Misr J.Ag Eng. 19 (2) : 297 – 312

PERFORMANCE OF SOLAR-POWERED DRIP-IRRIGATION SYSTEM

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ABSTRACT

A solar-powered drip irrigation system has been developed and tested in sandy soil. The system used 10 photovoltaic modules with a total receptive area of $4.27 m^2$. It produced a power of 530 W with 108.5 V. The solar-electric generation efficiency was found 8-9 %. The max. Pumped discharge and head were $10\ m^3/h$ and 8 m respectively.

The EU of the drip system increased to 92 % with head up to 4.5 m. This suggests using dippers to suit low heads within 5 m.

The solar system gave better moisture-distribution with soil depth, due to longer daily operation duration and little water release rates, which encourages horizontal moisture diffusion against deep percolation, in addition to reduced surface evaporation.

The solar system also showed desirable characteristics of developing max. power at noon, where evapotranspiration peaks up. Moisture accumulation at 50-75 depth in sandy soil also encourages deep rooting of plants.

In conclusion, drip irrigation is the most suitable for solar operation, because of low flow rate and relatively little pressure-head requirement. The system also suits remote areas, where fuel and labor are scarce, in spite of high initial cost requirement.

Key Words

Solar-drip-irrigation, solar-pumping, solar-electric-efficiency, emiss-ion uniformity (EU), moisture-distribution.

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I. INTRODUCTION

Solar-powered drip-irrigation system is of great interest. It runs on clean and renewable energy source, and suits remote areas, where traditional fuel on energy sources are not available.

Solar pumps have been manufactured for two decades, and can now be bought as shelf item (Lenehan, 1996, Branscheid, 1977, and Girard, 1988).

Labor and maintenance demands are nearly null with solar systems. However they are capital intensive, and can only provide meager flow rates and pressure heads.

Solar system would thus suit drip irrigation (for its little flow rate), but requires less pressure head than is usual. Such system is possible in flat lands. For one case, Awady et al. (1976) developed a drip system, which was the first in Egypt, that used a pressure head of barely about 50 cm.

Helikson et al. (1989) stated that the use of photovoltaic (PV) power for irrigation is a well-matched application of solar energy supply to energy need, because both the plant water needed and the availability of water supplied by a photovoltaic system depend upon the solar irradiance available.

Hafner and Marotz., (1991) said that in regard to the use of solar power systems for irrigation facilities, there are various possibilities for usage ranging from micro-irrigation systems with as little as 100W up to one kW range. Note the following advantages for photovoltaic systems:

- For use in less developed areas,
- In the flexibility of the type of module/ collector,
- Simple installation,
- Extremely low need for maintenance,
- Long life span,
- The fact that no means of production are needed,
- For use in the low output range (100 W up to 2k W), since diesel facilities are uneconomical in comparison.

A diesel motor aggregate first started to be economical when a minimum of 400 m^3/ d are required. The hydraulic power equivalent for pump systems is stated at m^3/ d, which is the product of the height of lift H in m, and the transported water Q in m^3 per day.

Mueller et al. (1989) said that due to the high initial costs of PV-generators, the power requirement of the system has to be minimized from the beginning. Since the hydraulic power is the product of flow and pressure, following targets are set:

- Reduction of the required flow by avoidance of water losses and
- Reduction of pressure loss by an optimum hydraulic system layout.

The cost of photovoltaic-powered water pumping systems is decreased. The cost of photovoltaic modules has fallen 400% in the last 30 years and this trend continues. Photovoltaic technology also continues to improve the power conversion efficiency of the photovoltaic cell. Increases in photovoltaic cell efficiency decrease the cost of photovoltaic power, because fewer modules are required to produce the same amount of power. (Helikson et al., 1989).

Lenehan (1996) mentioned that the nature of the energy source utilized by PVP system determines that they are environmentally friendly. Solar energy is renewable with no noxious by-products. Local utilization of solar power is therefore significant with respect to the sustainable energy consumption on a global scale.

A network of small-scale PVP system also results in less impact to the hydrological systems and riparian ecosystem than one large-scale water supply project.

The objectives of this research are to: -

- Study the characteristics of a solar-powered drip-irrigation system.
- Establish the suitability of the system for particular situations in local agriculture.
- Prepare for comparative studies with other systems in different situations.

II. MATERIALS AND METHODS

2a- Experimental site

Experiments were carried out at the "Nuclear Research Center, Inshas Atomic Energy Authority of Egypt" to collect data usable in comparing between systems. Texture and characteristics of soil of the experimental field are presented in tables 1 and 2.

Table (1): Soil texture of the experiment field in Inshas, NBC. *

Fraction	Size (mm)	%
Sand, coarse	0.63-2.00	45.6
Sand, medium	0.20-0.63	38.6
Sand Fine	0.06-0.20	11.4
Silt, coarse	0.02-0.06	0.0
Silt, medium	0.006-0.02	1.5
Silt, fine	0.002-0.006	0.0
Clay	<0.002	2.9

* Cited from Mueller et al., (1998).

Table (2): Characteristics of the soil under study For Inshas area.*

Soil layer (cm)	CaCO3 %	EC (m/mhos) / cm	Organic matter	pH
0.25	0.15	0.41	0.28	7.4
25-45	0.20	0.40	0.20	7.5
45-65	0.20	0.40	0.20	7.7

* Cited from El Gendy (1981).

Inshas lies on 30 36 latitude, with min-max mean temperature 15-28 °C In 1991, an orchard of 1.7 ha area was planted with a mixed pattern of 510 citrus trees and 170 date palms. Each citrus tree row is followed by a row of date palms, and so on.. The tree spacing is 5× 5m.

2b- Drip-Irrigation Systems

The total irrigated area was 15 fed (fed = 4200 m^2). The mainline 500-m long (300 m PVC tube of 90 mm diameter, and 200 m of 75 mm diameter). Three submains branch off with 63 mm diameter, and 90-m long. Two 8 L/h emitters (long path) were installed peratree on 16 mm PE (t-tape), with 5-m spacing between trees. The working pressure was 1.2 bar at submain inlets (Fig. 1).

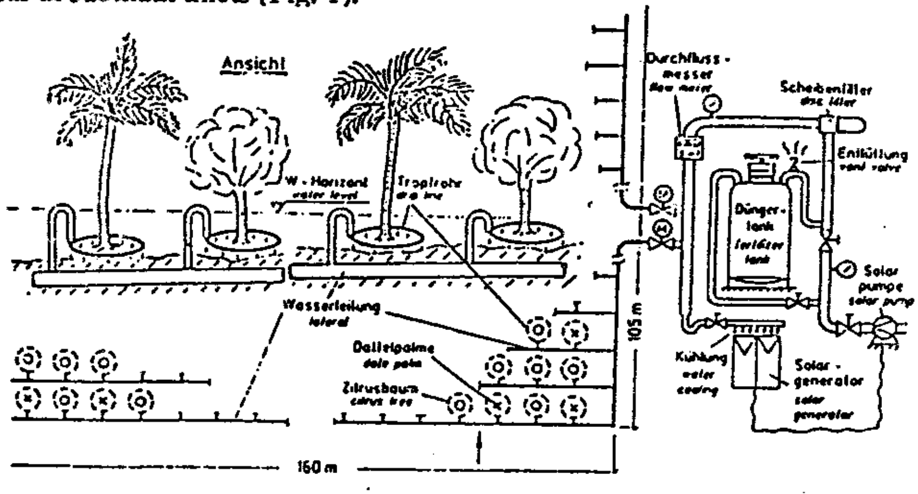


Fig. (1): Schematic diagram of the solar powered drip irrigation system. (Mueller et al. 1998)

Emission uniformity (EU) of systems was calculated using the following equation:

$$EU = Qn / Qa, \qquad (1)$$

Where: "Qn" = mean of the lowest quarter of discharge of the selected emitters, and "Qa" = mean of the total discharge rate.

Solar drip-irrigation network was designed to fulfil the following demands:

1- Varying head and flow according to the daily sunshine.

2- Minimizing head losses and power consumption.

3- Distributing water uniformly over the field area.

2c- The Solar Unit

The solar photovoltaic (PV) – powered drip-system was installed in the experimental in Inshas. The power unit consisted of ten solar modules. Each five modules were connected in series as a unit. The resulting two unit were shunted in parallel. The total area of the PV panels was 4.27 m^2. Resulting rated power was 530 W at 108.5 V.

Efficiency of the solar generator (η sol) was calculated according to Mueller et al. (1998) as follows:

$$\eta \text{ sol} = V.I / A.G,.$$

Where "V" is the voltage, "I" current in amp, "A" is the area of solar collector, and "G" is the solar incident intensity in W / m^2.

2d-The pumpsets

Two models of single-stage centrifugal pumps were installed. The first pumpset had a brushless DC-motor, directly connected to the solar generator. The motor max. permissible power was 450 W, with a max. short-circuit current of 8.4 amp. The pump is a floating type. The volute casing is kept under water surface to ensure priming.

The second pumpset comprised a single stage centrifugal pump. It is driven by a DC-motor of the permanent magnet brush type. It covers the range from 180 to 1000 W at 2500 rpm and 60V to 1745 rpm and 45 V. the max. discharge was 10 m^3/h, and max. head was 8m.

The pump efficiency (η pum) was calculated as follows:

$$\eta \text{ sol} = Q.\ H.W / V.I,$$

Where "Q" is the flow rate in m^3/s, "H" is the total head in m, "W" is the specific weight of water (1000 N/ m^3), and "V and I" as defined before.

The overall (solar-pump) efficiency (η sol-pum) was calculated:

$$\eta \text{ sol-pum} = \eta \text{ sol} \cdot \eta \text{ pum}.$$

2e- Measurement of Soil-Moisture Distribution

Experiment was conducted to study moisture distribution and its suitability for rooting depth. Neutron Moisture Meter (NMM) was used (CPN 503 DR, 50 mci). Access tubes (AT) were installed to determine the moisture distribution. Bare of soil was selected for AT to avoid heavy soil added around trees. AT's were located as in Fig.2. They are at distances of 0, 30, and 60 cm from drippers (8 L/h drippers on 16 mm dia laterals). Moisture measurements were taken at depths of 25, 50, and 75 cm down the AT's.

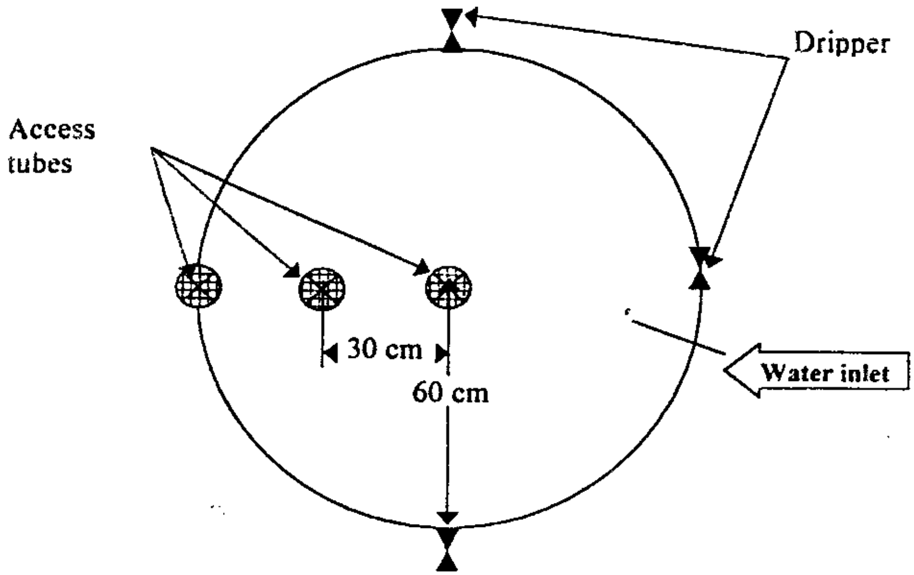


Fig. (1): Access tubes location

The NMM was calibrated in field at soil depth of 25, 50, and 75 cm, according to (IAEA, 1976). Table 3 shows the calibration data.

Table (3): Neutron Moisture Meter calibration equations for different depths of area under investigation.

Soil depth (cm)	Linear equation (y = a + bx)	Correlation coefficient (%)
25	C. R* = 0.2009+0.0412 θv **	99.99
50	C. R* = 0.2948+0.0284 θv	99.99
75	C. R* = 0.2734+0.03313 θv	99.44

*** C.R: Count ratios for Neutron Moisture Meter model CPN 503 DR (50mci).**
****θv % : Volumetric soil water content %.**

III. RESULTS AND DISCUSION

3a- Uniformity of Moisture Distribution from Drip System Using SolarPump

Design and installation of this special system were specifically carried out for the sake of this experiment. "EU" was calculated using Eq.1.

Referring to Fig. (3), the pump actuation had a daily cycle, starting at about 7:00 AM and ending at about 6:35 PM. Near the extremes of the start and end, electric current and motor functioning fluctuating due to electric charge condensing and discharging. After starting, the filling of the piping system takes some 45 minutes after with pressure drops while full flow of water establishes.

The system reaches the highest head and flow point at noon, then it starts to come down again with the sun.

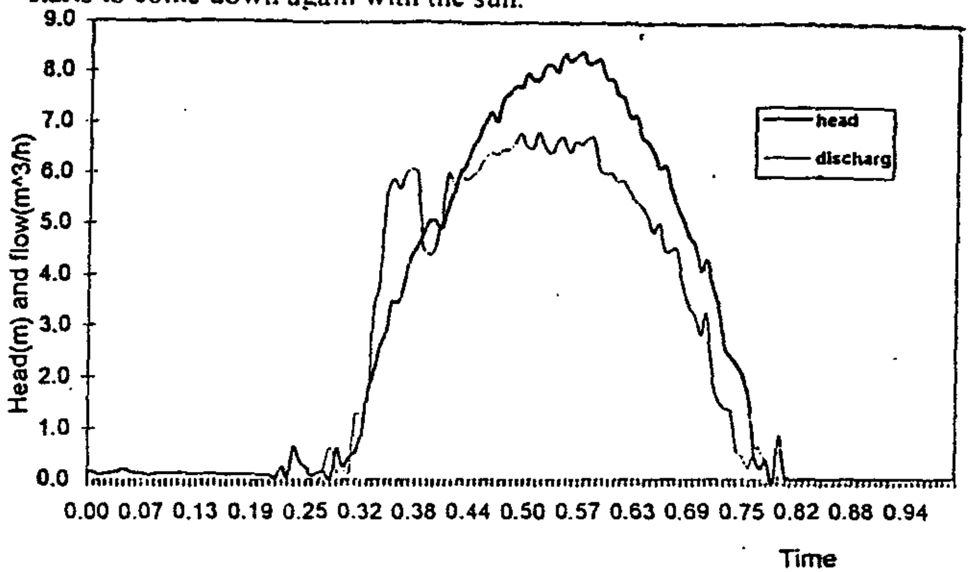


Fig (3): Solar pump output (head (m) and flow (m^3/h) for a selected day(15/6/1998).

The solar radiation (Intensity) showed, in Fig. (4), that it reached about 970 W/ m^2 in the midday.

Maximum solar generator efficiency was 9%, Fig. (5), while the manufacturer stated that it should be around 12% (25° C and 1000 W/ m^2). One of the reasons for deficiency is the high temperature of the array in the summer midday and the dust accumulation (soiling) on the glass surface of the solar generator, which decreases the transmission of the glass and the generated power. Fig. (6) illustrates the decrement of measurements (values in W/ m^2) due to the soiling effect over one of the pyranometers (up to 23% from the total power generated after 30 days) comparing another having a daily dust removal.

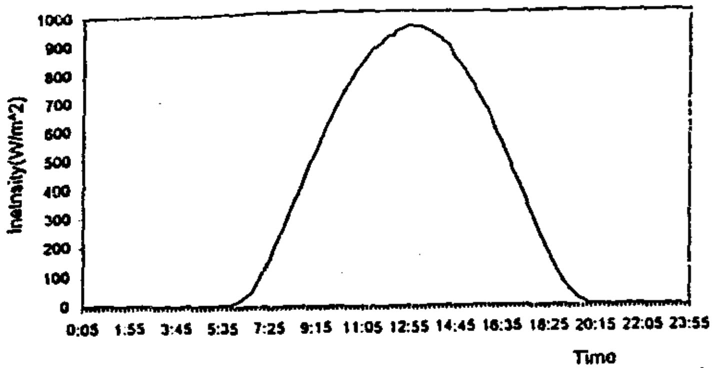


Fig. (4): Solar intensity(W/m^2) for a selected day (15-6-1998).

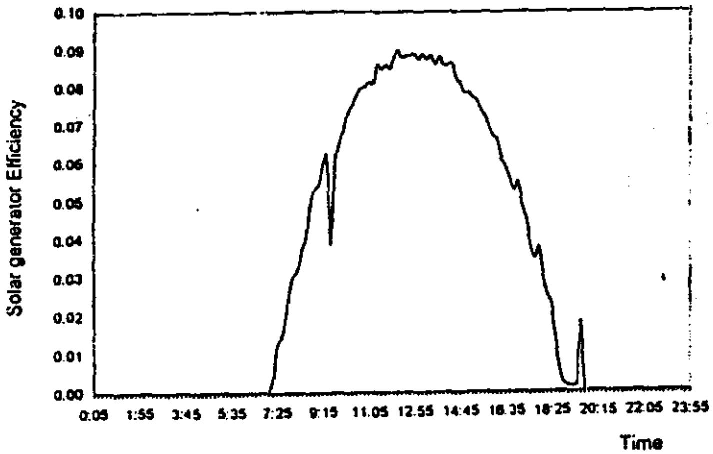


Fig.(5): Solar Generator Efficiency.

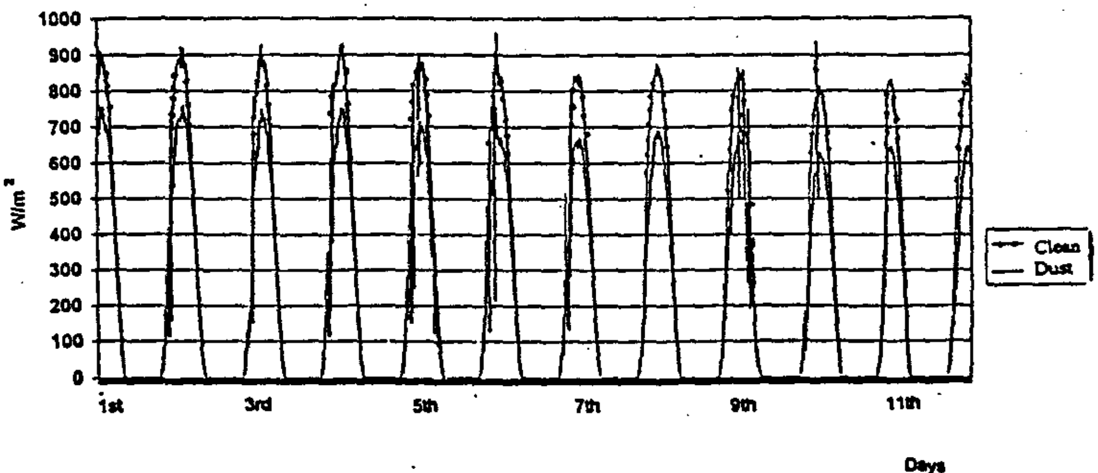


Fig. (6): Soiling effect of the solar radiation measurments.

The head and flow of the system were unsteady due to the fluctuation of solar radiation. Consequently, EU was calculated using data collected under different heads (1, 2, and 4.5 m), as shown in Fig.7.

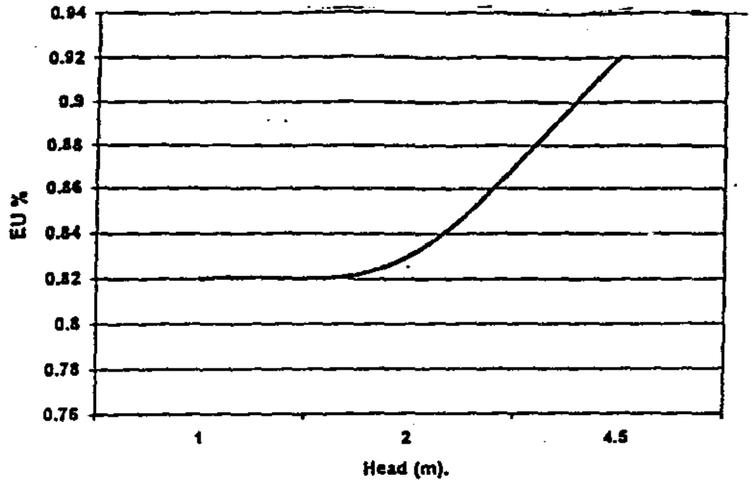


Fig. (7): Drip irrigation system Emotion Uniformity under three different head values :1, 2 and 4.5 m.
(Solar powered)

It is noticed from the figure that EU increases to 92% with head up to 4.5 m. lower EU-values at lower heads are because drippers used are designed to work at heads above 5 m. It is thus advisable to use emitters adaptable to lower pressure, which were not available on the market by the time of experimentation.

3b. Drip System Using Electric Pump

This system was used on olive grove, with 5-year-old trees, planted on 5×5 m spacing.

Table 4 shows the distribution uniformity data from collector cans of 1-L capacity, graduated every 25 mL, for a common duration of about 3 min. the head was 12 m, which promised a good performance, in spite of the poor system condition. The resulting EU was about 80 %.

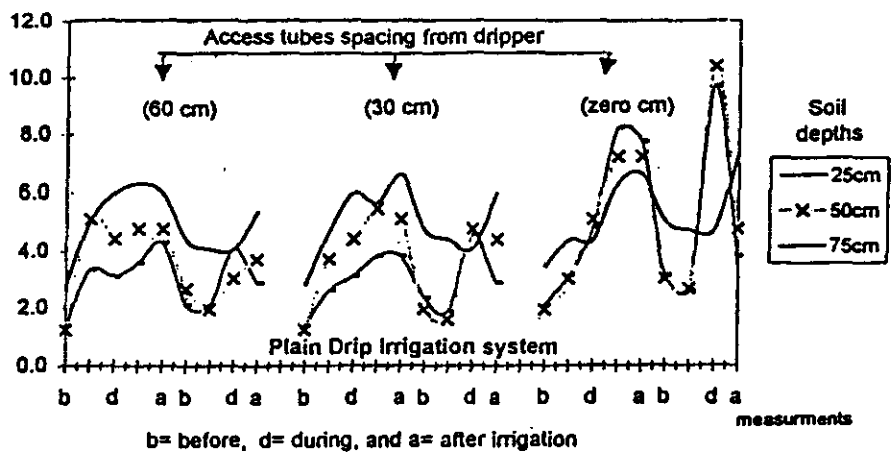
Table (4): Drip irrigation distribution* (ml/5min):

**Col. No.	Plot (1)	Plot (2)	Plot (3)	**Col. No.	Plot (1)	Plot (2)	Plot (3)
1	275	335	360	11	315	345	370
2	275	335	360	12	325	345	370
3	280	335	360	13	325	345	370
4	280	340	360	14	325	350	370
5	285	340	360	15	330	350	375
6	305	340	360	16	330	350	375
7	310	340	360	17	330	350	375
8	310	345	365	18	330	355	375
9	310	345	365	19	330	355	380
10	315	345	365	20	335	360	385
						Av.	381.03

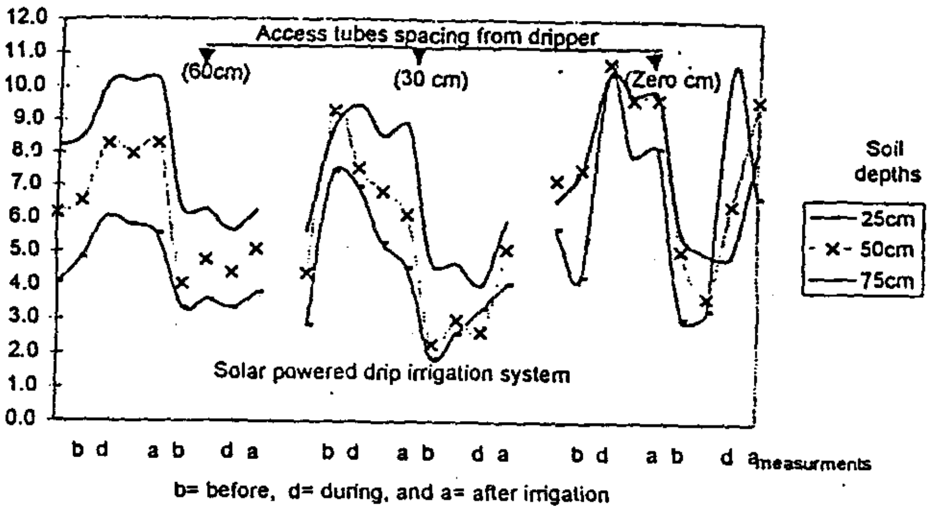
* Orchard
** Collector

3c- Soil-Moisture-Distribution under Drip Systems

Fig. 8. shows that the water distribution under the solar-drip system was more uniform than the plain drip system at different soil depths and along the studied period, especially around the access neutron-tube placed near the plant.



plain irrigation system.



Solar powered rrigation system.

Fig. (8): Moisture distribution under the drip systems

The plant stem, although the amounts of water applied for the two systems are nearly the same. This uniformity may be due to the following:

- The solar system applies low rate for longer durations (5-7 h/day) against (2h/day for plain system). This enhances capillary forces and horizontal diffusion. On the other hand, the plain system enhances gravity flow through the high percentage of macropores of the sandy soil (45.6 % coarse sand and 38.6 % medium sand).
- Decreased evaporation from the surface layer.
- Plant evapotransperation during the hottest hours of the day are met with peak power generation from the sun intensive irradiation.

It is also remarked that more moisture accumulated at the deeper layers of 50-75 cm, as shown in Fig. 9. The two systems are thus suitable for deep-rooted plants in sandy soils.

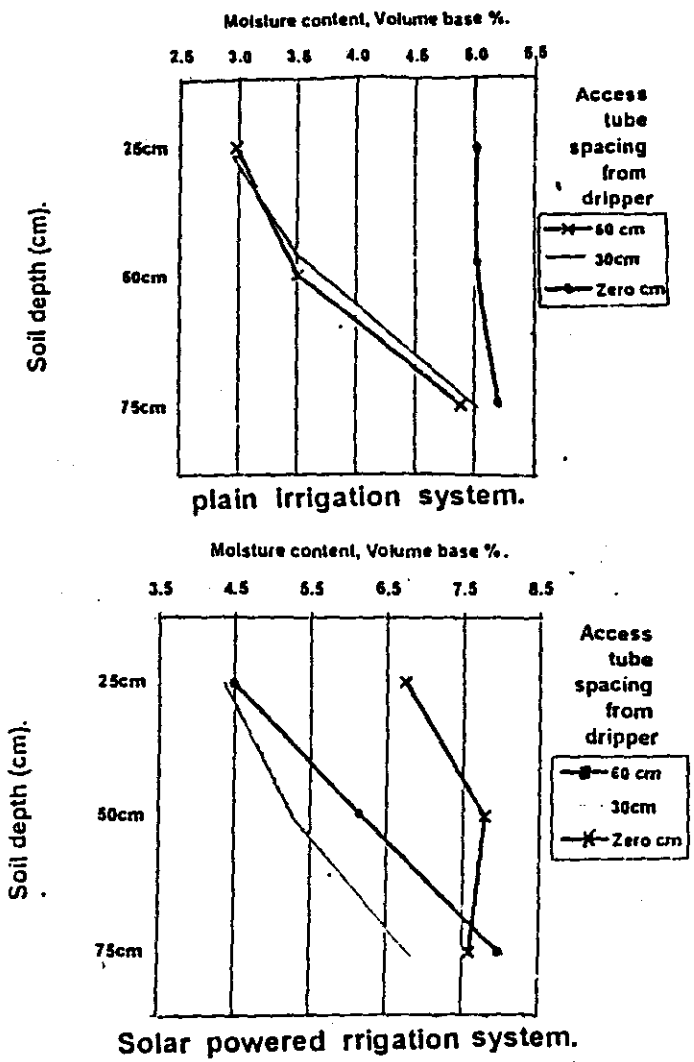


Fig. 9. Moisture distribution at different depths.

IV- SAMMARY AND CONCLUSION

Solar-drip system was developed and tested for operation in sandy soil. Solar generation efficiency was found 8-9 %. The developed system used 10 photovoltaic modules of a total area of 4.27 m^2. Resulting rated power was 530 W at 108.5 V. The max. discharge and head were 10 m^3/ h and 8 m respectively.

For the solar drip system, the EU increased to 92% with head up to 4.5 m. lower EU-values at lower heads are because drippers used are designed to work at heads above 5 m. It was thus recommended to use drippers adaptable to lower heads.

Moisture distribution at different soil depths from solar system was more uniform than the plain system, especially near the plant stem. This may be due to the low rates of water application in sandy soil, which enhances horizontal, diffusion, and reduces surface evaporation. The solar system provides max. Power at midday when plant evapotransperation peaks up. It is also remarked that more moisture accumulated at the deeper layers 50-75 cm, which suits deep-rooted plants.

In conclusion, drip irrigation is the most suitable for solar-power utilization, since it requires little flow-rate along with relatively low pressure. It suits remote areas, where fuel and labor are scarce, in spite of requiring high initial cost.

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أداء جهاز ري بالتنقيط يعمل بالطاقة الشمسية

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ملخص البحث

جري تطوير نظام للري بالتنقيط يعمل بالطاقة الشمسية، ، وتم تجربته للعمل في الأراضي الرملية.

وقد احتوي النظام المطور علي عشرة وحدات كهروضوئية مساحة استقبالها الكلية ٤,٢٧ م٢. وقد نتجت قدرة ٥٣٠ وات علي ١٠٨,٥ فولت. وكان أقصي معدل تصرف وارتفاع ضاغط ١٠م٣/ س و ٨ م علي الترتيب . ووجدت الكفاءة الشمسية لتوليد القدرة الكهربية ٨ - ٩%

أما إنتظامية التوزيع للنظام الشمسي فقد زادت إلي ٩٢% مع الضاغط لغاية ٤,٥ م . أما قلة الإنتظامية تحت ضغوط أقل فترجع إلي تصميم مخارج التنقيط المستخدمة والذي يعتمد علي ضغوط أعلي من ٥م . لذلك يوصي باستخدام مخارج تناسب الضغوط الأقل.

أما توزيع الرطوبة عند اعماق تربة مختلفة تحت النظام الشمسي فقد كان أكثر إنتظاماً من نظام التنقيط المعتاد ، وخصوصاً قرب جذوع النبات. ويرجع ذلك إلي انخفاض معدلات استخدام المياه في الأراضي الرملية ، مما يشجع الإنتشار الأفقي ويقلل من التبخر السطحي. ومن مزايا النظام الشمسي أيضاً أنه يوفر أقصي طاقة عند الظهيرة ، عندما يكون الإستهلاك عند حده الأقصي أيضاً . كما تلاحظ تراكم الرطوبة عند أعماق التربة الكبيرة (٥٠ – ٧٥ مم) ، مما يناسب تعمق جذور النبات .

وفي الخلاصة ، فإن الري بالتنقيط هو الأنسب للاستخدام مع الطاقة الشمسية ، حيث يتطلب الأمر تقليل معدل السريان. ويناسب النظام أيضاً المناطق النائية حيث يندر الوقود والأيدي العاملة ، علي الرغم من ارتفاع تكاليف المشروع الرأسمالية.

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علي الترتيب: أستاذ مساعد وأخصائي ، القسم الزراعي لبحوث الأراضي والمياه مركز البحوث النووية ، هيئة الطاقة الذرية ، القاهرة.