Performance Assessment of Subsurface Drip Irrigation System Using Pipes of Varying Flexibility

TALAT FARID AHMED*, HASHIM NISAR HASHMI**, AND ABDUL RAZZAQ GHUMMAN**

RECEIVED ON 02.03.2009 ACCEPTED ON 01.06.2009

ABSTRACT

Subsurface drip irrigation method may play a significant role in overcoming the shortage of water particularly in arid regions. An experimental investigation was carried out to examine the efficiency of varying flexibility pipes installed in subsurface drip irrigation system. The study was also aimed to investigate the effect of subsurface drip irrigation on water requirement and yield of date palms. The testing was undertaken at Al-Qassim, Saudi Arabia.

A considerable effect of pipe stiffness was observed on water consumption and yield. It was found that the quantity of irrigation water reduced to 49-53% for drip pipes with low flexibility as compared to that for medium and high flexibility pipes respectively. The yield of date palms also increased and it was found 45-49% more than that for the other two types.

Key Words: **Subsurface Drip Irrigation, Date Palm, Arid Region, Pipe Flexibility.**

1. INTRODUCTION

Augmenting the performance of irrigation water is one of the economically feasible alternatives in overcoming the shortage of water. This is not only vital for the sustainable agricultural yield but also to meet the challenges of current environmental issues and justice, financial problems and physical impediments in the developing countries.

The subsurface drip irrigation is a low-pressure and slowly discharging irrigation method that uses buried drip tubes. Farm operations become free of hurdles that normally exist above ground with any other pressurized irrigation system. Subsurface application of water directly wets the root zone, improves yield by reducing the incidence of disease and weed. Germination of annual weed seed is reduced, which lowers weed growth. Water is conserved, fertilizer efficiency is enhanced and labour needs are reduced. In addition, other field operations are possible even when irrigation is applied.

The subsurface drip irrigation system has not been used normally in the developing countries of Asia and Africa because of high initial cost and uncertainty about its life. However, due to increasing concern about water conservation and its quality protection, irrigators are looking for more efficient irrigation methods.

* Seinior Engineer, Farm Operation & Services, National Agricultural Research Centre, Islamabad.
** Professor, Department of Civil Engineering, University of Engineering and Technology, Taxila.

Al-Amoud-Al et. al. [1] investigated the response of date palm trees under different water regimes (50, 100 and 150% of pan evaporation rate), using 3 irrigation methods, viz., basin, bubbler and trickle irrigation systems. The maximum yield was produced from palm trees irrigated with the trickle irrigation system followed by the basin method. The water use efficiency was the maximum for trickle irrigated plots followed by the basin plots. Al-Lawati et. al. [2] investigated the management of irrigation water on date palms plots. The soil-water balance method was used to estimate the temporal distribution of the crop coefficient under modern and traditional irrigation systems. The process was accomplished using TDR (Time Domain Reflectometry) measurements of soil-water content, a computerized irrigation scheduling package, and meteorological data from an automated weather station at the site. This study produced important baseline information on the crop water requirements of date palms under modern and traditional irrigation systems. Hussein, F.A. [3] investigated the effect of varying irrigation applications (12-24 annually) on growth, yield, and fruit quality of dry dates. He found that the leaf growth, leaf size, fruit fresh weight, moisture content and TSS contents were increased with increasing irrigation. Heavy irrigation increased mean yield/palm but produced fruit of high moisture content and thus delayed maturity. Irrigation based on 12 applications per year of 300m^3/acre at intervals of about 4 weeks is considered best. The effect of saline water on the performance of date palm was investigated by Jain and Pareek, [4]. They used drip irrigation system and applied saline water of varying salinity to the date palm for 15-18 times per year. They found no significant effect of saline water on the growth of date palm. Saeed et. al. [5] carried an experimental study and suggested irrigation scheduling for date palms under Al-Hassa (name of a city) conditions, based on results of field experiments and soil moisture and evapotranspiration studies.

Heakal and Al-Awajy [6] made a comparison of long-term effects of irrigation on date-palm production. Soil profile specimens of four date-palm orchards under irrigation for a period of 10 -23 years were compared with one another and with a profile from the nearby barren desert. They found that the total amount of carbonates were several times larger in profiles from the older orchards than that in the desert. They also suggested that organic matter levels were 2-3 times as high in the profiles in the orchards as that in the desert. Khalifa et. al. [7] compared the changes in the orchard soil under irrigated date palm to that of the desert. They proposed that the difference in the soil profiles could be related to the length of time under irrigation and also to the quality of irrigation water. A localized micro-flooding irrigation method was proposed by Falciai and Giacomin, [8] for date palm and grapefruit. They found this method economical and also no special emitters were required. Abou-Khaled et. al. [9] investigated the response of irrigation water scheduling on date palm. They proposed 10 irrigations per annum recommending a schedule of 2 irrigations each in June, July and August, one irrigation each in May, September and October and only one irrigation from November to April.

Stone et. al. [10] demonstrated that treated effluent can successfully be applied through a subsurface drip irrigation system and efficiently utilize the excess nutrients in an environmentally friendly manner. Stone et. al. [11] also applied the drip irrigation method on corn crop and found a great deal of variability among rows when corn is grown in 38cm spacing over buried laterals for wide-row crops. Higher plant populations placed closer to the laterals may increase productivity.

Subsurface drip irrigation system was found to be more efficient than surface drip irrigation system on improving tubers yield quantity, quality parameters and nutrients concentration content, in addition to soil fertility after harvesting Selim et. al. [12]. Payero et. al. [13] investigated that the good relationships obtained in the study between crop performance indicators and seasonal ETc demonstrate that accurate estimates of Etc. on a daily and seasonal basis can be valuable for making tactical in-season irrigation management decisions and for strategic irrigation planning and management.

The model performance in simulating soil water was evaluated by comparing the measured and predicted values using three parameters namely, AE, RMSE and model efficiency. This model helped in designing the subsurface drip system for efficient use of water with minimum drainage, Patel et. al. [14].

Vories et. al. [15] made a detailed experimental investigation on corn crop under subsurface drip irrigation. The results of their study suggested that replacing 60% of the estimated daily evapotranspiration with SDI is sufficient for maximum corn yields, additional observations will be needed to determine whether corn production with SDI is feasible in the region and to develop recommendations for farmers choosing to adopt the method.

In the literature reviewed, little or no research studies have been found to investigate the effect of various flexible pipes for subsurface drip system performance and crop production. The research in this paper was undertaken with the following specific objectives:

(1) To assess the performance of varying flexibility drip pipes installed in subsurface irrigation system.

(2) To determine the water consumption and efficiency of the system

(3) To investigate the effect of subsurface drip irrigation on date palms yield

2. MATERIALS AND METHOD

2.1 Site Description

Field testing was carried out on an experimental site with an area 2.1 ha having 170 date palm trees. The row to row and tree to tree distances were approximately 9.5m. The experimental site is situated in the deserts of Al-Qassim (Buraidah), Saudi Arabia. The area consists of sandy loams with traces of gravel.

The climate is moderately hot and dry. The average monthly highest temperature varies from 30°C (minimum) to 48°C (maximum). Relative humidity is about 34.6%, wind speed is 175 km/day and annual ETo (Reference Evapotranspiration) is 2489mm. The climatic data is plotted and shown in Fig. 1.

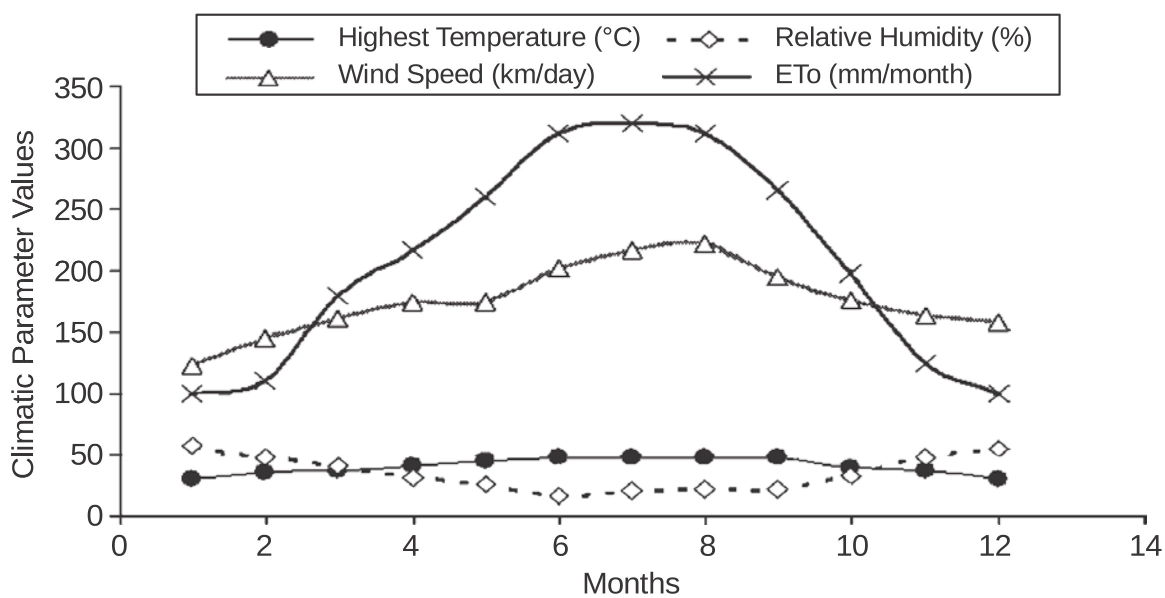

FIG. 1. AVERAGE MONTHLY CLIMATIC DATA FOR AL-QASSIM, SAUDI ARABIA

2.2 Experimental Design

The site was divided into five sub-areas, each having four rows of trees. In order to investigate the effect of pipe flexibility on the experimental parameters, drip pipes of different brands were used in the subsurface irrigation system. The drip pipes had varying wall thickness, i.e. 45 mil (1.125mm) 15 mil (0.375mm) and 9 mil (0.225mm) and consist of continuously self-cleaning pressure compensating emitters welded to the inside walls of the pipes.

The drip pipes with wall thickness 45, 15 and 9 mil had low, medium and high flexibility respectively. Considering the flexibility of drip pipes installed, the sub-areas were designated as LFDP (Low Flexible Drip Pipe), MFDP (Medium Flexible Drip Pipe) and HFDP (High Flexible Drip Pipe) areas. The MFDP area was divided into two sub areas as MFDP-1 and MFDP-2. Similarly HFDP area was divided into two sub areas as HFDP-1 and HFDP-2 as shown in Fig. 2.

Trenches were excavated mechanically and dressed manually. The drip pipes were installed at 40cm depth from ground surface. The system was checked for leakage prior to back-filling.

At the inlet of water supply line, a main flow control valve, a pressure gauge and a filtration unit were fitted. The main line was connected to sub-main which leads water to sub-areas through laterals. Each sub-area was divided into two wings fitted with a separate set of valves. The set includes a solenoid valve, a water meter and a flow control valve.

The irrigation of all sub-areas was scheduled and controlled by a unit called Total Central Control Panel [i.e. TORO Custom Command] as shown in Fig. 3.

2.3 Irrigation Scheduling and System Operation

Irrigation scheduling consists of applying the right amount of water at the right time. Its purpose is to maximize irrigation efficiency by applying the appropriate amount of water needed to replenish the soil moisture to the desired level.

Soil sampling of the experimental site was carried out. The testing was done and analysis revealed that the soil had low permeability and alkalinity.

Monthly irrigation schedule was prepared as per guidelines suggested by Al-Zeid, A. A., et. al., [16] and tabulated as shown in Table 1.

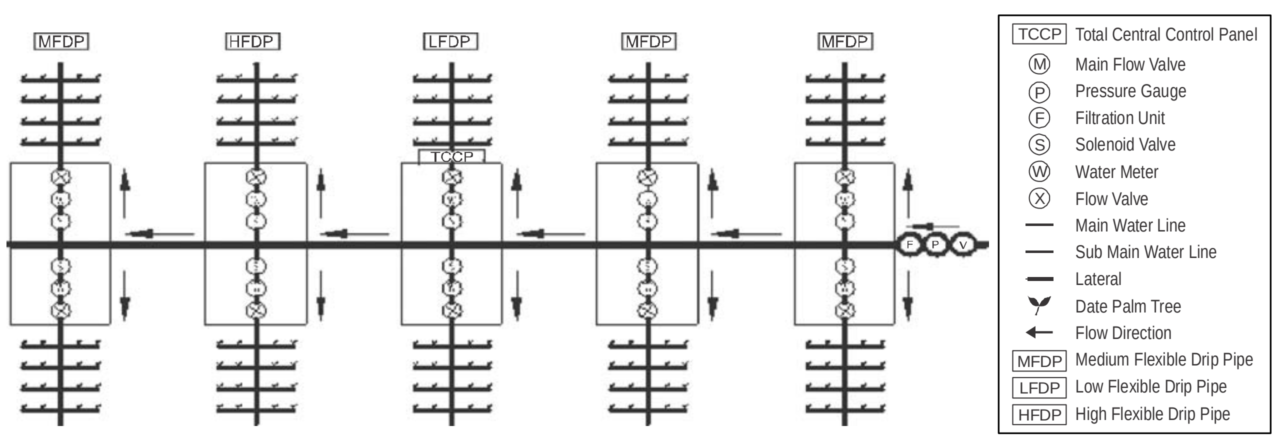

FIG. 2. LAN VIEW OF EXPERIMENTAL SITE SHOWING IRRIGATION LAYOUT AND MONITORING

Soil meter was used to monitor the moisture content of the soil before and after irrigation application. Before using soil meter, it was calibrated using two soil samples (400 and 800ml). Water quantities ranging from 10-50ml (millilitre) and 20-100 ml were applied to 400 and 800 ml soil samples respectively. The corresponding readings of the moisture meter were recorded. Moisture meter scale ranges from 0-10 degrees, zero indicates a fully dry condition, 2-4 represents average dry state, 4-6 is for average state, 6-8 means average wet state and while 10 shows fully wet condition. Soil moisture calibration curves were plotted for each sample. The calibration curve for 400ml sample is shown in Fig. 4.

3. RESULTS AND DISCUSSION

The water to all sub-areas was applied as per irrigation scheduling. The quantity of irrigation water applied to each sub-area was plotted on monthly basis and shown in Fig. 5.

It can be seen in the figure that the quantity of water applied for LFDP is the least of all three types.

The quantity of irrigation water/day/tree for each drip pipe type was also determined and depicted in Fig. 6.

For the same period, in the LFDP type, the total quantity of water used was 229.04m^3 as compared to 450.63m^3 and 484.89m^3 for MFDP and HFDP types respectively. The

FIG. 3. TOTAL CENTRAL CONTROL PANEL

TABLE 1. MONTHLY IRRIGATION SCHEDULE (m^3)

Month	HFDP		LFDP	MFDP	
	Block-1	Block-2	Block	Block-1	Block-2
January	5.52	11.3	11.9	9.93	8.27
February	4.03	8.27	8.67	7.26	6.05
March	9.4	19.3	20.2	16.9	14.1
April	12.6	25.8	27	22.6	18.9
May	12.6	25.8	27	22.6	18.9
June	19	38.9	40.8	34.2	28.5
July	21.9	44.8	47	39.4	32.8
August	21.6	44.2	46.4	38.8	32.4

maximum water use efficiency was observed in LFDP because there was no opening of joints resulting in no leakage of water and non-blockage of built-in emitters. This quantity is 49 and 53% lower than that used in medium and high flexible pipe types respectively. The quantity of water used under low flexible pipe type for the peak period, i.e. for July and August, was also determined. It was found to be 35 litres per tree per day.

The drip pipes were installed 40cm (as advised by the manufacturer) from ground surface having overloaded soil which was further compacted due to mechanical operation on the experimental field. This resulted in constriction of the high flexible pipes which were less stiff. This obstructed water flow which in turn affected the performance of emitters. The increased water pressure in

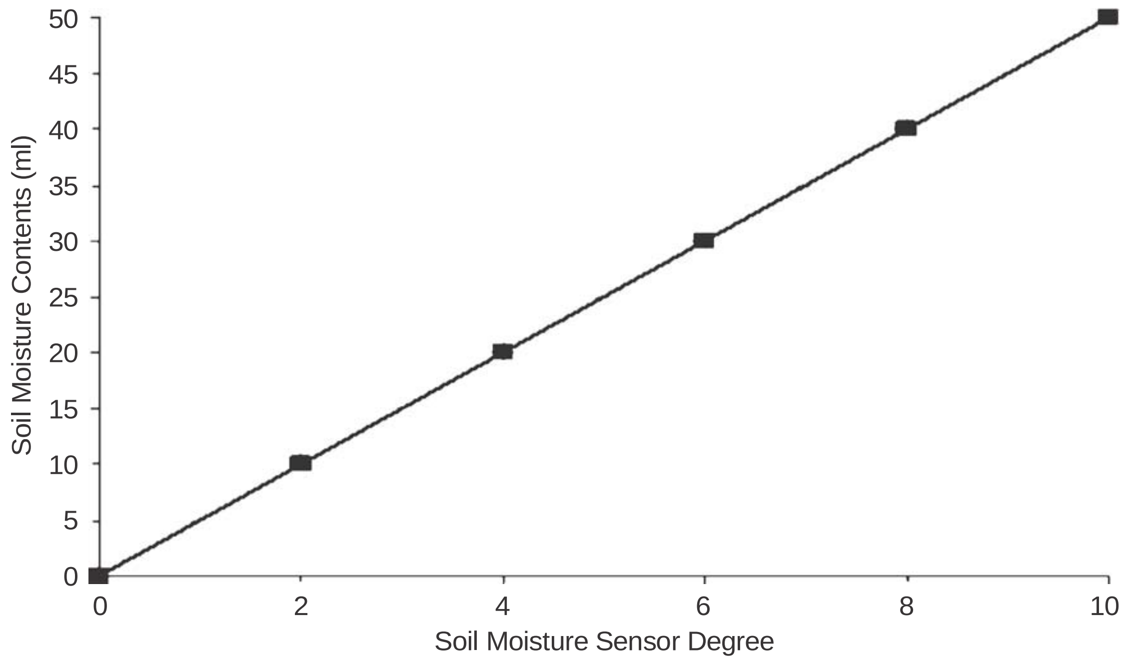

FIG. 4. SOIL MOISTURE CALIBRATION CURVE USING SOIL MOISTURE METER

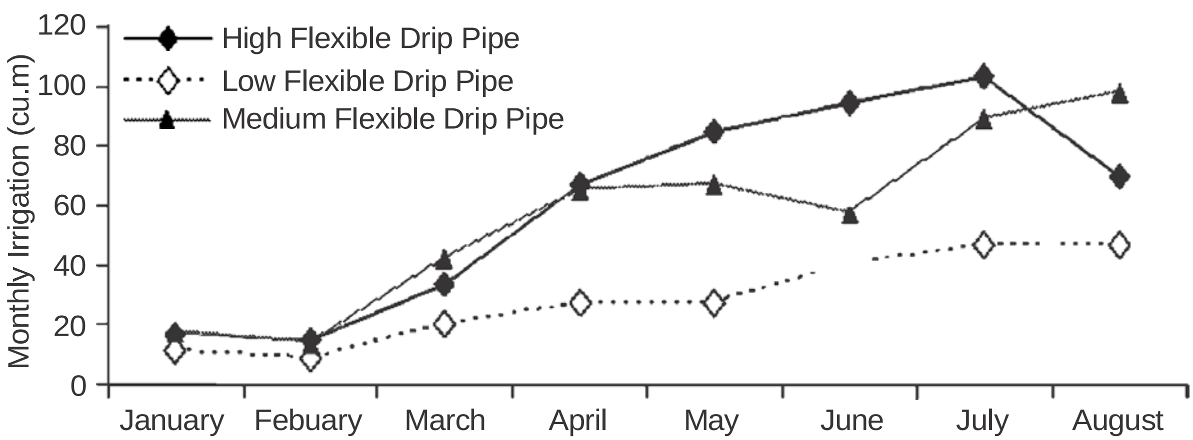

FIG. 5. MONTHLY IRRIGATION APPLICATION TO DATE PALM USING LOW, MEDIUM AND HIGH FLEXIBLE DRIP PIPES

the pipes produced leakage or even opening of the joints. These trickling joints caused water losses. This problem was found less prominent in the medium flexible pipes and the least in the low flexible pipes. Water consumption efficiency trend for all the pipe types can be seen in Figs. 5-6. The joints and emitters in the low flexible pipes worked well so no extra maintenance for this type was required throughout the study period. It can be concluded that the high flexible pipe type is less efficient under subsurface irrigation system but is suitable for surface drip irrigation system. It is because they cannot bear the weight of overburden soil and pressed resulting in the blockage of their built-in emitters.

The yield of the dates per tree for the area under the low flexible pipe type was found to be 120.7 kg/tree whereas the yield for the areas under the medium and high flexible pipe types was 66.0 and 61.4 kg/tree respectively. Thus the trees under low flexible pipe type produced 49 and 45% more yield than those under medium and high flexible pipe types respectively. The comparison of the date production is shown in Fig. 7.

The comparison of date yield for each type of drip pipe under one cubic meter of water was also carried out. It is shown in Fig. 8.

The water use efficiency for low flexible pipes has been calculated as 21.5 and 9 kg/m^3 and 7.3 kg/m^3 in case of medium and high flexible pipes respectively. Quantitative analysis shows that the dates water use efficiency in low flexible pipe type is 58 and 66 % more than that under the medium and high flexible pipe types respectively.

The cost analysis of all three pipes was also carried out. The price for low flexible pipe type (i.e. US$0.25/rft (Running Foot)) is more that that for medium (i.e. US$0.05/rft) and high flexible pipes (i.e. US$0.022/rft). Although the use of low flexible pipe will enhance the initial cost of the system yet it has low maintenance cost and has long-life.

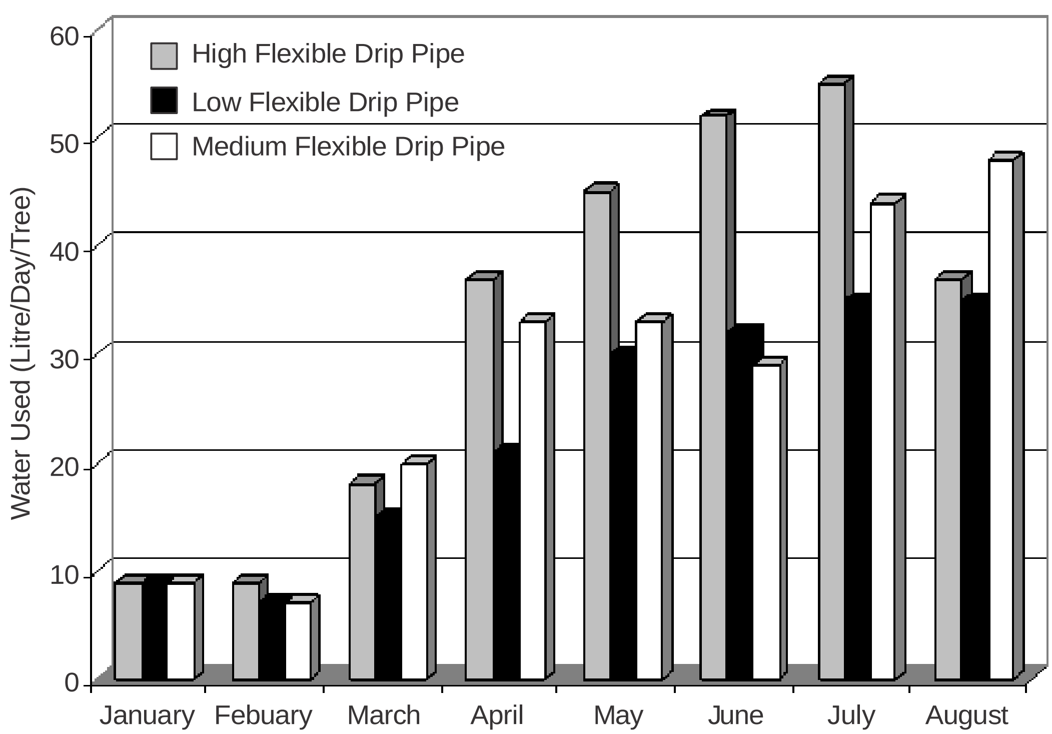

FIG. 6. MONTHLY IRRIGATION UNDER LOW, MEDIUM AND HIGH FLEXIBLE DRIP PIPE TYPES

It was observed that the use of subsurface irrigation facilitated the mechanical field operation as all the pipes were underground at depth of 40cm. As the irrigation was applied in the root zone so the loss of water due to evapotranspiration and wind action was also reduced significantly.

4. CONCLUSIONS

This study examined the performance of a subsurface irrigation system using pipes of varying flexibility. Based on the experimental results, the following conclusions can be drawn from this investigation:

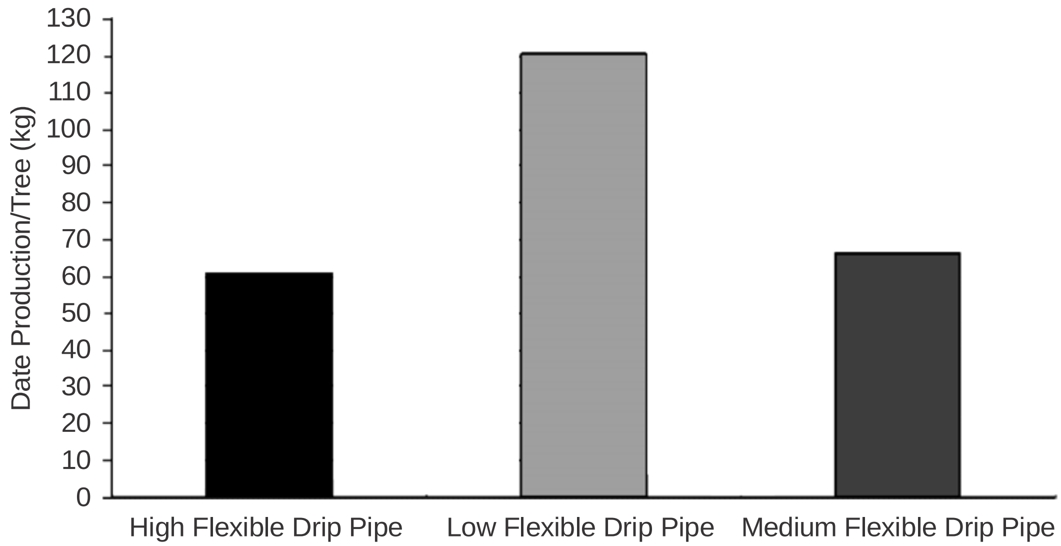

FIG. 7. A COMPARISON OF DATE PRODUCTION FOR THREE DRIP PIPE TYPES

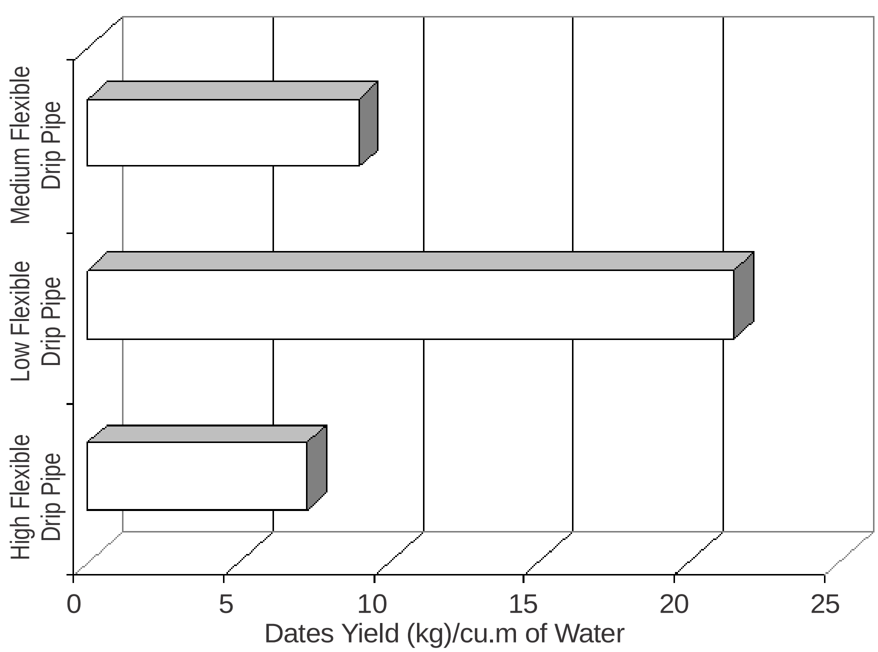

FIG. 8. COMPARISON OF DATES PRODUCTION PER TREE PER M3 OF WATER CONSUMPTION UNDER THREE DRIP PIPE TYPES

(i) Under the subsurface irrigation system, it was found that the hydraulic performance of the LFDP was much better than that of the MFDP and HFDP types. It can save more than 50% irrigation water than that in the other two types.

(ii) The dates yield from the area under the LFDP type was also found to be more than that from the areas under the MFDP and HFDP types. The date production per tree from the area under the LFDP type was found to be more than 45% of the yield/tree obtained from that under other two types.

(iii) The cost of LFDP type is more than the other two pipe types but its maintenance cost is much lower and is also more durable.

(iv) The HFDPs were found to be not suitable for subsurface drip irrigation system, however, they could be used safely for surface drip irrigation system.

(v) The water use efficiency in case of LFDP pipe is much more than the same the for the other two pipe types.

5. SUGGESTIONS

Further investigation of subsurface drip irrigation under varying flexibility drip pipes needs to be undertaken for other crops to confirm the benefits of the use of LFDPs over the other drip pipes.

It is also recommended to maintain a low pressure such as 10-12 psi in the drip pipes to avoid opening of joints. Air relief and flush valves are fitted in the system at the highest and the lowest level. The fertilizing unit can also be installed in the system if required.

ACKNOWLEDGEMENT

The staff of Al-Watania Agriculture Company and its Director General, Dr. Khalid Al-Maulahey, are highly acknowledged for their coordination and cooperation in setting-up experimental facility and collection of data. The cooperation and guidance of Dr. Ahmad Al-Amoud, Consultant to Al-Watania Agriculture Company, is also appreciated and acknowledged.

REFERENCES

[1] Al-Amoud, A.I., Bacha, M.A., and Al-Darby, A.M., "Seasonal Water Use of Date Palms in the Central Region of Saudi Arabia", International Journal of Agricultural Engineering, Volume 9, No. 2, pp. 51-62, Saudi Arabia, 2000.

[2] Al-Lawati, E.A.M., McCann, I.R., and Shayya, W.H., "Date Palm Water Requirements in the Interior Region of the Sultanate of Oman", ASAE Annual International Meeting, Orlando, Florida, USA, Paper No. 982185, pp. 13-20, ASAE, 12-16 July, 1998.

[3] Hussein, F.A., "Effect of Irrigation on Growth, Yield and Fruit Quality of Dry Dates Grown at Asswan", Proceedings of the First Symposium on the Date Palm in Saudi Arabia, pp. 168-173, 1983.

[4] Jain, B.L., and Pareek, O.P., "Effect of Drip Irrigation on Soil and Performance of Date Palm under Saline Water Irrigation", Annals of Arid Zone, Volume 28, Nos. 3-4, pp. 245-248, 1989.

[5] Saeed, A.B., Etewy, H.A., Hassan, O.S.A., "Watering Requirement and Scheduling of Date Palm", AMA, Agricultural Mechanization in Asia, Africa and Latin America, Volume 21, No. 4, pp. 49-52, 1990.

[6] Heakal, M.S., and Al-Awajy, M.H., "Long-Term Effects of Irrigation and Date Palm Production on Torripsamments, Saudi Arabia", Geoderma, Volume 44, No. 4, pp. 261-273, 1989.

[7] Khalifa, E.M., Reda, M., and Al-Awajy, M.H.,"Changes in Soil Fabric of Torripsamments under Irrigated Date Palms, Saudi Arabia", Geoderma, Volume 44, No. 4, pp. 307-317, 1989.

[8] Falciai, M., and Giacomin, A., "A Microflooding Irrigation Method", Su Di Un Metodo Di Irrigazione a Microportata Di Erogazione Per Rivista-Di-Ingegneria-Agraria, Volume 14, No. 1, pp. 35-39, 1983.

[9] Abou-Khaled, A., Chaudhri, S.A., and Abdul-Salam, S., "Consumption of Water by Date Palms: Preliminary Results of a Date Palm Irrigation Experiment in Central Iraq", Date-Palm-Journal, Volume 1, No. 2, pp. 23-32, 1981.

[10] Stone, K.C., Hunt, P.G., Millen, J.A., Johnson, M.H., Matheny, T.A., Vanotti, M.B., and Burns, J.C., "Forage Subsurface Drip Irrigation using Treated Swine Wastewater", Transactions of the ASABE, Volume 51, No. 2, pp. 433-440, 2008.

[11] Stone, K.C., Bauer, P.J., Busscher, W.J., and Millen, J.A., "Narrow row Corn Production with Subsurface Drip Irrigation", Applied Engineering in Agriculture, Volume 24, No. 4, pp. 455-464, 2008.

[12] Selim, E.M., Mosa, A.A., and El-Ghamry, A.M., "Evaluation of Humic Substances Fertigation through Surface and Subsurface Drip Irrigation Systems on Potato Grown under Egyptian Sandy Soil Conditions", Agricultural Water Management, Volume 96, No. 8, pp. 1218-1222, August, 2009.

[13] Payero, J.O., Tarkalson, D.D., and Irmak, S., Davison, D., and Petersen, J.L., "Effect of Irrigation Amounts Applied with Subsurface Drip Irrigation on Crop Evapotranspiration, Yield, Water Use Efficiency, and Dry Matter Production in a Semi Arid Climate", Agricultural Water Management, Volume 95, pp. 895-908, 2008.

[14] Patel, N., and Rajput, T.B.S., "Dynamics and Modeling of Soil Water Under Subsurface Drip Irrigated Onion", Agricultural Water Management,Volume 95, No. 12, pp. 1335-1349, December, 2008.

[15] Vories, E.D., Tacker, P.L., Lancaster, S.W., and Glover, R.E., "Subsurface Drip Irrigation of Corn in the United States Mid-South", Agricultural Water Management, Volume 96, No. 6, pp. 912-916, June, 2009.

[16] Al-Zeid, A.A., et. al., "Guide for Crop Irrigation Requirements in the Kingdom of Saudi Arabia", Ministry of Agriculture and Water, Department of Agricultural Development, pp. 54-73, 1408H, 1988