediment in the pond. In both cases, it is assumed that sediment so collected is redistributed to fields on the farm.

Results

To analyze the efficiency and effectiveness of these alternative control practices, a linear programming model was constructed to represent a typical Magic Valley farm. The model maximized net returns to land, management, and overhead. Simultaneously, the model provided estimates of crop production, resource use, sediment and nitrogen losses for each of the alternative control practices. The Magic Valley model farm contained 300 acres of irrigated cropland. Crops were initially irrigated using current furrow irrigation methods on a silt loam soil with 1.5 percent slope. The cropping pattern was: wheat--80 acres, alfalfa--80 acres, potatoes--80 acres, and dry beans--60 acres. Crop prices represented an average for the years 1975-77. Costs of each abatement control practice were measured as changes in net farm returns.

This analysis also estimated energy intensity or energy use changes imposed by control practices for affecting pollution abatement. Table 1 shows annual per acre energy requirements for various irrigation systems and sediment retention devices used on the Magic Valley model farm. This table includes estimates of

Table 1.--Annual per Acre Energy Requirements for Various Irrigation Systems and Sediment Retention Devices Used on the Magic Valley Model Farm

Item	Embodied Energy[a]	Fuel Energy[b]	Pumping Energy	Fertilizer Energy	Total Energy
	(1,000 BTU/acre)				
Irrigation System:					
Present Furrow (PFRW)	39	2,167	0	3,380	5,586
Improved Furrow (IFRW)	39	2,167	0	3,220	5,426
Cut-Back Furrow (CTBK)	39	2,167	0	3,060	5,266
Pump-Back Furrow (PMPBK)	162	2,221	570	3,380	6,332
Gated Pipe Furrow (GPIPE)	1,043	2,167	0	2,980	6,190
Multi-Set Furrow (MLTST)	553	2,210	12	2,770	5,545
Side-Roll Sprinkler (SDRL)	1,540	2,031	4,041	3,030	10,642
Sediment Retention Device:[c]					
Filter Strips (FSTRP)	42	2,181	0	3,380	5,603
Sediment Pond (SPND)	45	2,221	0	3,380	5.646

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[a] Includes the embodied energy of irrigation systems, sediment retention devices, land preparation, and tractors and machinery (assumed to be 30% of the fuel requirement). (Hagan, R.M., Energy in Western Agriculture--Requirements, Adjustments and Alternatives, California Contributing Project Report for the Western Regional Research Project, Department of Land, Air and Water Resources, Water Science and Engineering Section, Davis, Calif., April 1978.)

[b] Includes the fuel requirements for: crop production, sediment excavation and spreading operations for sediment retention devices and irrigation ponds; grading, trenching and pipe-laying operations for installing irrigation systems.

[c] Includes the annual energy requirements of the present furrow irrigation system.

energy for manufacture of physical facilities (embodied energy), fuel, water pumping, and fertilizer. Using the present furrow system as a benchmark, it is shown that very little change of energy inputs is required for most of the control practices considered in this analysis. Only the side-roll sprinkler system results in significant increases in energy use. Of course, the center pivot irrigation system would require even greater amounts of energy if adopted.

Net returns, input use, and pollution losses associated with each of the control practices are summarized in Table 2. All values shown in this table are on a per acre basis and they represent averages for the entire 300 acre farm.

Table 2.--Pollutant Losses, Net Returns, Energy and Input Use for Alternative Control Practices

Item	Sediment Loss (T/ac)	Nitrogen Loss (lb/ac)	Net Returns ($/ac)	Energy Use (million btu/ac)	Water Use (ac-in/ac)	Labor Use (hrs/ac)
Irrigation System:						
Present Furrow (PFRW)	6.6	18	225	5.59	61	9.6
Improved Furrow (IFRW)	5.7	14	223	5.43	54	9.6
Cut-Back Furrow (CTBK)	3.3	11	216	5.27	45	13.4
Pump-Back Furrow (PMPBK)	0	17	213	6.33	42	9.7
Gated Pipe Furrow (GPIPE)	2.6	10	216	6.19	41	6.0
Multi-Set Furrow (MLTST)	0.2	5	175	5.54	31	6.0
Side-Roll Sprinkler (SDRL)	0	13	196	10.64	39	7.2
Sediment Retention Devices:						
Filter Strips (FSTRP)	5.5	18	224	5.60	61	9.6
Sediment Pond (SPND)	2.0	18	217	5.65	61	9.6

The present furrow irrigation system is used as a benchmark for comparing the results of alternate control practices on the Magic Valley farm. It is shown in Table 2 that sediment losses equal 6.6 tons per acre, and nitrogen losses approach 18 pounds per acre for this system.

Consider first the effectiveness of sediment abatement on this farm. Only two systems, the pump-back furrow and side-roll sprinkler, result in complete elimination of sediment losses from the farm. Others, such as the multi-set furrow and gated pipe furrow systems, substantially reduce sediment losses. Also it is shown that the sediment pond, as a retention device, substantially reduces farm losses of sediment.

Nitrogen losses are most effectively reduced by the multi-set furrow and gated pipe irrigation systems. These are the systems which most effectively control deep percolation losses. Obviously, neither of the sediment retention devices change the per acre losses of nitrogen for this farm since they do nothing to affect the amount of water allowed to filter through the soil profile.

Energy consumption affected by alternate irrigation systems or sediment control devices parallel the information shown in Table 1. There are small increases in energy consumption for the pump-back furrow system primarily because of energy required to pump water from the bottom of the field to the farm head ditch. The gated pipe furrow irrigation system also increases energy consumption due to the embodied energy in the irrigation system itself. The side-roll sprinkler system, which is frequently chosen for reasons other than its abatement effectiveness, nearly doubles the energy requirements of this farm due to relatively large embodied and pumping energy requirements. Thus, it may be concluded that adjustments in current gravity flow irrigation systems such as those described in Table 2 do not necessarily increase the energy intensity of production agriculture. However, the use of sprinkler systems to abate agricultural pollution or to improve the productivity of selected farms may result in considerable increases in energy intensity.

Table 2 also shows the net economic returns to farming under each of the abatement control practices. Only the multi-set furrow system and the side-roll sprinkler system, both requiring substantial capital investment, result in significant reductions of net farm income. The economic efficiency, as well as the energy intensity, of these alternate control practices are most easily compared by using Figures 1 and 2.

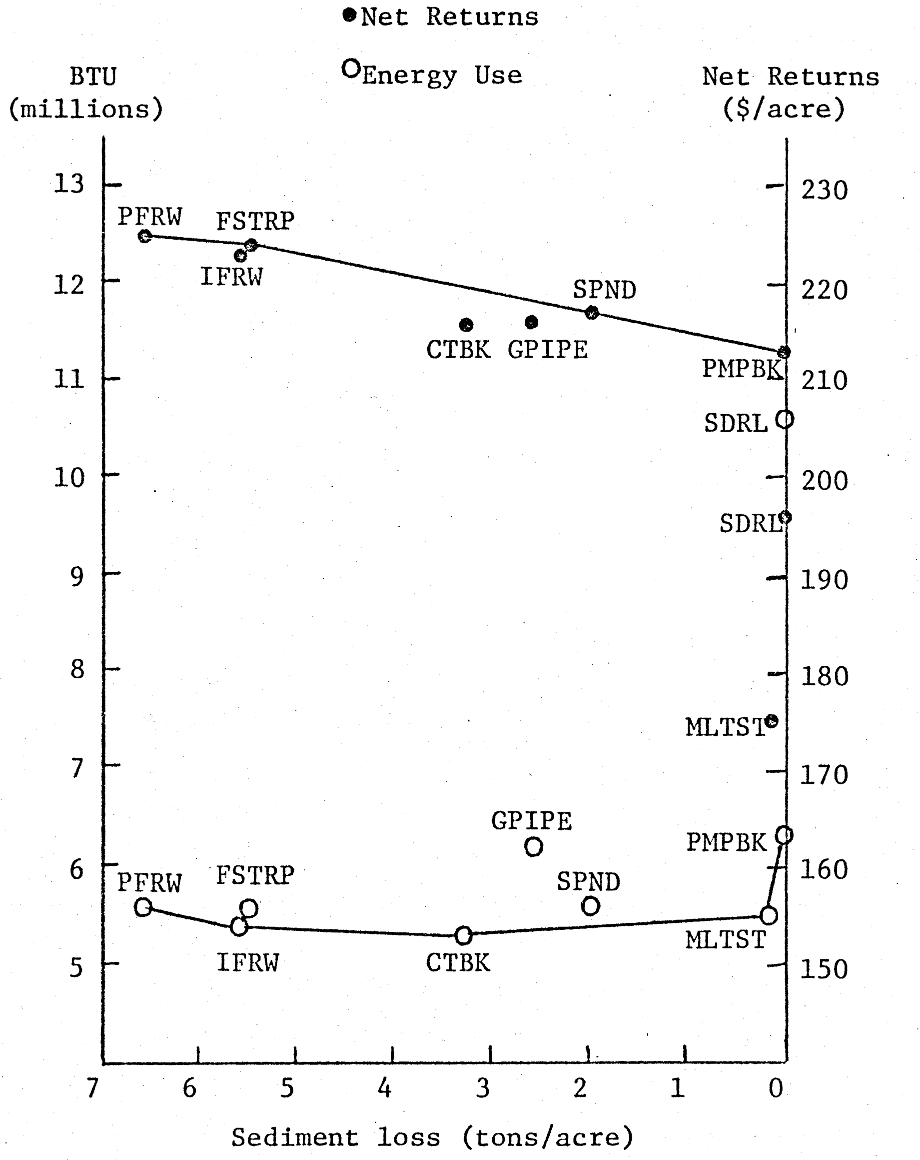

Figure 1.--Energy and economic efficiency comparisons for alternative control practices used in reducing sediment losses

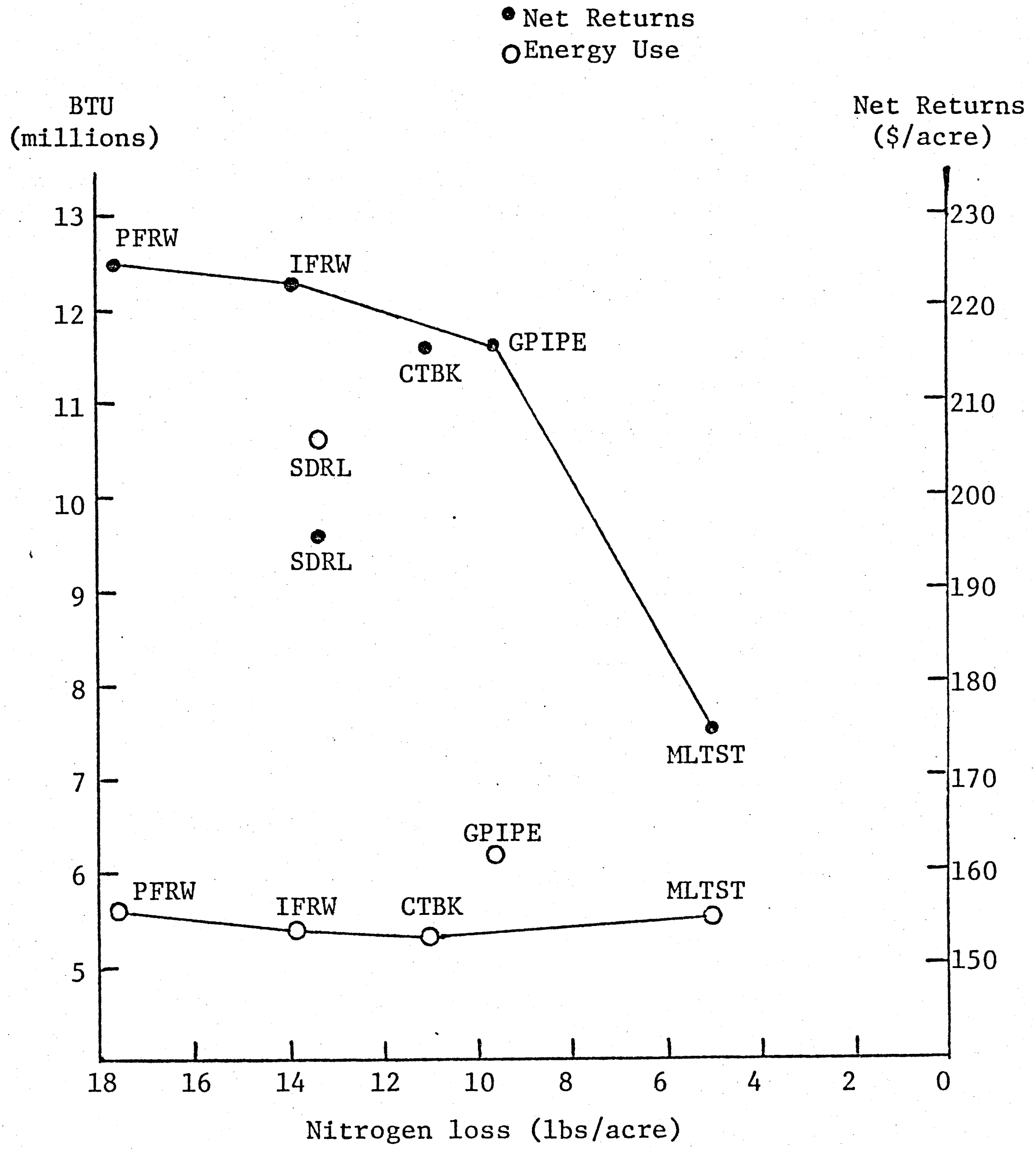

Figure 2.--Energy and economic efficiency comparisons for alternative control practices used in reducing nitrogen losses

Sediment Abatement

Figure 1 compares the per acre net returns, energy use, and sediment loss for each of the irrigation systems and sediment retention devices. A cost efficiency frontier is shown connecting those control practices which result in the most efficient abatement choices for given levels of sediment loss. Similarly, an energy efficiency frontier is shown for the same group of control practices. Figure 1 shows that net returns per acre are $225 under the present furrow system (PFRW), while sediment loss is 6.6 tons per acre. The most efficient means of reducing sediment to approximately 5.5 tons per acre, a 16 percent improvement, would be to use the filter strips (FSTRP) wherever possible. Net returns are reduced only $1 per acre. Reducing sediment losses to 2 tons per acre could be accomplished most efficiently by using a sediment pond (SPND). Net returns would be reduced approximately $8 per acre. Sediment losses could be completely eliminated by the adoption of the pump-back system (PMPBK) at a cost of $13 per acre.

All control practices lying below the efficiency frontier are more costly in reducing sediment losses than those on the frontier. The improved furrow system (IFRW) would result in about the same amount of sediment loss improvement as the filter strips, but at about twice the economic cost. Use of the cut-back (CTBK) or gated pipe (GPIPE) furrow systems would be $2-$4 per acre more costly to the farm than the use of either the sediment pond or pump-back systems in reducing sediment losses. Net returns could be reduced by $29 per acre with a side-roll sprinkler system (SDRL), and $50 per acre with a multi-set furrow system (MLTST); these are effective, but costly, alternatives to the pump-back system in eliminating sediment losses.

Figure 1 shows that the energy intensity of agriculture would be relatively unchanged by the use of any control practice lying on the energy efficiency frontier with the exception of the pump-back system. Of course, choosing the side-roll sprinkler system to reduce labor inputs or improve crop yields beyond attainable means with furrow irrigation methods may increase energy intensity for reasons other than strict pollution abatement. Some of the furrow irrigation methods may actually reduce the energy requirements of this particular type of farm. Savings in energy are largely derived through reductions of nitrogen and phosphorus fertilizer requirements. Phosphorus losses, though not described here, are closely related to sediment losses. Thus, the use of a control practice that results in lower sediment losses would also result in lower phosphorus losses and fertilizer application rates.

Nitrogen Abatement

Figure 2 compares the same control practices for economic efficiency, energy requirements and their effectiveness in controlling nitrogen losses from the farm. Those practices which are most efficient in controlling nitrogen are not necessarily the same practices to efficiently reduce sediment losses. This is not surprising since sediment losses result from surface runoff while nitrogen losses result from deep percolation of water.

Figure 2 shows that small improvements in nitrogen losses can be achieved most efficiently using the improved furrow irrigation system, primarily an improvement in management with the current system. The gated pipe system would reduce nitrogen losses by 50 percent at a cost of about $9 per acre. The multi-set irrigation system would substantially reduce net farm income, but could effectively control nitrogen losses to a level of approximately 5 pounds per acre. Those practices which are on or near the efficiency frontier for controlling nitrogen losses also result in small changes in the energy budget for the farm, except for the gated pipe irrigation system which lies substantially above the energy boundary.

Summary and Conclusions

The results of this paper suggest that it may be possible to improve environmental quality without increasing energy consumption. It may not be necessary to turn toward higher energy inputs to effectively reduce pollution for this particular farming situation. Extrapolating the results of this farming situation to other irrigated conditions should be done with caution, however. Some soils or slopes may not be efficiently converted to improved furrow irrigation practices for pollution abatement purposes. In these cases, sprinkler irrigation may be required to achieve necessary water use efficiencies.

Basing control practice choices on two or more criteria simultaneously, such as cost, energy use, sediment abatement, and nitrogen abatement, can also alter the picture. Considering only energy conservation, the improved furrow, cut-back furrow, and multi-set furrow systems should be used to reduce sediment losses to increasingly lower levels. This recommendation, however, is not consistent with an economic efficiency criteria, especially at high levels of abatement. On purely economic efficiency criteria, the filter strips, sediment pond, and pump-back furrow systems should be chosen for sediment loss abatement. None of these are effective in abating nitrogen losses, however.

The multi-set system effectively reduces both sediment and nitrogen losses, but is very costly ($50 per acre). But since it is the only control practice capable of reducing nitrogen losses beyond 50 percent, it may be a necessary choice. The cut-back furrow is an example of a system that is efficient in reducing both sediment and nitrogen losses while meeting both energy and economic efficiency criteria. However, the labor requirement of this system is large and the total amount of abatement is not large (Table 2).

Occasionally, farmers may be concerned about other factors such as water use, fertilizer, and labor inputs for the farm. For example, to conserve water, the capital intensive multi-set furrow system or the side-roll sprinkler system should be selected (Table 2). However, both of these alternatives are expensive and the latter requires additional energy.

In conclusion, substantial improvements can be achieved in the water quality of irrigation return flows at relatively low cost and without danger of increasing agricultural energy requirements. The energy requirements of pollution abatement in irrigated areas should not be a major concern in most cases. Energy use may eventually become a more important criteria for choosing abatement practices, but at present the choice should continue to be made on the basis of abatement effectiveness and economic efficiency.

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