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RISK ANALYSIS FOR AGRICULTURAL PRODUCTION FIRMS: CONCEPTS, INFORMATION REQUIREMENTS AND POLICY ISSUES

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RISK ASPECTS OF IRRIGATION DECISIONS*

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Antle recently demonstrated that risk considerations are important in dynamic stochastic production problems regardless of the risk preferences of the decision maker. Production risk is of particular concern in agriculture since the biological processes of production introduce elements of risk unlike other types of risk faced by non-agricultural firms. Weather patterns and biological pests (e.g. insects, weeds, diseases) directly affect yields and indirectly prices (Tew _et al_.).

Irrigation has long been used in arid regions to increase yields and reduce production risk (Mapp and Eidman, Zaveleta _et al_.). More recently, irrigation has gained popularity as a production risk management practice in humid and subhumid regions (Burt and Stauber; Apland _et al_.; Tew _et al_.; and Boggess _et al_.).

In a broader context, irrigation also has important implications for other types of firm risk including: price, financial, institutional, and management or information. Investment in an irrigation system can significantly increase a firm's exposure to financial risk. Potential changes in water district rules as a result of increasing population or declining water supplies introduce significant institutional risks. Finally, technological developments in irrigation equipment, plant stress sensors and irrigation scheduling algorithms add complexity to an already complex management environment.

The purpose of this paper is to outline what is known about the effects of irrigation in humid and subhumid areas on firm risks. Both irrigation investment and irrigation scheduling decisions are considered.

Irrigation As A Variable Input

Most risk measures are based on the probability distribution of income. One of the major components of income is output and thus it is

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of interest to know what impact variations in input use (e.g. irrigation) have on the variance of output and profit.

Three approaches have been used to model the stochastic, dynamic relationships between irrigation and yield. Just and Pope developed a single equation stochastic production function specification that satisfies eight propositions deemed desirable in risk analyses. A second more common approach in applied irrigation studies is the use of biophysical simulation models consisting of a soil water balance model coupled to a single equation yield response function. The yield function commonly expresses the ratio of actual to potential yield as a multiplicative power function of the ratios of actual evapotranspiration to potential evapotranspiration in each of several crop growth stages. The third approach substitutes process level crop growth models in place of single equation yield functions in biophysical simulation models. These models are mathematical representations of the biological, physical, chemical, and physiological processes determining crop growth (Wilkerson et al.). The functional forms of the equations are derived from theories about the underlying processes, and the coefficients are empirically determined. Stochastic input-output relationships are derived by simulating alternative irrigation strategies over a series of stochastic weather conditions.

Numerous studies have shown that irrigation reduces yield variability and thus income variability. In arid regions, irrigation dominates dryland production of many crops (Harris and Mapp, 1981; Zaveleta et al.). Harris and Mapp (1981) indicate that expected net returns of irrigated sorghum in Oklahoma are more than twice dryland expected net returns, while the variance of irrigated net returns is nearly an order of magnitude smaller than dryland net returns. Similar, though less dramatic, results have also been found in subhumid and humid regions. Burt and Stauber reported that irrigating corn in Missouri increased expected gross returns by 34 percent and reduced the standard deviation of gross returns by 50 percent. Apland et al. found that irrigating corn in Illinois increased expected net returns by only 2 percent but reduced the variance of net returns by more than 75 percent. Similar results were found for peanuts, corn, and soybeans in Georgia (Tew et al.).

These results indicate that under current prices and costs, that irrigated production dominates dryland in arid regions. Most of the research in arid regions has focused on increasing the efficiency of use of the scarce water resource. However, as water tables fall and nonagricultural demands for water increase, the comparative advantage of irrigation may decline. Thus the primary risk-aspects of irrigation in arid regions concern long run implications of changes in water costs and institutional arrangements.

In humid and subhumid regions on the other hand, the results indicate that irrigation is a break-even proposition depending upon crop grown, soil type, location, weather and irrigation system. These regions are generally also blessed with plentiful water supplies. In these areas it appears that the primary risk aspects of irrigation are the reduction in variability of net returns and the potential impact of irrigation investments on firm financial risks.

The primary short run risk management effect of irrigation obviously is mitigation of the impacts of rainfall variability on crop yields. Two aspects of irrigation are of particular importance, the amounts of irrigation and the timing of irrigations. Recent studies have begun to focus on the timing issue using a variety of optimal control and stochastic simulation techniques (Zaveleta et al.; Harris and Mapp (1980)). A related effect of irrigation is the plant's increased tolerance of other stresses. For example, Swaney, Jones et al. found that irrigation can compensate for the effect of delayed planting in soybeans. Preliminary research also suggests that optimal pest thresholds for insects, weeds, and nematodes may be significantly higher in irrigated soybeans than in dryland (Wilkerson, Mishoe et al.). In the case of VBC, they found that the optimal insect threshold in irrigated soybeans may be twice that of dryland soybeans. This appears to be fruitful ground for further research.

Tradeoffs Among the Components of Net Return Variance

Although the primary risk aspect of irrigation is the reduction in yield risk, net returns are a function of a number of random variables. One of the more important problems encountered in estimating the variance of net returns is the selection of the appropriate set of variables. In most short-run agricultural situations, input costs are nonstochastic (Dillon) and are not included in the estimation of variance although their costs remain in the calculation of expected returns. Because irrigation scheduling costs are a function of water requirements and subsequently are not fixed at the beginning of the production period, such costs introduce a stochastic element unlike nonirrigated production.

As an illustration, the expected net returns and variance of net returns for irrigated soybeans in Florida are analyzed. The expectation of profit is calculated from a 17 year series of prices and simulated yields (Boggess et al.). This expectation can be expressed as:

$$(1) \quad \overline{\pi} = (\overline{P})(\overline{Y}_i) + COV(P_j Y_i) - (\overline{R})(\overline{X}_i) - COV(R_j X_i)$$

where π_i is the net return over variable costs for irrigation strategy i, P is the price of soybeans, Y_i is the yield of soybeans under irrigation strategy i, R is the price of irrigation water applied and X_i is the amount of irrigation water applied under strategy i.

The variance of net returns is computed using the derivations of Goodman; Borhnstedt and Goldberger; and more recently, Anderson, Dillon and Hardaker. The exact variance of net returns is

$$(2) \quad V_{\pi_i} = V(PY_i) + V(RX_i) - 2\,COV(PY_i, RX_i)$$

The variance of the revenue and cost portions of the equations are respectively:

$$(3)\quad V_{PY_i} = (\bar{P})^2 V_{Y_i} + (\bar{Y})^2 V_P + V_P V_{Y_i} + \mathrm{COV}^2(P, Y_i)$$

and

$$(4)\quad V_{RX_i} = (\bar{R})^2 V_{X_i} + (\bar{X}_i)^2 V_R + V_R V_{X_i} + \mathrm{COV}^2(R, X_i)$$

The exact covariance between two products is:

$$\begin{aligned}(5)\quad \mathrm{COV}(PY_i, RX_i) = {} & (\bar{P})(\bar{R})\mathrm{COV}(Y_i, X_i) + (\bar{P})(\bar{X}_i)\mathrm{COV}(Y_i, R) \\ & + (\bar{Y}_i)(\bar{R})\mathrm{COV}(P, X_i) + (\bar{Y}_i)(\bar{X}_i)\mathrm{COV}(P, R) \\ & + \mathrm{COV}(P,R)\mathrm{COV}(Y_i, X_i) + \mathrm{COV}(P, X_i)\mathrm{COV}(Y_i, R)\end{aligned}$$

Expanding equation (2) to include equations (3), (4) and (5) results in an exact expression for the variance of net returns requiring only an assumption of multivariate normality. Incorporating independence assumptions between soybean price and yield, soybean price and amount of irrigation, cost of irrigation and water applied and between yield and the cost of irrigation[1] reduces the variance formula to

$$\begin{aligned}(6)\quad V_{\pi_i} = {} & (\bar{P})^2 V_{Y_i} + (\bar{Y}_i)^2 V_P + V_P V_{Y_i} + \bar{R}^2 V_{X_i} + (\bar{X}_i)^2 V_R + V_{X_i} V_R \\ & -2\,[(\bar{P})(\bar{R})\mathrm{COV}(Y_i, X_i) + (\bar{Y}_i)(\bar{X}_i)\mathrm{COV}(P,R) + C(P,R)C(Y_i, X_i)]\end{aligned}$$

Equations (1) and (6) are used to calculate the expected value and variance for 11 different irrigation strategies. The strategies range from dryland production to "no water stress". Each strategy consists of a soil water threshold at which irrigation is initiated and an amount of irrigation applied when the threshold is reached.

The relative contribution of each component random variable to the variance of net returns is analyzed by normalizing equation (6) (Burt and Finley). The normalization procedure entails dividing (6) by the

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[1] The analysis implicity assumes that an individual farmer follows a fixed irrigation strategy based on soil water threshold. Thus there is no interaction between soybean price and irrigation applied, between water costs and irrigation application or between yield and water costs. For applications using observed data based on profit maximizing behavior, one would expect that $\mathrm{COV}(P,X) > 0$, $\mathrm{COV}(R,X) < 0$, and $\mathrm{COV}(Y,R) < 0$.

sum of the individual variance components main effects (e.g. $(\bar{Y}_i)^2 V_P + (\bar{P})^2 V_{Y_i} + (\bar{R})^2 V_{X_i} + (\bar{X}_i)^2 V_R$). The calculated expected net returns, standard deviation of net returns and proportion of net returns variance by components are reported in Table 1.

Several interesting relationships between the individual variance components emerge from the results. First, the proportion of net returns variance attributable to yield variability dominates dryland production, but rapidly decreases under increased irrigation. This result merely substantiates that the primary risk effect of irrigation is a reduction in yield risk. Second, although water quantities and costs are stochastic, their impact on net returns variance are insignificant except under extremely high levels of irrigation for soybeans in Florida. Finally, the results indicate that price risk is the major component of net returns risk for irrigated soybeans in Florida. However, irrigation by reducing yield variability, may take much of the risk out of the use of forward contracts or the futures market for managing price risk.

Similar results were reported by Boggess et al. However, in that study an approximation of the variance of net returns suggested by Burt and Finley was used rather than the exact derivations of equation (6). The results are quite similar although it appears (as you might expect) that the approximation underestimated the true variance. The revised variance calculations are significantly larger than the earlier approximation for dryland production and low frequency irrigation strategies.

Plotting expected net returns against the standard deviation of net returns results in a "loop" in E-V space (Figure 1). The explanation for this loop is imbedded in the relationships between the individual component random variables and the covariance. The sum of the covariance terms is negative for low levels of irrigation and increases steadily as the level or irrigation increases. The negative covariance arises from a negative correlation between yield and water applied. For low-frequency strategies, drought damage to the crop has occurred before the threshold is reached, but the water applied is relatively effective. Since the low thresholds are reached more often in dry years than in wet years, there is a tendency for low yields to be accompanied by relatively large applications of irrigation water and vice versa. As the threshold is increased, less stress occurs before irrigation is initiated.

The joint effect of the decrease in yield variability, the offsetting increase in price variability and the increase in the covariance is that net returns variance declines, reaches a minimum under intermediate levels of irrigation and then steadily increases as irrigation frequency increases. It appears that these results are related to the concept of "available" water (Lynne et al.). The plant responds to available water and production functions, cost functions and irrigation strategies should be formulated in terms of managing the reservoir of "available" water rather than water applied. In contrast to arid production, the humid or subhumid producer faces the prospect of irrigating today and receiving sufficient rainfall the next day (Burt and Stauber). In that event much

Table 1. Expected Net Returns, Yield Response, Water Applied, Standard Deviation of Net Returns, and Proportion of Net Returns Variance by Components for Alternative Soybean Irrigation Strategies in Florida.

Strategy[a]	Expected Net Returns	Yield Response[b]	Water Applied[c]	Std. Dev. Net Returns	Proportion of Net Returns Variance				Covariance[d]
					Price	Yield	Cost	Water	
	$/Ha.	Kg/Ha.	cm/Ha.	$/Ha.					
0,0	344	0	0	241.0	0.29	0.71	0.0	0.0	0.0
30,6	428	466	7	195.2	0.63	0.36	0.0	0.01	-1,432.1
50,2	496	782	9	195.5	0.83	0.15	0.0	0.01	-3,313.4
50,3	510	876	11	182.5	0.87	0.12	0.0	0.01	- 674.9
50,4	513	945	13	183.2	0.89	0.08	0.0	0.02	- 687.5
60,2	531	1,038	14	182.0	0.93	0.05	0.0	0.02	- 374.2
60,3	540	1,128	17	184.1	0.94	0.04	0.01	0.02	- 159.0
70,1	553	1,287	21	187.0	0.96	0.02	0.01	0.01	234.1
70,2	544	1,289	23	186.0	0.96	0.02	0.01	0.01	317.1
80,1	489	1,394	37	189.6	0.95	0.02	0.03	0.01	896.9
90,1	295	1,410	72	193.9	0.88	0.02	0.09	0.02	1,646.5

[a] Percent soil water remaining when irrigation is initiated and centimeters of water applied per application.

[b] Average yield response in kilograms per hectare.

[c] Average total seasonal irrigation in centimeters per hectare.

[d] Sum of the three covariance terms in equation (6).

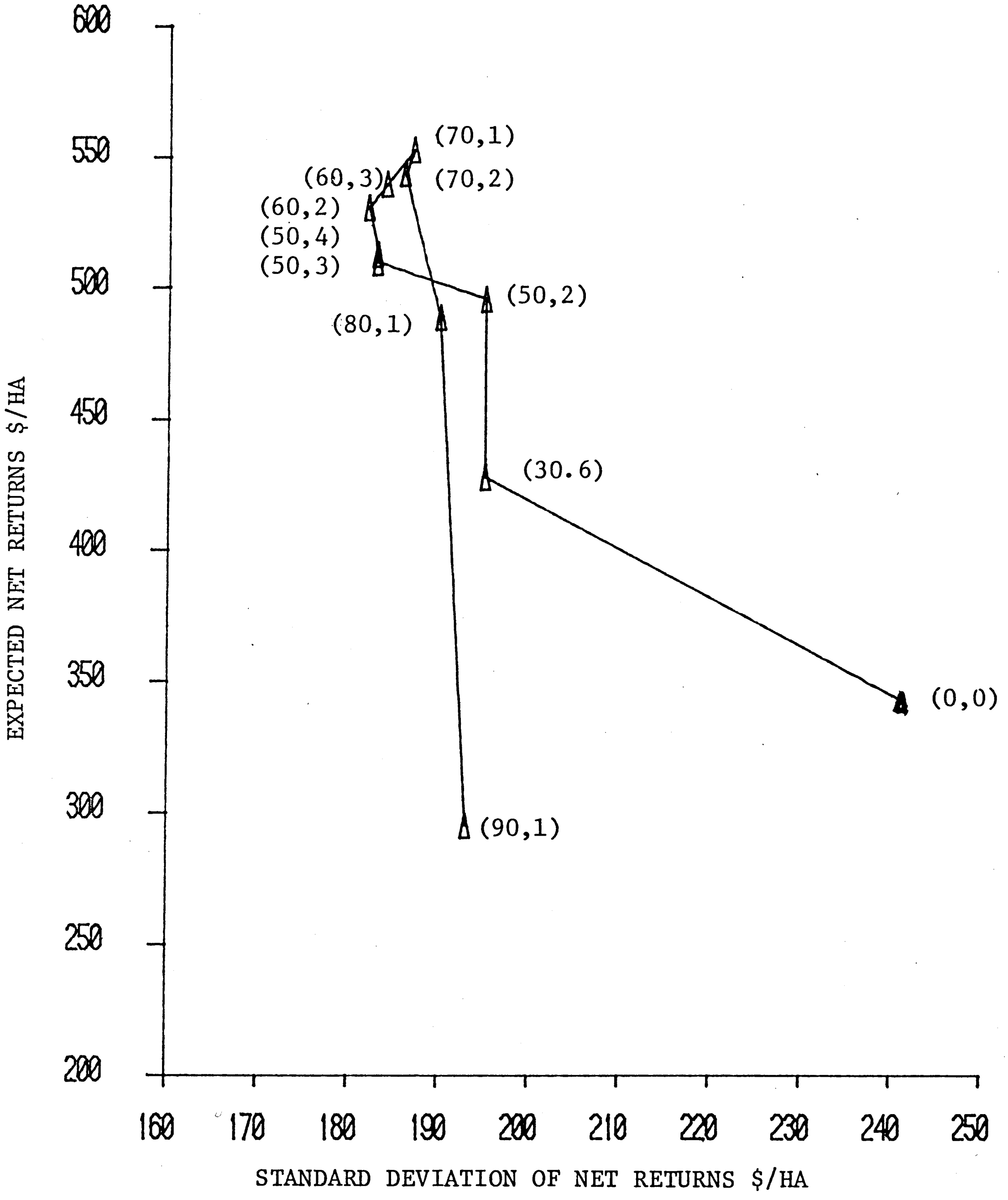

Figure 1. Plot of Expected Net Returns Versus Standard Deviation of Net Returns for Irrigated Soybeans in Florida.

of the irrigation water is rendered ineffective. "Deficit" irrigation strategies (e.g. strategies that do not refill the soil profile and thereby leave storage capacity for following rainfall) have been identified as one means of increasing the effectiveness of irrigation water (Boggess et al.; Tew et al.).

Several additional risk factors deserve mentioning. First, institutional risks in the form of changing water district rules relating to water supplies, pumping permits, or timing of water availability pose even larger implications for irrigators as population pressures mount and water tables fall. Irrigators in the arid West have been fighting this battle for years and the war promises to intensify. In the humid East, water supplies appear for the most part to be more than adequate. One notable exception is South Florida where increasing population growth and economic development have taxed the water supplies to the extent that pipelines to carry water from North to South Florida have been suggested.

Second, "management" risk will become increasingly important. The Agriculture 2000 report provides some insight into this increasing source of risk: "Farmers will benefit from a rapidly growing array of electronic technologies which will provide more information, on a more timely basis, with more analytical capabilities. How well farmers manage this information will be an important factor in business success." In the case of irrigation, sophisticated developments in irrigation equipment, crop stress sensors, and irrigation scheduling algorithms will require increased skills to effectively manage. This suggests that research on decision algorithms that reduce data requirements and management time will be in demand. Research is already underway in the areas of automated weather data systems (Chang et al.), sophisticated irrigation scheduling algorithms (Swaney, Jones et al.), and minimum weather data needs (Swaney, Mishoe et al.). One interesting result of the latter area of research is that using weather service daily forecast probabilities of precipitation didn't improve scheduling performance compared to historical based probabilities. It appears that this result is unique to areas with tropical weather patterns and differs when weather systems are characterized by frontal storms. However it provides some measure of vindication for your farmer friends who are constantly damning the weather service.

Irrigation Investment Risks

The decision to invest in an irrigation system potentially exposes the firm to additional financial risk. The degree of additional exposure obviously depends on the leverage ratio of the firm and the interest rate of outstanding debt. The key issue is whether or not (or the probability that) an irrigation system will pay for itself (e.g. is the NPV positive). The answer to this question obviously depends on the expected returns to irrigation but also on the variability of net returns, particularly in humid areas.

In a recent study we computed the NPV of investments in alternative irrigation systems for use on corn, soybeans, and peanuts (Boggess and Amerling). The stochastic effect of various sequences of weather years over the life of the investment was evaluated using crop simulation models and Monte Carlo techniques.

Expected net present values were a mixed bag, ranging from $69,329 to $-30,955 (Table 2). But perhaps even more important from a risk perspective are the magnitudes of the standard deviations. The cumulative probability functions for net present values of investing in a low pressure center pivot system for corn, soybeans, and peanuts on both sands and sandy loams are presented in Figure 2. These figures suggest that there are a few "sure bets" such as irrigating corn or peanuts on sands. Likewise irrigation investments for soybeans and peanuts on sandy loams might be considered "sure losers". But more important is that systems to irrigate corn on sandy loams or soybeans on sands have negative NPV's 40 percent of the time, even though their expected NPV's are over $8,000. In these cases the investment decision could significantly increase the firm's financial risk.

The importance of this source of risk ultimately depends on the degree of variability in rainfall across years. Regions with relatively stable climates (either arid or humid) will have much clearer decisions: Invest or don't invest. Likewise other factors that mitigate the effects of rainfall variability (e.g. soil types or drought tolerant crops) will also reduce the potential financial risk. On the other hand, changes in prices, interest rates, credit reserves, and tax provisions over time increase the potential financial risk.

Conclusions

The evidence clearly suggests that the primary risk effect of irrigation in humid regions is a reduction in downside yield variability. This effect is achieved by offsetting rainfall variability and increasing the plant's tolerance to other biological stresses. Yield risk is the major component of net returns risk for dryland production, whereas price risk is the major component for irrigated production. However, the reduction in yield risk under irrigation facilitates the use of price risk management tools such as forward contracts and hedging. Irrigation water amounts and price are insignificant factors in the variance of net returns except under extremely high levels of irrigation.

Irrigation also has the potential to increase firm risks. In many areas, investments in irrigation could expose firms to increased financial risks that partially offset the reduced production risks. Finally, irrigation may introduce additional institutional and management risks into the firm's decision making environment.

Table 2.--Expected Net Present Values and Standard Deviations (in parentheses) of Investing in Four Alternative Irrigation Systems for Irrigating Corn, Soybeans and Peanuts on Sands in North Florida.

	Systems[a]			
Crops	LPCP	MPCP	CTTG	HTTG
Corn	$25,663 (14,323)	$ -5,111 (13,881)	$-18,964 (9,263)	$-29,275 (9,196)
Soybeans	$ 8,143 (10,573)	$-15,296 (10,110)	$-23,738 (6,657)	$-30,955 (6,618)
Peanut	$69,329 (26,334)	$ 40,969 (25,138)	$ 13,721 (16,530)	$ 3,876 (16,310)

[a] Low pressure center-pivot (LPCP), medium pressure center-pivot (MPCP), cable tow traveling gun (CTTG), and hose-tow traveling gun (HTTG).

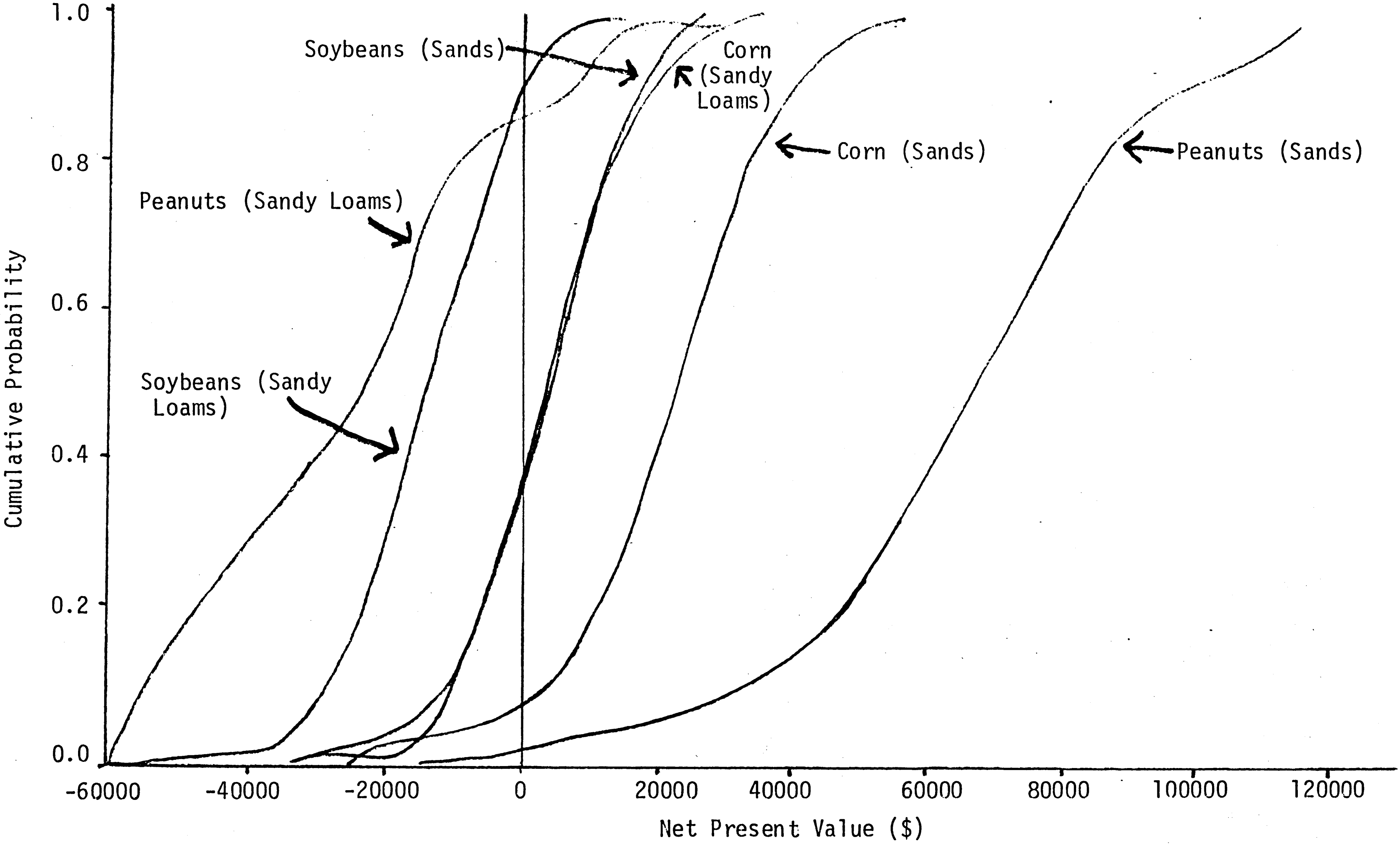

Figure 2. Cumulative Probability Functions for Net Present Values of Investing in a Low Pressure Center - Pivot System for Corn, Soybeans and Peanuts on Sands and Sandy Loam Soils.

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