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ECONOMIC VIABILITY AND SELECTION OF IRRIGATION SYSTEMS USING SIMULATION AND STOCHASTIC DOMINANCE

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1 SUMMARY

In humid areas, irrigation systems are used to increase the crop yield. The selection of irrigation system to be used is a decision made under uncertainty. This paper shows a procedure that is an association between Monte Carlo simulation method and the criterion of Stochastic Dominance to analyze the viability and identify the best economic option under risk condition. To illustrate the applicability of the procedure, three types of irrigation systems are evaluated to be used in a citrus orchard in Sao Paulo State, Brazil. The irrigation systems evaluated are: drip, microirrigation, and traveling sprinkler. The decision indicator is the present value of net benefit associated with the increase of yield obtained with the irrigation system adopted. The Monte Carlo simulation method is used to generate the cumulative distribution of the present value for each one of the irrigation systems. These curves allow to analyze the economic viability of the three irrigation systems. According to the First Degree Stochastic Dominance, traveling sprinkler system was the best alternative with 95.7% probability of obtaining a positive present value. The second best option was the microirrigation with 82.7% and the worst result (57.3%) was obtained with drip irrigation.

KEYWORDS: Economic viability, simulation, irrigation systems, stochastic dominance, citrus.

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2 RESUMO

Em regiões úmidas, sistemas de irrigação são utilizados para aumentar a produtividade das culturas. A escolha do sistema de irrigação a ser utilizado é uma decisão feita sob incertezas. Este trabalho apresenta um procedimento que associa o método de simulação de Monte Carlos e o critério de Dominância Estocástica para analisar a viabilidade e identificar a melhor opção econômica sob condição de risco. Para exemplificar a aplicabilidade do procedimento, três sistemas de irrigação são avaliados para uso em pomar de citros no Estado de São Paulo, Brasil. Os sistemas de irrigação avaliados são: gotejamento, microaspersão e autopropelido. O indicador de decisão é o valor presente do lucro associado com o aumento de produtividade obtido com a adoção da irrigação. O método de simulação de Monte Carlos é utilizado para gerar a distribuição acumulada do valor presente para cada sistema de irrigação avaliado. Estas curvas permitem analisar a viabilidade econômica dos três sistemas de irrigação. De acordo com o

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primeiro grau de dominância estocástica, o sistema autopropelido foi a melhor alternativa com 95,7% de probabilidade de obtenção de valor presente positivo. A segunda melhor opção foi a microaspersão com 82,7% e a terceira escolha foi o gotejamento com 57,3%.

UNITERMOS: viabilidade, simulação, sistemas de irrigação, dominância estocástica, citros.

3 INTRODUCTION

In humid areas, irrigation systems are used to increase the crop yield. The decision to irrigate and the selection of the irrigation system are made under uncertainty. The citrus for juice industry in Sao Paulo State, Brazil, is an example (Favetta, 1998). Irrigation is applied to increase and to assure yield but it is very difficult to analyze the net benefit because of the fluctuations in the citrus price, equipment cost and in the yield increase generated by different irrigation systems.

The initial investment, operation and maintenance costs, and irrigation efficiency are key choice parameters in the selection of irrigation methods (Hamilton & Schrunk, 1953). For, Keller (1965), the selection must be done by system costs and by the effect of the method on water-conservation management. Holzapfel et al (1985) showed a procedure to select an optimum irrigation method for specified field conditions that consisted of an analytical - technical step and a technical-economic step. None of these papers considers the cost variations and the their effects on the net benefit obtained with the irrigated crop.

Three irrigation systems have been used in the citrus orchard, in Sao Paulo State, Brazil. They are: traveling sprinkler, microsprinkler and drip irrigation. Technically, all of them can be used. The questions are: Are the irrigation systems economically feasible?. Which option is economically optimal ?. To answer these questions this paper proposes a procedure that is an association between Monte Carlo simulation method and the criterion of Stochastic Dominance.

The Monte Carlo method makes possible the simulation of any process influenced by random factors (Sobol, 1974).

There are many criteria that can be used for decision making under risk, with special attention in the mean-variance criterion and in the stochastic dominance criterion.

The mean-variance criterion has been commonly used in portfolio selection and it is applicable when the decision maker maximizes expected utility and either the decision maker's utility function is quadratic or the probability distribution of returns is normal (Feldstein, 1969 ; Hakansson, 1972).

There are many criticisms in the application of this criterion. The quadratic form of utility function is not consistent with observed behavior and implies increasing absolute risk aversion. Stochastic dominance is most commonly applied in finance and the economics of uncertainty (Levy, 2006) and it is advantageous because it accommodates skewness and other data irregularities and permit more general assumptions about the utility function of the decision maker (McNamara, 1998).

Wilde et. al (2009) applied stochastic dominance to study subsurface drip irrigation (SDI) systems under different scenarios included three water distribution uniformities represented by flow variations of 5%, 15%, and 27%, with each irrigated at two levels, a base irrigation amount and 60% of the base irrigation amount. The producer's risk aversion level affected their choice of design uniformities. A more risk averse producer preferred a more uniform design and was willing to pay a higher installation cost for a more uniform system. A less risk averse producer preferred a less uniform system design with a lower initial cost.

The objective of this paper is to analyse the viability of three irrigation systems and to select the best economic option to be used in a citrus orchard, in Sao Paulo State, Brazil, applying a methodology based in the Monte Carlo simulation method and in the stochastic dominance criterion.

4 MATERIAL AND METHODS

1.1. Methodology

The First Degree Stochastic Dominance will be the criterion to be used in the selection of alternatives. It is based in the comparison between the cumulative probability distribution among options with varying risk.

The indicator selected to compare the irrigation systems performance is the present value (PV), given by:

$$PV = \sum_{t=0}^{N} \frac{B_t}{(1+\rho)^t} \qquad (1)$$

where PV is the Present Value (US$/ha) for a selected discount rate (ρ), N is the irrigation system life cycle and B_t is the net benefit (US$) in the year t, estimated by:

$$B_t = Y_p P_t - (IC_r + PC_s) \qquad (2)$$

where B_t is the increase of yield in the year t, Y_p is the citrus price at probability level p, IC_r is the irrigation cost at probability level r and PC_s is the production cost at probability level s. The irrigation cost includes the initial investment, the pumping annual cost and the costs with maintenance and repairs.

1.1.1. First degree Stochastic dominance criterion

Let F(X) and G(X) be the cumulative distributions of two distinct uncertain options. Then, G(X) dominates F(X) by First Degree Stochastic Dominance (FSD), if G(X) is preferred to F(X) by all decisions makers with increasing utility functions $u' \geq 0$. Necessary and sufficient conditions for G(X) to dominate F(X) by FSD are (Levy, 1992 ; McNamara, 1998):

$$F(X) \geq G(X) \quad \text{for all X} \qquad (3)$$

with the strict inequality holding for some X.

In words, G(X) dominates F(X) by FSD if the cumulative probability distribution G(X) lies below F(X). The FSD rule implies that if F(X) ≥ G(X), for every possible state of nature, G returns more than F, and the expected utility for the cumulative distribution of returns F(X) is less than or equal to that of G(X) (McNamara, 1998).

1.1.2. Monte Carlo Simulation Method

The present value cumulative distribution of each irrigation system is obtained using the Monte Carlo simulation method (Sobol, 1974). For this method, the basic steps are: (1) to identify the probability distribution of the variables that show greatest fluctuation (uncertainty); (2) to generate a random probability level for each relevant variable and identify these variables values from theirs probability distributions; (3) to estimate the present value each time that the set of relevant variables is identified ; (4) to stop the process when the frequency distribution of the present value is clearly defined. In this paper, this was obtained with 200 estimations of present value.

1.2. Data

1.2.1. Citrus

To illustrate the aplicability of the procedure, three irrigation systems will be evaluated to be used in a 40 ha citrus orchard, at Sao Paulo State, Brazil. They are: traveling sprinkler, microsprinkler and drip irrigation.

The citrus yield depends on the tree age and the irrigation system adopted (Table 1).

Table 1. Citrus yield (kg/tree) in function of the tree age and irrigation system adopted.

Age of tree	Without irrigation (kg/tree)	Traveling sprinkler (kg/tree)	Microsprinkler (kg/tree)	Drip (kg/tree)
6	81.6	114.2	106.1	102.0
7	122.5	187.7	167.3	163.2
8	122.5	208.1	183.6	175.4
9	122.5	212.2	183.6	179.5
10	122.5	265.2	224.4	212.2
11	122.5	285.6	236.6	224.4
12	122.5	310.1	253.0	240.7
13	122.5	359.0	289.7	273.4
14	122.5	379.4	301.9	285.6
15	122.5	412.1	326.4	306.0

The irrigation system will be feasible if the profit obtained with yield increase is enough to pay the irrigation system costs (investment, operation and maintanance). Thus, the irrigation viability will be analysed as a function of the yield increase due to irrigation system selected (Table 2).

In Table 2, the crop yield is associated with the life-cycle of each irrigation system: 7 years for traveling sprinkler and 10 years for drip/microsprinkler.

Table 2. Increase of yield (kg/tree) due to irrigation system.

Age of tree	Traveling sprinkler (kg/tree)	Microsprinkler (kg/tree)	Drip (kg/tree)
6	322.6	24.5	20.4
7	65.3	44.9	40.8
8	85.7	61.2	53.0
9	89.8	61.2	57.1
10	142.8	102	89.8
11	163.2	114.2	102.0
12	187.7	130.6	118.3
13	-	167.3	151.0
14	-	175.4	163.2
15	-	204.0	183.6
Average	110.2	110.2	97.9

The citrus price fluctuate greatly. Table 3 shows the citrus prices from 1980 to 1988.

Table 3. Citrus price (US$/kg) from 1980 to 1999.

Year	Citrus price (US$/Kg)
1980/81	0.076
1981/82	0.093
1982/83	0.076
1983/84	0.059
1984/85	0.10
1985/86	0.127
1986/87	0.042
1987/88	0.085
1988/89	0.127
1989/90	0.110
1990/91	0.034
1991/92	0.068
1992/93	0.034
1993/94	0.034
1994/95	0.051
1995/96	0.034
1996/97	0.034
1997/98	0.051
1998/99	0.076

Using data from Table 3, an equation was obtained to be used in the simulation procedure.

For $0.0275 < t \leq 1$: $$P_t = 0.1210\ t - 0.000641 \quad (4)$$

with r^2=0.984

and

For $t \leq 0.275$ $P_t = 0.034$ (5)

where t is the random probability level and P_t is the citrus price in US$/kg, at probability level t.

1.2.2. Irrigation systems costs

To obtain an equation to represent the cumulative distribution of the irrigation system initial cost, a triangular distribution was applied to the data obtained from the manufacturers. This distribution is based in the lowest, highest and most frequently observed price (Table 4).

Table 4. Lowest, highest and most frequently observed irrigation system prices (US$/ha) for a 40ha citrus orchard.

Irrigation system	Lowest price (US$/ha)	Highest price (US$/ha)	Most frequently price (US$/ha)
Traveling sprinkler	880	1790	1190
Microsprinkler	1625	2310	1920
Drip	1865	2670	2310

Table 5 shows the other costs associated with each irrigation system (Favetta, 1998). For these costs, there is no difference between drip and trickle irrigation.

Table 5. Costs associated with the management and operation of the irrigation systems.

	Traveling sprinkler	**Trickle irrigation**
a) Irrigation management		
Manpower/ha/year	9.56	3.88
Tractor hour/ha/year	2.11	0
Management cost(US$/ha/yr)	**42.5**	**6.9**
b) Pumping cost		
Power/ha (CV/ha)	2.83	1.07
Hours of irrigation/yr	650	870
Pumping cost (US$/ha/hour)	0.100	0.0415
Pumping cost(US$/ha/yr)	**65.0**	**36.1**
c) Total Operation Cost(US$/ha/yr)	**107.5**	**43.0**

The maintenance and repairs costs can be expressed as an annual percentage of the initial equipment cost. For the travelling sprinkler this value is 6%/yr and for microsprinkler and drip irrigation the value is 3% (Keller and Bliesner, 1990).

The Linear Method was used to calculate the equipment depreciation, considering zero the residual value. In the calculation of the Present Value it was assumed an annual discount rate of 12%.

5 RESULTS

Table 6 shows the simulation results for each alternative. The 200 values were subdivided in 40 classes. The average present value of each class and the associated probability level were used to generate the present value cumulative distribution, for each irrigation system (Figure 1).

Table 6. Frequency distribution of the Present Value (US$/ha) for each irrigation system.

Traveling sprinkler		Microsprinkler		Drip	
Probability (%)	PV (US$/ha)	Probability (%)	PV (US$/ha)	Probability (%)	PV (US$/ha)
0.5	-802.164	0.5	-1166.43	0.5	-2471.34
1	-597.017	1.5	-1023.37	0.5	-2334.98
1	-391.87	2.5	-880.318	1	-2198.61
2.5	-186.723	3.5	-737.262	2	-2062.25
4.5	18.42436	6	-594.206	2.5	-1925.88
6	223.5714	7.5	-451.15	3	-1789.52
9	428.7184	9.5	-308.094	4	-1653.15
10	633.8655	14	-165.038	5.5	-1516.79
11.5	839.0125	16.5	-21.9822	8.5	-1380.42
15.5	1044.16	21.5	121.0737	9.5	-1244.06
18.5	1249.307	26	264.1297	11.5	-1107.69
24	1454.454	28	407.1856	15.5	-971.327
26.5	1659.601	33	550.2415	18.5	-834.962
30.5	1864.748	38	693.2975	21.5	-698.597
35.5	2069.895	43.5	836.3534	26.5	-562.232
41	2275.042	47	979.4093	30	-425.867
44.5	2480.189	52.5	1122.465	32.5	-289.502
48.5	2685.336	58.5	1265.521	38	-153.137
52.5	2890.483	61	1408.577	42	-16.7721
57.5	3095.63	68	1551.633	47.5	119.5929
63.5	3300.777	72.5	1694.689	52	255.9579
67	3505.924	75	1837.745	58	392.323
71	3711.071	80.5	1980.801	64	528.688
75	3916.218	85.5	2123.857	71.5	665.0531
77.5	4121.365	89.5	2266.913	77.5	801.4181
82.5	4326.512	93.5	2409.969	81	937.7832
86.5	4531.659	95	2553.025	87	1074.148
88	4736.806	98	2696.081	90.5	1210.513
91.5	4941.953	98	2839.136	92	1346.878
93.5	5147.1	98	2982.192	95.5	1483.243
95	5352.247	99	3125.248	97	1619.608
96	5557.394	99.5	3268.304	97.5	1755.973
97	5762.541	99.5	3411.36	99	1892.338
97.5	5967.688	99.5	3554.416	99	2028.703
98	6172.835	99.5	3697.472	99.5	2165.069
98.5	6377.982	99.5	3840.528	99.5	2301.434
99	6583.129	99.5	3983.584	99.5	2437.799
99	6788.276	99.5	4126.64	99.5	2574.164
99	6993.424	99.5	4269.696	99.5	2710.529
100	7198.571	100	4412.752	100	2846.894

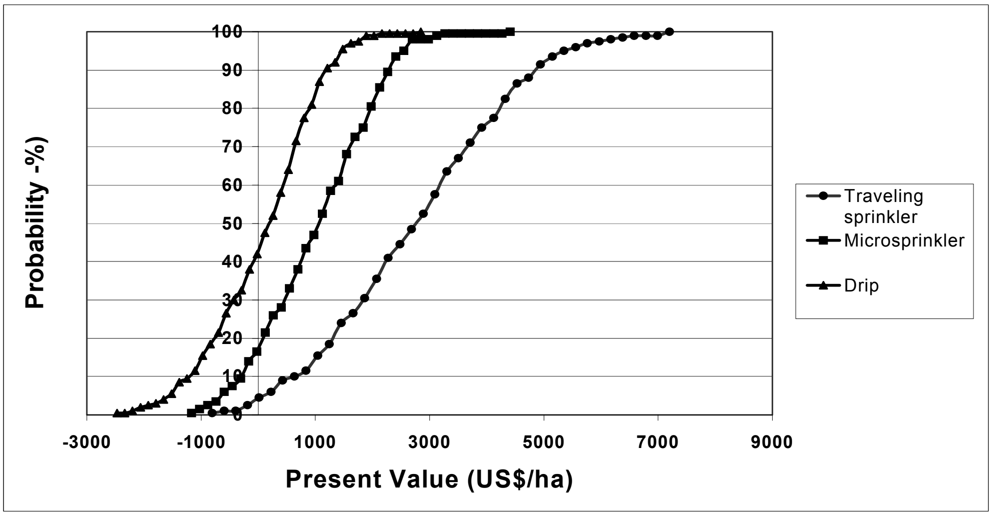

Figure 1. Present value cumulative distribution for the irrigation systems evaluated.

For the First Degree Stochastic Dominance, if F(X) and G(X) are the cumulative distributions of two distinct uncertainty options, then, G(X) dominates F(X) if the cumulative probability distribution G(X) lies below F(X). Therefore, the traveling system dominates microsprinkler and drip irrigation, and microirrigation dominates drip irrigation.

For the FSD, the traveling sprinkler system is the best alternative, followed by microsprinkler. The drip irrigation is the worst option.

Traveling sprinkler, microsprinkler and drip irrigation have, respectively, 95.7% , 82.7% and 57.3% probability of obtaining a positive present value.

6 CONCLUSIONS

For citrus in Sao Paulo State, Brazil, there is 95.7 % probability of obtaining a positive present value with traveling sprinkler. Microsprinkler and drip irrigation have 82.7% and 57.3%, respectively. According to the First Degree Stochastic Dominance, traveling sprinkler is the best option, followed by microsprinkler and, finally, by drip irrigation.

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