DRIP IRRIGATION SYSTEM BY MICROTUBES KIT WITH PUMP POWERED BY SOLAR ENERGY[1]

L. R. Sobenko[2], E. Saretta[3], A. P. de Camargo[4], T. A. Botrel[5]

ABSTRACT: In this study we designed and evaluated a microtube irrigation kit, pressurized by a pump powered by solar energy; and presented the cost of the developed kit. The kit consisted of irrigation laterals, positive displacement pump, photovoltaic generator, battery, charge controller and solenoid valves. The first step was to design microtubes and lateral lines to compose a kit, followed by selecting the appropriate pump. After testing the pump in laboratory conditions, four lateral lines were installed on beds cultivated with lettuce in order to evaluate their performance in field conditions. In both, laboratory and field conditions, the kit presented uniformity greater than 94%. Estimates indicated that the selected pump could irrigate up to 15 beds (270 m²), though its efficiency did not overcome 10.8% on the evaluated conditions. During days of long irrigation routine, the pumping system presented efficiency of 9.7% for the motor pump set, 36.6% for energy conversion and 2.4% for the overall system. The total fixed cost of deployment kit developed for irrigation of 15 beds was R$ 4,313.33, including irrigation controller and solenoid valves, or R$ 3,083.33 without these items. Therefore, the kit developed was considered technically feasible for lettuce irrigation.

KEYWORDS: microirrigation, photovoltaic solar energy, water pumping

KIT DE IRRIGAÇÃO LOCALIZADA COM MOTOBOMBA ALIMENTADA POR ENERGIA SOLAR

RESUMO: No presente trabalho, teve-se por objetivo dimensionar e avaliar um kit de irrigação por microtubos, pressurizado por bomba alimentada com energia solar; e apresentar o custo do material que compõe o kit. O kit foi composto por linhas laterais de

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[1] Extracted from first author master's dissertation.
[2] PhD Student, University of São Paulo, College of Agriculture "Luiz de Queiroz" (ESALQ/USP), Biosystems Engineering Dept. Av. Pádua Dias, 11, Postal Code 9, Piracicaba, SP. Phone: (19)34478549. E-mail: luizsobenko@usp.br.
[3] PhD, Professor, Cachoeira do Sul Campus, UFSM, Cachoeira do Sul, RS.
[4] PhD, Researcher of INCT-EI, ESALQ/USP, Piracicaba, SP.
[5] PhD, Full Professor, Biosystems Engineering Dept., ESALQ/USP, Piracicaba, SP.

irrigação, motobomba de deslocamento positivo, gerador fotovoltaico, bateria, controlador de carga e válvulas solenoides. A primeira etapa foi o dimensionamento e avaliação dos emissores e das linhas laterais, seguido da seleção do conjunto de bombeamento adequado. Após testes da bomba em condições de laboratório, quatro linhas laterais foram instaladas em canteiros de cultivo de alface a fim de se avaliar o desempenho em condições de campo. Para as condições de laboratório e campo, o kit apresentou uniformidade maior que 94%. Estimativas mostraram que o conjunto de bombeamento selecionado é capaz de irrigar até 15 canteiros (270 m²), apesar da sua eficiência não ter sido maior que 10,8%. Para os dias com maior tempo de irrigação, o sistema de bombeamento apresentou eficiências de 9,7% para o conjunto motobomba, 36,6% para a conversão de energia e 2,4% para a global. O custo fixo total de implantação do kit desenvolvido para a irrigação de 15 canteiros foi de R$ 4.313,33 com controlador de irrigação e válvulas solenoides, ou R$ 3.088,33 sem esses itens. Assim, o kit desenvolvido mostrou-se tecnicamente viável para irrigação de alface.

PALAVRAS-CHAVE: microirrigação, energia solar fotovoltaica, bombeamento de água

INTRODUCTION

Recently the water demand has been increased due to population growth and thus the availability of water has become more crucial than ever before. Drip irrigation has been highlighted in this context, since the flow rate and operating pressure of the system are lower when compared to sprinkler irrigation systems. According to Kumar et al. (2015), drip irrigation technologies are widely considered as one of the most effective and efficient method of irrigation when properly designed and operated.

The drip irrigation systems have numerous advantages, but high initial cost (Mantovani et al., 2012). An alternative to this is the use of microtubes, which has easy handling, low cost and the possibility of high efficiency. Alves et al. (2014) points out that this irrigation system is an important tool for increasing the technological level of smallholders. The use of microtubes has been growing especially in poor countries in Asia and Africa. As an example, we can mention the microtube irrigation system powered by a standalone direct pumping photovoltaic system developed in India by Kumar et al. (2015), which presented application uniformity greater than 91%.

Hydraulically, a microtube is a dripper of polyethylene material and diameter ranging from 0.5 to 2.0 mm, which length can be adjusted as required (Souza & Botrel, 2004; Alves et al., 2012). Thus, the microtube can be used in systems that operate under low pressure, such as those where only gravity is used.

Photovoltaic energy has recently been used for power generation for water pumping, especially in locations where other sources of energy are unavailable or limited. This enables the use of irrigation in these remote locations, and with it a number of benefits, such as the non-use of any kind of fuel or the extensive maintenance required by diesel pumps (Narale et al., 2013).

The initial investment cost for a photovoltaic system for pumping is still higher when compared to a conventional one, but over its useful life it may become more advantageous, which allows to combine low pressure irrigation system, such as microtubes, with the water pumping by solar energy.

Two strategies can be adopted in irrigation projects by microtubes with pump powered by solar energy: directly, through the use of direct current pumps, or indirectly, when converting direct current to alternating current and using a conventional pump. The direct drive has the advantage of not needing any device for the energy conversion, presenting lower electrical losses and simplifying the system. However, the studies of the operational behavior of direct current pumps for this application are still few, in addition to having low power, limiting the irrigated area size. In this case, it becomes interesting to use a set in which the microtubes can be used especially for a pump with these characteristics.

In this work, the objective was to design and evaluate a microtubes irrigation kit that operates with low pressure, using a pump powered by solar energy, and present the total fixed cost of the developed kit.

MATERIAL AND METHODS

The initial tests were carried out at the Irrigation Laboratory at College of Agriculture “Luiz de Queiroz” (ESALQ), University of São Paulo (USP), Piracicaba, São Paulo, Brazil. Field tests were performed at an experimental area (latitude 22°42’S; longitude 47°37’W; 548 m in altitude).

The development of the irrigation kit was carried out according to the following steps: 1) design and evaluation of emitters and lateral; 2) selection of a direct current pump, and its evaluation in laboratory; and, 3) installation of the kit over beds to cultivate lettuce (1.25x15 m).

Design and evaluation of emitters and lateral line

Firstly, for the design of the lateral lines, the internal diameter (D_m) of a microtube was determined by hydraulic measurement model, as descripted by Almeida & Botrel (2010).

A local head loss coefficient (K) of 8.164 (Souza & Botrel, 2004) was used and an emitter flow rate of 1 L h^{-1} was set at a pressure of 39,2 kPa (4 water meter column) in the last microtube. The head loss in each section along the lateral line was estimated by Darcy-Weisbach equation. With these data and with the D_m determined by the hydraulic method, the length of each microtube was calculated by the model developed by Souza & Botrel (2004). The authors associated the equations of friction and local head loss, and kinetic energy in a single equation.

Each microtube installed along the lateral presents a length, which is longer at the beginning of the line, to compensate higher pressures, and shorter at the end. It may challenge the assembly of the lateral line, especially for the farmers who could assemble their own kits. To avoid such complications, a constant length was chose for all microtubes, the average length of all microtubes. However, this implies in smaller water application uniformity.

Four lateral lines of 18 m length were built using the microtubes and a 20-mm diameter PVC pipe. The emitters were fixed throughout the lateral line, regularly spaced at 7.5 cm, which resulted in 240 emitters. Insertion of the microtubes at each point of emission in the lateral line was performed according to Figure 1.

In order to verify the hydraulic performance of the irrigation system using the mean length of the microtubes, in laboratory conditions, a lateral line was submitted to the uniformity test to obtain the Christiansen (CUC), distribution (CUD) and statistical (UE) uniformity coefficients (Eqs. 1, 2, and 3, respectively).

$$CUC = \left(1 - \frac{\sum \left|qi - q_{med}\right|}{n\ q_{med}}\right)100 \qquad (1)$$

$$CUD = \left(\frac{q_{25}}{q_{med}}\right)100 \qquad (2)$$

$$UE = \left(1 - \frac{S_q}{q_{med}}\right)100 \qquad (3)$$

where,

CUC – Christiansen uniformity coefficient, %

qi – *i*th emitter flow, L h^{-1}

q_{med} – average flow, L h^{-1}

n – number of the emitter on the lateral, dimensionless

CUD – distribution uniformity coefficient, %

q_{25} – average of the lower quartile of emitter flow, L h^{-1}

UE – statistical uniformity, %

S_q – standard deviation of emitter flow, dimensionless

During the test, the inlet pressure was adjusted using a needle valve and monitored with a transducer, in order to keep emitter's flow rate at 1 L h^{-1}. Three replicates were performed, measuring the flow of 40 emitters, 10 of each quartile of the line, and the values obtained were evaluated according to Kruse (1978), Keller et al. (2001) and Mantovani (2012).

Selection of the pumping and evaluation in laboratory

Flow of the lateral line and the calculated inlet pressure at each bed were used to select the appropriate pump. The model must operate with direct current (DC) to ease the wiring to solar panels without energy converters.

The Shurflo S8000 pump was selected, as it presented a lower acquisition cost per area to be irrigated (0.87 R\$ m^{-2}), meeting the project demand and presented a potential to irrigate up to 28 beds, considering six hours of solar radiation. Evaluations of the pump were performed in laboratory conditions, determining the characteristic curves of pressure and efficiency.

In addition to the hydraulic pump, the components to irrigate the field required a solar panel; a battery to enable continuous supply of power to the pump, especially during periods of cloudiness; a charge controller required by the pump; and solenoid valves to control the entry of water into the beds. The technical specifications of these components are described in Table 1.

Installation of the kit over beds for irrigation distribution evaluation

Performance of the kit was tested in field conditions, irrigating lettuce culture in four flowerbeds. A general scheme of the layout is shown in Figure 2.

During the crop growing period, the following variables were evaluated and monitored: electric current and voltage required by the pump (energy consumption); flow and pressure supplied by the pump; and solar radiation. All measurements were stored in a datalogger (Campbell Scientific, CR23X model). The datalogger also controlled the system by triggering the pump and solenoids of the beds for the irrigation time required. Daily, this time was estimated based on agrometeorological water balance, and manually informed to the datalogger.

With all the variables daily monitored and stored, the efficiencies of the motor pump set (η_{mp}), energy conversion (η_{conv}) and overall (η_{global}) were calculated. It was considered that η_{mp} is the ratio between net and absorbed motor powers. The relation between the electric energy consumed by the pump and the energy supplied by the solar panel was considered as η_{conv}. The relation between hydraulic energy supplied by the pump and energy supplied by solar panel was considered as η_{global}.

Two tests were performed to characterize the hydraulic performance in the field, one before transplanting of the seedlings and the other after harvesting. Water volume of 20 emitters per lateral line, five of each quartile, was collected during 12 minutes. Uniformity coefficients, q_{var}, CUC, CUD, and UE were calculated.

Investment costs of the proposed kit were presented, including the expenses with the irrigation system and the solar pumping system. The price of each item was obtained in companies near Piracicaba, SP.

RESULTS AND DISCUSSION

The D_m determined by hydraulic measurement model was 0,787 mm. Considering the length of lateral lines of the kit, the average length of emitters used was 126.7 cm. Table 2 shows the estimated mean flow of emitters, as well as the uniformity coefficients.

Regarding to uniformity, the three coefficients were greater than 90%, which can be considered as "excellent" according to ASAE EP405.1 (2014), both for laboratory and field conditions (Table 2). The flow variation (q_{var}) did not exceed the limits allowed in the subunit, following recommendations of Frizzone et al. (2012).

In the evaluations, the pump presented a flow rate of 358 L h^{-1} at 39 kPa of pressure. Considering the required flow at each bed, there was a potential to irrigate up to 15 lettuce beds of the size used in this study. On the other hand, the maximum pump efficiency was 10.8%.

It can be observed in Figure 3 that the highest efficiency of the pump (38%) occurred in the flow and pressure head of 270 L h^{-1} and 37 m, respectively. This shows the importance of determining the characteristic curve of the pump experimentally, and it is possible to verify the limits for better execution of the project.

During the evaluation period, the pumping set had a mean and maximum η_{mp} 6.45% and 9.71%, respectively. For η_{conv}, it was observed a mean value of 9.81% (maximum of 36.58%). Also for η_{global} the mean and maximum values were, respectively, 0.64% and 2.4%, reaching 9% if the 15 beds that the pump has potential are being irrigated.

In field, some microtubes were clogged and easily unobstructed when they occurred. Irrigation management was carried out in an adequate and simple manner, informing the controller of the irrigation time. The battery charge controller indicated every day that the battery was fully charged, showing that the system can operate at any time of day, especially in cloudy periods.

Microirrigation kits like this one only using gravitational energy have already been developed and with proven technical feasibility (Souza et al., 2006; Kumar et al., 2015). In the study carried out by Kumar et al. (2015), when using solar energy to pump water to a high reservoir, a limitation was observed regarding the period of use of the irrigation system due to the availability of solar radiation (4 hours per day).

According to Kumar et al. (2015), the design of the developed kit is specific to the experimental irrigated area, and any change in irrigated area size eventually demanding changes in one or more design parameters as: pumping system, solar power generation unit, hydraulic head, diameter of different pipe section and accordingly configuration.

Table 3 lists the items that would be used in the irrigation kit and their respective costs if 15 flowerbeds were irrigated, and the total fixed cost of implantation as well. If the user opts for an option without automation, not including irrigation controller and solenoids (49% of the total irrigation system cost), the kit would have an initial cost of R$ 3,088.33.

CONCLUSIONS

The kit developed using fixed length microtubes and lateral lines of PVC pipes is technically feasible for irrigation of vegetables, since it presented excellent uniformity.

The obtained efficiencies showed that the project could be better optimized if there was greater availability of equipment with different characteristics in the market.

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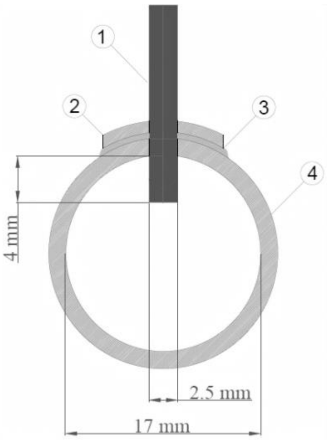

Figure 1. Schematic of the emitter insertion (1), clamp (2) and sealing (3) on the lateral line (4).

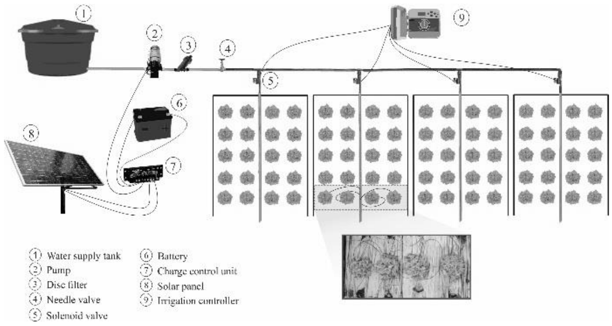

Figure 2. General scheme of the components of the kit, irrigation system and beds.

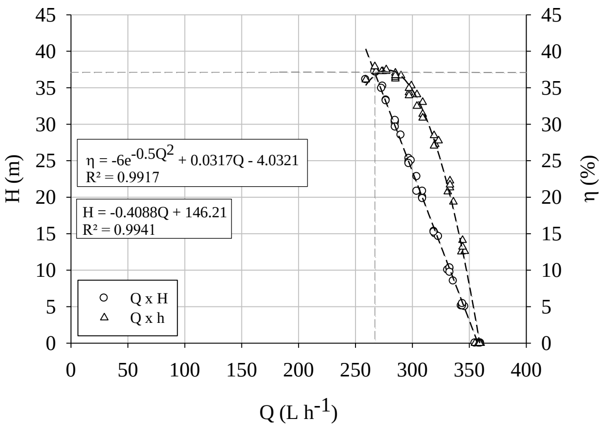

Figure 3. Characteristic curves of pressure head (Q x H) and efficiency (Q x η) of the Shurflo S8000 pump.

Table 1. Kit components wise minimum specifications.

Component	Model	Specification
Pump	Shurflo S8000	- Power voltage: 12 V_{DC} - Power current: 7 A - Type: positive displacement – three diaphragm chambers
Solar panel	Kyocera KD140SX	- Power output: 140 W - Maximum power voltage: 17.7 V - Power current: 7.91 A - Dimensions: 1500 x 668 x46 mm - Manufacturer efficiency: 15%
Battery	Freedom	- Type: stationary - Rated voltage: 12 V - Charge voltage: 14.4 – 15.5 V_{DC} - Normal capacity: 50 – 70 Ah
Charge control unit	MorningStar SS-20L	- System voltage: 12 V_{DC} - System current: 20 A - Regulated voltage: 14.4 V_{DC} - Low voltage disconnection: 11.5 V_{DC} - Low voltage reconnection: 12,6 V_{DC} - Own demand: 6 – 10 mA

Table 2. Hydraulic evaluation of irrigation system.

Lateral line	q_m (L h^{-1})	q_{var} (%)	CUC (%)	CUD (%)	UE (%)
Estimated	1.000	1.5	99.6	99.6	99.9
Laboratory	0.992	13.1	96.5	95.8	98.5
1	1.013	14.0	96.7	94.4	95.9
2	1.008	12.8	97.1	95.9	96.4
3	1.001	14.4	96.2	94.8	95.6
4	0.993	17.6	95.6	93.7	93.7
System average	1.004	14.7	96.4	94.7	95.4

Table 3. Costs for the acquisition of irrigation and solar pumping systems.

Items	Useful life (years)	Quantity	Unit	Unitary value (R$)	Total value (R$)
a) Irrigation system					
Green strip microtube	5	4,562	m	0.09	410.58
PVC tube (20 mm x 6 m)	5	45	m	10.00	450.00
Irrigation controller	15	2	un	500.00	1000.00
Solenoid valves	5	15	un	15.00	225.00
Disc filter	5	1	un	65.00	65.00
Water tank (150 L)	15	1	un	160.00	160.00
Hydraulic fittings	5	-	-	-	192.75
Total	-	-	-	-	2,503.33
b) Solar pumping					
Shurflo S8000 pump	15	1	un	450.00	450.00
Solar panel	25	1	un	750.00	750.00
Charge controller unit	10	1	un	320.00	320.00
Battery	4	1	un	290.00	290.00
Total	-	-	-	-	1,810.00