EVALUATION OF CROP ROTATION AND IRRIGATION PRACTICES UNDER LIMITED WATER AVAILABILITY

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Abstract

Since 1991, the drought conditions in Central Oregon have seriously impacted the amount of water delivered to the North Unit Irrigation District (NUID). The objective of this economic study was to determine how irrigation practices and crop rotations should be managed in response to reduced water supplies, and how that will impact profitability. A mathematical programming model was developed to evaluate the economics of adopting such practices on a representative farm in Jefferson County. The 500-acre farm produced bluegrass seed, carrot seed, garlic seed, wheat, and peppermint, using sprinkler and furrow irrigation systems. New practices for water conservation included irrigation scheduling and laser leveling of fields, alternating furrow, and surge furrow irrigation. Assumptions were based on the fixed and variable cost, crop rotation, and water-use of farms in Jefferson county. Results showed that the adoption of water-conserving management practices can increase net returns over traditional systems. When 24 and 36 acre inches of water were available, the irrigation systems employed in the profit-maximizing solution included alternating furrow with gated pipe, surge furrow, and some traditional continuous furrow irrigation. But when available water was limited to 18 acre inches, the best returns were from surge furrow and surge furrow with a pumpback system on limited, specific crops. Finally, allocating 12 acre inches per acre took approximately one-third of the farm out of production and utilized surge furrow with a pumpback system. The affordable price of additional water, in this scenario, was determined by the model to be over ten times greater than the NUID price. Continuous furrow and wheel-line sprinklers produced lower net returns for the representative farm than implementation of alternate systems. Interestingly, the model-optimized crop rotations *excluded* peppermint at the present yield and price due to low net returns and high irrigation requirements. While the above results may not hold for all seed producing farms in Jefferson County, the model showed an economic incentive exists for adopting water-conserving practices.

Introduction

Research at OSU Experiment Stations has focused on water-conserving irrigation systems. Specifically, the efficiency and runoff from surge, alternate-furrow, and alternating-furrow irrigation systems has been researched (Miller and Shock, 1993; Mitchell and Stevenson, 1994). The financial benefits and costs of modifying current irrigation management practices or adopting non-traditional systems has not been addressed. The economics of modifying management practices is an important consideration because the investment in new equipment and the changes in variable irrigation costs may be significant.

The most common irrigation systems utilized by Jefferson County irrigators are sideroll sprinklers (SP) and the traditional every-furrow (EF) irrigation with siphon tubes (S). Systems that are not widely implemented but have shown potential for water conservation include alternate furrow (AF) (where every other furrow is irrigated, resulting in water never flowing down half of the furrows), alternating furrow (AGF) (every other furrow is irrigated with every other irrigation set), and surge furrow irrigation (SF) (an automated valve is used to apply water intermittently). Siphon tubes or gated pipe (G) can be used for most furrow irrigation practices. The exception is surge, which requires gated pipe. Additional practices such as irrigation scheduling (IS) (monitoring field and weather conditions to schedule irrigation sets) and laser levelling (LL) (levelling fields with the aid of a laser for accuracy) can also reduce the amount of irrigation water required to meet crop needs. When water is applied in excess of evapotranspiration, the excess leaves the field as runoff or percolation below the root zone. Consequently, irrigation amounts can be reduced by monitoring the soil water content. The uneven slopes on a field affects how and where irrigation water will penetrate the soil, particularly when furrow technologies are used. Laser levelling results in a uniform slope, thus reducing the chance of uneven water distribution.

One technique to evaluate the costs of adopting various management practices is a linear programming model. A linear programming model can optimize profits given limited resources and management choices. Our objective was to use the linear programming model to determine the profit-maximizing crop rotation and management practices for a representatvie farm under different water availability. We used crop production costs from recent enterprise budgets, and estimated production costs associated with adopting new irrigation management techniques. A second objective was to determine the affordability of water under water-limiting conditions.

Methods

Data and Assumptions

The economic data was obtained from extension agents, local growers, agricultural businesses, and the North Unit Irrigation District in 1993 and 1994. Several growers and two extension agents assisted in the development of enterprise budgets for a representative vegetable seed-producing farm in Jefferson County. The budgets were based on typical practices for a farm producing garlic seed, carrot seed, peppermint, wheat, and bluegrass seed on 500 acres. Two separate budgets were necessary to represent the production and establishment costs of bluegrass seed and peppermint. First, the establishment budget represented the land preparation, planting, and first-year harvest period. Second, the production budget outlined the common cultural practices for an average production year. Bluegrass and peppermint stands were both assumed to have a 4-year life, including the establishment year.

The enterprise budgets are not representative of any particular farm. A summary of the production costs, typical returns, and current irrigation systems are presented in Table 1. All of the crop budgets except wheat have been published as of the printing of this report and are available from the Extension Service. From the base-line budgets, additional budgets were generated which incorporated the alternative practices. Crop yield was assumed constant across all management practices. In the base-line budgets, a water charge of $0.96 per acre inch is included to represent the North Unit Irrigation District per acre water charge. In the linear programming model, the variable water charge was replaced by a fixed water charge of $24.45 per acre for the first 2 acre feet and $13.20 per acre foot for the third foot, based on the NUID 1994 Deschutes right water charge including construction fees.

Table 1. Summary of Base-line Enterprise Budgets for Major Crops Produced in Jefferson County Oregon, 1994

	Garlic Seed	Carrot Seed	Mint Estab.	Mint Prod.	Bluegrass Estab.	Bluegrass Prod.	Wheat
Base-line	SP	SP/EF[2]	EF	EF	EF	EF	SP
Irrig. System[1]							
Total Irrig. Applied (in/acre)	25.5	35.5	39	45	53	40	18
Yield (Unit/acre)	17,000 lbs	400 lbs	60 lbs	75 lbs	800 lbs seed 1 acre straw	1,000 lbs seed 1 acre straw	120 bu
Price/Unit	.14	6.00	16.00	16.00	1.00 seed 10.00 straw	1.00 seed 10.00 straw	4.00
Variable Cost ($/acre)	1,424	964	1,014	691	625	576	296
Fixed Cost ($/acre)	237	231	196	223	177	162	194
Total Cost ($/acre)	1,192	1195	1,210	914	801	738	490
Net Returns ($/acre)	1,188	1205	-250	286	7	272	-9

[1] although other irrigation systems may be in operation, these systems were determined to be commonly used and are considered as the base-line systems
[2] carrot seed is sprinkler irrigated in the fall and furrow irrigated in the spring

The alternate irrigation practices were chosen based on the availability of previous research data, water conservation potential, and the technological feasibility of adopting practices. Table 2 outlines the water savings assumptions for each alternative practice and the associated fixed costs. The water application levels presented in the baseline enterprise budgets were determined to be an average application by growers who assisted in the preparation of the enterprise budgets. The fixed costs consist of interest and depreciation. Interest cost (IC) was calculated as follows:

$$IC = \left[\frac{PP + SV}{2}\right] * I \qquad (1)$$

where PP = Purchase Price, SV = Salvage Value, and I = Interest Rate. The interest rate used for this study was 8 percent. Depreciation (Dep) was calculated with the formula:

$$Dep = \frac{PP}{UL} \qquad (3)$$

where UL = Useful Life.

Table 2. Water Savings Over Every Furrow and Irrigation Fixed Cost

System	Water Required as a Percent of EF-S	Fixed Cost ($/acre)	Labor Hours Per Set Per Acre	% Water Applied Available for PB[3]
EF-S	100%	2.16	.25	27%
EF-PB	80%	9.41	.25	
EF-G	100%	8.17	.05	27%
AF-S	60%	1.08	.17	18%
AF-PB	51%	8.33	.17	
AF-G	60%	8.17	.05	18%
AGF-S	60%	1.08	.17	18%
AGF-PB	51%	8.33	.17	
AGF-G	60%	8.17	.10	18%
SF	50%	12.95	.02	18%
SF-PB	44%	20.20	.02	
SP	60%	54.00	.50	0%
IS	80%[1]	1.86	.50 or .25 [2]	27% EF
LL	80%[1]	13.50	.50 or .25 [2]	27% EF

[1] expressed as a percent of water required for current practices
[2] based on the irrigation system in the base-line budgets
[3] includes runoff less evaporation and seepage loss, assumed to be 10 percent of runoff

The standard practice of irrigating every furrow is the greatest water consumer for the management strategies considered. Alternate furrow, alternating furrow, and sprinklers use 40 percent less than standard furrow irrigation based on data from Miller and Shock (1993) and Mitchell and Stevenson (1994). Siphon tubes and gated pipe are assumed to require the same amount of water, although fixed and labor costs will differ. Hired labor, charged at $7 per hour is used for sprinkler irrigation. All other systems are managed by the owner at a charge of $15 per hour. Surge furrow requires only 50 percent of the water required for every furrow. Irrigation scheduling, using water mark sensors, and laser levelling both are assumed to result in a 20-percent water savings. A pumpback system (PB) allows the collection and reuse of irrigation runoff and will result in increased irrigation efficiency. Runoff amounts are presented in Table 2. We assumed 90 percent of the runoff is pumped back to the top of the field while the remaining 10 percent evaporates or seeps into the soil. The reduction in water use by various systems over current practices is assumed uniform across crops.

Model

The objective of the linear programming model was to maximize net returns to land and management. The management decisions choices in the model were limited to simple combinations of new practices. The adoption of multiple strategies (e.g. including irrigation scheduling, laser levelling, alternating furrow, and pumpback all together) are not allowed in the model. We believed this was a safe assumption because initial investments will tend to limit the number of management changes occurring at once, although growers may adopt several new practices over time. In the model, IS and LL may be added individually to the baseline budgets. EF, AF, AGF, and SF systems can also be adopted individually. SF requires gated pipe to disperse water into the furrow but other furrow systems may be chosen as a management practice utilizing either gated pipe or siphon tubes. Any furrow system may or may not be combined with a pumpback system to capture and reallocate runoff. GAMS, a linear programming software, was used in this study to solve the model. Table 3 outlines the possible crop rotational choices allowed in the model.

Table 3. Crop Rotation Sequence Definitions

Crop Rotation Seq. Number	Cropping Sequence (previous/current crop)	Crop Rotation Seq. Number	Cropping Sequence (Previous/Current crop)
1	Garlic / Wheat	13	Mint Prod. / Fallow
2	Garlic / Bluegrass Est.	14	Wheat / Mint Est.
3	Garlic / Fallow	15	Wheat / Garlic
4	Carrot / Wheat	16	Wheat / Carrot
5	Carrot / Fallow	17	Wheat / Wheat
6	Bluegrass Est. / Bluegrass Prod.	18	Wheat / Fallow
7	Bluegrass Prod. / Carrot	19	Wheat / Bluegrass Est.
8	Bluegrass Prod. / Wheat	20	Fallow / Mint Est.
9	Bluegrass Prod. / Fallow	21	Fallow / Garlic
10	Mint Est. / Mint Prod	22	Fallow / Wheat
11	Mint Prod. / Wheat	23	Fallow / Bluegrass Est
12	Mint Prod. / Bluegrass Est.	24	Fallow / Carrot

Other model assumptions were imposed as resource constraints to better describe the representative farm. Land was limited to 500 acres. One percent of the 500 production acres contained irrigation ditches and access roads. Acreage restrictions for garlic and carrot seed are set based on contract limits for these crops, as follows: total carrot seed acreage cannot exceed 20 acres, and garlic seed cannot be produced on more than 40 acres.

Since the amount of water allocated to NUID growers with Deschutes water rights is dependent on availability, the model was run seperately with 12, 18, 24, and 36 inches per acre.

Results and Discussion

The crop rotation, acreage and management practice associated with each crop are presented in Tables **4A,** 4B, and 4C for 24 and 36 inches, 18 inches, and 12 inches of water, respectively. If the water limit is extended to 2 or 3 acre feet per acre, the crop rotation and the net returns do not change. The crop acres shown in the tables represent the acres in the optimal solution in any given year of the rotation. The profit-maximizing crop rotation consists of garlic seed, carrot seed, bluegrass seed, and wheat regardless of the water constraint. Peppermint never enters the optimal crop rotations. While production year net returns and water use for mint and bluegrass seed are similar, negative net returns for the mint establishment year and the labor required for the additional irrigation sets required to produce mint appears to keep mint out of the rotation.

A disadvantage of using a linear program to solve a crop rotation problem become apparent in Tables 4A, 4B, and 4C. The crop acreages are not necessarily equal to typical field sizes. The model is given the constraints for the crop-acreage levels which optimize the objective function without regard to a set field size. Field size can not be set in a linear programming model.

Based on the assumptions presented in Table 2, the optimal irrigation practices were found to be alternate-furrow-gated pipe (AF-G), surge-furrow (SF), and surge with pump-back (SFPB). In this study, SF and SF-PB required the least amount of water and labor of all systems. AF-G used the same amount of water as sprinklers, but sprinklers did not enter the optimal solution due to the AF-G lower fixed cost and labor requirements.

Restricting the water available to 18 inches per acre does not significantly change the crop rotation but does affect the irrigation practices. Surge with and without pumpback would be utilized under this strict water restriction. Net returns fall from $163,124, with the two highest water constraint levels, to $157,631 with water allowance of 18 inches per acre. This small change in net returns is due to the adoption of more efficient irrigation practices that do not significantly reduce returns. The 8.2 acres of unproductive land included 5 acres of roads and ditches, and 3 acres for the pumpback systems. With 18 inches per acre available, all of the available land would be in production. Full land utilization would be possible because of the high efficiency assumptions for SF-PB. If only 12 acre inches, or 500 total acre feet are allotted, about one-third of the farm would be fallow at any given time, reducing net returns to $110,494.

Water Affordability

The model was run to determine the affordability of water when only 12 acre inches are allocated per acre and growers may purchase water from other district users. If one additional acre inch of water were available to the grower, it would increase the objective function, or net returns to land and management, by $19.23. This is the short-run price the grower could afford to pay for an additional acre inch to increase net returns. In the long run, where the grower would need to cover both fixed and variable costs, the affordable price would be reduced to $12.30 for an additional acre inch.

Conclusions

The linear model showed that an adoption of non-traditional systems could increase net returns. Furthermore, small water shortages can be offset by changes in irrigation management and crop rotation so that profits can be maintained. However, when water allotments are reduced to 12 acre inches per acre, profits decline greatly. In this scenario, the affordable price of additional water is much greater than the NUID price.

This study is not suggesting all seed producers in Jefferson County should adopt new irrigation management practices. The farm in the study is not representative of a particular farm. Farm-level data should be used to determine the optimal rotation and irrigation management on individual farms. It may be economically feasible for some growers to change their crop rotations and management practices to increase net returns given the cost, yield, and irrigation assumptions outlined in this study. Under limited water supplies, operating AF, AGF, SF, and PB systems can conserve water, reduce labor requirements, and increase net returns over traditional systems.

The results of this study are highly dependent upon the assumption of variable and fixed production costs, irrigation efficiency, and crop rotation. Irrigation system efficiency can vary widely based on soil type, climate, and level of management. Fixed irrigation charges will vary with individual farms as farmers would purchase equipment to fit the layout of each individual farm. This study attempted to represent average efficiencies and management. Varying efficiency assumptions could significantly change the results. Therefore, it is important to have accurate data concerning the irrigation efficiency of various systems. Although we assumed the irrigation regimes in this study would not change yield, incorporating yield response data to alternate irrigation systems, if it were available, would increase the accuracy of the results.

References

Miller, John and Clint Shock. 1993. The effect of surge irrigation on onion yield and quality, irrigation efficiency, and soil nitrogen losses. Malheur County Crop Research Annual Report, 1992. AES OSU, Special Report 924, 1993:43-50.

Mitchell, Alan and Karen Stevenson. 1994. Surge flow and alternating furrow irrigation of peppermint to conserve water. Central Oregon Agricultural Research Center Annual Report, 1993. AES OSU, Special Report 930, 1994:79-87.

Table 4A. Summary of Linear Programming Results, Water Constraint of 24 and 36 Inches Per Acre for Representative Jefferson County 500-acre Farm

Crop	Previous Crop	Management Practices	Acres	Net Returns Per Acre	Total Net Returns
Bluegrass					
Estab.	Garlic Seed	AF-G	40	$ 49	$ 1,963
Estab.	Wheat	AF-G	47	65	3,059
Prod.	Bluegrass Seed Estab.	AF-G	261	282	73,495
Wheat	Carrot Seed	AF-G	20	67	1,936
	Bluegrass Seed Prod.	AF-G	67	48	5,215
Carrot Seed	Bluegrass Prod.	SF	20	1,280	25,607
Garlic Seed	Wheat	EF-S	7.6	1,314	9,990
	Wheat	SF	32.4	1,311	42,481
Unproductive Land			5	-124	-622
Total			500		163,124

Table 4B. Summary of Linear Programming Results, Water Constraint of 18 Inches Per Acre for Representative Jefferson County 500-acre Farm

Crop	Previous Crop	Management Practices	Acres	Net Returns Per Acre	Total Net Returns
Bluegrass					
Estab.	Garlic Seed	SF-PB	40	$ 41	$ 1,637
Estab.	Wheat	SF-PB	46.4	57	2,638
Prod.	Bluegrass Seed Estab.	SF-PB	259.1	269	69,802
Wheat	Carrot Seed	SF	20	95	1,899
	Bluegrass Seed Prod.	SF	66.4	76	5,039
Carrot Seed	Bluegrass Prod.	SF-PB	2.9	1,271	3,723
	Bluegrass Prod.	SF	17.1	1,278	21,857
	Wheat	SF-PB	40	1,301	2,060
Garlic Seed					
Unproductive Land			8.2	-124	-1,025
Total			500		157,631

Table 4C. Summary of Linear Programming Results, Water Constraint of 12 Inches Per Acre for Representative Jefferson County 500-acre Farm

Crop	Previous Crop	Management Practices	Acres	Net Returns Per Acre	Total Net Returns
Bluegrass					
Estab.	Fallow	SF-PB	56.8	$ 59	$ 3,348
Prod.	Bluegrass Seed Estab.	SF-PB	170.5	269	45,935
Carrot Seed	Fallow	SF-PB	20	1,304	26,083
Garlic Seed	Fallow	SF-PB	40	1,304	52,140
Fallow	Garlic		40	-124	-4,978
	Carrot		20	-124	-2,489
	Bluegrass Prod.		56.8	-124	-7,072
	Wheat		44.1	-124	-5,482
Wheat	Fallow	SF-PB	44.1	90	3,975
Unproductive Land			7.8	-124	-967
Total			500		110,494