IRRIGATION AND POTENTIAL DIVERSIFICATION BENEFITS IN HUMID CLIMATES

Lonnie R. Vandeveer, Kenneth W. Paxton, and David R. Lavergne

Abstract

Income variability and means for managing risk continue to receive much attention in farm management research. In this paper, irrigation is presented as a risk-management strategy that offers potential diversification benefits. Potential diversification opportunities largely result from a wider range of enterprise production activities. A portfolio analysis of dryland and irrigated farm scenarios indicates that income stabilizing and diversification effects of irrigation substantially modify the risk-return position of a typical farm in northeast Louisiana. Safety-first considerations along with Target MOTAD programming procedures also are used to evaluate the impact of irrigation on the farm's financial performance.

Key words: irrigation, income variability, risk, diversification, MOTAD, Target MOTAD, safety-first.

Irrigation represents a technology that may be used to affect the variability of yield and farm income in humid areas. Various studies have examined the returns to irrigation in humid areas (Hatch et al. and Salassi et al.); however, fewer studies have investigated how irrigation affects variability of farm income. Boggess et al. (1983) noted that one of the primary attractions of irrigation in humid areas is its potential for reducing income variability, yet they reported that few studies have considered its risk implications. Other research has questioned the riskiness of irrigation investment (Boggess and Amerling). Bioeconomic simulation of crop enterprises in Florida suggests a trade-off between production and financial risk, with the net effect depending on the situation and weather of the area. More recently, studies of perceptions and responses to risk indicate that producers recognize weather as the most important source of variability in crop production (Patrick et al. and Boggess et al., 1985). Results suggest that irrigation is a common management response among producers to rainfall variability, while enterprise diversification is a major means for managing production variability. These findings lead one to question whether there are diversification benefits from irrigation. Previous studies have recognized the potential advantages of reduced enterprise yield and expected return variability from irrigation; however, relatively few studies have considered the potential whole-farm diversification effects of irrigation in humid areas.

The general hypothesis of this paper is that irrigation in humid areas not only provides the potential for reducing enterprise yield variability but also has the potential of providing whole-farm enterprise diversification opportunities. With enterprise diversification, a producer is expected to choose some combination of enterprises to stabilize farm income so that variance decreases without a corresponding reduction in expected returns to the farm. Investment in irrigation provides potential diversification benefits to a farm by providing a wider range of production activities. If the relative amount of variability for irrigated crop enterprises is less than for dryland enterprises, then the farm's risk-return frontier (E,V) with irrigation is likely to be different from that under dryland conditions. These changes in turn are expected to affect the financial performance of the farm.

This study uses a portfolio approach for evaluating the impact of irrigation on farm income and variability of income. MOTAD and Target MOTAD programming procedures are used to estimate a farm's risk-return frontier (E,V) under dryland and irrigated conditions.

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Expected income (E) and variance of income (V) for optimal cropping combinations under both dryland and irrigated scenarios are estimated using MOTAD programming procedures and compared for a typical northeastern Louisiana farm. The effect of irrigation on the farm's financial performance is further evaluated in a safety-first decision framework using the Target MOTAD model. Research in producer's management responses to risk provides evidence which supports safety-first considerations in decision processes (Patrick et al.). In the following analysis, fixed cash obligations under dryland and irrigated scenarios are estimated for the typical farm and specified as target income levels. Irrigation is analyzed by comparing results of optimal solutions estimated by Target MOTAD models.

PROCEDURES

The general objective of this study is to estimate the effect of irrigation on the risk position of the farm. A portfolio approach is used in the analysis where the effect of irrigation is measured in E,V space. A set of efficient E,V farm plans is estimated for a dryland scenario and compared with another set of efficient E,V farm plans for an irrigated scenario. Differences in these two efficient E,V frontiers provide a basis for evaluating the effect of irrigation on the risk-return relationship of the farm. Moreover, differences in the two efficient E,V frontiers reflect potential diversification benefits attributed to irrigation.

The MOTAD model, which may be solved by a linear programming algorithm, is used in the analysis to estimate sets of efficient E,V farm plans. The MOTAD model is formulated following the specification outlined by Hazell and Norton and is estimated using a microcomputer algorithm developed by Laughlin. The model is specified as:

$$(1)\ \text{Min} = \sum_t (Z_t^+ + Z_t^-),$$

subject to:

$$(2)\ \sum_j (c_{jt} - \bar{c}_j) X_j - Z_t^+ + Z_t^- = 0, \text{ for all t},$$

and:

$$(3)\ \sum_j \bar{c}_j X_j = E,$$

$$(4)\ \sum_j a_{ij} X_j \leq b_i, \text{ for all i},$$

$$(5)\ X_j, Z_t^+, Z_t^- \geq 0, \text{ for all j, t},$$

where:

- c_{jt} = the gross margin of enterprise j in period t;
- $\bar{c}_j$ = the expected gross margin of enterprise j;
- X_j = the level of enterprise j;
- Z_t^+ = positive deviation of gross margin from mean in period t;
- Z_t^- = negative deviation of gross margin from mean in period t;
- b_i = total availability of resource i;
- a_{ij} = requirement of resource i by one unit of enterprise j; and
- E = expected total gross margin.

The MOTAD model is used to estimate optimal farm plans for different expected income levels. The variance of income (V) for each farm plan is estimated using (Elton and Gruber):

$$(6)\ V = \sum_j X_j^2 \sigma_j^2 + \sum_j \sum_k X_j X_k \sigma_{jk},$$

where σ_j^2 represents the gross margin variance of enterprise j and σ_{jk} represents the covariance between enterprises j and k, $j \neq k$. Expected income levels from optimal farm plans along with respective estimated variances provide the basis for tracing out the E,V efficiency frontiers for both dryland and irrigated scenarios. The impact of irrigation on the farm's risk-return relationship is isolated by the difference in variability of income for the two scenarios at specified income levels.

Irrigation is further analyzed by assuming a safety-first decision framework. Within this framework, Target MOTAD programming procedures are used to evaluate the effect of irrigation on the farm's financial performance. The Target MOTAD model is used because it allows for the comparison of alternative farm scenarios at a common level of risk (Watts et al.). Moreover, portfolios identified by the model solutions are a subset of portfolios which are second-degree stochastic efficient (Tauer). The Target MOTAD model, in this analysis, provides a basis for comparing dryland and irrigated farm scenarios at a common level of risk. Target income in this analysis is defined as a minimum income necessary to meet farm fixed cash obligations during a specified production period. Financial performance is evaluated in each scenario by whether income from model solutions equals or exceeds specified target income levels.

The mathematical specification of the Target MOTAD model is (following Hazell and Norton):

$$(7)\ \text{Max } E = \sum_j \bar{c}_j X_j ,$$

subject to

$$(8)\ Y_o - \sum_j c_{jt} X_j - Z_t^- \leq 0, \text{ for all t},$$

$$(9)\ \sum_t p_t Z_t^- = \delta,$$

$$(10)\ \sum_j a_{ij} X_j \leq b_i , \text{ for all i},$$

$$(11)\ X_j, Z_t^- \geq 0, \text{ for all j, t},$$

where Y_0 represents a target income level, Z_t^- represents a deviation below the target income level, p_t represents a probability of state of nature t, and δ is parameterized to vary from 0 to some large number. Variances of income for solutions again are estimated by equation (6).

Comparison of model results under dryland and irrigated conditions at a common risk level (such as δ = 0) provides a means for evaluating the impact that supplemental irrigation would have on the ability of the farm business to meet its financial obligations. Irrigation investment is considered desirable if it improves the ability of the farm to meet these obligations. Specifically, δ is specified at 0 for both scenarios, which means that no negative income deviations are allowed in any of the time periods. The results are then interpreted within the safety-first conceptual framework.

DATA

Irrigation is empirically evaluated on a typical farm in the Macon Ridge area of Louisiana. This area in Northeast Louisiana is characterized by loessial soils which respond well to irrigation. Area average annual rainfall is 55 inches; however, it ranges from approximately 29 to 79 inches per year.

Irrigation scenarios for the typical owner-operated farming situation are shown in Table 1. The scenario with no irrigation includes cropping alternatives of cotton, soybeans, and wheat. The second scenario is partially irrigated and includes dryland enterprises of cotton, soybeans, and wheat and irrigated enterprises of cotton, soybeans, corn, and double-crop wheat and soybeans. The double-crop enterprise includes dryland wheat with irrigated soybeans. For this enterprise, irrigation provides needed soil moisture for the timely planting and harvest of soybeans. Each farm scenario is assumed to have a 527-acre cotton base, and each farm scenario is assumed to participate in the government cotton program (1988). No government program base is assumed for corn and wheat; however, it is assumed that the farm scenarios are organized in such a way that specified crops are produced.

Target income for each scenario (Table 1) is estimated to represent an expected income level that allows the farm to just meet all of its financial commitments. The target income level for the dryland scenario ($36,886) is specified by the sum of cash overhead and family withdrawals. The irrigated scenario includes a 300-acre gated pipe irrigation system with an investment requirement of $51,128. This type of irrigation system is typical for the area and provides relatively more flexibility in the number of acres irrigated than other types of systems. The irrigation system is assumed to be fully financed with debt capital to better reflect the ability of the farm business to recoup its investment in the irrigation system. With this assumption, the target income level ($49,814.24) includes principal and interest payments associated with irrigation.

Summary yield statistics for typical enterprises produced under dryland and irrigated conditions in the area are presented in Table 2. Estimates are from commercial variety tests conducted over the period 1975–87 at the Macon Ridge Research Station. Comparison of dryland and irrigated yields indicates that irrigation increases cotton lint yield by approximately 332 pounds per acre, while soybean yield increases by 14 bushels per acre. The coefficient of variation suggests that variability of irrigated cotton and soybeans is much less relative to variability of these crops under dryland conditions.

Estimated enterprise gross margins and relevant statistics for the distributions are presented in Table 3. Per-acre enterprise gross margins over the period 1975–87 were estimated as the difference between nominal per acre gross returns by crop and the sum of variable production costs and total variable irrigation costs. Per-acre gross returns were estimated from experimental yields and commodity price data (Zapata et al.). Price deficiency payments based on the 1988 government program were included in gross return estimates. Total variable irrigation costs were estimated from the number of irrigations each year (experimental data) and variable costs of each ir-

TABLE 1. TYPICAL OWNER-OPERATED FARM SCENARIOS, MACON RIDGE AREA, LOUISIANA, 1988

Item	Farm scenario	
	No irrigation	Partial irrigation
Cropland acreage		
Dryland	700	400
Irrigated	0	300
Total	700	700
Irrigation investment ($)[a]	0	51,128
Enterprise costs ($/ac.)[b]		
Dryland cotton	277.16	277.16
Dryland soybeans	61.97	61.97
Dryland wheat	55.23	55.23
Irrigated cotton	—	322.35
Irrigated soybeans	—	61.97
Irrigated corn	—	167.50
Wheat-soybean double-crop	—	110.04
Variable cost of one irrigation	—	6.02
Target income		
Cash overhead expense	18,886.00	18,886.00
Family withdrawals	18,000.00	18,000.00
Irrigation prin. and interest[c]	—	12,928.24
Total	36,886.00	49,814.24

[a] Estimated to represent the cost of a 300-acre gated pipe irrigation system. The irrigation system is assumed to be fully financed with debt capital.

[b] Per-acre non-irrigation variable costs are assumed constant in the analysis. Irrigation costs in the analysis are estimated to vary with the number of irrigations required in each of the 13 years.

[c] Irrigation loan is for seven years with equal principal payments and interest charged at 11 percent on the outstanding principal balance.

TABLE 2. ENTERPRISE PER ACRE CROP YIELD SUMMARY STATISTICS, MACON RIDGE, LOUISIANA, 1975–1987[a]

Item	Mean	Standard deviation	Coefficient of variation (Percent)
Dryland			
Cotton lint (lb.)	722.62	309.78	42.90
Soybeans (bu.)	22.08	8.14	36.87
Wheat (bu.)	45.08	18.42	40.85
Irrigated			
Cotton lint (lb.)	1,054.54	220.21	20.88
Soybeans (bu.)	36.16	6.42	17.74
Corn (bu.)	115.46	23.58	20.42

[a] Based on commercial variety experiments from 1975 through 1987 at the Macon Ridge Research Station. Cotton, wheat, soybean, and corn varieties represented in the analysis are Stoneville 213, Coker 762, Centennial, and Pioneer, respectively.

rigation estimated in 1988 dollars (Vandeveer and Salassi). Enterprise production costs (Paxton et al.) were held constant in the analysis, and gross margins reflect yield variability, commodity price variability, and variability of irrigation costs.

Enterprise gross margin estimates were statistically tested for trend and normality. Linear regression analysis was used to test for trend in each gross margin distribution. Results of the analysis did not indicate any statistically significant trend effects in any of the enterprise gross margins. Similarly, each enterprise gross margin was separately tested for normality using the Shapiro-Wilk test. Results of each test did not indicate a departure from normality.

MEAN-VARIANCE ANALYSIS

Estimates from Table 3 along with the MOTAD model were used to estimate optimal farm plans at given expected income levels for both dryland and irrigated scenarios. The dryland model was constrained by total acres and cotton base acres, while the irrigated scenario was constrained by these same restrictions plus a limitation of 300 irrigated acres. The models also required a fixed government cotton set aside acreage (12.5 percent of base acreage) for each acre of planted cotton. Costs for maintaining set-aside acreage were included in model solutions. In addition, the models required a fixed amount of set-aside

TABLE 3. DISTRIBUTION OF ENTERPRISE GROSS MARGINS, MACON RIDGE AREA, LOUISIANA, 1975-87[a]

Year	Dryland cotton	Dryland soybeans	Dryland wheat	Irrigated cotton	Irrigated soybeans	Irrigated corn	Wheat-soybean double-crop
				.... Gross margins per acre ($)			
1975	349.28	78.86	57.17	366.83	83.65	171.50	147.97
1976	37.67	64.95	70.17	261.52	177.65	241.50	254.98
1977	268.74	109.12	43.89	306.03	153.48	-39.88	204.53
1978	146.05	-3.11	63.72	379.44	98.11	30.44	168.99
1979	365.21	148.61	120.27	320.02	148.61	131.54	276.04
1980	26.00	-16.32	59.15	430.54	145.88	145.50	212.19
1981	91.84	58.42	110.53	428.25	123.52	172.18	241.21
1982	308.81	39.17	104.77	308.58	111.33	48.99	223.26
1983	386.33	144.71	210.81	743.30	273.90	292.88	491.87
1984	700.45	113.23	169.47	678.57	198.99	174.91	375.62
1985	393.75	57.21	158.62	358.46	89.31	214.06	255.09
1986	170.38	23.13	-55.23	346.14	25.23	42.47	-22.84
1987	308.12	82.33	84.77	426.13	111.87	54.79	203.80
Mean[b]	273.28	69.25	92.16	411.83	133.96	129.29	233.29
St. Dev.	183.22	51.36	66.75	142.88	61.37	95.95	118.75

[a] Gross margins were estimated as the difference between gross receipts and the sum of variable production costs and total variable irrigation costs.

[b] The Shapiro-Wilk test was used to test for normality in each of the enterprise gross margin distributions. Results of each test did not indicate a departure from normality.

TABLE 4. DRYLAND AND IRRIGATED MOTAD SOLUTIONS, TYPICAL MACON RIDGE OWNER-OPERATED FARM, LOUISIANA, 1988

	Optimal farm plans					
Item	1	2	3	4	5	6
			.... Dryland			
Expected income ($)[a]	25,000	50,000	75,000	100,000	125,000	141,476
Variance (millions)	229.82	919.27	2,050.19	3,803.26	6,220.01	8,386.45
Coeff. of variation	60.64	60.64	60.37	61.67	63.09	64.73
Cotton (acres)	29.05	58.09	101.91	212.75	362.63	461.29
Soybeans (acres)	119.34	238.69	284.21	0.00	0.00	0.00
Wheat (acres)	95.82	191.65	299.31	456.82	285.51	172.74
Set aside (acres)	4.15	8.31	14.57	30.42	51.86	65.96
			.... Irrigated			
Expected income ($)	25,000	50,000	75,000	100,000	125,000	150,000
Variance (millions)	90.19	360.78	762.98	1,207.74	1,925.83	2,864.23
Coeff. of variation	37.99	37.99	36.83	34.75	35.11	35.68
Dry cotton (acres)	0.00	0.00	.99	18.64	30.52	8.93
Dry soybeans (acres)	8.12	16.24	27.39	4.72	0.00	331.28
Dry wheat (acres)	0.00	0.00	0.00	0.00	0.00	15.42
Dry set aside (acres)	4.10	8.20	14.40	30.84	43.95	44.18
Irr. cotton (acres)	28.68	57.35	99.87	197.02	276.86	300.00
Irr. soybeans (acres)	54.23	108.46	149.70	79.07	0.00	0.00
Irr. corn	0.00	0.00	0.00	23.90	23.14	0.00
Wheat-soybeans[b]	23.13	46.26	50.43	0.00	0.00	0.00

[a] Solution six represents the maximum attainable income under the dryland scenario.

[b] Includes a double-crop enterprise with dryland wheat and irrigated soybeans.

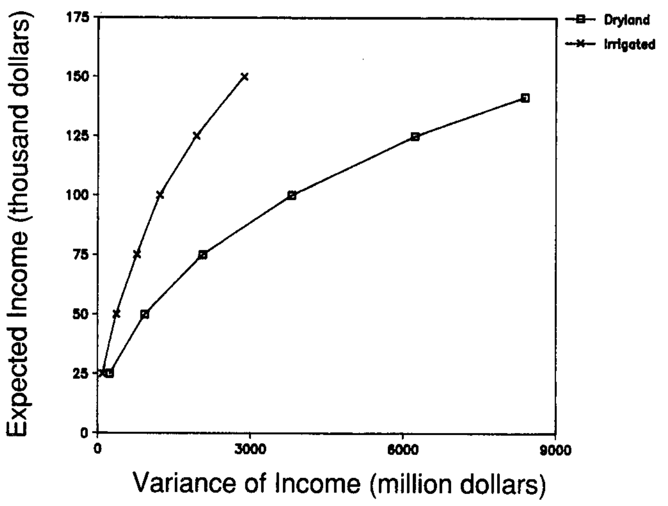

Figure 1. Efficient E,V Frontiers, Typical Owner-operated Farm, Macon Ridge Area, Louisiana, 1988.

acreage for each acre of planted cotton included in solutions. Enterprise statistical data from Table 3 along with equation (6) were used to estimate an expected income variance for each farm plan.

Results from parametric analysis of expected income using the MOTAD model are shown in Table 4. Expected income for farm plan six under the dryland scenario differs from expected income under the irrigated scenario because maximum attainable income for the dryland scenario is estimated at $141,476. Although not shown in Table 4, parametric analysis indicates that the maximum expected income for the irrigated scenario is estimated at $183,486. The results indicate that variance of expected income for each farm plan under the irrigated scenario is less than variance of expected income for corresponding dryland farm plans. Similarly, coefficient of variation estimates for farm plans indicate that the relative amount of variation in expected income for the irrigated scenarios is less than those of corresponding dryland scenarios. For the dryland scenario as expected income increases, cotton and wheat production replace soybean production. Results from the irrigated scenario indicate that cotton is produced on irrigated acreage and cotton, soybeans, and wheat are produced on dryland acreage for the highest expected income level.

Results presented in Table 4 are illustrated in Figure 1. Relationships between expected income levels and respective variances indicate that the impact of adding the 300-acre irrigation system is to shift the farm's risk-return relationship upward to the left. The slopes of the two relationships also appear to differ, with the irrigated scenario reflecting a more favorable tradeoff between risk and returns than the dryland scenario. In general, these results suggest that diversification effects of irrigation substantially improve the risk-return relationship for the typical farm. Although these results indicate risk benefits from irrigation, a question still remains whether these benefits are sufficient to offset the risks associated with irrigation investment.

FINANCIAL ANALYSIS

Irrigation and its effect on the farm's financial performance are examined using the Target MOTAD model. Specifically, the model is used to determine if irrigation increases the farm's potential in meeting its fixed cash obligations. Target incomes, which include principal and interest payments for the irrigation investment, were estimated (Table 1), and the model was used to identify farm plans that could be used to meet respective target levels of income.

Financial performance in each scenario is analyzed in the Target MOTAD model by setting the risk measure (δ) at 0. At this level, no negative income deviations are permitted, and the results follow a safety-first decision framework. Results of the Target MOTAD analysis are presented in Table 5. With δ at 0, the analysis found no feasible solution for the target income under the dryland scenario, while a solution was found to exist for the irrigated scenario. Parametric analysis under the dryland scenario indicated that a solution exists (δ = 0) at a lower target income of $29,295.

These results suggest that the operator cannot be assured of meeting all cash expenses including family withdrawals and cash overhead expenses in every year under the dryland scenario. Solution 2 for the dryland scenario indicates that target income ($36,886) can be achieved if the decision maker is willing to accept more risk.

Parametric analysis of the risk measure (δ) for the irrigated scenario yielded only one solution. The risk measure (δ) for this solution was estimated at zero which implies that expected income was not constrained by risk. Results for the irrigated scenario presented in Table 5 indicate an expected mean income of $183,486.15 with an expected income standard deviation of $85,950.43. These estimates are based upon a diversified portfolio that includes dryland cotton, irrigated cotton, and the double-crop dryland wheat and irrigated soybean enterprise activities. The cropping plan provides the farm with the opportunity for servicing fixed cash obligations including principal and interest payments on irrigation investment in every year. The maximum target income level with no risk (δ=0) for the optimal solution of the irrigated scenario in Table 5 is estimated at $89,909. This result suggests that irrigation increases the credit capacity of the farm. In general, the results suggest that the diversification benefits of irrigation are sufficient to offset the risks of irrigation investment and that irrigation may be used to improve the farm's financial performance.

SUMMARY AND CONCLUSIONS

The general hypothesis of this study was that irrigation in humid areas provides potential farm income stabilizing opportunities through enterprise diversification. Potential diversification benefits of irrigation result from a wider range of enterprise alternatives that may be added to the farm's portfolio. A portfolio approach was used in this analysis to identify the effect of irrigation on a farm's risk-return position in E,V space. Application of MOTAD programming procedures to an owner-operated farming situation in Northeast Louisiana indicated that irrigation shifts the farm's efficient E,V frontier upward and to the left from what it was under dryland conditions.

Target MOTAD programming procedures were used to analyze and evaluate the effect of irrigation on the farm's financial performance. Target incomes were estimated for dryland and irrigated scenarios and defined as the minimum income necessary for the farm to service fixed cash obligations. Financial performance was evaluated in each scenario by

TABLE 5. DRYLAND AND IRRIGATED TARGET MOTAD BASIC SOLUTIONS, TYPICAL MACON RIDGE OWNER-OPERATED FARM, LOUISIANA, 1988

Item	Dryland		Irrigated
	Solution 1	Solution 2	Solution 1
Expected income ($)	113,070.65	118,509.67	183,486.15
Standard deviation ($)	70,243.59	74,093.91	85,950.43
Risk measure (δ)[a]	0.00	807.00	0.00
Coefficient of variation (%)	62.12	62.52	46.84
Target income ($)	29,295.00	36,886.00	49,814.24
	Acres		
Dryland cotton	291.05	323.65	334.03
Dryland soybeans	0.00	0.00	0.00
Dryland wheat	367.33	330.07	0.00
Irrigated cotton	—	—	127.26
Irrigated soybeans	—	—	0.00
Irrigated corn	—	—	0.00
Double-crop wheat-soybeans	—	—	172.74
Set aside	41.62	46.28	65.97

[a] A feasible solution did not exist for δ = 0 for the dryland scenario for comparison with the irrigated scenario. Parametric analysis of the dryland scenario indicated that a solution exists for δ = 0, if the target level of income equals $29,295. Only one solution was indicated in parametric analysis of the irrigated scenario.

whether expected income from model solutions satisfied target incomes. With risk at a minimum level, analyses provided no feasible solution for the dryland scenario, while a solution was found for the irrigated scenario. The irrigated scenario resulted in a diversified portfolio with expected income sufficient to service cash obligations of the farm, including principal and interest payments on the irrigation investment.

The results generally show that irrigation in humid areas may be used as a risk-management strategy. The results also suggest that a portfolio approach may be used to more completely evaluate irrigation investment. Enterprise income stabilizing and diversification effects from irrigation were found to improve the risk-return position of the farm in this analysis. However, these results are limited to one resource situation in one area. Irrigation opportunities in other areas are likely to vary with factors such as crop yield responses to irrigation, enterprises considered, and type and layout of the irrigation system. Similarly, the analysis did not include irrigation management opportunities, such as irrigation scheduling, which would be expected to further modify the farm's risk-return relationship. Consideration of these factors in modeling efforts would be expected to provide improved estimates for evaluating irrigation in humid areas.

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