A Report-Generating Computer Program for Evaluation of Field Drip Irrigation Systems

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ABSTRACT

A computer program for evaluation of field drip irrigation system is introduced. The program provides fast and accurate calculations of various evaluation parameters. The program is constructed such that it is capable of generating an evaluation report with system and situation description, remarks and recommendations. Evaluation parameters determined by the program include distribution uniformity (*DU*), emission uniformity (*EU*), low quarter potential and actual application efficiencies (*PELQ* and *AELQ*, respectively), system potential and actual application efficiencies ($PELQ_{system}$ and $AELQ_{system}$, respectively), wetted area percentage (*P*%), and average application depths (for wetted area D_{aw}, overall D_a, and minimum, D_n). This enables the grower or irrigator to progressively improve the system as it operates. Evaluation tests showed consistent response of the program to successive changes in the system (deterioration as well as improvements) and evaluation reports appeared to give the appropriate recommendations for every situation. It is believed that the program can be used as a useful tool for improving the performance, hence the efficiency, and management competence of field drip irrigation systems.

Key words: drip irrigation, trickle irrigation, irrigation evaluation, irrigation efficiency.

INTRODUCTION

Since it was first introduced in the early 60s of last century, drip (trickle) irrigation has been the subject of extensive examinations and studies, involving its design, operation, efficiency and management principles (e.g. Keller and Karmeli 1975); Goldberg *et al.* (1976); (Merriam and Keller 1978); Howel *et al.* (1981); (Nakayama and Bucks 1986); (Keller and Bliesner 1990). Advantages, disadvantages, and effects on the crop yield under different regional and climatological conditions were the objectives of numerous studies throughout the world (e.g. Schweers and Grimes 1976; Maber 1979; Mostaghimi *et al.* (1981); (Pai Wu 1982); (Armstrong and Wilson 1982); Oron *et al.* (1982); (Wamble and Farrar 1983); (Oron 1984); Tekinel *et al.* (1989); (Çetin 1997); (Ertek 1998); (Keser 1998); (Senyigit 1998). Ever since trickle irrigation was accepted as a new standard method of irrigation, it has undergone many improvements and enhancements (Jobling 1973); (Bucks and Davis, 1986); (Tekinel and Kanber, 2002) and the components of trickle systems were markedly augmented, namely emitters and piping designs and materials, pumps, and filters. Emitters in particular have recently developed significantly. Many new highly efficient designs and more durable and reliable material emitters became available and are now successfully used across the world.

Drip irrigation is based on high frequency–low volume, localized deliverance of water over a long period of application time, utilizing low-pressure for operation Hagan *et al*, (1967), (Bucks and Davis 1986), (Tekinel and Kanber, 2002). In drip irrigation systems, water is conveyed to the soil near the plant through a pipeline network where it is delivered directly into the plant's root zone through emitters (drippers) or injectors. Water leaves the dripper at zero pressure and gravity moves it to the soil and downward.

Although drip irrigation has several advantages over other types of irrigation, it is very susceptible to problems and drawbacks. The fact that water is delivered to the soil through small orifices makes incessant maintenance of emitters (i.e. cleaning, testing, replacing, etc.), and closely-watching the system in general, crucial issues for successful operating. Emitters are constantly exposed to damage, clogging or malfunctions. Emitter clogging, which represents a common and severe problem, can be caused by a variety of factors (van't Woudt, 1969); Davely *et al,* (1973); (Booher, 1974) including salt accumulation, particularly when irrigation water contains significant quantities of calcium or magnesium bicarbonates. These salts lead to the formation of carbonate encrustations on the outer side of the orifices, reducing the flow of water. Also, water containing dissolved iron may precipitate iron oxides and plug the outlets. Fertigation, or the injection of fertilizers such as phosphates or ammonia into irrigation water, could result in the formation of precipitates of calcium or magnesium compounds, leading to clogging of emitters or flow orifices. The growth of algae or filamentous bacteria inside the supply tubing can also plug orifices or emitters (Booher, 1974).

Trickle systems involve the use of plastic pipes that are prone to cracking, tearing, deterioration, or collapse which drastically affect their performance (Davely *et al,* (1973), (Booher, 1974).

Pressure and pressure control valves represent another principal concern in trickle system operation, where discharge is influenced greatly by pressure fluctuations, and variation among different parts of the system or pressure failures in parts of the network. In designing drip systems, it is often the case that supply line must follow an uneven surface, which requires that allowances must be made to compensate pressure differences induced by elevation variations (Booher, 1974; Merriam and Keller, 1978). Where supply lines are laid down a slope, special considerations must be given to gravity gains and friction losses in flow lines to maintain pressure distributions as uniform as possible. Selection of the appropriate tubing diameter plays a significant role in guaranteeing uniform pressure distribution and hence a uniform water flow. Pipes should be sufficient in diameter to avoid excessive friction losses (Rolland, 1972), (Withers and Vipond, 1980).

It is clear that due to this high vulnerability of trickle irrigation systems and its constant susceptibility to several adverse elements, continuous monitoring and evaluation of system performance and efficiency must be taken seriously and should be regarded as an essential operational task (Merriam and Keller, 1978).

In this article, an evaluation approach that depends on the use of computer is introduced. Computer programming facilitates the performance of multiple and subsequent tests and evaluations quickly and accurately. The introduced program is directed at providing the users- mostly growers or irrigationists-with accurate estimates as well as comprehensive evaluation and recommendation reports on different aspects of the system, and thus helping them to improve system performance and management.

MATERIALS AND METHODS

The program

The drip irrigation evaluation program is based principally on the approach adopted by (Merriam and Keller1978). The program is compiled using Turbo Basic language (Boreland, International, Inc., 1987). Required information is supplied in the form of line inputs. Calculations are performed by the program and results are presented both as screen displays and independent output files. Results consist of two sections: i) calculations and evaluation summary, and ii) evaluation report and recommendations. Output file is created in a plain text format that can be read on any computer machine.

The logic of report creation by the program is based on a process of conditional selection of statements from a broad database of information. For a given case, and for each determined value of a parameter or a combination of parameters, the program identifies the case, defines its conditions and limits, and selects the appropriate statements accordingly. These statements include descriptions, remarks, decisions and recommendations.

Program development and compilation were concluded in 2004. Validation and testing runs took place between 2004 and 2006.

Basic definitions and concepts

An understanding of a group of basic definitions and concepts closely pertinent to the subject of irrigation in general as well as some other parameters relevant particularly to drip irrigation is necessary for the use of the program.

A detailed overview section is included in the program. The overview comprises the background, definitions, and equations used in the program and can be accessed by user prior to data entering. Background and concepts presented in the *overview* section follow closely the terminology and definitions as presented by Merriam and Keller (1978). These include: soil moisture terms such as soil moisture deficit (*SMD*), management allowed deficit (*MAD*), and efficient operation with regard to soil moisture. Concepts also include soil uniformity and efficiency parameters such as: distribution uniformity (*DU*), emission uniformity (*EU*), potential application efficiency of low quarter (*PELQ*),

Information, equipment, field procedures and methods of utilization of field data to perform essential calculations are also presented, including the following: average application depth both for the wetted area (D_{aw}) and the overall average depth applied (D_a), average daily discharge per tree, and the overall minimum depth applied (D_n). The above terms and concepts are defined in the following section.

Soil moisture parameters

Soil moisture deficit (SMD): *SMD* is defined as an indicator of the dryness of the soil. It equals the depth of water (cm or inch) to be replaced by irrigation. It is more important to know the depth of water needed to bring the soil moisture to the desired degree of wetness than to know how much water (as depth) exists actually in the root zone (Merriam and Keller1978); Hansen *et al,* (1980) . The degree of dryness permissible under given conditions is closely related to the limit of soil moisture tension at which a crop can grow well.

Management allowed deficit (MAD):

MAD is an expression of the preferred *SMD* limit at the time of irrigation. It is hence an indicator of the maximum limit of soil dryness a crop can survive and keep producing an acceptable yield.

Efficient operation with regard to soil moisture:

Efficient operation with regard to soil moisture is a term that indicates the performance and capability of the irrigator or the system manager. Basic questions a grower or an irrigationist needs to answer in order to maintain an efficient operation of an irrigation system is whether the soil is sufficiently dry enough so irrigation can be started, and whether it is sufficiently wet to seize irrigation.

Uniformity and efficiency parameters

Parameters involved in uniformity and efficiency of irrigation system include:

Distribution uniformity (DU):

Distribution uniformity is a parameter that reflects the evenness or uniformity of infiltration of irrigation water into the soil of a given field. An expression for distribution uniformity is as follows:

$$DU = \frac{\text{average depth infiltrated in the lowest one quarter of the area}}{\text{average depth of water infiltrated}} \times 100 \quad [1]$$

where the average low quarter depth of infiltrated water comprises the lowest ¼ of determined values (measured or estimated). Values referred to here should be determined for equal areas of the field. Unlike surface irrigation, and provided that no runoff takes place, the depth of water infiltrated in drip irrigation is approximately equal to the water depth applied. Distribution uniformity *DU* presents a very adequate means of expressing distribution problems, where low *DU* indicate excessive deep percolation losses. A *DU* lower than 67% is regarded as poor or unacceptable.

Emission uniformity (EU): Emission_uniformity is evaluated in order to indicate whether the efficiency of operation of drip system is satisfactory. The following formula is used

$$EU = \frac{\text{minimum rate of discharge per plant}}{\text{average rate of discharge per plant}} \times 100 \quad [2]$$

where the minimum referred to is the average of the lowest quarter.

Classes of *EU* values for systems operating for a season or more are: >90%, "excellent"; 80-90%, "good"; 70-80%, "fair"; and < 70%, "poor".

Potential application efficiency of low quarter (PELQ):

PELQ is an indicator of system performance that can be achieved under reasonably efficient management under application of desired irrigation plans.

$$PELQ = \frac{\text{average low quarter depth infiltrated when equal to MAD}}{\text{average depth of water applied when MAD just satisfied}} \times 100 \quad [3]$$

Application efficiency of the low quarter (AELQ):

The parameter *AELQ* represents an indicator of how well the system is being utilized. It is expressed as:

$$AELQ = \frac{\text{average low quarter depth of water stored in the root zone}}{\text{average depth of water applied}} \times 100 \quad [4]$$

Potential application efficiency:

Under drip irrigation water is applied to parts only of the field and it is always difficult to estimate *SMD* because parts of the wetted soil in the root zone often remain near field capacity even under irrigation frequencies of several days. *SMD* estimates are therefore prone to significant error, and some safety margin is allowed. Generally, about 10% more water than estimated *SMD* (or evapotranspiration) is applied to areas with the least water. Accordingly, *PELQ* is calculated as *PELQ* = 0.9 *EU*

Efficiency reduction factor (ERF):

The majority of drip irrigation systems are not equipped with pressure or flow regulators at the inlet to each lateral, and most systems have only a means of pressure control at the inlets to the manifolds. It is important that inlet pressures of the manifolds are carefully adjusted, or otherwise system *PELQ* will be lower than the *PELQ* of the tested manifold. An efficiency reduction factor, *ERF*, is computed from the minimum lateral inlet pressure, *MLIP*, along each manifold by the equation:

$$ERF = \frac{\text{average } MLIP + 1.5 \times \text{minimum } MLIP}{2.5 \times \text{average } MLIP} \quad [5]$$

System potential application efficiency $PELQ_{system}$

Efficiency reduction factor (*ERF*) and test *PELQ* are used to calculate an approximated estimate of *system PELQ*. The following equation is used:

$$PELQ_{System} = ERF \times Test\ PELQ \quad [6]$$

Another, more accurate method of determining *ERF* is possible if the emitter discharge exponent, *x*, is known. The equation is:

$$ERF = \left(\frac{\text{minimum } MLIP}{\text{average } MLIP}\right)^x \quad [7]$$

System application efficiency ($AELQ_{system}$)

As is the case with *PELQ*, *AELQ* also must be corrected for drip irrigation systems. Efficiency or effectiveness of the system can be checked through estimates of the amount of applied irrigation water that is stored in the root zone and is available for plant consumptive use. Considering that under drip irrigation, losses due to evaporation or runoff are virtually negligible when areas with least water are under irrigated, then:

$$AELQ_{System} = ERF \times \text{Test } EU \quad [8]$$

On the other hand, If the least irrigated areas receives excess water, then the equation becomes:

$$AELQ_{System} = \frac{\text{SMD in wetted area}}{\text{average depth applied to wetted area}} \times 100 \quad [9]$$

Utilization of field data

Average application depth to the wetted area (D_{aw}):

$$D_{aw} = \frac{1.605 \times N \times gph \times hours}{\text{wetted area}} \text{ inch} \quad [10]$$

where *N* is number of emitters, the wetted area (ft^2) is determined from field measurements, and the number 1.605 is a conversion factor.

Overall average application depth (D_a):

The overall average depth applied, D_a (applied depth with regard to whole field), is calculated with the replacement of tree spacing for the wetted area in Eq. [10], giving:

$$D_a = \frac{1.605 \times N \times gph \times hours}{l \times w} \text{ inch} \quad [11]$$

where l and w are spacing (ft) in the longitudinal and across directions, respectively.

Overall Minimum Depth Applied (D_n)

A useful relation in management of irrigation scheduling is obtained as the product of the overall average depth applied to the total area, D_a, and system *PELQ*.

If there is under irrigation and *AELQ* is > *PELQ*, *AELQ* is used instead of *PELQ*, that is:

$$D_n = D_a \times (PELQ_{system} \text{ (or } AELQ_{system}) / 100) \text{ inch} \quad [12]$$

RESULTS AND DISCUSSION

Program validation

The program was put through a large number of tests for validation. One complete, 3-case evaluation test is presented below as a typical detailed example.

The original test data used by (Merriam and Keller 1978) for system evaluation were used in this evaluation test as a case with a solid reference to compare with. Here we compare program results with manually calculated values. The test has three successive cases (stages). These will be referred to as: casel, case 2, and case 3. The first evaluation case with original data is thus "evaluation case 1".

Tables (1a, b and c) show the original input field information and measurements used in the evaluation process, including orchard and tree information, emitter flow measurements and manifold pressures. The test farm had a design similar to the diagram presented in Figure (1). Tests can be applied to fields of similar design or other designs provided that the system (or a block in the system) comprises a mainline, sub-mains, manifolds and laterals as shown.

Flow measurements were taken for 16 locations on 4 laterals on the test manifold and flow rates were determined on 4 locations on each lateral as well. For each of the 16 locations, the discharges of 2 emitters were collected (total measurements of 32). Averages of each 2 emitters were used.

Results obtained by the program for above input data Table (2) were quite accurate and matched exactly those obtained by manual calculations. Program calculations are shown in Table (3a).

In addition to calculated results, the program determines the appropriate class of emission uniformity (*EU*). The class in this test case was "*good*".

A principal and important advantage of this program is that it creates a comprehensive analysis report describing the situation and providing the user with remarks on drawbacks, defects, or operational problems, suggesting the appropriate solutions. The diagnostic report of this test is shown in Table (3b) (test case 1).

The analysis handles 4 main characteristics: 1) pressure variations within the system, 2) uniformity of application, 3) percentage of the wetted area, 4) potential application efficiency *PELQ* and application efficiency *AELQ*.

As seen in Table (3b), the program calculated pressure variations of 9.195%, and indicated that this percentage falls within the acceptable limit of 20%. The report suggests the need for better valve control to avoid more differences and to improve current condition. The report points out that pressure variations are more pronounced among manifolds (19.048 %) and suggests that such a high value reflects poor valve control and that the problem must be fixed. It reiterates that manifold inlet valves should be adjusted to give nearly the same *MLIP* on each manifold in order to increase the system application efficiency.

Table 1a: General agronomic and system information

Type: citrus orchard- 7 years old
Tree spacing 22 × 22 ft
Root depth: 4 ft
Percent area covered or shaded = 70%
Soil texture: silt loam
Available moisture: 2 in ft^{-1} (0.16 by volume)
Irrigation duration: 6 hours
Frequency: daily
MAD = 10%
Filter pressure: inlet = 60 psi, outlet = 55 psi and loss= 5 psi
Emitter make SP - type: flushing, point spacing: 6 ft
Rated discharge per emission point = 3.0 gph at 30 psi
Number of emission points per plant = 4, with total discharge of 72 gallons $plant^{-1}$ day^{-1}
Hose: diameter= 0.58 in, material PVC, length 150 ft, spacing = 22 ft.

Table 1b: Flow averages of the 16 points for the laterals on the test manifold

Outlet location on lateral	Lateral location on the manifold – Discharge in gph (average 2 emitters/location)			
	Inlet end	1/3 down	2/3 down	Far end
Inlet end	2.32	2.77	2.64	3.18
1/3 down	2.60	2.80	2.74	2.78
2/3 down	2.88	2.38	2.23	2.54
Far end	2.34	2.58	2.98	2.18
Average flow rate of all points = 2.62 gph				
Average flow rate of lowest ¼ = 2.27 (low quarter values are underlined)				
	Pressures (psi)			
Lateral inlet	47.5	45.0	45.5	45.0
Closed end	46.0	43.3	45.0	44.0
	Wetted area (ft^2 and %)			
ft^2	150	125	140	145
%	31	26	29	30

Table 1c: Minimum lateral inlet pressures, *MLIP*, on all operating manifolds within block (8 manifolds)

Manifold	Test	A	B	C	D	E	F	G	Average
MLIP, psi	45	49	47	43	42	50	48	45	46.1

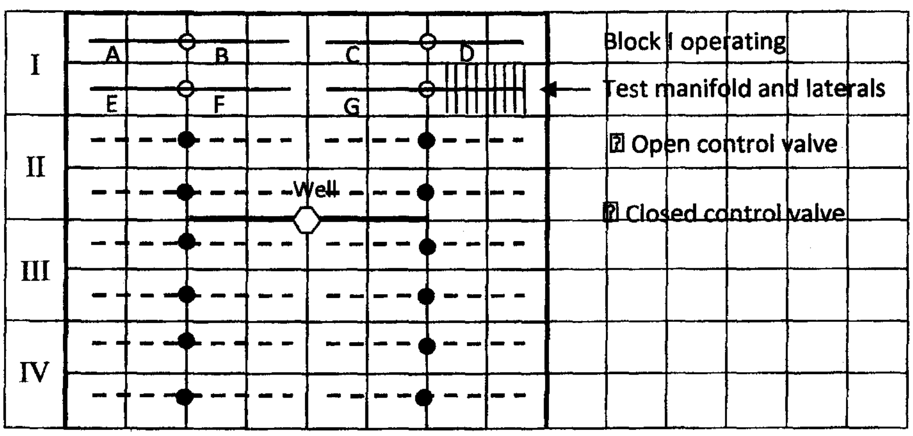

Fig. 1: Example of system layout

The report then addresses the subject of uniformity of application (emission uniformity, *EU*) and comments on the value of 86.641 % determined for the system as one that reflects a *'good'* level of distribution uniformity, and indicates a satisfactory system performance and management. It finally indicates that most of the lack of uniformity of application resulted from variations in operation of the individual emitters suggesting that this could be verified by examining emitters discharge data. It points out that emitters may have considerably different flow, despite having almost similar pressures indicating that in that case the conditions of individual emitters should be evaluated.

The next parameter evaluated in the report is the percentage of wetted area. The program calculated a wetted area of 28.93 % and reported that it was slightly less than the recommended one third of the area required for efficient system performance. The report suggests that the wetted area may be increased either by increasing the number of emitters from the current number (4 emitters per tree) by one or two more and reducing the operation pressure accordingly. Increasing the operation duration together with increasing irrigation frequency is based on the fact that longer applications wet more soil volume.

Table 2: Sample input screen showing inputs for test case 1. Results are presented in subsequent Tables

INPUT SCREEN

Do you want to change the output file name? y
Enter new name (8 letters or less): case_1.out

DATA & MEASUREMENT
What type is your trickle system? Orifice type (o) or tube type (t)?:o
Enter number of emission points per tree, N: 4
Enter average gph at emission points: 2.62
Enter the number of hours of operation per irrigation: 6
Enter measured wetted area for 4 points on laterals along manifold, squared foot: 150,125,140,145
Enter spacing in the long (length) direction (ft): 22
Enter spacing in the short (width) direction (ft): 22
Enter avg. emission point discharge from the lowest quarter, use average of manifolds lowest quarter (gph): 2.27
Enter irrigation interval (frequency) in days- Inter 1 for daily: 1
Pressures among all operating manifolds:
Enter highest measured minimum lateral inlet pressure, MLIP of all operating manifolds (psi): 50
Enter minimum of the minimum lateral inlet pressure, MLIP (psi): 42
Enter average minimum lateral inlet pressure, MLIP (psi): 46.1
Enter minimum lateral inlet pressure, MLIP of the test manifold (psi): 45
Pressures of laterals on test manifold:
Enter highest measured pressure of all laterals of test manifold (psi): 47.5
Enter lowest measured pressure of all laterals of test manifold (psi): 43.5

Table 3a: Program results and evaluation output report for test case 1 (original data)- Part 1: calculations and system *EU* classificatio

TRICKLE IRRIGATION SYSTEM EVALUATION

I. RESULTS

The average depth applied per irrigation Daw = 0.731 inch
Overall average depth applied Da = 0.212 inch
Average daily gallons per tree = 63.793 gallons per day

1. Emission Uniformity
Emission Uniformity EU = 86.641 % **Note: EU class is: Good**

2. Potential Application Efficiency:
Test Potential Application Efficiency PELQ = 77.977 %
Efficiency Reduction Factor ERF = 0.947
System Potential Application Efficiency PELQsys = 73.816 %

System Application Efficiency AELQ = 82.018 %

4. Overall minimum depth applied:
Overall minimum depth applied Dn = 0.156 inc

The fourth element evaluated by the program report is the potential application efficiency (*PELQ*) and application efficiency (*AELQ*). The report reminds the user of the significant differences in pressure among manifolds, indicating that the markedly high value of 19.05 % determined for differences between lateral inlets on the test manifold could influence both *PELQ* and *AELQ* of the system. The report suggests that the manifold inlet valves should be adjusted to give the same minimum lateral inlet pressure on each manifold. This would increase the system's *PELQ* and *AELQ* to the *PELQ* and *AELQ* of the tested manifold, which is an increase of 4.16 % according to program estimates.

It can be seen that the computer–generated analysis and recommendation report provides the grower or the program user with a vital and useful evaluation and presents him with a number of important suggestions that can be valuable in improving system performance.

In order to track the response of the program to various system situations, the above data were re-entered after introducing two alterations derived from actual pressure-flow relations of the system.

The first alteration was intended to simulate a,

Table 3b: Program results and evaluation output report for test case 1 (original data) - Part 2: evaluation analysis and recommendations

II. ANALYSIS AND RECOMMENDATIONS:

The following observations and recommendations are made based on the analysis of system data and the computations of pressure differences, EU, percentage of wetted area, PELQ and AELQ.

1. Pressure Variations:

Pressure differences throughout the test manifold are within acceptable limits for orifice-type emitters. Pressure variations of 20% for orifice-type emitters result in flow differences of about 10 %.

Therefore; the determined differences of 9.195 % among laterals on test manifold are acceptable.

However, these values still reflect an imperfect valve control system.

i.e. they can take more adjustment and improvement to make sure the differences are reduced, or - at least - do not increase.

Valve control problems are reflected more dramatically in minimum lateral inlet pressure variations (MLIP) among different manifolds. These pressure variations were calculated as 19.048 %. This value apparently indicates poor valve control. This problem must be fixed and manifold inlet valves should be adjusted to give nearly the same MLIP on each manifold in order to increase the system application efficiency.

2. Uniformity of Application:

Emission Uniformity

The Emission Uniformity EU determined for the system = 86.641 %

This value reflects a 'good' level of distribution uniformity and indicates a satisfactory system performance and management.

Good distribution uniformity seen here is apparently the result - partly at least - of the good pressure distribution on the laterals, as reported above (section 1 of this report).

It appears, therefore that most of the lack of uniformity of application resulted from variations in operation of the individual emitters. This can be verified by examining the emitters discharge data. Emitters may have considerably different flow, despite having almost similar pressures.

In this case the conditions of individual emitters should be evaluated.

3. The Percentage of Wetted Area:

The determined percentage of wetted area of 28.93 % seems too small relative to the recommended minimum for arid areas. A reasonable design objective for arid regions is to wet at least one-third (P = about 33 %) of the cropped area.

Improving the percent of wetted area is necessary. It should be raised to more than one-third of the area.

This could be achieved by:

- increasing the number of emitters per tree by adding one or two emitters to each tree in addition to the 4 emitters operating now, and decreasing the operating pressure accordingly.
- doubling the current operating hours of 6 per day to 12 hours and increasing the frequency to 2 days, because longer applications wet more soil volume.

4. Potential Application Efficiency PELQ and Application Efficiency AELQ:

As reported before, the differences in pressure among manifolds are high

The value of 19.05 % determined for differences between lateral inlets on the Test manifold is high and could influence both the Potential Application Efficiency (PELQ) and the Application Efficiency (AELQ) of the system. The manifold inlet valves should be adjusted to give the same minimum lateral inlet pressure on each manifold. This would increase the system's PELQ and AELQ to the PELQ and AELQ of the tested manifold, which is a 4.16 % increase.

END OF REPORT

case of over-all drop in system pressure to < 35psi where the flow rates and wetted areas are accordingly affected, and the low quarter discharge rate dropping to 1.1 gph. A summary of this low pressure case data (given the name: case 2) is shown in Table 4. Flow rates and wetted area values were obtained by interpolation of actual data. Obviously, completely theoretical input data could be utilized for evaluation as well, but it was preferred here to have input values based on original data. The only assumed value in this case is the low quarter average. The idea is to check the program response to a much lower flow rate in the lowest quarter under conditions of lower-than-optimum operation pressure, then examining the response once again, through another alteration (test case 3) as the low quarter average undergoes relative improvement.

Improvement in this case will involve simulation of fixing emitter problems (e.g. repairing or replacing clogged or damaged emitters) while operating the system still under the same low pressure. Results of case 3 will be discussed in a subsequent section.

Results of case 2, shown in Table (5), reflect major deterioration of the system performance as a result of pressure drop from a range of 42-50 psi, with an average of 46.1 (original data, case 1, Table 1a,b and c) to a range of 18.0 to 34.3 with an average of 26.99 psi Table (4). According to the report, the new determined *EU* value of 67.24% is classified as *"poor"*. The report describes pressure differences throughout the test manifold (determined as 22.78%) as "too high" indicating that they fall outside acceptable limits. It attributes this to poor control valves. Report identifies differences of >90% in *MLIP* values among different manifolds. The report attributes poor *EU* to system performance and/or management problems, emphasizing the need for significant improvements, and pointing out in particular to variations in pressure, and hence in flow, as the most likely cause. It suggests inspection and corrections of possible leaks, control valves, and emitter clogging and damage. The report refers as well to the considerably low percentage of wetted area (20.04%) and suggests ways to correct it.

Continuing with this case, and in order to inspect the program's response to subsequent system modification, a new change was introduced to simulate partial fixing of the above problems. The average of the low quarter flow rate was increased from 1.10 gph to 1.30 gph. Concurrently, the flow rates of three of the manifolds with lower flow rates which appeared to be affected by emitter problems such as clogging and damage (namely, the test manifold, and manifolds B and D) increased to 1.80, 1.10 and 1.50 gph (corresponding to increases in flow rates of about 5-10%). The program was re-run to evaluate this new case (case 3) with partial correction, but still at low-pressure conditions. Results are shown in Table (6) along with cases 1 and 2. Partial excerpts of the output result/report relevant to system changes are shown in Table (7).

As seen in Tables (5 and 6 and 7,)a relative improvement of the system performance is observed as partial repair (fixing emitter clogging, etc.) was accomplished, although the system still suffers from low operating pressure. Improvements (case 3) were reflected in increases that ranged from slight to significant in comparison with case 2. The average depth of applied irrigation (D_{aw}) increased by 7.57%. Overall average depth applied (D_a) increased by 10.24% and average daily gallons per tree by 10.02%.

Table 4:Input data simulating low-pressure and low flow rate of the lowest quarter (case 2)

Manifold*	Pressure (psi)	Flow rate (gph)	Wetted area (ft^2)
All manifolds			
Test	28.1	1.64	87.34
A	25.1	1.46	78.01
B	18	1.05	55.95
C	27.7	1.61	86.10
D	24	1.40	74.60
E	34.4	2.00	106.61
F	28.5	1.66	88.58
G	30.2	1.76	93.87
Average	**27.0**	**1.57**	**83.88**
Test manifold			
Lateral location on the manifold	**Pressure (psi)**	**Flow rate (gph)**	**Wetted area (ft^2)**
Inlet end	34.5	2.01	107.2
1/3 down	32.0	1.86	99.5
2/3 down	30.6	1.78	95.1
Far end	28.1	1.64	87.3
Average	**31.3**	**1.82**	**97.3**

*Refer to Fig 1.

Table 5:Program results and output report for case 2 (low-pressure and low flow rate of the lowest quarter)

TRICKLE IRRIGATION SYSTEM EVALUATION

I. RESULTS

The average depth applied per irrigation Daw = 0.634 inch
Overall average depth applied Da = 0.127 inch
Average daily gallons per tree = 38.318 gallons per day

1. Emission Uniformity

Emission Uniformity EU = 67.237 % **Note: EU class is: Poor**

2. Potential Application Efficiency:

Test Potential Application Efficiency PELQ = 60.513 %
Efficiency Reduction Factor ERF = 0.800
System Potential Application Efficiency PELQsys = 48.420 %

3. Application Efficiency:

System Application Efficiency AELQ = 53.800 %

4. Overall minimum depth applied:

Overall minimum depth applied Dn = 0.062 inch

II. ANALYSIS AND RECOMMENDATIONS:

The following observations and recommendations are made based on the analysis of system data and the computations of pressure differences, EU, percentage of wetted area, PELQ and AELQ.

1. Pressure Variations:

Pressure differences throughout the test manifold are too high!
They are not within acceptable limits for this type of emitter.
Pressure variations greater than 20% for orifice-type emitters result in flow differences that exceed 10%.
Therefore; the determined differences of 22.776 % among laterals on test manifold must be lowered.
Obviously, it is important that each control valve be adjusted accurately to ensure uniform pressures throughout the field.
Apparently, this is not the case here.
In addition to these variations on test manifold, minimum lateral inlet pressure variations (MLIP); calculated for different manifolds as 90.556 % reflect very poor valve control. This problem should be fixed and manifold inlet valves should be adjusted to give nearly the same MLIP on each manifold in order to increase the system application efficiency.

2. Uniformity of Application:

Emission Uniformity
The Emission Uniformity EU determined for the system = 67.237 %
This value reflects a 'poor' level of distribution uniformity and indicates that the system performance and/or the management need major improvements.
It seems from the considerable pressure variations determined and described before (section 1) that radical corrections in the pressure (and consequently the flow) distribution system are needed; namely:

1. leaks,
2. checking the control valves, and
3. emitters clogging and damage

It is imperative that problems should be checked and fixed to improve the system performance.

3. The Percentage of Wetted Area:

The determined percentage of wetted area of 20.04 % seems too small relative to the recommended minimum for arid areas. A reasonable design objective for arid regions is to wet at least one-third (P = about 33 %) of the cropped area.
Improving the percent of wetted area is necessary. It should be raised to more than one-third of the area.
This could be achieved by:
- increasing the number of emitters per tree by adding one or two emitters to each tree in addition to the 4 emitters operating now, and decreasing the operating pressure accordingly.
- doubling the current operating hours of 6 per day to 12 hours and increasing the frequency to 2 days, because longer applications wet more soil volume.

4. Potential Application Efficiency PELQ and Application Efficiency AELQ:

As reported before, the differences in pressure among manifolds are high
The value of 90.56 % determined for differences between lateral inlets on the test manifold is high and could influence both the Potential Application Efficiency (PELQ) and the Application Efficiency (AELQ) of the system. The manifold inlet valves should be adjusted to give the same minimum lateral inlet pressure on each manifold. This would increase the system's PELQ and AELQ to the PELQ and AELQ of the tested manifold, which is a 12.09 % increase.

END OF REPORT

Table 6: Change in calculated parameters as a result of varying system operating conditions. A comparison between test cases

Determined variable	Case 1: Original	Case 2: low pressure	Case 3: low pressure-emitters fixed
Average depth applied per irrigation, D_{aw} (in)	0.731	0.634	0.682
Overall average depth applied, D_a (in)	0.212	0.127	0.140
Average daily gal./tree	63.79	38.32	42.16
Emission uniformity, *EU*	86.64%	67.24%	72.22%
EU class	Good	Poor	Fair
Test potential application efficiency, *PELQ*	77.98%	60.51%	65.00%
System *PELQ*	73.82%	48.42%	52.01
System application efficiency *AELQ*	82.02%	53.80%	57.79
Overall minimum depth applied D_n (in).	0.156	0.062	0.073
Pressure diff. among laterals on test manifold	5.56%	22.78%	22.78%
MLIP among manifolds	19.05%	90.56%	90.56
Percentage of wetted area	28.93%	20.04%	20.51%

Table 7: Partial excerpts of program output report for case 3 (low pressure with partial corrections)

TRICKLE IRRIGATION SYSTEM EVALUATION

I. RESULTS

The average depth applied per irrigation Daw = 0.682 inch
Overall average depth applied Da = 0.140 inch
Average daily gallons per tree = 42.160 gallons per day

1. Emission Uniformity

Emission Uniformity EU = 72.222 % Note: EU class is: Fair

2. Potential Application Efficiency:

Test Potential Application Efficiency PELQ = 65.000 %
Efficiency Reduction Factor ERF = 0.800
System Potential Application Efficiency PELQsys = 52.010 %

3. Application Efficiency:

System Application Efficiency AELQ = 57.788 %

4. Overall minimum depth applied:

Overall minimum depth applied Dn = 0.073 inch

II. ANALYSIS AND RECOMMENDATIONS:

The following observations and recommendations are made based on the analysis of system data and the computations of pressure differences, EU, percentage of wetted area, PELQ and AELQ.

1. Pressure Variations:

Pressure differences throughout the Test manifold are too high!
They are not within acceptable limits for this type of emitter. Pressure variations greater than 20% for orifice –type emitters . . .

↓

2. Uniformity of Application:

Emission Uniformity
The Emission Uniformity EU determined for the system = 72.222 %
This value reflects a 'fair' level of distribution uniformity and indicates an acceptable system performance. It may indicate also that the performance and/or the management can take some improvement.
It seems from the significant pressure variations determined and described above that corrections in the pressure (and consequently the flow) distribution system are needed. In fact, based on the poor pressure distribution reported earlier, the emission distribution uniformity of the system could be even worse than determined in this test block. The improvements and corrections needed should examine and fix problems related to:
1. leaks,

2. the control valves, and

3. emitters clogging and damage

3. The Percentage of Wetted Area:

The determined percentage of wetted area of 20.51 % seems too small relative to ....

↓

4. Potential Application Efficiency PELQ and Application Efficiency AELQ:

As reported before, the differences in pressure among manifolds are high.
The value of 90.56 % determined for differences between lateral inlets on the test manifold is high and could influence both the Potential Application Efficiency (PELQ) and the Application Efficiency (AELQ) of the system. The manifold inlet valves should be adjusted to give the same minimum lateral inlet pressure on each manifold. This would increase the system's PELQ and AELQ to the PELQ and AELQ of the tested manifold, which is a 12.99 % increase.

END OF REPORT

Emission uniformity, *EU* gained an increase of 7.41%, test potential application efficiency, *PELQ*, had an increase of 7.42%, while system *PELQ* increased by 7.41%. System application efficiency, *AELQ*, increased by 7.42%, overall minimum depth applied D_n by a marked 17.74%, while the percent of the wetted area increased by merely 2.25%. As a result of these partial improvement, *EU* class rose from "*poor*" to "*fair*". Obviously, all above parameters are still lower than those of case 1 which had the most appropriate operational conditions of all three cases.

These results lucidly reflect good response of the program to changing system operating situations and to subsequent alterations of system characteristics, which endorses the belief that it could represent a useful and practical tool for improvement of system performance as well as management competence.

SUMMARY AND CONCLUSIONS

The introduced drip irrigation evaluation program showed consistent performance and produced fast and accurate results. Program validation showed its good capability to provide the user with reliable evaluation results, which cover mainly uniformity and efficiency, as well as a detailed report including case description, evaluation, remarks and recommendations. Iterative use the program on field situations undergoing successive improvements, based on recommendations and suggestions, is supposed to enable the user to improve the system performance as well as management efficiency. It is thus believed that the program can provide a very practical and useful tool for better management of field drip irrigation systems.

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الملخص العربي

برنامج حاسب آلي ذو إمكانية إصدار تقرير لتقييم نظم الري الحقلي بالتنقيط

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يقدم البحث برنامجا للحاسب الآلي تم تصميمه من أجل عمل تقييم لنظم الري الحقلي بالتنقيط. يقوم البرنامج بإجراء الحسابات بسرعة ودقة عاليتين لكل عناصر التقييم المطلوبة. تم تصميم البرنامج بحيث يكون قادرا على إصدار تقرير للتقييم، يشمل وصفا لحالة النظام، والملاحظات المهمة الخاصة به، كما يعطي مجموعة من النصائح والتوصيات من أجل تحسين الأداء. تشمل عناصر التقييم كلا من تجانس التوزيع *(DU)*، تجانس التنقيط *(EU)* ، كفاءة الإضافة الممكنة والفعلية للربع الأقل (*PELQ* و *AELQ* على الترتيب)، كفاءة الإضافة الممكنة والفعلية لنظام الري بالكامل ($PELQ_{system}$ و $AELQ_{system}$ على الترتيب)، نسبة المساحة المبتلة *(P%)*، والأعماق المتوسطة للإضافة (للمساحة المبتلة D_{aw} ، ولكل النظام D_a وكذلك الحد الأدنى D_n).ومن شأن هذا انه يمنح المُزارع أو القائم على الري فرصة لتحسين النظام تدريجيا أثناء عمله. أوضحت اختبارات التقييم استجابة البرنامج للتغيرات المتتالية في أداء النظام (سواء بالتدهور أو بالتحسن) وأعطى مابدا أنه النصائح المناسبة لكل موقف. في تقديرنا أن هذ البرنامج يمثل أداة مفيدة يمكن استخدامها لتحسين أداء نظام الرى، وبالتالي كفاءته، كما أنه يساعد في رفع كفاءة إدارة .