Economic Assessment of Irrigation Management in Muscadine Grapes

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SUMMARY. This study evaluates the effect of irrigation on the profitability of the muscadine grape (*Vitis rotundifilia*) operation. Data from a 3-year experiment in which muscadine grapes were grown under four irrigation regimes were used to establish the relationship between yields and irrigation. Assuming a muscadine fruit price of $0.50/lb, harvesting costs of $0.21/lb, and irrigation costs of $16.75/acre-inch, the profit-maximizing level of irrigation was estimated to be 13.1 acre-inches for a season, or 7 gal/day per plant. Water requirements for profit maximization are 9% lower than water requirements for yield maximizing. Moreover, it is concluded that the effect of an adequate use of irrigation in the profitability of the muscadine grape operation can be substantial.

Muscadine grapes are native to the southeastern United States. This crop is being explored by researchers and farmers as a production alternative to more conventional crops. In a review of muscadine production guidelines produced by university cooperative extension personnel, Clark and Spiers (2001) found that irrigation was rarely mentioned as a recommended cultural practice. Recent droughts in the otherwise humid southeastern U.S. have heightened farmers' interest in irrigation. Producers are now more aware of the need for a more efficient use of water resources. This study evaluates the effects of drip irrigation on the profitability of the muscadine grape operation and estimates the level of irrigation that maximizes profits.

This study is in line with a recently proposed change in the paradigm for irrigation management (English et al., 2002). Conventional irrigation practices have traditionally been designed with the objective of yield maximization. The approach used in this study to obtain the optimal levels of irrigation is based on the maximization of profits.

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Materials and methods

In this study we used methods developed by economists to determine the profit-maximizing levels of irrigation. All the calculations were made on a per acre basis. The yields are expressed in pounds and the irrigation units are acre-inches.

The profit ($\prod$) of any enterprise is the difference between the income (I) obtained from the sale of the product (I) and the total costs of production (C):

$$\prod = I - C \qquad [1]$$

Income is obtained by multiplying the price p of the product times yield (y):

$$I = p \times y \qquad [2]$$

Total costs of production (C) include fixed costs of production (Fc), that is, the costs that do not change with the level of production, and also variable costs. In this study, we only consider harvesting (Hc) and operating costs of irrigation (OIc) as variable costs of production:

$$C = Fc + (Hc + OIc) \qquad [3]$$

Total harvesting costs are obtained by multiplying harvesting cost per pound (h) times total yield (y):

$$Hc = h \times y \qquad [4]$$

Operating irrigation costs (OIc) are calculated by multiplying the per acre-inch cost of irrigation (r) times the total annual acre-inches applied to the crop (w):

$$OIc = r \times w \qquad [5]$$

Using the previous definitions and recognizing the fact that the yield of a crop is a function of the level of irrigation, $y = y(w)$, the profit function in equation [1] can be rewritten as follows:

$$\prod(w) = p \times y(w) - [Fc + h \times y(w) + r \times w] \qquad [6]$$

The level of irrigation that maximizes profit is found by taking the derivative of the profit function with respect to w, making it equal to zero, and then solving for w:

$$\frac{\partial \Pi(w)}{\partial w} = p\frac{\partial y(w)}{\partial w} - h\frac{\partial y(w)}{\partial w} - r = 0 \qquad [7]$$

Formally, w maximizes $\prod(w)$ if

$$\frac{\partial \Pi(w)}{\partial w} = 0 \text{ and } \frac{\partial^2 \Pi(w)}{\partial w^2} < 0$$

Equations [6] and [7] indicate that the necessary elements to calculate the profit-maximizing level of irrigation are the following:

1) The relationship between yields and levels of irrigation, and

2) Muscadine grape prices and irrigation and harvesting costs of production. In addition, calculation of profits requires estimates of the fixed costs of production.

In order to obtain the relationship between yields and levels of irrigation we used the data obtained from a field

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
102.7902	acre-inch(es)	m^3	0.0097
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
9.3540	gal/acre	$L \cdot ha^{-1}$	0.1069
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
6.8948	psi	kPa	0.1450

experiment (NeSmith, 2005) and then used regression analysis to estimate the relationship between yields and irrigation. Fixed and variable costs of production were obtained from several sources.

Field experiment. The field experiment was conducted during 1997 through 1999 in an established 'Southland' muscadine vineyard located on a University of Georgia Experiment Station Research Farm near Griffin. Plant arrangement in the vineyard was 10-ft spacing in the row and 12-ft spacing between rows. Plants had been trained to a single-wire trellis. Crop management practices were typical for a commercial vineyard (Krewer et al., 2002).

In late Spring 1997, drip irrigation plots were installed on the plants. There were four irrigation regimes: no irrigation, or rates of 4, 6 and 8 gal/d per vine. Irrigation was applied for 2 h daily, beginning in late May and running through the middle of October each year (140 d). Each irrigation plot contained three plants and was replicated four times. The experimental arrangement was a randomized complete-block design. More information about the experiment can be found in NeSmith (2005).

Costs of production. The calculations of costs of production are based on a representative 10-acre vineyard. It is assumed that this acreage is rectangular in shape and relatively flat. The vineyard includes 40-ft turn rows for machinery operation and a 30-ft central alley. Producing vines are located on two regions, each 330 × 660 ft, and together total 10 acres of producing vines. The entire acreage, including the turn rows and central alley, is 11.7 acres. This arrangement results in 55 rows of 330 ft in each region. The assumed plant arrangement was similar to the arrangement present in the experimental plots: 10-ft spacing in the row and a 12-ft spacing between rows, which results in a total of 363 vines planted per acre.

The assumptions regarding the size and layout of the operation were similar to those used by engineers in the design of the drip irrigation system. The assumed source of water is a pond and the system was designed to irrigate simultaneously areas of 2.5 acres. A brief description of the equipment and the costs of design and installation of the system are presented in Table 1. The estimated investment costs of the drip irrigation system are \$2205/acre.

Given the fact that the investment in irrigation is part of the establishment costs of the vineyard, this cost, plus interest, must be allocated as a cost over the productive years of the enterprise (year 4 of production and thereafter). These costs were allocated using the cost recovery (annuity) method as suggested by the American Agricultural Economics Association (2000). Assuming 20 years of production for the vineyard and a 7% nominal interest rate, the estimated annual fixed costs for the establishment of the irrigation system are \$255/acre.

Other costs of production of muscadine grapes were obtained from two basic sources: the *Georgia Muscadine Production Guide* (Krewer et al., 2002) and the *2005 Production Budgets for Arkansas Wine and Juice Grapes* (Noguera et al., 2005). Some costs were recalculated to correspond more closely to the system of production used in the field experiment. Specifically, manual pruning costs and fertilization costs were re-estimated to account for the fact that the number of vines in the experiment was higher than the number of vines assumed on those budgets. Except for irrigation and harvesting, all of the other costs were assumed fixed. All of the assumptions regarding muscadine costs of production and prices are shown in Table 2.

To calculate the variable costs of irrigation we used the simplifying assumption that the different levels of irrigation can be obtained by regulating the period of time that the irrigation system is operated. The irrigation variable costs include energy costs, costs of repair, and maintenance and labor irrigation costs.

The calculation of the energy costs followed the work of Buchanan and Cross (2002). Given the fact that the irrigation system was designed to irrigate 2.5 acres simultaneously, the energy costs are calculated for the 2.5 acres and later transformed to energy costs per acre-inch. Electricity consumption costs per hour (ELC) were calculated using the following equation:

$$\text{ELC (\$/h)} = \frac{\text{FR(gal/min)} \times \text{TH(psi)} \times \text{Er (\$/kW-h)}}{1714.3 \times \text{PE} \times 1.07} \quad [8]$$

where FR is flow rate, TH is total head (pressure the pump has to work against), Er is the electricity rate and PE is pump efficiency. The flow rate and the total head are technical characteristics of the system which are defined by design. The assumed values for this study were a flow rate of 60.5 gal/min, a total head of 56 psi, a pump efficiency of 60%, and an electricity rate of \$0.09/kW-h. Using the previous figures and expressing the costs in the required units, the cost of energy is \$2.07/acre-inch.

Repair and maintenance costs for drip irrigation systems have been estimated by Ooeshuizen et al. (2005). These authors estimate repair and maintenance costs as a percentage of the initial cost of the machinery (purchase price plus design and installation costs). The assumed values in our study are: 0.18% for the pump, 0.32% for the filter, 0.09% for the tubing, 0.25% for the emitters, and 0.05% for other components for every 100 h of use of the equipment. Our estimated costs for repair and main-

Table 1. Estimated costs for the materials, design, and installation of a drip irrigation system for a 10-acre (4.0 ha) 'Southland' muscadine grapes vineyard.

	Single-wire trellis	
Item/description	Quantity	Cost (\$)
Design of the irrigation system		250.00
5-horsepower (3.7 kW) electric pump	1	2000.00
18-inch (45.7 cm) media filter set	1	3418.85
Drip tubing [0.7 × 0.6 inch (17.8 × 15.2 mm)], 1000 ft (304.8 m)	37	3093.20
Bowsmith 2 gal/h (7.6 $L \cdot h^{-1}$) pressure compensated (PC) emitter	7260	2105.40
Other materials		4178.24
Installation		7000.00
Total		22,045.69

tenance of the irrigation system total \$5.14/acre-inch.

Labor requirement assumptions were taken from Turner and Anderson (1980). These authors estimate that labor requirements in a drip irrigation system are approximately 6% of the irrigation time per acre. Assuming labor costs of \$8.50/h, labor irrigation costs are estimated in \$9.54/acre-inch.

Differences in prices as a result of quality differences were not considered. The study revealed no differences in berry size or soluble solids in response to irrigation. The average price assumed for the analysis was \$0.50/lb. Prices for muscadine grapes in direct market operations can be as high as \$1.25/lb (Safley et al., 2001). Harvesting costs were assumed to be \$0.21/lb as estimated by Krewer et al. (2002).

Results and discussion

Yields in response to irrigation are shown in Table 3. The data indicate a quadratic response of yields to irrigation. This quadratic response suggests that yields increase at increasing levels of irrigation, reach a maximum at some point, and then decrease if more water is applied beyond the maximum. Given the data, a quadratic function was estimated to model the relationship between yields (pounds) and irrigation (acre-inches). The estimated equation was the following:

$$y = 11083 + 636w - 22w^2 \quad (R^2 = 0.49,\ P < 0.01) \quad [9]$$

Figure 1 shows the estimated relationship between yields and irrigation. The maximum yield according to this model is reached at 14.5 acre-inches, which corresponds to 7.7 gal/d per vine. The quadratic response implies that the marginal response of the yields to irrigation is decreasing up to the maximum yield. A decreasing marginal response means that the response of yields to an additional unit of irrigation gets smaller as the yield level approaches the maximum. For example, the increase in yields obtained by going from no-irrigation to 1 acre-inch is about 614 lb/acre, on the other hand, the yield increase of applying 12 acre-inches compared to 11 acre-inches is only 130 lb/acre.

According to the estimated model if the objective of the producer was to maximize yields, the amount of water

Table 2. Fixed and variable costs and prices for the production, harvesting, and marketing of 1 acre (0.4 ha) of 'Southland' muscadine grapes.

Item/description	Cost per unit (\$)[y]
Fixed costs	
Fixed costs[z]	675/acre
Fixed irrigation costs	255/acre
Variable costs	
Preharvest variable costs[z]	1460/acre
Harvest and marketing costs	0.21/lb
Variable irrigation costs	
Electricity	2.07/acre-inch
Irrigation labor	9.54/acre-inch
Irrigation repair and maintenance costs	
Pump	1.00/acre-inch
Filter	3.04/acre-inch
Tubing	0.16/acre-inch
Emitters	0.36/acre-inch
Other	0.58/acre-inch
Price	
Muscadine grape price	0.50/lb

[z]These two items exclude irrigation costs.
[y]\$1.00/acre = \$2.4711/ha; \$1.00/lb = \$2.2046/kg; \$1.00/acre-inch= \$0.9729/100 m^3.

Table 3. Total fruit yield for 'Southland' muscadine grapes in response to different drip irrigation rates in Griffin, Ga., during 1997, 1998, and 1999.

Daily irrigation amount/plant (gal/d)[z]	Total annual irrigation[z] (acre-inches)[y]	Total yields (lb/acre)[y] 1997	1998	1999	3-year average
0	0	13,496	11,819	10,621	11,979
4	7.48	14,934	15,493	12,778	14,401
6	11.22	17,250	18,048	14,375	16,557
8	14.96	17,250	17,090	12,857	15,732

[z]To transform gallons/day per plant to acre-inches the following calculation is required: acre-inches = gallons/day per plant × 363 plants/acre × 140 d × 1 gal/27,150 acre-inches.
[y]1 gal = 3.7854 L; 1 acre-inch = 102.7902 m^3; 1 lb/acre = 1.1209 $kg \cdot ha^{-1}$.

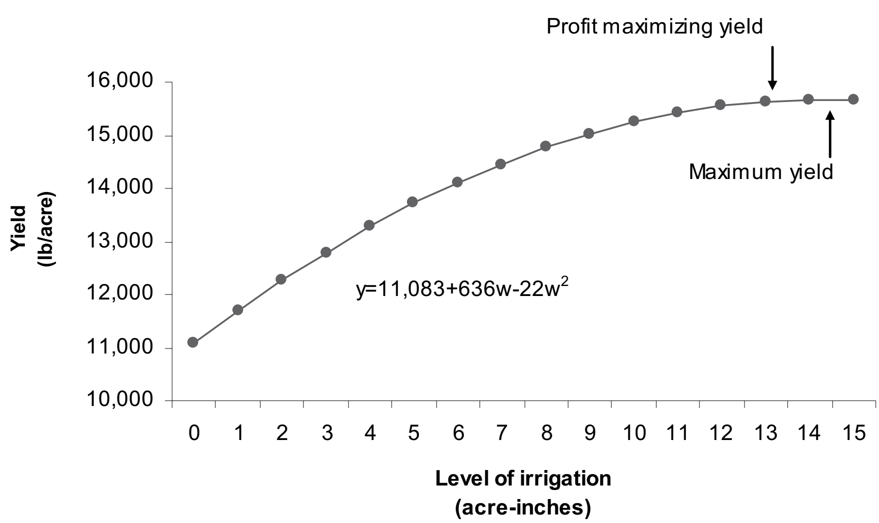

Fig. 1. Estimated relationship between 'Southland' muscadine grapes yields and irrigation (1 acre-inch = 102.7902 m^3; 1 lb/acre = 1.1209 $kg \cdot ha^{-1}$).

that should be applied is 14.5 acre-inches or 7.8 gal/d per vine. However, as mentioned in the methods section if the objective of the producer is to maximize profits, the costs of production should be taking into account for the analysis. Using the estimated yield-water relationship from equation [9] the profit equation can be written as

$$\prod = p \times (11083 + 636w - 22w^2) - Fc - h \times (11083 + 636w - 22w^2) - r \times w \quad [10]$$

By taking the derivative of this equation with respect to w, making it equal to zero and solving for w, the equation to determine the profit maximizing level of irrigation w^* results:

$$w^* = 14.45 - \frac{r}{44(p-h)} \quad [11]$$

Using the estimated costs of production for our representative Georgia muscadine vineyard (harvesting costs, h = $0.21/lb; operating irrigation costs, r = $16.75/acre-inch) and a muscadine grape price of $0.50/lb, the estimated profit maximizing level of irrigation is 13.1 acre-inches or 7 gal/d per vine. Even though the profit maximizing level of irrigation results in a decrease in yields of 40 lb with respect to the yield maximizing level of irrigation (see Fig. 1), profits are increased by $11/acre and 1.3 acre-inches of water are saved. Water requirements for profit maximization are 9.1% lower than water requirements for yield maximizing.

Only three studies have reported on the topic of irrigation effects on muscadine grapes (Clark and Spiers, 2001). None of these studies explored the economic aspects of this cultural practice. Moreover, previous studies on the economics of drip irrigation for grapes have been limited to vinifera grapes and have been restricted to the comparison of profits between grapes grown at a constant and unique level of irrigation and no irrigation (e.g., Cuykethendall et al., 1999). In contrast, this study included different levels of irrigation, which allows the determination of an economic optimal level of irrigation.

The procedure outlined in this study is general and can be used for the economic assessment of drip irrigation for other types of grapes and under other conditions (e.g., in arid areas). However, the procedure would need to be modified if the levels of irrigation affect quality characteristics of the fruit that receive premiums or discounts in the market.

Equation [11] expresses the relationship between the optimal level of irrigation and the economic parameters: operating irrigation costs, price of the fruit, and harvesting costs. The equation makes clear that the optimal level of irrigation is not static, but changes, depending on the economic parameters: irrigation costs, harvesting costs, and irrigation costs. Equation [11] specifically suggests that the profit-maximizing level of irrigation decreases if the operating costs of irrigation increase or the differential between the price and harvesting costs decreases. To emphasize this aspect, the profit-maximizing level of irrigation can be calculated under alternative scenarios. For example, in a pessimistic scenario in which muscadine grape price decreases to $0.40/lb, harvesting costs increase to $0.25/lb, and water variable costs increase to $30/acre-inch, the profit-maximizing level of irrigation would be 9.9 acre-inches, which corresponds to 5.3 gal/d per vine. In an optimistic scenario with muscadine grape prices of $0.75/lb and harvesting and irrigation costs at the same assumed levels, the profit-maximizing level of irrigation would be 13.8 acre-inches or 7.3 gal/d per vine.

In the current study, irrigation was applied every day, regardless of rainfall received. In practice, irrigation can be turned off during rain events, thus conserving water and lowering costs. The sensitivity of the results to the way in which irrigation was applied was evaluated, using the assumption that irrigation had been turned off for 3 d after every rainfall event of 1 inch or more. For the 3 years during which the experiment was carried out, on average, five of these events occurred (six events occurred in 1997, five events in 1998, and four events in 1999). This represents 15 fewer days of irrigation and corresponds to around 10% savings in operational irrigation costs. Using this assumption, the profit-maximizing level of irrigation is 13.3 acre-inches or 7.1 gal/d per vine, which is not very different from our previous estimate.

Estimated costs, returns, and profits at different levels of irrigation are shown in Table 4. At the 1-acre-inch level of irrigation, profits obtained from muscadine production are lower compared to a vineyard without irrigation. In other words, the increase in returns obtained from higher yields is smaller than the increase in costs due to irrigation. After this point, the profits generated would allow the producer to obtain returns to pay the investment in the irrigation system, pay the additional variable costs, and make additional profits. The increase in profits due to the use of irrigation can be quite substantial. Under the assumptions of this

Table 4. Estimated costs, returns and profits for the production, harvesting, and marketing of 1-acre (0.4 ha) of 'Southland' muscadine grapes under different levels of irrigation.

Irrigation level (acre-inches)[z]	Net returns	Total costs	Profits	Marginal profits
	($/acre)[z]			
0	5541.56	4942.95	598.60	
1	5848.56	5343.64	504.91	–93.69
2	6133.56	5480.09	653.46	148.55
3	6396.56	5607.30	789.25	135.79
4	6637.56	5725.27	912.28	123.03
5	6856.56	5834.00	1022.55	110.27
6	7053.56	5933.49	1120.06	97.51
7	7228.56	6023.74	1204.81	84.75
8	7381.56	6104.75	1276.80	71.99
9	7512.56	6176.52	1336.03	59.23
10	7621.56	6239.05	1382.50	46.47
11	7708.56	6292.34	1416.21	33.71
12	7773.56	6336.39	1437.16	20.95
13	7816.56	6371.20	1445.35	8.19
14	7837.56	6396.77	1440.78	–4.57
15	7836.56	6413.10	1423.45	–17.33

[z] 1 acre-inch = 102.7902 m^3; $1.00/acre= $2.4711/ha.

study, profits from a vineyard using the profit-maximizing level of irrigation are more than double compared to a vineyard without irrigation.

The calculations of the profit-maximizing level of irrigation have assumed that the amount of water available for irrigation is not restricted. However, the information generated in this study can also be used if irrigation water becomes limited. Table 4 shows the additional profits generated by each additional acre-inch of irrigation (marginal profit). For example, the increase in profits obtained by increasing the level of irrigation from 12 to 13 acre-inches is $8/acre. If irrigation water were limited, the $8/acre increase in profits could be compared with the increase in profits obtained by applying the same inch of water to other crops or to an additional acre of grapes. A limited availability of water can also cause an increase in the price of water, which would result in a lower optimal level of irrigation.

The results obtained in this study have several limitations. First, these results are specific for the environmental conditions present in the experimental station (e.g., weather conditions, soil type, etc.) and one muscadine cultivar, 'Southland'. More work is required to determine the relationship between muscadine grape yields and irrigation levels for other conditions and cultivars. Second, the study has not considered aspects of risk into the analysis. For example, irrigation has important implications for reducing the risk of low yields if a drought occurs. Finally, the study has only taken into account the benefits of irrigation in an established vineyard. The benefits of irrigation in the establishment of the vineyard, such as faster plant growth and fewer replanting costs, have not been considered.

In summary, using data from a 3-year experiment, this study has determined economic optimal levels of irrigation for 'Southland' muscadine grapes. Economic optimal levels of irrigation are shown to be different than biological optimal levels of irrigation. Under an assumed price of $0.50/lb, harvesting costs of $0.21/lb, and irrigation costs of $16.75/acre-inch, the economic optimal level of irrigation was estimated to be 13.1 acre-inches, which corresponds to 7 gal/d per vine during the growing season (May to October). This optimal level needs to be reconsidered if the price of muscadine grapes or the costs change, or if water becomes a limiting resource. Water requirements for profit maximization are 9% lower than water requirements for yield maximizing. The effect of an adequate use of irrigation in the profitability of the muscadine grape operation can be quite substantial. Under the assumed conditions of this study, the profits obtained when using the economic optimal level of irrigation more than double the profits obtained without irrigation.

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