On-Farm Evaluation of Low-Pressure Drip Irrigation System for Smallholders

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Abstract

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The aim of this paper was to evaluate the performance of a low-pressure drip system (LPS) for three years of service, to calculate the consumptive working time and costs of maintenance and laterals retrieving before harvesting and to determine benefits and problems with drip irrigation. Drip irrigation provides the opportunity to save water and the potential to increase net income by applying water at the right quantity and at the right time. Small to medium fields would benefit from the LPS irrigation system which has the ability to distribute the amount of water applied. LPS is a well-researched system for drip irrigation, typically that available for furrow irrigated crops. There are significant agronomic advantages of using a low-pressure, low-flow drip system. These advantages translate into measured improved distribution uniformity when compared to flood irrigated crops and energy savings compared to flood and sprinkler irrigated crops. The old (reused) drip line leads to a decrease in distribution uniformity and an increase in costs, when the distribution uniformity decreased by 10.5 and 21.6% for reusing the laterals in the second and third year, respectively. Moreover, the cost of repairing laterals was more than 5 and 6.5 times higher for both the 2nd and 3rd season. Many disadvantages of drip lines retrieval can be observed, because labour and maintenance are more intensive; there is a risk of mechanical damage to laterals especially if they are reused; increased management skills and experience are needed; and increased retrieval costs arise season after season.

Keywords: low head system; maintenance; performance; retrieving

The contribution of irrigation to agricultural production is very significant for the world's food supply. However, current irrigation practices such as furrows are inefficient, causing environmental hazards such as salinity, runoff and contamination of water bodies. Irrigated agriculture has played a vital role in supporting a dramatic increase in global food production over recent decades. While only 20% of the world's agricultural land is irrigated, it produces 39% of the world's food supply (FAO 2011). Irrigation also improves the efficiency of other production inputs such as fertilizers, improved seeds and agrichemicals. Hence, the low-input irrigated farming is often more productive than the high-input rainfed farming (Rosegrant *et al.* 2002). Therefore, irrigated agriculture will be a dominating feature of future farming in order to be able to produce sufficient food for an ever-growing world population. Drip irrigation is one of the most efficient methods of watering crops. Its field application efficiency can be as high as 90% compared to 60–80% for sprinkler and 50–60% for surface irrigation (Dasberg & Or 1999).

Drip systems have often been associated with capital-intensive commercial farms. The largest barriers to its expansion to small-scale farmers have been high capital costs, typically starting from US $ 1500 per ha and the lack of system sizes suitable for small plots. The high cost of most commercially available drip systems is due to components that are optimized for fields of four hectares or larger and designed to minimize labour and management costs. By contrast, early drip systems were simple, but these designs were abandoned because they did not fit the needs of large-scale farmers in developed countries. They are, however, well suited for drip irrigating small plots (Andersson 2005).

The drip irrigation technology frees the farmer from the limitations of rainfed farming, enabling him to cultivate all the year round, grow a wider variety of crops, have higher cropping intensity and do priority farming. Good irrigation technologies and agricultural practices coupled with enhanced participation of the poor in the markets are the key to income generation (IDE 2004). The drip irrigation systems described below are examples of the most common among the variety of low-cost systems (Postel *et al.* 2001).

The low-pressure system (LPS) is a systematic development of a low cost drip irrigation system. The system is designed to operate at low pressures (30–50 kPa) by taking advantage of the slopes graded into furrow-irrigated fields. Thus, LPS provides an effective low energy and economical upgrade for furrow irrigation. Furthermore, LPS mitigates environmental issues arising from difficult-to-control surface irrigation, nonpoint source pollution, deep percolation of soluble salts and pesticides, erosion and sedimentation of watersheds (Dowgert *et al.* 2007). The introduction of LPS provides an alternative initial low cost, low energy systems with a multiyear life expectancy, displaying a number of advantages associated with permanent drip irrigation (DI) and subsurface drip irrigation (SDI) systems.

The major objective of LPS is to provide a one-to-five-year life span irrigation system with water and fertilizer application advantages of DI and SDI systems, but at a lower initial cost. The initial LPS cost is dependent on the sophistication level of the system.

Arid countries, which have limited water resources, have to use modern irrigation systems, especially drip irrigation. The expansion of drip irrigation faced some problems. Egypt (as a case study) is an arid country which depends on the Nile River for its water supply with an annual allocated flow of 55.5 billion m^3/year. Evapotranspiration is very high (from 60 mm/month in winter to 220 mm/month in summer). The total cultivated area is 3.4 million ha and 99.8% of this area is irrigated. Surface irrigation is practiced on 3 028 853 ha (88.5% of total cultivated area).

Small-farming is typical of Egyptian agriculture: about 50% of farmers have an area smaller than 0.4 ha (1 feddan) in the original land and 2 ha in the reclaimed land, and this is a big problem for the expansion of modern irrigation. So the aim of this study was to evaluate a new low-pressure drip irrigation system as a one of the important systems suitable for small and medium areas. The focus of this research was to evaluate the uniformity of the low-pressure drip system, determine how the discharge characteristics of reusable tubes change with time and calculate the consumptive working time and costs of repair, maintenance and laterals retrieving.

MATERIAL AND METHODS

Netafim Germany (the developer and manufacturer of LPS) sponsored this study by installing a low-pressure system in a field of 3.5 ha at Federal Research Institute for Rural Areas, Forestry and Fisheries (vTI), Institute of Agricultural Technology and Biosystems Engineering, Braunschweig, Germany (formerly Federal Agricultural Research Centre (FAL), Institute of Production Engineering and Building Research).

Evaluation of the irrigation system. The technical components include the head unit, the distributor hose and the drip tubes as shown in Figure 1.

Head control up to 70 m^3/h includes double screen filter 3'', water meter 4'', polyvinyl chloride (PVC) pipes 4'', low-pressure (LP) valve, float device, glued stand pipe, PVC connection pipes, PVC flanges, screws sand gaskets.

Float control valve (to assure that the system is operated at the recommended pressure and to prevent overflushing): the main control valve is regulated by a float, located in the pipe at the present maximum water level (4 m). The valve is hydraulically controlled by the float and opens or closes to maintain a constant water level and head pressure on the downstream LPS system.

Standpipe (to accurately sustain the required pressure within the system): the main purpose for the standpipe is to accurately control the pressure applied to the LPS dripper lines. Standpipes are 5 m high and 0.3 m in diameter with 4'' flange inlet connection with 6'' outlet.

Water level and downstream pressure control are achieved by using a float which activates the float control valve shown upstream of the standpipe as in Figure 1. A clear, external water level tube allows the operator to visually determine the water level in the standpipe. Inlet and outlet pipes are connected to the standpipe by bolted flanges. In areas where wind gusts are occurring, the standpipe can be anchored to the ground by three or more steel cable ties.

The field distribution system consists of:

(1) Polynet XF™ water supply and distribution hose 163 mm in diameter and 125 m long consists of lateral connectors.

(2) Air vents and manual clamps (the most efficient way to control air).

(3) Drip lines 22 mm in diameter and 350 m long are connected to the distributor hose at a distance of 1.5 m. These lines are conventional drip tubes including Dripnet PC™ with a flow rate of 0.6 l/h per emitter and an emitter distance on the tube is 0.4 m. The terrain inclination in the flow direction of the water is 1 m.

The evaluation method. The evaluations have been carried out according to Merrian and Keller (1978) recommendations, which were followed in later works of other authors (Keller & Bliesner 1990; Ortega *et al*. 2002).

In order to carry out the evaluation, the first step is to choose the standard representative subunit from the studied operational irrigation unit, then to determine the flow discharged by the emitters.

Three laterals are taken into account in the study. In each lateral, three emitters are selected as control points and repeated every 50 m along the lateral as shown in Figure 2. The emitters are evaluated at each of the control points.

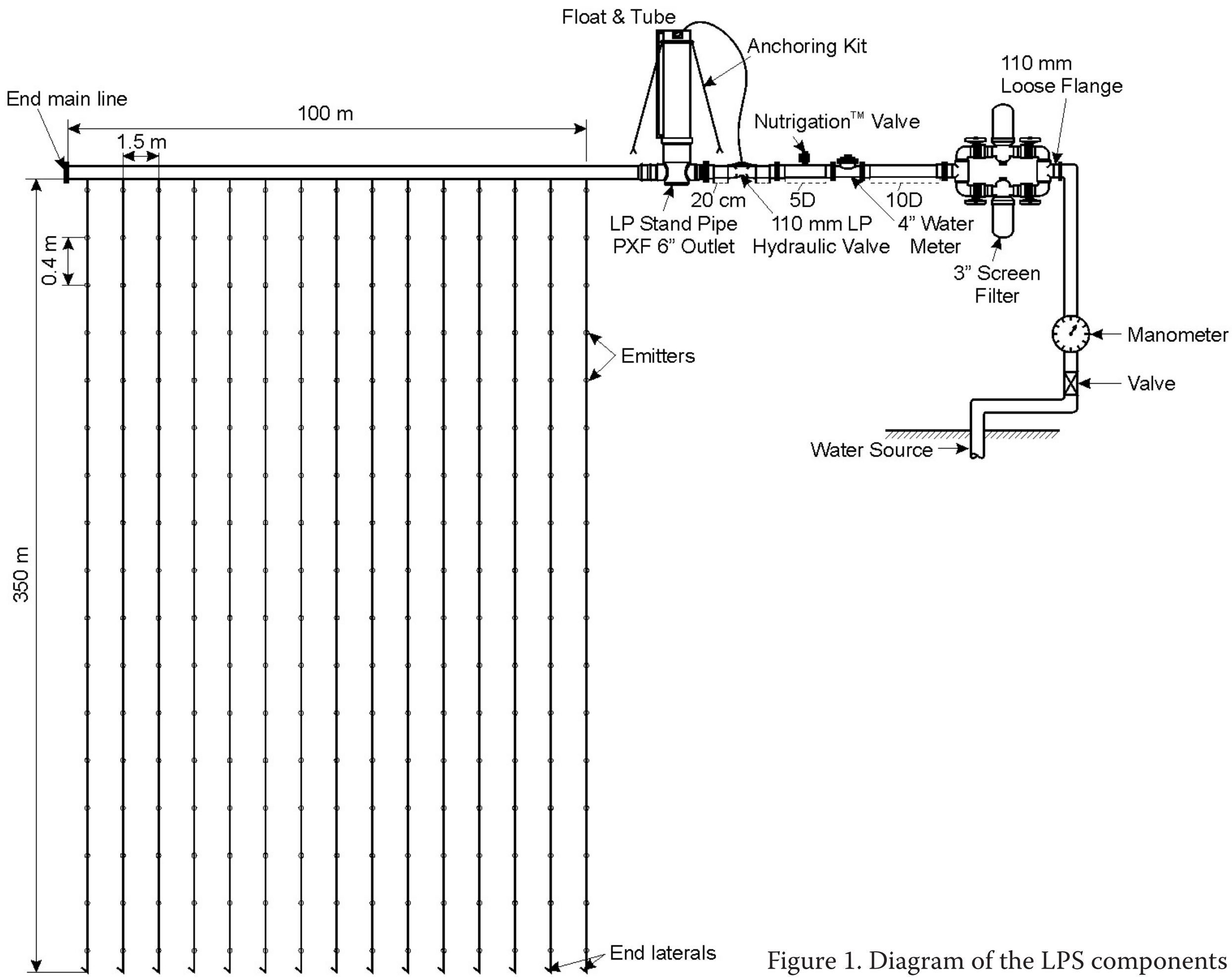

Figure 1. Diagram of the LPS components

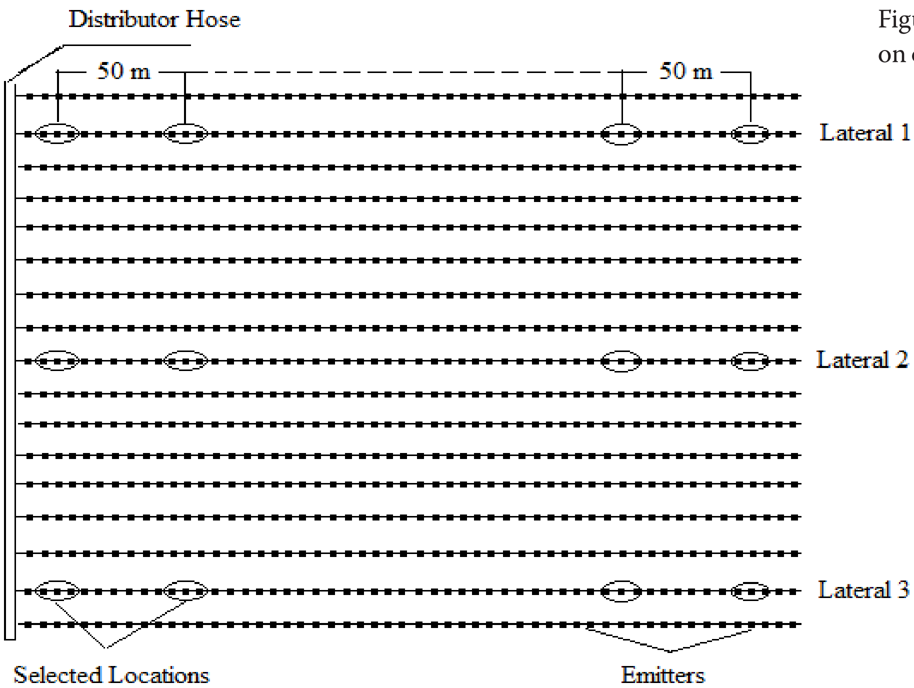

Figure 2. Diagram of the localization of control points in the test unit

The discharged flow at each control point is determined by measuring the volume of water discharged by each emitter during a definite time. Measuring time is usually 30 min, so that the experimental errors committed are minimised. Pressure was measured with gauges at the beginning and the end of each lateral. One-litre measuring cylinders were used to collect the water from the emitters. The measurements were repeated tree times for each season.

Evaluation parameters. Emission uniformity (*EU*) is determined as a function of the relation between the average flow emitted by 25% of the emitters with the lowest flow and the mean flow emitted by all the control emitters, as Eq. (1) shows (ASAE 1996a):

$$EU = \frac{\overline{q}_{25\%}}{\overline{q}_{\mathrm{a}}} \times 100 \qquad (1)$$

where:
EU – emission uniformity (%)
$\overline{q}_{25\%}$ – average of 25% of the lowest values of flow rate (l/h)
$\overline{q}_a$ – average flow rate (l/h)

The evaluated system is classified according to ASAE (1996a, b).

Absolute emission uniformity (EU_a) was defined by Keller and Karmeli (1974), and it considers not only the possible effects derived from the lack of water at certain points of the plant zones, but also the excess produced as a consequence of the application heterogeneity of the system. Its expression is exposed in Eq. (2).

$$EU_a = 0.5 \times \left[\frac{\overline{q}_{25\%}}{\overline{q}_a} + \frac{\overline{q}_a}{\overline{q}_{12.5\%}} \right] \qquad (2)$$

where:
$\overline{q}_{12.5\%}$ – average flow perceived by 12.5% of the plants which perceive the highest flow in the test subunit.

Flow variation coefficient (CV_q) is determined as related to the typical deviation of flow data and mean flow, as described in Eq. (3) (ASAE 1996b).

$$CV_q = SD/q_a \qquad (3)$$

where:
SD – standard deviation of flow (l/h)

Measurement of the consumptive working time. The study was focused on the consumptive time for repair and maintenance required for the laterals during the growing season. In addition, it was aimed at the consumptive time for the laterals retrieving before harvesting to calculate the costs and to find the problems that may occur during this operation.

After the drip system was installed, two persons were needed to maintain and repair the lateral bores and cracks by cutting these parts and using flare connectors (coupling or fittings) to connect the two lateral parts. Each worker used a stopwatch to calculate the consumptive time.

At the end of the season for maize, the installed laterals must be retrieved before harvesting because the harvesting procedure will destroy the tube. The machine manufactured by Netafim Company was used to collect or retrieve all laterals from the field. This machine requires a tractor and two workers.

A hydraulically driven reel is mounted to the rear of a trailer and an operator must manually overlook the operation.

The procedures for retrieving drip laterals from the field vary from grower to grower. But before retrieving the laterals, it must be made sure that there is no crop interference, and that the laterals have no water in them.

Before retrieving, the team must first disconnect the laterals from the PolyNet distributor hose manually (connectors, fitting) between the distributor hose and laterals. The drip lateral retriever remains at the field edge during operation. All operating times were measured according to Sourell *et al.* (2010) and the labour costs were calculated according to KTBL (2009).

RESULTS AND DISCUSSION

Uniformity of drip system

Performance uniformity of (new) unused laterals. Evaluation of uniformity parameters for the new LPS laterals according to ASAE EP458 method was done by Netafim working team (Dowgert *et al.* 2007). The experiment was conducted with the same laterals which were described in our study: with laterals 80 m in length and pressure of 30 kPa. The mean value for emitter discharge in unused irrigation laterals was 0.625 l/h with standard deviation ± 0.015 l/h (Figure 3).

Uniformity parameter values in two new irrigation laterals were similar. The highest mean values were EU = 99 and EU_a = 98.5%, and the lowest values were 98% for both of them. Emitter performance for each of the two new irrigation laterals was < 0.2, implying that there was no uniformity problem originating from hydraulics (Dowgert *et al.* 2007). The coefficients of variation of flow rates were 0.02 and 0.04, which was classified as excellent during the entire experiment in the irrigation system that was in operation in the first season.

Performance uniformity of used laterals. The performance parameters of the installed drip system are shown in Table 1 and Figures 4 and 5. The operating pressure of the system was 40 kPa during the 2nd and 3rd growing seasons.

Uniformity of discharge rate. The mean discharge rate of all emitters was 0.616 and 0.578 l/h for the 2nd and the 3rd season, respectively. Figure 4 shows that most emitters operate close to the mean discharge rate with standard deviation ranging from ± 0.05 to ± 0.08 l/h. However, the three laterals showed almost even discharge rates. On the other hand, Figure 5 shows that partial plugging of emitters for more than the 1st and 2nd season led to high variation between the emitter flows with high standard deviation (from 0.086 to 0.115 l/h).

According to the data plotted in Figures 3–5 the mean flow rate of the used laterals was lower than that of the new ones. The used laterals, probably the internal spiral layer of the laterals, stretched during the lateral installation or the retrieving operation at the end of last the season, which led to decreased discharge. In addition, some emitters are partially clogged (Safi *et al.* 2007).

Distribution uniformity. Evaluation of uniformity parameters and the variation observed in EU and EU_a for the 2nd and the 3rd seasons are shown in Table 1. The emission uniformities for all three laterals during the 2nd season ranged from 84.9 to 89.7%, meaning they were completely good according to Marriam and Keller (1978) and ASAE (1996a), and ranged between acceptable and good according to IRYDA (1983) for both EU and EU_a.

In contrast, the emission uniformities were determined for the 3rd season (Table 1) when the EU

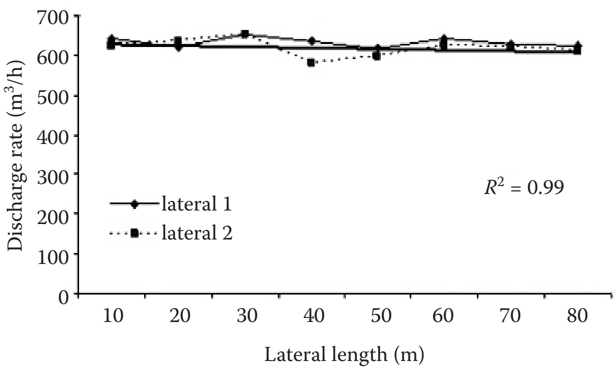

Figure 3. Discharge rate of selected emitters for the first season

Table 1. Distribution uniformity parameters for three laterals during two growing seasons

Distance from inlet (m)	Mean emitter discharge rate (means, l/h)					
	2nd season			3rd season		
	lateral 1	lateral 2	lateral 3	lateral 1	lateral 2	lateral 3
20	0.647	0.643	0.650	0.636	0.637	0.643
50	0.683	0.633	0.627	0.624	0.643	0.627
100	0.666	0.570	0.583	0.650	0.563	0.507
150	0.640	0.582	0.573	0.603	0.587	0.545
200	0.633	0.656	0.643	0.630	0.627	0.593
250	0.630	0.603	0.623	0.490	0.617	0.623
300	0.637	0.628	0.577	0.573	0.593	0.510
350	0.617	0.613	0.620	0.537	0.553	0.573
Average	0.636	0.602	0.609	0.580	0.581	0.573
SD (l/h)	0.054	0.080	0.051	0.095	0.115	0.086
CV_q	0.08	0.13	0.08	0.16	0.20	0.15
EU (%)	89.8	84.9	89.7	78	75.2	78.6
EU_a (%)	89	87.6	89.3	83	81.6	83

SD – standard deviation; CV_q – flow variation coefficient; *EU* – emission uniformity; EU_a – absolute emission uniformity

and EU_a values were 77.3 and 82.5% respectively. These values classified the system uniformity between poor and acceptable for *EU* and between acceptable to good for EU_a (ASAE 1996b; IRYDA 1983). In addition, by the partial clogging of some emitters, these results probably influenced some defects occurring during the retrieving operation at the end of the last season.

Flow variation coefficient (CV_q). The value for CV_q used in these calculations was taken from field estimated variability. The low CV_q indicated a good performance of the system throughout the cropping season. The coefficients of variation of flow rates were 0.08 to 0.13 during the second season and ranged from 0.15 to 0.20 during the third season (Table 1). Taking into account ASAE (1996b) classification, CV_q was marginal during the entire experiment in the irrigation system in the second season. In the third season, the CV_q value was unacceptable for most of the experiment. Similar results were estimated by Patel and Rajput (2007) for the in-line labyrinth type dripper, they were reported to between 0.046 and 0.066, indicating a good performance of the drip system. The problem must have been due to the clogging of some emitters. These results agree with those of the emission uniformities.

Consumptive working time

The installation working time of the drip system per hectare was calculated and plotted in Figure 6.

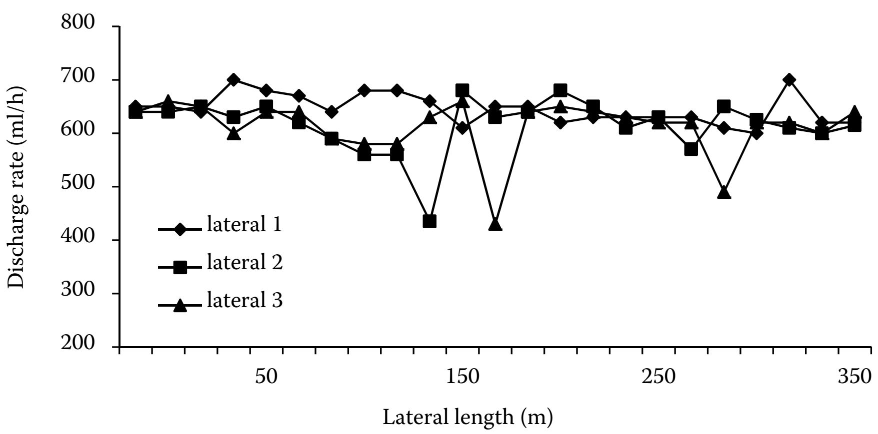

Figure 4. Discharge rate of selected emitters for the second season

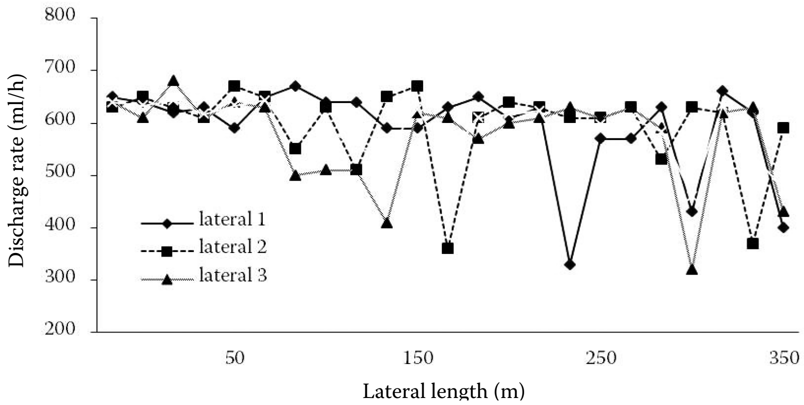

Figure 5. Discharge rate of selected emitters for the third season

There is no difference between the installation time spent for the new and the reused system (reused means the average data for both the second and the third season), where the installation time for the head station and distribution hose was 1.04 and 1.05 h/ha, respectively. On the other hand, there is a small increase in the installation time of reused laterals (from 6.9 to 7.56%). The reason for this increase was some splices or fittings which hindered the installing machine and took some time to repair.

Figure 7 shows the repairing time and number of problems for the three seasons (repairing time means the summation of all repair time during the season). There is a big difference between the new and the reused systems in the time spent on repairs and their number, where the number of repairs for the reused systems was 8 to 12 times higher than the number of repairs for the new one. The time spent on repairs was 0.52, 1.04 and 3.12 h/ha for the three seasons, respectively. It was observed that the repairing time was increased each season because of bores and laterals creaks which occur during the retrieval operation at the end of each season.

At the end of each season, especially for the annual crops, the drip system had to be removed from the field before harvesting. The system either had to be laid out in another field (in this case the whole drip system must be removed) or stored until needed again (in this case only the laterals must be retrieved). The data plotted in Figure 8 shows that there is no difference in the time spent in removing the head station and main line between both the new and reused systems (reused means the average data for both the second and third season). However, there is a small increase in the spent time for the reused laterals (7.25%) vs. the new ones.

This increase is caused by problems with fittings, when: (1) leading to stop the retrieving machine for

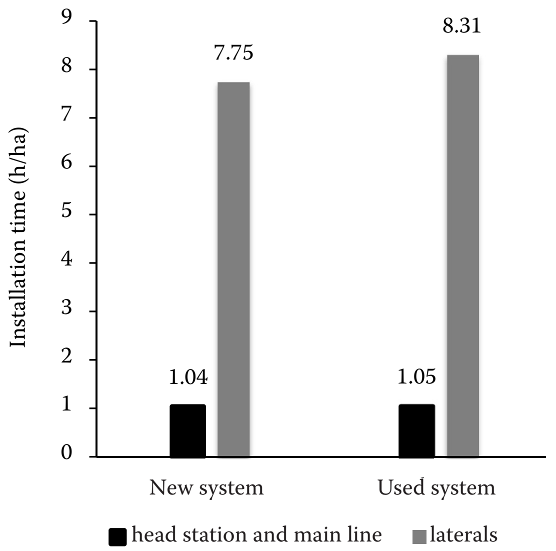

Figure 6. The installation working time of the drip system per hectare

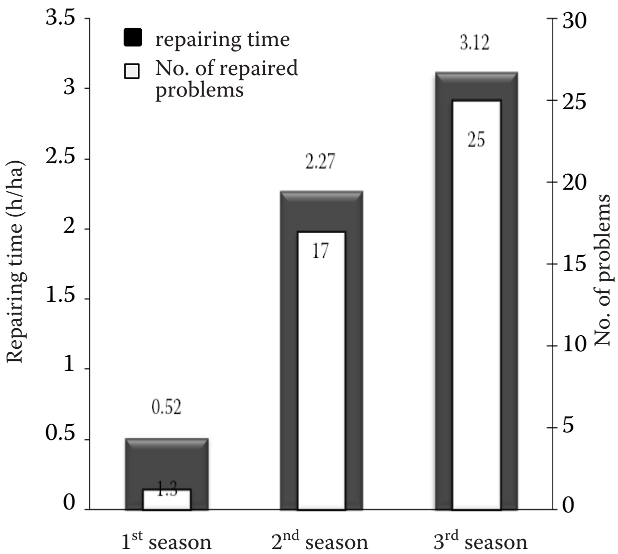

Figure 7. Spent time and the number of repairing problems for LPS laterals during three growing seasons

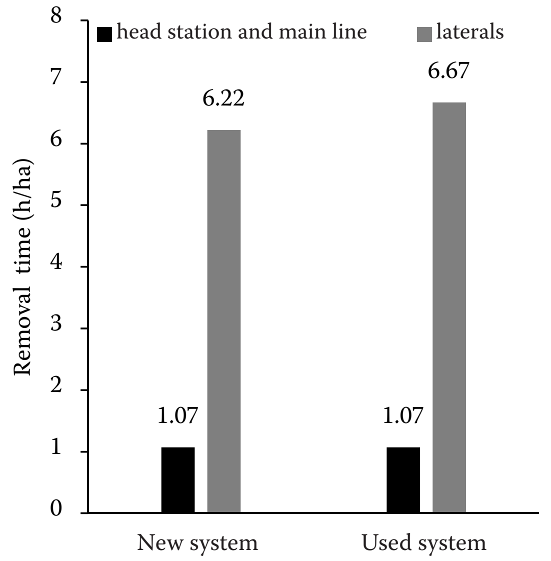

Figure 8. Spent time in removing the system during the 1st (new system), 2nd and 3rd season (used system)

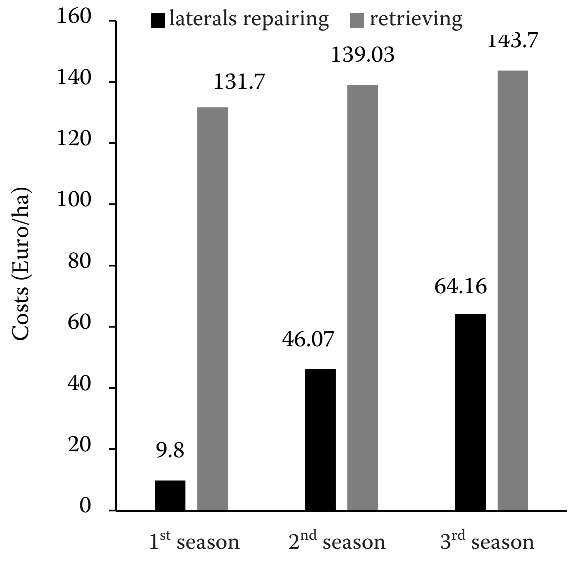

Figure 9. Total costs of repairing and retrieving laterals (€/ha)

some time (made rewinding the laterals difficult), (2) the fitting could fail in dividing the lateral into two pieces, so it had to be repaired and put back to work, and (3) sometimes the fitting stopped between two plants and could prevent the lateral retrieving. All of these reasons lead to an increase in the time needed for removing laterals.

Cost estimation of drip line repairing and removing

The total costs of laterals repairing and retrieving are shown in Figure 9. The repairing of laterals including the fitting price, the labour costs and the retrieving costs include the cost of tractor, retrieving machine (Netafim list price 2009) and labour (work-hour value according to KTBL (2009).

A comparison between repairing the laterals and retrieving both the new and reused systems (Figure 9) showed that the repairing cost for the reused laterals was 6.55 and 5.12 times higher than the new one. At the same time there is a small difference in retrieving costs between the three seasons. The results caused by the difference in working time were explained before (Figures 7 and 8).

CONCLUSION

LPS is a well-researched system for drip irrigation, typically that available for furrow irrigated crops. There are significant agronomic advantages of using a low-pressure, low-flow drip system specifically related to greater lateral water movement in the soil and a better air-water ratio. These advantages translate into measured improved water use efficiency when compared to furrow irrigated crops and energy savings compared to flood and sprinkler irrigated crops. Poor distribution uniformity of the system is caused by manufacturing variability, emitter blockage and wear and tear. Emitter clogging can be addressed by cleaning the emitters.

Also the repairs will immediately improve the field distribution uniformity. Over time, wear and tear will then become the main problem (e.g. damage which occurs during the laterals retrieving at the end of the last season adds to performance variability). The field defect variation estimates the effect of blockages and wear and tear on distribution uniformity by comparing the emitter emission uniformity to manufacturing variation. The coefficient of variation due to blockages, wear and tear is $CV_{defect} = 0.34$ (Barber 2006). This is at least 5 times, and probably more than 8 to 10 times, higher variation than it would be expected compared to new emitters.

Repeated reuse of the drip line leads to a decrease in the distribution uniformity and an increase in costs, when the distribution uniformity decreased by 10.5 and 21.6% for reusing the laterals in the second and third year, respectively. Moreover, the cost of repairing laterals was more than 5 and 6.5 times higher for both the 2nd and 3rd season.

It was observed that the laterals removal needed to be executed with care, otherwise there is a risk of stretching, especially if it is retrieved in the mid-afternoon. Stretching the laterals will cause non-uniformity because it increases the emitter spacing, causing the flow rate to decrease. Also, if stretching occurs, the wall of the lateral becomes thinner, meaning it could burst under field conditions. The laterals removal requires intensive labour because the work team must first undo the tail ends of the drip lines that are going to be retrieved in order to flush the water out.

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