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COST ANALYSIS OF WATER PUMPING USING SOLAR ENERGY AND DIESEL IN DRIP IRRIGATION

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1 ABSTRACT

There are several sources of power for driving motors, but electric motors and diesel engines are most commonly used in irrigation in Brazil. However, the use of diesel engines typically occurs in areas without electricity nearby, making it generally viable. Another option is to use sunlight as an alternate energy source, but this system is not widely used due to its high initial cost, and its use is mainly limited to places where there is no electricity. In view of this, the economic analysis of water pumping systems in agriculture is critical, because the capital employed is often high and the annual costs may or may not enable the agricultural activities that use them. Therefore, the objective of this study was to compare water pumping costs using an electric motor powered by solar energy and a diesel motor in a drip irrigation system with microtubes. It was considered an area of 1 ha, planted with vegetable crops whose water demand is 5.6 mm, under drip irrigation. This area was divided into eight parts, each of them being irrigated for 1 hour. The lift system for pumping water that used solar energy had lower total cost and higher initial investment cost. The lift system with solar energy is more economically viable when compared with the system running on diesel. The pumping cost was the deciding factor in the analysis of the costs of water pumping systems.

Keywords: Microirrigation, microtube, economic analysis

2 INTRODUCTION

The use of energy for the supply of irrigation systems is of great importance for crop production crop. Even though there are several sources of energy to turn on motors, electric and diesel motors are the most commonly used in irrigation in Brazil and, therefore, are more emphasized in papers dealing with costs of pumping systems.

According to PERES (2011), the only advantage of the diesel motor compared to electric motor is that it does not require an expensive line of power transmission for its operation. According to MONTEIRO et al. (2007), the electric energy appears as the most economically viable option to turn on pumps for irrigation, being used by approximately 70% of irrigators in the country. Frizzone et al. (1994) compared the costs of the irrigation in the

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bean crop using center pivot and found that for different combinations of planting time pumping system with diesel showed an annual cost of approximately 70% greater than the system powered with electricity.

Thus, the use of diesel motors typically occurs in areas without electricity nearby, making it generally feasible. Another option is to use sunlight as an alternate energy source. However, despite being one of the most important technologies for sustainable development, this system is not widely used due to its high cost and limited use, mainly to places where there is no electrical network. Generally, they are small farmers who inhabit these locations and basically live from family farming, which plays an important role in the Brazilian economy and society (IBGE, 2006).

In view of this, the economic analysis of water pumping systems in agriculture is fundamental, because the invested capital is often high and the annual costs may or may not make viable the agricultural activities that use them (FRIZZONE et al., 2005).

Several parameters affect the cost of a lift system; however, pipeline diameter is the most controversial one, since the others are defined according to flow rate, length of pipeline, geometric height and pressure at the end of the adductor. This variables are related according to the site's physical conditions and the requirements of the equipment used at the end of the water main (FRIZZONE et al., 2005). According to MONTEIRO et al. (2007), the cost in energy used for irrigation depends on the type of the motor drive, on the installed power and on the efficiency of the motor-pump set. However, the focus will be given to the type of motor used for pumping water for irrigation, because it also causes intense variation in the cost of an lift system. Therefore, the aim of this study is to evaluate the best option for pumping water in drip irrigation systems for a place lacking electric power.

3 MATERIAL AND METHODS

It was considered an area of 100 x 100 m, planted with vegetable crops whose water demand is 5.6 mm, under drip irrigation. This area was divided into eight parts, each of them irrigated for 1 hour. A schematic representation of the lift system is shown in Figure 1 and Figure 2.

For pumping water to occur, it is necessary a supply system, workforce and infrastructure. The water captured from a source passes through the water main which will then deliver the flow rate needed for the development of crops.

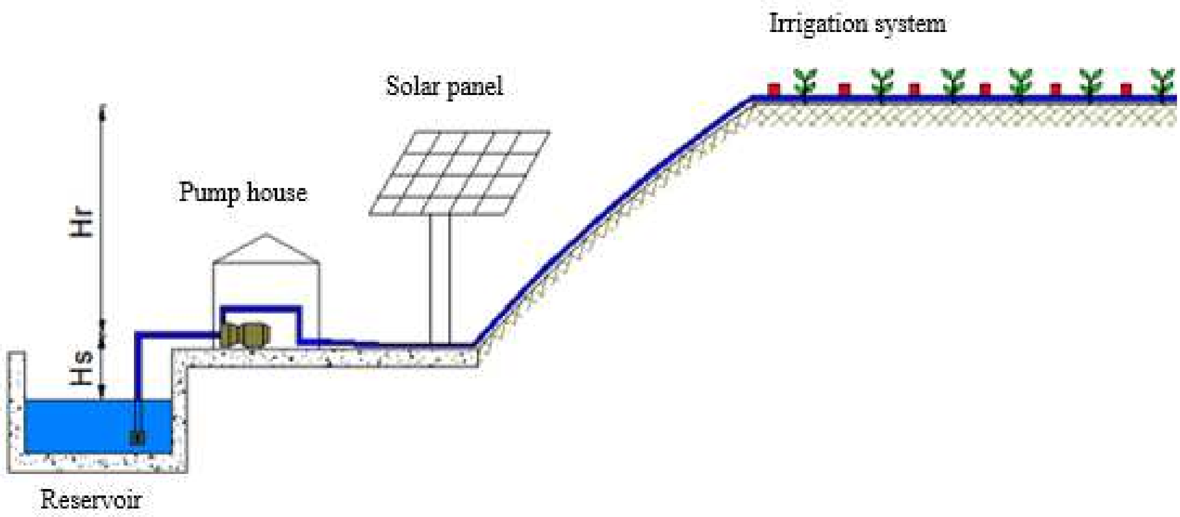

Figure 1. Schematic representation of the lift system using the electric motor powered by solar energy

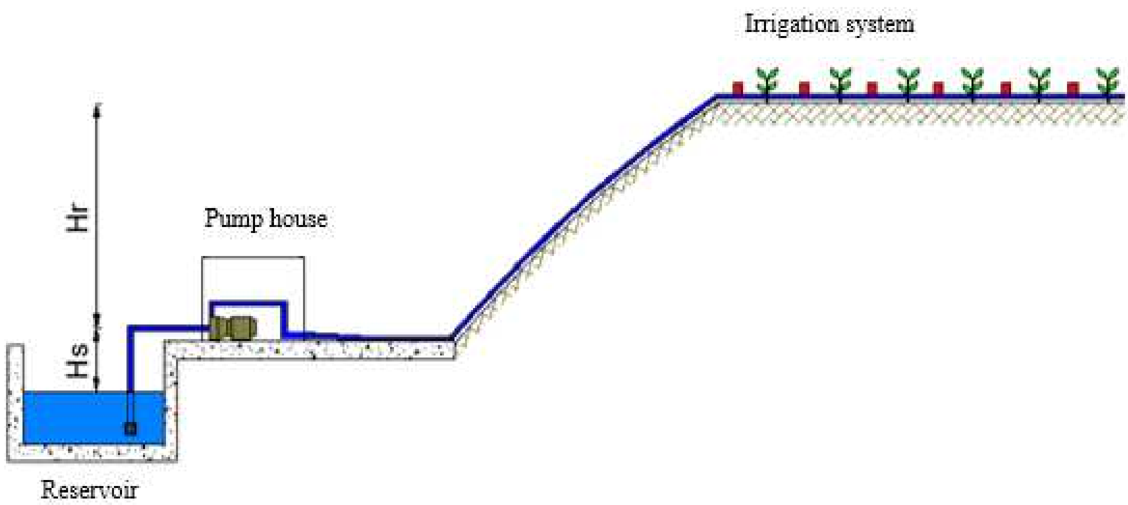

Figure 2. Schematic representation of the lift system using diesel motor

Hs – suction height
Hr – head height

The energy used in the electric motor will come from the battery, which in turn will be recharged by the solar panel (Figure 1). Solar energy will be captured by means of photovoltaic panels and converted into electricity, which will power the electric motor and will turn on the water pump that will pump the water to the irrigation system and then irrigate crops. The other motor is powered by diesel and will turn on the water pump in this same way (Figure 2).

Dimensioning the lift system

The economic internal diameter of the discharge piping was calculated by the ABNT (Equation 1).

$$D = 0.586T^{0.25}\sqrt{Q} \quad (1)$$

where:
D: economic diameter of the head pipeline, m;
T: daily operation time, h day^{-1}; and
Q: pumping flow rate, m^3 s^{-1}.

General characteristics of the project:
Q: flow rate the of the pumping: 7.71 m^3 h^{-1};
T: daily functioning time: 8 h;
Hs: suction height: 2.0 m;
Hr: head height: 8.0 m;
PF: manometric load required at the end of the water main: 10 m;
Ls: suction line length: 10.0 m with PVC material (C = 150) and diameter fixed in 60 mm;
Lr: head line length: 100 m with PVC material (C = 150) and diameter fixed in 50 mm;
Operating days during the year (AD): 275 days; and
Location: Garanhuns-PE.

For the determination of head loss in the pipelines the Hazen-Williams formula was used (Equation 2).

$$h_f = 6.807 \frac{LV^{1.852}}{C^{1.852}D^{1.167}} \quad (2)$$

where:
hf: head loss, mca;
L: suction line length or head line length, m;
D: pipeline diameter, m;
V: average velocity of water, m s^{-1}; and
C: rugosity coefficient (PVC = 150).

The local head losses were calculated through the equivalent length method (AZEVEDO NETTO et al., 1998). The manometric height was determined by Equation 3.

$$H_{man} = PF + Hs + Hr + h_{fs} + h_{fr} \quad (3)$$

where:
H_{man}: manometric height, mca;
hfs: head loss in the suction, mca; and
hfr: head loss in head, mca.

The power required by the hydraulic pump was determined by Equation 4.

$$P_B = \frac{\gamma Q H_{man}}{\eta} \quad (4)$$

where:
PB: power required by the hydraulic pump, W;

γ: specific weight of water, N m^{-3};
Q: flow rate, m^3 s^{-1};
H_{man}: manometric height, J N^{-1}; and
η: efficiency of the hydraulic pump, decimal.

In choosing the electric and the diesel motors, it was admitted safety margins of the motor power equal to 30% and 25%, respectively.

The data concerning flow rate, manometric height, hydraulic pump power and motors power can be seen in Table 1.

Table 1. Calculated values of flow rate, manometric height, hydraulic pump power, electric motor power and diesel motor power

Q (m^3 h^{-1})	**H_{man} (mca)**	**P_B (kW)**	**P_{ME} (kW)**	**P_{MD} (kW)**
7.71	22.9	0.80	1.03	0.99

PB: power required by the hydraulic pump; PME: electric motor power; PMD: diesel motor power

The technical specifications for the selected motor pumps can be viewed in Table 2. It is noteworthy that a diesel motor pump with power of 3.68 kW was selected because it was the best adapted to the characteristic curve of the system.

Table 2. Technical specifications for the selected motor pumps

Technical data	**Buffalo Motor pumps**	**Schneider Motor pumps**
Code	BFD:70512	BC-92S/T GB
Motor	3.68 kW diesel	1.10 kW electric
Tank Capacity	2.5 L	-
Average consumption	1.4 L $hour^{-1}$	-
Number of rotors	1	1
Rotor diameter	120 mm	130 mm
Maximum manometric height	26 mca	30 mca
Maximum flow rate	35 m^3 h^{-1}	15.5 m^3 h^{-1}
Suction and head	2” x 2”	1 ¼” x 1”

Dimensioning of the Photovoltaic System

We conducted a survey of electricity consumption (Table 3). The current was determined by Equation 5.

$$I = \frac{P}{V} \quad (5)$$

where:
I: current, A;
P: power, W; and
V: tension, Vcc.

In the calculation of the current, the tension of the battery bank (24V DC) was considered. For the calculation of the losses of the inverter, 20% of the power and 20% of the total current were considered.

Table 3. Electricity consumption

Equipment	Tension (V)	Power (W)	Usage (h day^{-1})	Current (A)
Motor pumps	220	1,103.25	8	45.97
Losses of the inverter	-	220.65	-	9.19
Total	**-**	**1,323.9**	**-**	**55.16**

The amount of battery required was calculated considering the depth of discharge at the end of the autonomy of 50%. For the dimensioning of the fotovoltaic generator, the Equation (6) was used.

$$\mathrm{Wp} = \frac{\text{Total consumption. Vmp module}}{\text{Equivalent hours of full sun. Losses and safety factor}} \quad (6)$$

where:
Total consumption: total daily energy consumption, Ah dia^{-1};
Wp: minimum total power of the set of modules required to produce the energy required by the load;
Vmp module: maximum power tension of the module to be used (29.16 V);
Equivalent hours of full sun (hour day^{-1}): 4; and
Losses and safety factor: 0.8.

For the design of the charge controller, it was verified the maximum current to support modules and charges, and the highest value was adopted.
The sizing of the inverter is obtained based on the maximum power of the selected motor pump.

Materials needed for pumping water

The materials required for pumping water are shown in Table 4.

Table 4. Materials required for pumping water

Description	Material	Quantity	Unitary value (R$)	Total (R$)
Suction	Curve of 90^0	1 unit	17.00	17.00
	Valve	1 unit	30.00	30.00
	Register	1 unit	218.00	218.00
	PVC tube	10.0 m	17.0	170.00
Head	Curve of 90^0	2 units	8.00	16.00
	Curve of 45^0	2 units	5.00	10.00
	Register	1 unit	85.70	85.70
	Retention valve	1 unit	30.00	30.00
	PVC tube	100.0 m	11.00	1,100.00
Solar energy	Solar panel (240 W)	13 units	1,800.00	23,400.00
	Battery (120 A)	8 units	720.00	5,760.00
	Inverter	1 unit	1,199.00	1,199.00
	Load controller (60 A)	1 unit	1,113.00	1,113.00
	Electric motor + pump	1 unit	696.00	696.00
Diesel	Diesel motor + pump	1 unit	1,740.00	1,740.00

We considered the investment for the construction of pump house and related structures equal to R$ 4,560.00 (FRIZZONE et al., 2005). The field operational capacity of mechanized systems, fuel consumption and depreciation of machinery were also considered.

It was considered an annual interest of 10.0% and useful life of 20 years for all materials used for pumping water, except for the battery which has a useful life of 4 years.

Cost of pumping

The costs of the two motors were compared in order to determine which one has the lowest cost. The method used to calculate the cost analysis of the pumping is described below.

Annual variable cost (AVC)

This cost was obtained by adding the annual cost of pumping to the annual cost of maintenance and repairs. In this calculation, it was taken into account the cost of replacing the battery at the end of every four years.

The price of diesel oil was considered as equal to R$ 1.966 per liter (Agência Nacional do Petróleo, Gás Natural and Biocombustíveis, 2012). The total consumption of diesel oil per year was calculated by Equation 7.

$$\mathrm{TCD} = \mathrm{AC.T.DP} \quad (7)$$

where:
TCD: total consumption of diesel oil per year, L;
AC: average diesel consumption by the motorpump, L h^{-1};
T: operation daily time, h; and
DP: days of pump operation during the year.

The annual pumping cost was obtained by multiplying the TCD by the adopted diesel price.

Total Cost

After determining the total annual cost, this value was converted into present value (P) (Equation 8) and was added to the initial investment cost.

$$\mathrm{P} = \mathrm{A}\frac{(1+\mathrm{j})^{\mathrm{n}} - 1}{\mathrm{j}.(1+\mathrm{j})^{\mathrm{n}}} \quad (8)$$

where:
P: present value, R$;
A: annual cost, R$;
n: useful life, years; and
j: interest, %.

The total cost of the lift system using solar energy for water pumping is obtained by summing spending with workforce, infrastructure, pump, electric motor and other materials used to transform the energy captured from the sun into electricity (solar panel, controller load, batteries and inverter).

4 RESULTS AND DISCUSSION

Cost analysis of the lift system

The costs of lift systems with pumping water using solar energy and diesel oil can be viewed in Table 5. It is observed that the initial investment of the lift system using solar energy was five times higher than the value of the lift system working with diesel motor, representing 60.07 and 11.72% of the total cost, respectively.

On the other hand, the system that used solar energy had the lowest total cost. This can be explained by the fact that this system does not have pumping cost, i.e., the consumed energy was only solar energy, which needs not to be accounted; while diesel consumption was accounted during the entire lifetime of the other system, and this spending surpassed other costs. Similar results were observed by MARQUES et al. (2006).

The pumping cost had the largest influence on the total cost of the lift system, being responsible for 75.76% of the total value. This resulted in a cost of 6.4% greater than the cost of the lift system using solar energy. According to COMETTA (2004), the annual energy savings are used to amortize the costs of buying solar panels.

From the two options, the water pumping system that used solar energy is the most economically viable, but in order to know whether it can be employed in a particular place so that the cost-benefit ratio is greater than 1, it is necessary to evaluate the crop to be implanted. Crops with higher economic value are indicated.

Table 5. Costs of water pumping systems using solar energy and diesel oil

Items	**Lift systems Eletric motor (R$)**	**Lift systems Diesel motor (R$)**
Initial Investment	38,404.70	7,976.7
CMO	25,527.23	8,513.56
Cost of pumping	-	51,552.01
Total	**63,931.93**	**68,042.28**

CMO: Cost of maintenance and operation

It was considered workforce of 5556 and 5564 hours for the lift systems using diesel and solar energy, respectively, during its lifetime. The total consumption of diesel oil during the lifetime of the system is 61,600 L. According to ROMANELLI (2002), for a system to be economical, it is necessary to employ technology with low energy consumption and high economic return. Another factor that must be considered is that solar energy is a clean energy and its use provides sustainable development.

5 CONCLUSION

The lift system for pumping water that used solar energy had lower total costs and lower overall energy consumption despite the higher initial investment cost and greater energy consumption of depreciation of machinery and equipment.

The lift system with solar energy is more economically viable when compared with the system working on diesel.

The cost of pumping was the decisive factor in the analysis of the costs of water pumping systems.

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