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The economics of broiler, grain, and trout production as a risk diversification strategy☆

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Abstract

A comprehensive farm-level stochastic and dynamic capital budgeting simulation model (AQUASIM) is used to evaluate the economic benefits of incorporating a small-scale trout enterprise with a grain and broiler farm. The simulation results indicate that combining aquaculture production with traditional agriculture increased expected income and reduced risk substantially. The use of external debt capital improved the after-tax net present values and internal rates of return but lowered net cash farm income. This study shows the importance of enterprise diversification in stabilizing variability in expected income.

Keywords: Economics; Agricultural risk diversification; Simulation

1. Introduction

The economic success and survival of agricultural enterprises are affected by many risk factors. In farming, enterprise selection requires output diversification, one of the most critical risk management decisions that farmers have to make. Enterprise selection requires some form of knowledge of the risks and returns of alternative enterprises so that farmers can analyze the trade-offs between specialized or diversified production. Producers are interested in learning the benefits from economies of scope as well as the costs associated with diversified production.

The purpose of this paper is to evaluate the risks and returns associated with the addition of a small-scale trout production enterprise to the diversified production of corn, soybean,

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and broilers under two financial structures: no debt (100% owner equity) owner equity and partial debt financing. Commercial aquaculture—the production of aquatic plants or animals in a controlled environment—is one of the fastest growing sectors of U.S. agriculture and is seen as a growth industry of the future. Along with poultry, aquaculture has excellent growth potential in view of increasing health concerns by consumers and the increasing environmental and resource constraints on wild stock fishery harvests. The demand for poultry and fish products has been projected to increase significantly in the coming years (Dicks and Buckley, 1990).

The first part of this paper briefly reviews risk and return analysis. The second part discusses the importance of trout production. This is followed by a discussion of the methodology and data construction, and the empirical results. Finally, the implications and conclusions of the study are presented.

2. Risk-return analysis

Sources of business risk are classified by Sonka and Patrick (1984) who divided risks into 5 categories: (1) production or technical risk; (2) market or price risk; (3) technological risk; (4) legal and social risk; and (5) human source of risk. Production or technical risk is the random variability inherent in production process such as weather and disease. Market or price risk exists when there are variabilities in input and/or output prices. Short-run fluctuation in input prices could affect income and cash positively or negatively. In the long-run, variabilities in input–output prices along with variation in interest rate and relative price movements may lead producers to change decisions about enterprise selections. Technological risk includes both changes in agricultural and non-agricultural technologies. These risks are generally greater for assets such as building and equipment which are less adaptable to other enterprises than farm machinery. Changes in government policies such as price and income support, tax, trade, credit, and environmental policies are examples of legal and social risk. Human sources of risks are associated with the function of labor and management in farm operation.

Many economic modelling approaches generate risk and return information that is difficult for the agricultural producer, investor, and lender to comprehend (e.g., mean-variance, covariance, beta-risk factor, systematic and unsystematic risks). Most farm producers and lenders prefer to discuss investment outcomes in terms of financial statements such as income statement and balance sheet. Instead of using traditional statistical techniques, a comprehensive farm-level, dynamic and stochastic capital budgeting simulation model is used to analyze the economic benefits of including trout production by a representative farm producing corn, soybeans, and broilers. To aid in the understanding of the simulation results, basic measures of financial performance such as production costs, net cash income and return to investments are utilized.

3. Trout production

Trout, specifically rainbow trout, is the second largest finfish species produced in the USA (after catfish). The species is characterized as fast-growing and needs a relatively short period of time to grow from egg to market-size fish compared with other finfish products like hybrid striped bass and tilapia. Rainbow trout requires approximately 12 months to achieve complete growth from eggs to a 0.65-kg market-size fish. Rainbow trout also tolerates cold water temperature from 0 to 27°C (Stickney, 1991) and is considered an efficient food converter (Rodger, 1991). Trout is also among the few species that could be reared continuously throughout the year in some areas to provide consistent supply. Trout production in the USA has grown from 20 412 tons in 1981 to 27 321 tons in 1993. Total consumption of food-size trout products has increased at an annual rate of 3.32%. The largest trout producers are located in the Northwest, with Idaho having the largest production. Other large producers include California, North Carolina, Utah, Pennsylvania and New York (Aquaculture Situation and Outlook Report, 1994).

The future growth of the freshwater inland trout industry in the Northeast and the Mid-Atlantic states will be constrained by the availability of water resources. Traditional culture systems in the Mid-Atlantic and Northeast regions consists of concrete or earthen raceway ponds that are operated in gravity-fed flow-through or serial-reuse water consumption modes. Water quality is considered as one of the most important factors affecting fish production. Trout systems require large water flows and high velocities to provide oxygen and remove metabolic wastes. One of the major causes of trout losses during the production process is poor water quality leading to stress-related disease outbreaks (Sedgwick, 1990). The trout culture system used in this study was designed at the Freshwater Institute and utilizes supplemental oxygen to increase the productive capacity of small water flows and inexpensive fiberglass circular tanks that provide a flexible, high-quality rearing environment at a low initial capital cost.

4. Materials and methods

Simulation model

Computer simulation is considered an appropriate tool for this study since the economic feasibility analysis involves complex production systems to be evaluated over a 10-year planning horizon. The computer simulation model used in this study (AQUASIM) can be categorized as a comprehensive farm-level dynamic and stochastic capital-budgeting computer-simulation model. Simulation is an analytical technique that quantifies and describes the behavior of a complex economic system. In a capital-budgeting framework, simulation provides a flexible technique for incorporating risk and uncertainty along with the time value of money in the investment decision-making analysis. Using the accounting and tax subroutines from FLIPSIM V (Richardson and Nixon, 1986) and CHICKSIM (Gempesaw et al., 1988), additional subroutines were written to model the production and financial performance of multiple output, multiple input, vertically or horizontally integrated aquaculture farms. FLIPSIM V has been used in several farm policy and tax reform impact studies. CHICKSIM has been applied extensively in the evaluation of poultry grow-out profitability (Gempesaw and Bhargava, 1990).

One attractive feature of AQUASIM is that it can model enterprises that produce outputs to be used as inputs in the next stage of operation (e.g., a farm is producing fingerlings in one pond to be used for stocking a separate grow-out pond). The model permits the simulation of multiple output/multiple input enterprises (e.g., concurrent production of poultry, fish, and feed grain). AQUASIM has the capability of simultaneously modelling products with different time periods (e.g., fish may take 8 months with one discrete stocking per year while poultry may require 2 months of production time with 6 discrete stockings annually). All system variables such as output prices and quantities, variable input cost, mortality rates, and feed conversion rates per stage can be simulated randomly using different probability distributions.

The analyst can also select output and price relationships such that a randomly selected output quantity will be inversely correlated with a output price. Since survival rates are estimated per month, annual variable costs of production can be estimated using pre-mortality stocking, average annual population, and post-mortality population. The estimation of the production costs can be evaluated on a per-head or per-weight basis and the allocation of costs can be distributed over time. For example, harvesting costs for trout could be specified to occur only during the last 2 months of an 8-month production cycle while the harvesting cost for grains could be specified to occur at the end of a 6-month

Table 1
Farm production configurations and initial capital asset requirements

Item	Base farm[a]	Base farm with trout
Production configurations		
Total land	83.00 ha	83.00 ha
Corn	41.50 ha	41.50 ha
Soybeans	41.50 ha	41.50 ha
Broilers	3 houses[b]	3 houses
Trout	–	10 tanks[c]
Capital assets		
Land and homestead	$ 200 000	$ 200 000
Broiler houses	300 000	300 000
Trout facility		
10 tanks w/covers	–	5 270
LHO[d] tank w/cover	–	1 120
Oxygenator[e]	–	1 725
Plumbing	–	500
Site development	–	6 500
Wood frame	–	150
Miscellaneous equipment	–	1 200
Subtotal		$ 16 465
Small tractor	10 000	10 000
Pickup truck (0.9 t)	7 000	7 000
Initial cash reserves	5 000	5 000
Total	$ 522 000	$ 538 465

[a] Corn, soybean, and broiler farm.
[b] Each broiler house is 12.80 × 152.40 m.
[c] Each tank holds 0.95 m^3 of water.
[d] Low head oxygen.
[e] The LHO oxygenator cost can be reduced to $695.00 by going with a plastic unit rather than aluminium.

cycle. AQUASIM also makes adjustments so that if there are excess (deficit) fingerlings from one stage for transfer to the next stage, the model will automatically sell (buy) excess (deficit) fingerlings. When modelling integrated stages, the user may specify how much to transfer or sell (buy) from one stage to the next stage. The model provides additional options for estimation of asset inventory (e.g., inclusion of growing fingerlings in ponds or tanks as part of total farm assets) and random simulation of feed conversion per production stage and time period.

AQUASIM provides detailed results regarding the economic and financial viability of the representative farm. The farm is simulated over a 10-year horizon with a maximum of 300 iterations. At the end of each iteration, values for each of the key production and financial variables are calculated. If the farm experiences a negative cash flow during the planning horizon, deficits are automatically covered by the model by obtaining a loan secured by existing equity if available. If the farm availed of this option and still cannot cover the cash flow deficit, the farm is declared insolvent and the model stops and prints the results up through the time that insolvency occurred. From the 300 iterations, means and variances of the performance variables are obtained. The complete model results include a 10-year projection of the income statement, balance sheet, and cash flow statement as well as descriptive statistical measures and cumulative probability distribution functions of the key output variables and probabilities of economic success and survival. In addition, the model also prints stochastic annual output and prices, variable costs, mortality rates and other random variables per production stage by enterprise.

Past studies of whole-farm simulation using FLIPSIM V have relied on empirical distributions of yield and output prices using historical data (Richardson and Nixon, 1986). In

Table 2
Initial production and financial characteristics common to all scenarios

Age of operator		45		
Annual cost of debt capital (%)		8.00		
Annual cost of interest on operating expenses (%)		9.00		
Annual off-farm income ($000)		20.00		
Annual family living expenses ($000)		12.00–14.00		
Labor wage rate ($/h)		6.00		
Property tax rate (%)		1.87		
After tax discount rate (%)		8.00		
Minimum cash reserves ($000)		2.50		
Solvency ratio		0.25		
Annual accountant, legal, insurance, and misc. expenses ($000)		7.73		
		Mode	*Min.*	*Max.*
Corn	Yield per ha. (ton)	8.47	4.39	12.55
	Output price ($/ton)	78.08	69.33	86.83
Soybean	Yield per ha. (ton)	2.22	1.41	3.03
	Output price ($/ton)	166.32	153.01	179.62
Broilers	Sets per house per year	6		
	Mortality (%)	4	1	7
	Output price ($/000 birds)	185	157	213

Table 3
Initial mode[a] variable operating expenses for the corn, soybean, and trout enterprises

Expense item	Corn (per ha.)	Soybean (per ha.)	Broiler (per set)	Trout (per stocking)
Seed/fingerlings	$ 44.48	$ 46.95	$ –	$ 896.00
Fertilizer/manure	72.03	–	–	–
Lime/chemicals	49.42	86.34	–	–
Custom work				
Planting	24.71	34.59	–	–
Tillage[b]	77.59	64.00	–	–
Harvesting	49.42	54.36	–	–
Hauling/drying	59.31	8.23	–	–
Electric/fuel	–	–	708.00	–
Feed	–	–	–	655.00
Repairs	–	–	278.00	–
Labor	8.30	–	960.00	75.00
Oxygen	–	–	–	38.00
Other production costs	12.36	12.36	416.00	–
Operating loan interest[c]	15.90	12.28	31.49	88.79
Total	$ 413.52	$ 319.11	$ 2,393.49	$ 1,752.79
Cost per unit	$ 43.92 per ton	$ 127.04 per ton	$ 90.32 per 000 birds	$ 1.72 per kg

[a] Variation about the modes for each input variable was 10% for the initial year. By the 10th year this variation was permitted to increase to 14.5%, except for trout fingerlings which increased to 28%.
[b] Includes deep plowing, disking, field cultivation, side dressing of N for corn, and subsoiling every five years.
[c] Interest at 8% for 6 months for corn a nd soybeans, 8% for 2 months for broilers and 8% for 8 months for trout.

the absence of historical cost and return data, particularly for new enterprises or technologies, a non-symmetric triangular probability distribution was used to represent the randomness of the control variables. A triangular distribution has three points: a minimum, mode, and maximum value. Skewness is determined by the relative position of the mode to the minimum and maximum values. The probability that values beyond the minimum and maximum will occur is zero. The density of the triangular distribution (Schmidt, 19894) used is as follows:

$$f(x)=2(x-a)/[(b-a)(c-a)] \quad \text{if } a\leqslant x\leqslant b, \tag{1}$$

$$f(x)=2(c-x)/[(c-a)(c-b)] \quad \text{if } b<x\leqslant c, \tag{2}$$

where a = minimum, b = mode, and c = maximum.
The distribution is as follows:

$$F(x)=0 \quad \text{if } x<a, \tag{3}$$

$$F(x)=(x-a)^2/[(b-a)(c-a)] \quad \text{if } a<x<b, \tag{4}$$

$$F(x)=1-\{(c-x)^2/[(c-a)(c-b)]\} \quad \text{if } b<x\leqslant c, \tag{5}$$

$$F(x)=1 \quad \text{if } c<x. \tag{6}$$

The triangular distribution is generally used as a first approximation of situations where there are very few and/or no available data (Taha, 1988).

Data assumptions and sources

The basic assumptions covering certain aspects of the production and financial characteristics of the representative farm were used in all scenarios for this study are presented in Tables 1, 2 and 3. The representative farm was assumed to have 83.00 hectares of farmland valued at $200 000. Eighty-one hectares were divided equally between corn and soybean production, with the remaining to hectares devoted to broiler and trout production. The introduction of the trout enterprise did not displace any broiler production because the trout system is small enough to fit between two adjacent broiler houses.

The solvency ratio of 0.25 constrained the farm to a maximum borrowing limit of 75% based on the current value of farm assets. If the farm, at any point in the simulation, reaches the maximum allowed debt and a cash flow problem occurs, then the model would prevent further debt and declare the business insolvent. Initial cash reserves were set at $5000 and the farm was required to maintain a minimum cash reserve of $2500 to be able to meet unexpected expenses. The annual family withdrawal against farm receipts ranged between $12 000 and $14 000 and was used to supplement the total annual family off-farm income of $20 000.

Data on projected inflation rates for the various variable costs were taken from forecasts provided by the WEFA Group (1992). The initial-year output price range for all enterprises

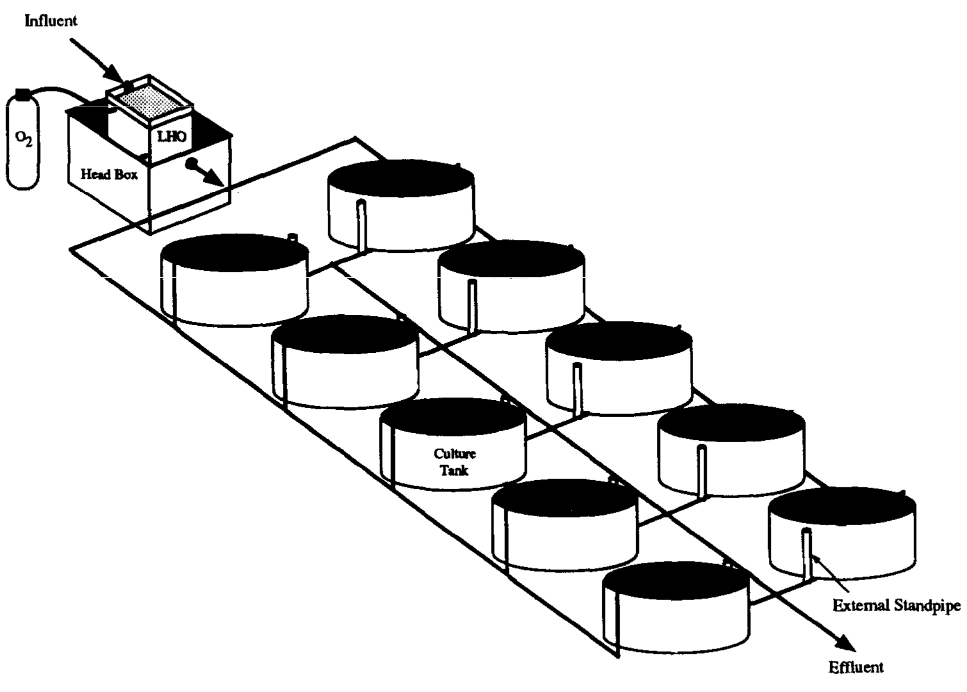

Fig. 1. Flow-through fish-culture system for trout aquaculture demonstration. Fiberglass rearing tank volumes are approximately 0.95 m^3 and volumes are exchanged 3 times per hour.

Table 4
First 2-year production schedule for small-scale trout production technology

Year	Month	Cohort I	Cohort II	Cohort III	Cohort IV
O	1	10.16 cm_S[a]			
N	3	15.24 cm	10.16 cm_S		
E	5	20.32 cm	15.24 cm	10.16 cm_S	
	7	25.40 cm	20.32 cm	15.24 cm	10.16 cm_S
	9	30.48 cm_H[b] 10.16 cm_S	25.40 cm	20.32 cm	15.24 cm
	11	15.24 cm	30.48 cm_H 10.16 cm_S	25.40 cm	20.32 cm
T W	1	20.32 cm	15.24 cm	30.48 cm_H 10.16 cm_S	25.40 cm
O	3	25.40 cm	20.32 cm	15.24 cm	30.48 cm_H 10.16 cm_S
	5	30.48 cm_H 10.16 cm_S	25.40 cm	20.32 cm	15.24 cm
	7	15.24 cm	30.48 cm_H 10.16 cm_S	25.40 cm	20.32 cm
	9	20.32 cm	15.24 cm	30.48 cm_H 10.16 cm_S	25.40 cm
	11	25.40 cm	20.32 cm	15.24 cm	30.48 cm_H 10.16 cm_S

[a] $_S$ indicates stocking of 10.16 cm fingerling.
[b] $_H$ indicates harvest of 30.48 cm market-size fish.

was allowed to increase through the 10-year time frame to reflect increasing uncertainty over the planning horizon. Due to the size of the farm operation, production-related activities for the corn and soybean enterprises were performed by custom operators, except for the spreading of broiler manure which was performed by the farmer using a rented spreader. Custom rates were obtained from personal interviews with custom operators in the Mid-Atlantic region.

Specific data for the broiler enterprise were gathered from personal interviews of contract broiler growers, poultry extension specialists, and poultry housing and equipment suppliers (Gempesaw and Bhargava, 1990). The broiler enterprise consisted of three broiler houses, each with an average capacity of 26 667 birds per placement. Each broiler house produced 6 flocks of birds per year. All variable costs not covered by the farm were, by contract, absorbed by the poultry integrator, who retained ownership of the birds.

The Freshwater Institute, located in Shepherdstown, West Virginia, provided actual production and financial data for the small-scale trout flow-through tank production system. The Institute supports several demonstration farms in Appalachia involved in trout production using the small-scale flow-through tank technology. The trout production technology is a flow-through tank culture using 10 tanks with a volume capacity of 0.95 m^3 per tank (Fig. 1). It is categorized as a semi-intensive system since some of the factors affecting fish growth are controlled. These include a standard trout feed of 38% protein and supplemental oxygen which are introduced into the fish habitat. The fish take 8 months to grow to market size. Stocking with 10.16-cm fingerlings weighing an average of 11.5 g is done every 2 months. A stocking density of 550–660 kg is desired under conditions of equilibrium or steady state. Market-size fish have an average length of 30.48 cm and mean weight of 0.65 kg per fish. After the initial 8-month start-up, harvesting occurs every 2 months. The average production is around 4545 kg of market-size fish per year. The production schedule for the first 2 years of operation is presented in Table 4. The small-scale production technology requires around $16 500 of investment (Table 1) and can be considered a farm diversification strategy since the potential producer can simultaneously produce other agricultural products such as grains and poultry.

The variable costs included in the small-scale trout production technology were fingerling, feed, oxygen, and labor costs (Table 3). The estimated feed cost was based on an average feed conversion of 1.25. The assumed mode mortality rate was set at 10.00% with a maximum deviation of ±5% about the mode. Initial first-year output price for the trout ranged between $2.91 and $4.37 per kg, with the 10th year price ranging between $2.69 and $6.00 per kg, reflecting greater uncertainty concerning future trout prices.

Four simulation scenarios were used in this study. The first two scenarios consisted of the base representative corn, soybean, and broiler farm simulated without any debt and then with a 50% debt load. The final two scenarios were the same as the first two except that the representative farm had added the small-scale trout enterprise to the farming operation. An economic analysis of the profitability of the trout technology as a specialized enterprise is provided in Gempesaw et al. (Agricultural Systems, 1994).

5. Discussion of results

AQUASIM generates several important economic measures of profitability and risk including the after-tax net present value (NPV), internal rate of return (IRR), discounted net cash farm income, probability of economic survival, and probability of economic success. The NPV is defined as the present value of the farm's stream of net cash flows plus the present value of the change in net worth minus the present value of annual off-farm income. The IRR is defined as the discount rate that equates the NPV equal to zero. The discounted net cash farm income is defined as total farm receipts minus all cash production expenses, interest payments, and labor costs discounted by an 8% interest rate. The probability of economic survival is defined as the probability that the farm will maintain the minimum financial ratios required for solvency over the planning horizon. The probability of economic success is defined as the probability that the farm will have a positive NPV using an 8.00% after-tax discount rate. Another statistical measure of risk is the coefficient of variation (CV), the standard deviation of a variable divided by its mean. This measure is used to compare the variability of returns of the different scenarios.

The simulation results for the four scenarios are presented in Table 5. All the estimated mean NPV values are positive. The representative farm under the two debt-level scenarios generated returns which were on average higher than the specified interest rate on debt capital. The diversification by the base farm using the small-scale trout technology had two effects. First, there was a significant increase in the estimated NPV values for both the total owner equity and the 50% debt scenarios. The mean NPV values for the fully diversified

Table 5
Simulation results over the 10-year planning horizon for the representative farm with different external debt levels

	Base farm[a]		Base farm with trout	
	Total owner equity	50% debt	Total owner equity	50% debt
After-tax net present value ($)				
Mean	979	20 909	33 109	56 644
CV[b]	2 309.34	120.46	69.97	44.98
Maximum	85 218	111 796	103 892	133 816
Minimum	−68 685	−56 790	−24 592	−6 161
Internal rate of return (%)				
Mean	7.01	7.41	7.72	8.76
CV	6.44	11.85	5.48	8.92
Maximum	8.66	10.37	8.88	10.81
Minimum	5.58	4.47	6.54	6.51
Discounted annual net cash farm income ($)				
Mean	27 041	18 083	31 601	23 018
CV	9.92	18.37	8.62	13.85
Maximum	67 301	46 787	74 677	58 416
Minimum	−2 761	−8 029	15 450	−6 764
Probability of economic survival (%)	100	100	100	100
Probability of economic success (%)	49.33	80.67	92.00	99.00

[a] Corn, soybean, and broiler farm.
[b] Coefficient of variation = (square root of the variance/mean × 100).

farm with the trout operation increased 34 times under the no-debt (total owner equity) scenario and 3 times when external debt was assumed at 50%. Second, there was a substantial decrease in the CV values, indicating that the addition of the trout enterprise to the base farm reduced the overall risk to the integrated farming operation.

An interesting result can be derived from the higher NPV values obtained by the representative farms operating under the 50% external debt scenario. The leverage impact as captured by the external debt scenario affects the simulated cash flow in three different ways: interest cost, tax payments, and changes in equity investment. With external debt, interest costs (plus principal payments) need to be paid, thus causing positive cash flow to decrease. However, external debt also causes tax payments to decline and therefore results in higher cash flow. In addition, the NPV is now associated with a lower equity investment. These combined effects resulted in higher NPV values over the total owner equity assumption. Among the scenarios simulated, the farm with the small-scale trout technology and 50% external debt achieved the highest NPV. Conversely, the lowest NPV was obtained from the farm without the trout enterprise and without debt.

Similar to the NPV values, the IRRs obtained from the simulation model were different across scenarios. The lowest IRR (7.01%) was generated by the base corn, soybean, and broiler farm with no debt. The highest IRR (8.76%) was achieved when the base farm added the small-scale trout enterprise and borrowed 50% of its investment. The simulation results show that the addition of the trout enterprise and/or external debt caused the IRR to increase.

In most cases, the representative farm managed to generate positive discounted annual net cash farm incomes. However, the discounted annual net cash farm income was not positive for all of the scenarios. This implies that there were times (iterations) when the producer had to borrow additional funds against their assets in order to cover their operating costs over the 10-year planning horizon. Only the farm with the trout enterprise under the total owner equity scenario generated a positive discounted annual net cash farm income for all iterations. Unlike the NPV and IRR results, the lowest average discounted annual net cash farm income was obtained under the 50% debt load scenario. As discussed previously, interest payments have to be paid when the producer borrows money. Therefore, when farmers use external debt to finance their investments, total cash expenses will increase causing a decrease in net cash farm income and an increase in the variability of expected income. In some iterations, a negative cash flow was experienced by the farm with the trout enterprise and 50% debt. This was caused by the trout technology not being operated at full capacity during the first year due to the staggered stocking and harvesting schedule. As a result, there were some iterations when total operating cost exceeded total revenue.

All scenarios resulted in a 100% probability of economic survival for the representative farm. This means that the producer has a very good chance of remaining financially solvent over the 10-year planning horizon. In contrast, none of the scenarios produced a 100% probability of economic success. This means that, across scenarios, the representative farm was not able to consistently generate more than the 8% return over the entire planning horizon. However, it must be noted that the introduction of the small-scale trout technology to the base farm as well as the proper use of debt significantly increased the probability that the farming operation would generate the desired rate of return.

6. Implications and conclusions

Uncertainty in expected income along with the lack of technological knowledge can negatively affect existing farming operations and even cause financial insolvency. Thus, there is a need to provide information to farmers, investors, and lenders on the viability of aquaculture as a risk diversification strategy in agricultural production. This study was conducted to evaluate the financial implications of a poultry and grain producer diversifying into small-scale trout production using a capital-budgeting simulation approach.

Several important results were found. First, the economic performance of the representative farm improved by diversifying into trout production. Furthermore, the stabilizing effect of having multiple products was captured in the much lower variability in the expected returns. The simulation results show that small-scale aquaculture production systems can be economically feasible when combined with traditional agriculture. Second, this study has shown the importance of modelling an aquaculture operation with assumptions of continuous stocking. Having several tanks of uniform but differently sized fish will allow the producer to make more efficient use of space and thereby harvest and market the fish gradually. This production strategy contributes to better cash flow management and lower income variability. Third, the proposition that using debt capital is better than using equity capital was found to be true. This proposition is likely to be true only for operations that could generate positive returns over the planning horizon. Finally, the small-scale flow-through tank system developed by Freshwater Institute can be considered an alternative source of farm income and can be utilized as a farm diversification strategy. It could also be suggested as an alternative enterprise for rural development purposes since by diversifying farm output, rural incomes will not be affected drastically when prices of traditional farm commodities decline.

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References

Aquaculture Situation and Outlook Report, March 1994. USDA, ERS, AQS-12.

Dicks, M. and Buckley, K., (Editors), 1990. Alternative Opportunities in Agriculture: Expanding Output Through Diversification. USDA, ERS, CED, Agricultural Economic Report #633, Washington, DC.

Gempesaw, C. and Bhargava, S., 1990. Interregional profitability analysis of contract broiler grower investment decisions. Poultry Sci., 69: 2092–2101.

Gempesaw II, C.M., Munasinghe, L.C. and Richardson, J.W., 1988. Description of CHICKSIM: A Computer Simulation Model for Broiler Growers. Delaware Agricultural Experiment Station Bulletin No. 477, Newark, DE.

Gempesaw, C.M., Bacon, J.R., Supitaningsih, I. and Hankins, J., 1994. The economic potential of small scale flow-through tank system for trout production. Agric. Syst., 47: in press.

Richardson, J.W. and Nixon, C.J., 1986. Technical Description of the Firm Level Income Tax and Farm Policy Simulation Model (FLIPSIM V). Texas Agricultural Experiment Station Bulletin B-1528, College Station, TX.

Rodger, R.W.A., 1991. Fish Facts, An Illustrated Guide to Commercial Species. Van Nostrand Reinhold, New York, NY.

Schmidt, J., 1984. Introduction to Systems Analysis and Modeling, Vol. 1. The Institute for Professional Education, Arlington, VA.

Sedgwick, S.D., 1990. Trout Farming Handbook, 5th edn. Blackwell Scientific Publications, Ltd., Oxford.

Sonka, S.T. and Patrick, G.F., 1984. Risk management and decision making. In: P.J. Barry (Editor), Risk Management in Agriculture, The Iowa State University Press, Ames, IA.

Stickney, R., 1991. Culture of Salmonid Fisheries. CRC Press, Boca Raton, FL.

Taha, H., 1988. Simulation Modelling and Simnet. Prentice Hall, Englewood Cliffs, NJ.

WEFA Group, November 1992. U.S. Agriculture and World Trade Long-Term Forecast and Analysis, No. 2. The WEFA Group, Inc., Bala Cynwyd, PA.