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Evaluation of Hydraulic and Irrigation Performances of Drip Systems in Nectarine Orchards in the Mediterranean Region

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Abstract: This study focused on evaluating the performance of the drip irrigation systems installed in 18 different nectarines (Prunus persica var. nucipersica) orchards in the Tarsus Plain in the Mediterranean region from 2017 through 2018. The performance of drip systems was evaluated based on parameters like average emitter discharge (Qavg), Christiansen uniformity coefficient (CU), distribution uniformity (DU), emission uniformity (EU), and system application efficiency (Ea). The results indicated that CU varied between 81-98%; DU changed from 82 to 97%; EU 61-92%; absolute emission uniformity (EUa) ranged between 93-98%; statistical uniformity (Us) changed from 85 to 97%; application efficiency of low-quarter (AELQ) varied between 45-97%; potential application efficiency of low-quarter (PELQ) ranged between 55-83%; system application efficiency (Ea) changed from 56 to 96%; storage efficiency (Es) fluctuated between 45-97%; pressure variation (Pv) 17-81% and emitter flow variations (qv) of 2-36% were determined. Although CU, DU, and EU values were acceptable, the variations in emitter flow rates and pressure were not acceptable. Results revealed that the lower performances might be attributed to clogging and/or lack of system design and application practices by the farmers. It is recommended that the farmers get appropriate training on the operation and management of drip irrigation systems.

Keywords: emitter flow variation; pressure variation; distribution uniformity; application efficiency; emission uniformity

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1. Introduction

The evaluation of operating irrigation systems aims at the understanding of the system's adequacy and the determination of the necessary procedures for improving the system's performance. It is recommended that the evaluation should be carried out soon after the system's establishment in the field or orchard, and periodically repeated, especially when considering drip irrigation systems due to their sensitivity to operational conditions along the time [1,2,3]. Drip irrigation, the most widespread micro-irrigation technique, is characterized by a high uniformity of water distribution and the capability to deliver the water directly to the root zone of the plant at a controlled timing, hence theoretically minimizing evaporation and deep drainage [4,5]. However, to be efficiently applied, irrigation water must be uniformly applied. That is, with each irrigation, approximately the same amount of water must be applied to all of the plants irrigated. If irrigation is not uniformly applied, some areas will get too much water and others will get too little. As a result, plant growth will also be nonuniform, and water will be wasted where too much is applied. Uniformity is especially important when the irrigation system is used to apply chemicals along with the irrigation water because the chemicals will only be applied as uniformly as the irrigation water.

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The successful performance of a drip irrigation system depends on the physical and hydraulic characteristics of the drip tubing. A best and desirable feature of drip irrigation is that the uniform distribution of water is possible, which is one of the most important parameters in the design, management, and adoption of this system [6]. Ideally, a well-designed system applies nearly equal amounts of water to each plant maintaining uniformity, meets its water requirements, and is economically feasible. The efficiency of drip irrigation system depends on application uniformity which can be evaluated by direct measurement of emitter flow rates. The main factors affecting drip irrigation uniformity are manufacturing variations in emitters and pressure variations caused by elevation changes, friction head losses throughout the pipe network, emitter sensitivity to pressure, irrigation water temperature changes, and emitter clogging [7,8]. Therefore, evaluating the hydraulics of drip irrigation systems helps improve the design of drip irrigation systems and better distribution of irrigation water [6].

The uniformity of water application from a microirrigation system is affected both by the water pressure distribution in the pipe network and by the hydraulic properties of the emitters used [7]. The emitter's hydraulic properties include the effects of emitter design, water quality, water temperature, and other factors on emitter flow rate. Factors such as emitter plugging and wear of emitter components will affect water distribution as emitters age.

Proper system design, management, and maintenance are essentials for higher irrigation efficiency [9]. Although the nonuniformity of water distribution by a drip system may be attributed to many factors, the hydraulic characteristics of emitters are considered the most important of these factors [10]. The variation in water distribution by emitters may occur due to pressure changes, manufacturing variations, emitter sensitivity to clogging, temperature effects, and others [11].

Drip irrigation has made tremendous strides in the past four decades, and has become the modern standard for efficient irrigation practices for water conservation and optimal plant responses. Micro irrigation is an extremely flexible set of technologies that can be economically used on almost every crop, soil type, and climatic zone, but it requires a high level of management [8]. Getting the expected benefit from drip irrigation depends on projects designed and managed carefully by trained specialists and carefully running the drip irrigation. The system should be carried out and processed as suggested in the project. The first investing expenses of drip irrigation are high and carrying out drip irrigation requires too much data and skill. Therefore farmers should be informed about the management of drip irrigation systems and they should be made conscious of the system. Thus, the systems should be used more effectively and efficiently.

It is stated that system evaluation techniques can be used to determine the system's potential for more economical and efficient operation by revealing irrigation performance under current operating conditions [1]. Such studies are important in deciding whether to continue with current implementations or whether business adjustments can be made. Parameters that affect the system such as system water application efficiency (Ea), lower quarter potential, and actual application efficiencies (PELQ and AELQ) to evaluate the irrigation performance of systems developed by researchers [12]. PELQ and AELQ indicate whether the system is properly operated, and display operating errors.

The hydraulic performance of the drip irrigation system is indicated by water distribution uniformity, which is measured by the uniformity coefficient, emission uniformity, coefficient of variation, and coefficient of manufacturing variation [13]. The uniformity coefficient and emission uniformity increased while the coefficient of variation decreased as the operating pressure head increased for all emission devices [14]. The different measures for the hydraulic performance of drip irrigation systems are very useful for the effective design and operation of the system [15]. The coefficient of uniformity (CU) and the distribution uniformity (DU) generally increase with increasing heads and decrease with increasing slope. The CU generally followed a linear relationship with either head or slope [16].

The use of microirrigation is rapidly increasing around the world, and it is expected to continue to be a viable irrigation method for agricultural production in the foreseeable future. With increasing

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demands on limited water resources and the need to minimize the environmental consequences of irrigation, microirrigation technology will undoubtedly play an even more important role in the future [8]. The use of drip systems has increased since the early 2000s for converting surface irrigation systems to drip through a national subsidy system by the Turkish Government. Therefore, through this subsidy program, many growers in Tarsus Plain located in the eastern Mediterranean region of Turkey have also converted their system to a drip system. Tarsus Plain has an important place in our country's agricultural activities. In 2017, 106.674 tons of products were obtained from 7252 ha nectarine orchards. In particular, the nectarine plant has started to be preferred extensively by the producers in the region [17].

The objectives of this study are to evaluate the performance of drip irrigation systems in the young nectarine orchards in the Tarsus Plain located in the eastern Mediterranean region of Türkiye. The performance evaluation of the drip systems was based on both the hydraulic performance criteria such as distribution uniformity, emission uniformity, Christiansen uniformity coefficient, pressure variation, flow rate variation, statistical uniformity coefficient, and irrigation management performance criteria such as application efficiency, potential application efficiency of the low quarter, actual application efficiency of the low quarter, storage efficiency under the grower's operation conditions. The performance parameters of the drip systems tested are compared with the standards set by ref. [18].

2. Materials and Methods

2.1. Experimental Site and Soil

The research was carried out between 2017-2018 in eighteen nectarine orchards in Tarsus, in the eastern Mediterranean region of Türkiye. The elevation of Tarsus is 12 meters above sea level and a typical Mediterranean climate prevails in the region. The average annual temperature in the region is 18.2°C. According to the long-term historical measurements (1965-2018), the average relative humidity is 70.2% and the annual evaporation is 1478 mm. The average annual rainfall is 630 mm, mostly distributed from September to May with a high inter-annual variability. The long-term historical average climate characteristics of the study are given in Table 1 [19].

Table 1. Long-term monthly mean climatic data for the nectarine orchards in Tarsus Plain.

Months	February	March	April	May	June	July
Tmin °C	6.9	9.2	12.9	16.8	20.9	24.0
Tmax °C	15.5	18.1	21.6	24.9	28.1	30.7
Tmean °C	11.1	13.8	17.5	21.3	25.0	27.8
Sunshine time (h)	5.6	6.8	7.6	8.5	9.8	10.0
Number of rainy days	9.2	7.6	6.6	5.1	2.2	0.9
Monthly precipitation (mm)	85.1	55.2	34.7	23.4	9.0	6.8

Tmax: maximum air temperature; Tmin: minimum air temperature; Tmean: mean air temperature.

This study was carried out on 18 selected nectarine orchards irrigated with a drip system in the Tarsus Plain. Nectarine orchard size ranged from 1.1 ha to 9.0 ha, and the age of orchards varied from 1 to 9 years. In the orchards, trees were planted with 3 m row spacing and 5 m in the rows.

The soils in the selected orchards were examined by taking gravimetric soil samples at four locations in each orchard; and the following analyses were carried out to determine water holding capacity, texture class, soil salinity, bulk density, organic matter content, lime amounts, and pH. In addition, double-ring infiltrometer tests were carried out to determine the infiltration rate of soils. The soil analysis in the laboratory revealed that soil water content at field capacity varied between 7.50-35.43%, wilting point values ranged from 5.35 to 27.12%, and bulk density values changed between1.27-1.60 g cm^{-1}. Soil infiltration rates (I) varied from 6.1 to 21.4 mm h^{-1} and soil salinity values (EC) fluctuated between 0.398-6.10 dS m^{-1}. Organic matter contents ranged from 0.46-1.50%, lime amounts ranged between 7.37-34.32% and pH values varied between 7.64-8.26. The soil textures were clay-loam in orchards P1 and P2, sandy-loam in orchards P7, P10, and P11, and clay in other orchards. Some of the physical and chemical properties of the soils of the selected orchards are given in Table 2.

Table 2. Some physical and chemical properties of the soils in the selected nectarine orchards.

Orchard No	Soil Depth cm	BD g cm^{-3}	FC % Pw	WP % Pw	Particle size distribution (%) Sand	Clay	Silt	Texture Class	I Mm h^{-1}	pH	EC dS m^{-1}
P_1	**0-30**	**1.38**	**26.86**	**17.57**	**33.9**	**29.5**	**36.7**	CL	8.2	7.92	0.598
	30-60	1.27	27.53	18.18	31.7	31.6	36.8	CL		8.05	0.755
	60-90	1.33	32.17	22.07	29.1	38.1	32.8	CL		7.84	1.098
P_2	0-30	1.40	27.13	17.88	27.2	31.7	41.1	CL	8.6	7.93	0.480
	30-60	1.43	25.93	17.60	31.5	29.6	38.9	CL		8	0.398
	60-90	1.44	27.25	18.43	29.4	31.6	38.9	CL		7.73	1.010
P_3	0-30	1.33	32.43	26.57	6.3	70.1	23.6	C	6.5	7.84	4.240
	30-60	1.39	32.88	27.12	6.0	70.3	23.7	C		7.8	7.550
	60-90	1.35	33.53	24.16	13.5	54.6	31.9	C		7.82	4.240
P_4	0-30	1.30	32.15	25.54	9.8	69.4	20.8	C	6.3	7.74	3.660
	30-60	1.32	32.12	26.44	7.6	67.3	25.1	C		7.85	4.680
	60-90	1.34	32.23	26.90	5.8	67.0	27.2	C		7.88	6.190
P_5	0-30	1.36	30.81	20.17	22.4	40.1	37.5	C	7.9	7.72	0.795
	30-60	1.47	29.85	18.27	24.8	35.8	39.4	CL		7.74	0.792
	60-90	1.41	31.17	19.32	18.4	37.9	43.7	SiCL		7.71	0.977
P_6	0-30	1.38	29.63	19.90	20.2	44.3	35.5	C	8.2	7.91	0.552
	30-60	1.37	30.62	20.68	22.1	40.2	37.6	C		7.88	0.626
	60-90	1.44	29.79	19.60	24.5	35.9	39.6	CL		7.9	0.634
P_7	0-30	1.52	8.98	6.95	79.6	10.2	10.2	SL	18.4	7.48	0.629
	30-60	1.55	7.73	5.55	83.7	8.1	8.1	LS		7.38	0.603
	60-90	1.60	8.23	5.82	83.7	8.2	8.2	LS		7.47	0.589
P_8	0-30	1.33	32.87	23.63	3.2	60.3	36.5	C	6.5	8.00	0.878
	30-60	1.39	32.91	25.04	11.4	54.1	34.5	C		7.98	1.311
	60-90	1.35	33.19	24.42	9.9	51.6	38.5	C		7.91	0.831
P_9	0-30	1.33	32.04	24.14	13.2	53.1	33.7	C	6.4	7.64	0.678
	30-60	1.39	31.40	25.37	23.8	55.2	21.0	C		8.1	0.656
	60-90	1.35	32.47	25.38	15.4	57.3	27.3	C		8.26	0.945
P_{10}	0-30	1.52	8.92	6.89	79.0	10.5	10.5	SL	19.6	7.45	0.633
	30-60	1.55	7.65	5.70	83.4	8.2	8.4	LS		7.33	0.608
	60-90	1.60	8.29	6.00	83.1	8.3	8.6	LS		7.44	0.594
P_{11}	0-30	1.51	9.01	7.04	79.2	10.5	10.3	SL	21.4	7.40	0.638
	30-60	1.57	7.50	6.50	83.4	8.5	8.1	LS		7.39	0.615
	60-90	1.60	8.40	5.35	83.2	8.4	8.4	LS		7.46	0.590
P_{12}	0-30	1.36	29.56	21.04	16.7	48.6	34.7	C	6.7	8.06	0.607
	30-60	1.43	32.52	23.79	11.4	57.7	30.8	SiC		8.02	0.756
	60-90	1.40	30.07	21.59	1.6	57.2	41.2	C		8.07	0.554
P_{13}	0-30	1.32	33.05	23.90	11.6	56.1	32.3	C	6.4	7.98	0.666
	30-60	1.40	34.09	23.56	15.7	56.2	28	C		8.12	0.602
	60-90	1.42	35.27	23.70	13.6	56.2	30.2	C		8.14	0.674
P_{14}	0-30	1.34	33.56	24.97	11.9	72.7	15.4	C	6.8	8.32	0.894
	30-60	1.44	33.82	25.35	9.8	74.9	15.4	C		8.46	1.295
	60-90	1.41	34.43	25.15	5.5	74.7	19.7	C		8.50	1.980
P_{15}	0-30	1.35	33.00	23.70	11.6	56.1	32.3	C	7.1	7.96	0.680
	30-60	1.41	35.45	23.78	15.7	56.2	28	C		8.10	0.615
	60-90	1.40	33.56	23.60	13.6	56.2	30.2	C		8.12	0.680
P_{16}	0-30	1.32	32.56	24.97	11.9	72.7	15.4	C	7	8.30	0.900
	30-60	1.41	32.82	24.35	9.8	74.9	15.4	C		8.40	1.300
	60-90	1.42	35.43	25.15	5.5	74.7	19.7	C		8.46	1.983
P_{17}	0-30	1.34	27.61	19.37	19.4	19.4	44.0	C	6.4	8.01	0.504

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	30-60	1.44	28.12	19.82	14.6	14.6	44.3	SiC		7.96	0.466
	60-90	1.41	29.35	21.48	12.2	12.2	44.5	SiC		7.91	0.684
	0-30	1.40	32.11	22.99	19.8	44.5	35.7	C		7.68	0.574
P_{18}	30-60	1.40	32.11	21.69	19.7	44.6	35.7	C	6.1	7.83	0.502
	60-90	1.42	31.61	21.01	21.7	44.7	33.6	C		7.87	0.598

FC, Field capacity; WP, Permanent wilting point; BD, Bulk density.

2.2. Components of Drip Irrigation Systems in Selected Orchards

The drip systems installed in the 18 nectarine orchards were inspected visually from the control unit to the laterals. On the control unit, filter types, pressure gauges, and fertilizer tanks were inspected. Then, mainline pipe material, length, diameter; manifold material, length and diameter, and lateral line length, emitter spacing were also examined.

2.3. Measurements and Analysis in the Field

Measurements and observations in the selected orchards were carried out in the irrigation system sub-units, to represent the production area. The evaluation tests were carried out in one subunit for the obtainment of the performance criteria. Some performance criteria such as uniformity (application uniformity, distribution uniformity, statistical uniformity, emission uniformity, emitter discharge coefficient of variation due to hydraulics, the change of hydraulics on manifold and laterals, etc.), irrigation efficiencies (maximum application depth, application efficiency, potential and actual application efficiencies in the low quarter, etc.), wetting pattern of the system, etc. were measured or estimated, analyzed and evaluated by using the mentioned measurement values. Emitter flow and pressure variation along the lateral line in selected irrigation subunits in each orchard were measured and how these measurements were made are explained in the following paragraphs.

2.4. Hydraulic Performance Parameters

2.4.1. Emitter Flow and Pressure Measurements

The emitter flow rate and pressure measurements in the trial orchards were carried out using the method given by ref. [1]. By measuring the emitter flow rates and emitter pressures, average, minimum and maximum emitter flow rates and average emitter pressures have been determined and evaluations have been made by comparing the values specified by ref. [18]. Emitter flow rates were determined volumetrically using shallow plastic containers under the emitters in tested laterals for 5-minute durations. Thus, flow measurements were made on at least 16 drippers in each lateral, and at least 64 drippers in each drip system. Mean emitter flow rates are determined by Equation (1) and average emitter pressures are determined by Equation (2).

$$qavg = \frac{1}{n}\sum_{i=1}^{n} q_i \quad (1)$$

In this equation, qavg is the average emitter flow rate, L h^{-1}; qi is the emitter flow rate of the ith emitter, L h^{-1}; n is the number of emitters.

$$Pavg = \frac{1}{n}\sum_{i=1}^{n} P_i \quad (2)$$

where Pavg is the average emitter pressure, bar; Pi is the pressure at the i^{th} emitter, bar; n is the number of emitter.

Pressure Variations in Laterals (Pv)

Pressure measurements were made at the inlets and outlets of the selected subdomains, and 4 laterals on each subdomain (at the inlet of the manifold and lateral, 1/3, 2/3, and the end) using pressure gauges. Emitter flow rates and pressure measurements were made at the selected laterals. Pressure measurements were made at the inlet, 1/3, 2/3 away from the inlet, and at the end of the lateral. The pressure variations were estimated using Equation (3).

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$$P_v = (P_{inlet} - P_{outlet})/P_{inlet} \quad (3)$$

where; Pv: manifold or lateral pressure variation, %; P_{inlet}: sub main or lateral inlet pressure, (bar); P_{outlet}: sub main or lateral outlet pressure, (bar). In drip irrigation system design, the maximum pressure variation allowed is 20% [1].

Emitter Flow Variation (qv)

Emitter flow variations in the laterals were calculated by the equation 4 [7].

$$q_v = [(q_{max} - q_{min})/q_{max}]x100 \quad (4)$$

where qv: Emitter flow variation, %, q_{max}: Maximum emitter flow rate, L h^{-1}, q_{min}: Minimum emitter flow rate, L h^{-1}. General standards for qv values are: 10% or less (desired) 10% to 20% acceptable and above than 25%, not acceptable [18,6].

Coefficient of Variation (Cv) of the Emitter Flow

The manufacturing variation coefficient is a measure of the flow variation of a randomly selected emitter that has been manufactured by a producer in a certain model and size, has never been used, or has not been worn. The estimated producer modification coefficient must belong to a new emitter operating at a constant temperature and operating pressure. The manufacturing variation coefficient was determined by Equation (5) and its evaluation was made according to ref. [18].

$$Cv = \frac{S_d}{qavg} \quad (5)$$

where, Cv: Manufacturing coefficient of variation Sd: Standard deviation of emitter flow rates L h^{-1}; qavg: Average emitter flow rate, L h^{-1}. The guidelines for classifying the manufacturing coefficient of variation are given in ref. [18].

Christiansen Uniformity Coefficient (CU)

Christiansen uniformity coefficient (CU) gives the information that how efficiently water is distributed in the field. CU is calculated using equation 6 given by ref. [20].

$$CU = 100.0 - 80.0\frac{Sd}{q_{avg}} \qquad (6)$$

where Sd: Standard deviation of emitter flow rates L h^{-1}; qavg: Average emitter flow rate, L h^{-1}. The guidelines for classifying the Christiansen uniformity coefficient (CU) are shown in Table 4 [18].

Distribution Uniformity (DU)

Distribution uniformity (DU) is another index of application uniformity. Distribution homogeneity (DU) is the ratio of the average amount of water in 1/4 of the land receiving the least water to the average amount of water retained in the whole land. The fact that the dripper uniformity values are a very good indicator that all the drippers measured in the system give very close flow values and that an equal amount of water is applied to the whole area. The distribution homogeneity (DU) was calculated with Equation (7) and its evaluation was made according to ref. [1].

$$DU = 100\frac{q_{lq}}{q_{avg}} \qquad (7)$$

In the equation, DU: Distribution homogeneity, %; qlq: The symbol shows the lower quarter average emitter flow rate, L h^{-1}, and qavg: the average emitter flow rate, L h^{-1}.

Emitter Flow Uniformity (EU)

For the emitter flow uniformity ref. [20] presented a design method to determine irrigation depth and interval, system capacity, emitter flow characteristics and uniformity, and hydraulic design considerations. Furthermore, they developed two formulas to estimate the design emission uniformity for drip irrigation systems; these formulas are expressed as follows in Equation (8) and its evaluation was made according to Table 4. [18].

$$EU = \left[1 - 1.27\frac{Cv}{N^{0.5}}\right]\frac{q_{min}}{q_{avg}} \quad (8)$$

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where, EU: Dripper flow emission (output) uniformity, %; N: Evaluated number of emitters for each plant; Cv: Coefficient of variation; qmin: minimum emitter flow rate, L h^{-1}; qavg average emitter flow rate, L h^{-1}.

Statistical Uniformity (Us)

Statistical Uniformity (Us) is calculated using the equation given below according to the principles given by ref. [21].

$$Us = 100\ (1 - C_v) = 100\ \left(1 - \frac{S_d}{q_{avg}}\right) \quad (9)$$

In the equation, Cv is: the coefficient of variation; Sd is the standard deviation of emitter flow rates L h^{-1}; qavg is the average emitter flow rate, L h^{-1}. Statistical uniformity is evaluated according to ref. [18] based on the classification criterion presented in Table 4.

Irrigation Management Performance Parameters

Irrigation performance evaluation is made on farmers' operation conditions in the selected nectarine orchards in one irrigation application for each orchard since the farmers apply a fixed irrigation scheduling (weekly water application and durations set by growers). The following criteria were evaluated for irrigation management.

Wetting Percentage (P)

The wetting percentage (P) was determined by equation 10 by measuring the wetted area in the field, taking into account the tree row spacing and tree spacing. The wetted area was estimated about 15 cm below the soil surface under an emitter following an irrigation in the selected nectarine orchards.

$$\mathrm{P} = 100\left(\frac{\mathrm{A_w}}{\mathrm{S_s S_a}}\right) \quad (10)$$

where P: Wetting percentage, %; Aw: Wetted area, m^2; Ss: Tree row spacing, m; Sa: Tree spacing, m.

Storage Efficiency (Es)

Storage efficiency is a criterion for irrigation efficiency determined by sufficient water application until the moisture deficit in the plant root zone reaches the field capacity. In calculations, the equation given by Ref. [22] was used.

$$E_s = 100 \times \frac{S_{rz}}{SMD} \quad (11)$$

In the equation Es: Storage efficiency, %; Srz: the amount of water stored in the root zone (or depth of soil to be wetted) during irrigation, mm; SMD: The amount of water deficit in the root zone before irrigation (the amount of water required to bring the available moisture to the field capacity), mm. SWD was determined by gravimetric soil sampling at three depths (0-30; 30-60; and 60-90 cm) a day before the date of irrigation scheduled.

Water Application Efficiency (Ea)

The application efficiency (Ea) of an irrigation system is defined as the percentage of total water applied accumulated in the plant root zone. When the plant root zone is fully irrigated according to the required water volume, the water application efficiency (Ea) ref. [23] calculated through the given Equation (12).

$$E_a = 100 \times \frac{Vs}{V_a} \qquad (12)$$

In the equation Ea: Water application efficiency, %; V_s: Required (water stored in the root zone) irrigation water, m^3; V_a: Total amount of water applied in the wetted area, m^3.

Potential Application Efficiency of Low-Quarter (PELQ)

Potential application efficiency in the low quarter (PELQ) is calculated using the approach given by Ref. [1].

$$PELQ = 0.9 \times EU \quad (13)$$

In the equation, PELQ: Potential application in the low-quarter; EU: Emitter flow uniformity, %.

Actual Application Efficiency of Low-Quarter (AELQ)

Actual application efficiency low-quarter (AELQ), is calculated using the approach given by ref. [1].

$$AELQ = 100\,\frac{SMD}{d} \quad (14)$$

where AELQ: actual application efficiency of low quarter, %; SMD: soil moisture deficit in the rootzone, mm; d: depth average water applied through emitters, mm.

2.5. Water Sources

Water supplied from deep wells in 7 of the orchards, and from open channel irrigation network in 10 orchards in the performance evaluation study. Water samples were taken for each orchard, and analyzed in the laboratory for water quality. Information regarding the water quality of canal water and well waters (EC and pH values) is presented in Table A1. In general, both water resources have good quality for irrigation but they are rich in CO_3 and HCO_3 which causes emitter clogging in the drip systems.

3. Results

3.1. General Properties of Drip Irrigation in Nectarine Orchards

General characteristics of the drip irrigation systems in the nectarine orchards are given in Table A1. The sizes of these orchards varied between 1.1-9.0 ha, planting spacing of fruit trees (tree row spacing x tree spacing in rows) 5x3 m, and tree ages between 2-10 years. System filters consist of hydrocyclone, sand-gravel, disc, and hydrocyclone + disc filters. Farmers supply water from the deep wells using hydrocyclone and disk filters and obtain water from open channel systems utilizing sand-gravel filters as primary filters along with disk filters. Polyethylene (PE) and PVC pipes are used in main pipe and manifold pipelines. Manifold pipe diameters vary between 50-90 mm, main pipe diameters 75-140 mm, manifold line lengths vary between 50 and 385 m and main pipe lengths change from 100 to 487 m. The lateral pipe diameters of 16 and 20 mm were used on the systems and lateral lengths vary between 50-191 m. Fertilizer tanks existed on the drip systems tested. However, only a few growers used them for fertigation, others used conventional fertilizer applications. Farmers in general cleaned filters at the beginning and in the middle of the growing season.

Inline emitters with 2 L h^{-1} discharge rates are commonly used for irrigation of orchards in the project area. Some growers used pressure-compensating emitters on their systems. Average emitter flow rates (q_{avg}) measured in the drip systems varied between 1.5-2.9 L h^{-1} and mean operating pressures (P_{avg}) changed between 110-350 kPa as shown in Table A1.

3.2. Evaluation of Hydraulic Performance Criteria

Lateral pressure variations (Pv) fluctuated between 17-81%, and emitter flow variations ranged from 2 to 36% as shown in Table 5. In drip irrigation design, the maximum pressure variation allowed as stated by ref. [8] is 20%. The lateral pressure variations in the tested plots remained above 20% in most of the 18 orchards except in P5, P6, and P16 orchards. The reason for greater pressure variations is due to using longer lateral lengths (>150 m) and partial clogging of emitters. Growers do not use any chemicals (acid treatment) to prevent emitter clogging in their systems. A major problem encountered in drip irrigation is the plugging or clogging of emitters. Emitter plugging can adversely affect the rate of water application and the uniformity of water distribution. Therefore, regarding the

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pressure variations in the laterals generally greater than 20%, should alter their system design and use acid injection for the prevention of clogging to reduce pressure variations in their systems.

Emitter flow variations observed in the tested drip systems were usually at acceptable levels. General standards for emitter flow variation (qv) values are 10% or less (desired) and 10% to 20% acceptable and above 25%, not acceptable. [18,6]. Emitter flow variation remained between 10-20% acceptable limits in P8 and P10 orchards. However, flow variations above 25% were observed in P12, P13, and P15 orchards which are unacceptable. Therefore, flow variations greater than 20% should modify their system design in order to reduce flow variations.

The coefficient of variation of the emitter flows (Cv) for the tested drip systems varied between 3–15% and their classifications were made according to ref. [18] shown in Table A1. (Appendix A). Calculated performance values and the Classification evaluation of some performance criteria for selected nectarine orchards are given in Table 4 and Table 6, respectively. In the classification of emitter flow rate change coefficient (Cv) in point source emitters Cv < 5% is classified as Excellent, Cv = 5-7% good, Cv = 7-11% medium, Cv = 11-15% low and CV> 15% unacceptable ref. [18]. It is understood that emitter flow rate variation coefficients are excellent in 5 orchards (P2, P9, P14, P16, P18) good in P3, medium in 9 orchards, and low in 3 orchards (P8, P12, P15). The research results reveal that Cv values are classified as excellent and medium in general, thus considering the magnitude of Cv values are acceptable for the drip systems tested. Growers of orchards with low Cv values should consider design changes in their system to reduce Cv values to acceptable levels.

Table 4. Classification of the some performance criteria for different uniformity expressions [23,1].

Classification	Cv (%)	CU (%)	DU (%)	EU (%)	Us (%)
Excellent	<5	>90	>85	≥94	>90
Good	5-7	80-90	70-85	81-87	80-90
Fair	7-11	70-80	60-70	68-75	70-80
Low	11-15	60-70	50-60	56-62	60-70
Unacceptable	>15	<60	<50	≤50	<60

To evaluate the distribution of irrigation water in the tested drip irrigation systems, the Christiansen uniformity coefficient (CU) was determined for the tested irrigations. Christiansen uniformity coefficient (CU) values of the test plots vary between 70-97% and are given in Table 5.

Table 5. Estimated drip system performance parameter values for the selected nectarine orchards.

Orchard No	q_{avg}	P_{avg}	q_v	P_v	C_v	CU	DU	EU	Us	E_s	E_a	PELQ	AELQ	Wetting Percentage
	L h^{-1}	bar	%	%	%	%	%	%	%	%	%	%	%	%
P_1	2.2	0.8	5	35	8	83	80	76	92	67	52	68	67	35
P_2	2.2	1.3	2	36	3	82	80	75	97	45	74	67	45	33
P_3	2.2	1.7	6	38	7	85	75	81	93	65	56	73	65	37
P_4	2.3	1.2	5	30	8	88	79	78	92	55	66	70	55	37
P_5	2.5	1.0	2	18	8	93	88	76	92	63	56	68	63	35
P_6	2.8	1.7	6	19	9	86	82	81	91	52	71	73	52	37
P_7	2.4	1.2	3	24	11	89	86	74	89	69	62	67	69	22
P_8	1.8	0.9	19	39	15	81	80	61	85	50	74	55	50	37
P_9	2.1	1.1	6	35	4	85	80	85	96	60	61	77	60	37
P_{10}	2.3	0.8	19	27	10	80	76	78	90	85	71	70	85	20
P_{11}	2.3	1.6	5.0	24	8	88	84	80	92	87	79	72	87	18
P_{12}	1.5	0.8	36	26	15	78	76	63	85	49	76	57	49	37
P_{13}	2.5	0.9	30	74	9	72	66	75	91	55	67	68	55	37
P_{14}	2.1	1.5	2	31	4	95	90	89	96	86	71	80	86	30
P_{15}	2.5	1.3	25	81	12	70	67	63	88	58	60	57	58	35
P_{16}	2.2	1.7	8	17	5	86	80	87	95	79	40	78	79	32
P_{17}	2.3	2.1	5	22	11	91	87	70	89	56	57	63	56	32
P_{18}	2.9	1.5	3	23	4	94	90	88	96	76	68	79	76	37

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Evaluation of CU; CU> 90% was considered excellent, CU = 80-90% good, CU = 70-80% medium, CU = 60-70% low, and CU < 60% was unacceptable (Table 4). Classification for evaluation of some performance criteria for selected nectarine orchards is given in Table 5. As shown in Table 5, CU in 4 orchards is classified as excellent, in 10 orchards good, and 4 orchards fair. Therefore, the CU values observed in the tested drip systems are all acceptable levels.

The distribution uniformity (DU) values of the test plots varied between 71-95% and are given in Table 5 and classification evaluation of some performance criteria for selected nectarine orchards is given in Table 6. As shown in Table 6, DU in 5 orchards are classified as excellent, in 12 orchards good, in 1 orchards fair. Accordingly, it has been observed that an acceptable level of uniform irrigation is applied. It has been observed that DU values for irrigation are always lower than CU values as expected. The reason for this is that while the mean of deviations from the means is used in the calculation of the CU value, the lower quarter average is used in the calculation of the DU value. Ref. [29] reported that CU values between 80-96% and DU values ranging between 68-94% for 11 drip systems in corn fields and walnut orchards in the Thrace region of Türkiye. Ref. [24] evaluated the drip system in Pakistan, and they found the water application uniformity above 80% which describes that the drip irrigation was designed on proper scale and dimensions.

Table 6. Classification of the some performance criteria for the drip systems in selected nectarine orchards.

Orchard	Classification Parameters				
No	C_V	CU	DU	EU	Us
P_1	Fair	Good	Good	Fair	Excellent
P_2	Excellent	Good	Good	Good	Excellent
P_3	Fair	Good	Good	Fair	Excellent
P_4	Fair	Good	Good	Fair	Excellent
P_5	Fair	Excellent	Excellent	Fair	Excellent
P_6	Fair	Excellent	Excellent	Fair	Excellent
P_7	Fair	Excellent	Excellent	Low	Excellent
P_8	Unacceptable	Fair	Fair	Low	Good
P_9	Excellent	Good	Fair	Good	Good
P_{10}	Fair	Fair	Fair	Fair	Excellent
P_{11}	Fair	Excellent	Excellent	Fair	Good
P_{12}	Unacceptable	Fair	Good	Low	Excellent
P_{13}	Fair	Fair	Good	Fair	Good
P_{14}	Excellent	Excellent	Excellent	Good	Excellent
P_{15}	Low	Fair	Good	Low	Good
P_{16}	Excellent	Excellent	Excellent	Good	Excellent
P_{17}	Fair	Excellent	Excellent	Low	Good
P_{18}	Excellent	Excellent	Excellent	Good	Excellent

The emission uniformity (EU) of the test orchards varied between 61.0-89.0% and is given in Table 5 and the classification evaluation of some performance criteria for selected nectarine orchards is given in Table 6. The evaluation of the EU was made according to ref. [18]. Emission uniformity (EU) describes how uniformly the overall system can distribute water from each emission device in the field and should be designed for at least 80% (90% with chemigation) [8]. As shown in Table 6, EU values in 6 orchards are classified as good, in 9 orchards fair, and 3 orchards low. Considering the recommended values for EU, the low water emission uniformity values in P7, P8, P12, P15, and P17 orchards are not acceptable and are outside the recommended limit values. The non-uniformity of emitter discharge is the result of several factors. The more important of these are the hydraulic and emitter discharge variations [9]. The hydraulic variation along the lateral line, submain, or manifold is a function of slope, pipe length and diameter, and emitter-discharge relations. Emitter variation at a given operating pressure is caused by manufacturing variability, emitter plugging (complete or partial), water temperature changes, and emitter wear [7]. Ref. [25] evaluated the existing drip irrigation network of Fadak Farmin in Irak, and they reported an EU value of 96.5%, and statistical uniformity coefficient of 97%, 6.85% for emitter flow variation, 0.026 for coefficient of variation, 96.5%

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for application efficiency, and 17% for pressure variation. They concluded that the drip irrigation system worked well and efficiently over the entire study region. Ref. [26] stated that the water emission uniformity (EU) of the drip irrigation system changed between 92-and 95% as a result of the study in which the performance of the drip irrigation system was determined in the ridge-planted citrus garden.

The statistical uniformity (Us) values for the tested drip systems varied between 85-97% and are given in Table 5 and the classification evaluation of some performance criteria for selected nectarine orchards is given in Table 6. When the Us values given in Table 5 are examined, drip systems in 13 orchards are in the excellent class and 5 orchards are in the good class. In general, Us values are at acceptable levels in the tested drip systems. Ref. [3] determined the performance of a drip system in an apple orchard, and they found that EU value of 74.% and a Us value of 77.7%.

3.3. Evaluation of Irrigation Management

The success of any irrigation method, particularly drip irrigation, depends to a large degree on the management of the irrigation system. With drip irrigation, precise information on the amount of water that the crop is using is required to determine adequately the irrigation amount. Control strategies using feedback information on soil water or plant water status can be used to determine if the irrigation applications are either too large or too small. In this study, the drip systems in the selected nectarine orchards were operated by the growers by themselves and irrigations were scheduled based on their experience without using any sensors for soil water content or any other sensors. In general, the growers irrigated their orchards at 5 to 7 days intervals adjusting irrigation duration by experience, short during the early season and longer during the flowering and fruit set and maturation stage. It was observed that none of the growers utilized scientific irrigation scheduling techniques.

The measured wetting percentages (P) of the parcels tested within the scope of the project varied between 18.3-37.3% and are given in Table 5. The reason why the rate of wetting area varies in such a wide range is due to differences in lateral intervals and the amount of irrigation water applied. The lowest wetting area ratio was measured as 21.7%, 20%, and 18.3%, respectively, in orchards P7, P10, and P11, where deficit irrigations were applied. In drip irrigation system planning, it is extremely important to determine the wetting area percentage (P) correctly. This rate generally varies between 30-37% of the total area, especially in orchards. For this reason, the wetting area percentage should be at least 30% in project designs. At least 30% in project designs. However, this value can be taken as the lower limit of 25% in humid regions and 35% in very arid regions [2].

Storage efficiency (Es) is a criterion for irrigation efficiency determined by sufficient water application until the deficient moisture amount in the plant root zone reaches the field capacity. The storage efficiency of the tested parcels varied between 45-87% (Es) depending on full irrigation, incomplete irrigation, and excessive irrigation conditions and are given in Table 5. Es values greater than 80% were found in 3 orchards (P10, P11, and P14); Es values between 70-80% were observed in 2 orchards (P16, and P18); Es values between 60-70% were found in 5 orchards (P1, P3, P5, P7, and P9); and Es values less than 60% were recorded in 8 orchards. While the drip method has great potential for high irrigation efficiencies, poor system design, management, or maintenance, can lead to low efficiencies. In some instances, the drip irrigation systems were installed with little concern for basic engineering hydraulic principles and resulted in nonuniform emitter discharges throughout the irrigated field. Irrigators to overcome this lack of uniformity found it necessary to over-irrigate [7].

The application efficiency (Ea) of an irrigation system is defined as the percentage of total water applied accumulated in the plant root zone. The most important factors affecting field water application efficiency are irrigation method, soil type and the amount of irrigation water applied. Application efficiency (Ea) values for the tested drip systems varied between 40% and 79% and are given in Table 5. In general, the Ea values are found to be low for the systems; in 7 orchards Ea values were between 70-79%; in 6 orchards Ea ranged from 60-70%; and in 5 orchards Ea was lower than 60%. These results reveal that there are serious irrigation management problems in the systems tested. When Es and Ea values are considered together, growers applied less irrigation than soil water deficit in the 90 cm root-zone depth, which means that insufficient water was applied to trees in the selected orchards. Although the uniformity parameters showed that the system performance was acceptable, the efficiency parameters (Es and Ea) indicated that irrigation management requires alterations to increase these values to acceptable levels. The duration of the irrigation should be increased in most of the systems tested to satisfy the soil water deficit in the root-zone depth. Ref. [3] determined the performance of a drip system in an apple orchard, and they found that Ea value of 100% and Es value of 47.8%. They concluded that increasing irrigation duration resulted in increased storage and application efficiency. Potential application efficiency of low-quarter (PELQ) values varied between 55-80%. When Table 5 is examined, the PELQ value was highest at 80% in the P14 orchard; in 8 orchards PELQ ranged between 70-80% in 6 orchards PELQ changed between 60-70%, and in 3 orchards PELQ values were lower than 60%. PELQ is an indication of how well the system can deliver water under optimum operating conditions. Low PELQ is a sign of planning problems [1]. Ref. [26] evaluated the drip performance in a citrus orchard and reported that the lower quarter potential application efficiency (PELQ) was 85%, the lower quarter actual application efficiency (AELQ) was 94% and the wet area percentage was 20%.

The low-quarter application efficiency (AELQ) varied between 45-87%. When Table 5 is examined, AELQ values were higher than 80% in P10, P11, and P14 orchards and the rest of the orchards remained below this value. AELQ is used as an indicator of the efficiency of drip irrigation systems, and how much of the applied water is stored in the root zone and is available for plants. The AELQ is the ratio of the water infiltrated and stored in the root zone in the least watered quarter of the land to the average depth of irrigation water applied and expressed as a percentage. The low quarter application efficiency (AELQ) both the uniformity of water distribution and adequacy of irrigation [1]. Although most of the system's performance is lower than the expected norms, it is within the range of what is normally found with in-field evaluations. The greater difference between AELQ and PELQ has been explained as an indicator of poor operation of the irrigation system [27,28]. Ref. [29] reported Ea values between 45-94% and AELQ values ranging between 54-84%, and PELQ values between 52-84% for 11 drip systems in corn fields and walnut orchards.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

4. Discussion

The performance of drip systems in young nectarine orchards in a Mediterranean environment was evaluated based on hydraulic performance parameters like average emitter discharge (Qavg), Christiansen uniformity coefficient (CU), distribution uniformity (DU), emission uniformity (EU), and irrigation management performance parameters such as system application efficiency (Ea), storage efficiency, AELQ, and PELQ. Although CU, DU, and EU values were at acceptable levels, however, the variations in emitter flow rates and pressure were not at acceptable levels. The results revealed that although hydraulic performance parameters were found to be at acceptable levels in general in tested drip systems the irrigation efficiency parameters were lower than expected norms, indicating that the main problem with these systems was not the design but the management and operation of these systems. Thus, the lower performances might be attributed to clogging and/or lack of system design and application practices by the farmers. In addition, the farmers have insufficient knowledge of drip irrigation systems and their operation, especially on irrigation scheduling. It is strongly recommended that the farmers get appropriate training on the operation and management of drip irrigation systems.

It is recommended that newly established drip irrigation systems need to be permanently tested to ensure long-lasting and reduce maintenance costs. Performance measurements should be done before and during the production season and should be linked to the developing technology. Thus, possible problems in the system can be detected early and drippers can be used for a longer period.

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Farmers should be trained on the use of the system and should maintain it at certain intervals. It is important to follow irrigation schedules, record the chemicals applied and maintenance procedures, and carry out economic analyses to improve the system.

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Abbreviations

The following abbreviations are used in this manuscript:

AELQ	Actual application efficiencies
CU	Coefficient of uniformity
CV	Coefficient of variation
DU	Distribution uniformity
Ea	Water application efficiency
Es	Storage uniformity
EU	Emitter flow uniformity
PELQ	Lower quarter potential
Pv	Pressure variations in laterals
qv	Emitter flow variation
Us	Statistical uniformity

Appendix A

Table A1. Drip irrigation system characteristics in the selected nectarine orchards and irrigation water supply and quality.

Orchard No/Properties	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
Area (ha)	1.5	3.5	2.5	2.5	5.0	5.0	2.0	9.0	9.0	1.8
Tree age (years)	8	3	6	6	7	2	4	2	2	4
Plant Row Spacing (m)	5	5	5	5	5	5	5	5	5	5
Plant Row (m)	3	3	3	3	3	3	3	3	3	3
Filter type	Hydrosyclone +Disc	Hydrosyclone+ Sand gravel+ Disc	Hydrosyclone+ Sand gravel +Disc	Hydrosyclone+ Sand gravel+ Disc	Hydrosyclone+ Sand gravel+ Disc	Hydrosyclone+ Sand gravel+ Disc	Hydrosyclone+ Disc	Sand gravel+ Disc	Hydrosyclone+ Sand gravel+ Disc	Hydrosyclone+ Disc
Main Pipe Material	PVC-PE	PVC-PE	PVC-PE	PVC-PE	PVC-PE	PVC-PE	PVC-PE	PVC-PE	PVC-PE	PVC-PE
Main Pipe Diameter (mm)	75	140	110	110	110	110	90	140	140	110

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Main Pipe Length (m)	226	223	172	487	168	465	135	450	400	100
Manifold Pipe Material	PE	PVC	PVC	PVC	PE	PE	PE	PE	PE	PE
Manifold Diameter (mm)	63	90-75-63	90-75-63	63	90-75-63	90-75-63	63	90-75-63	90-75-63	50
Manifold length (m)	207	385	131	120	70	103	200	140-160	150	185
Lateral Pipe Diameter (mm)	16	20	20	20	16	20	20	20	20	16
Lateral Pipe Length (m)	50	137	180	180	84	165	120	167	191	87
Lateral Spacing (m)	0.80	0.80	0.80	0.80	0.80	0.30	0.80	0.30	0.30	0.80
Emitter Flow ($L\ h^{-1}$)	2	2	2	2	2	2	2	2	2	2
Measured Avg. Emitter Flow Rate ($L\ h^{-1}$)	2.24	2.20	2.15	2.25	2.45	2.78	2.43	1.75	2.10	2.32
Measured Avg. Emitter Pressure (bar)	0.84	1.25	1.66	1.18	1.03	1.73	1.17	0.87	1.13	0.75
Emitter spacing (cm)	50	50	50	50	50	50	50	40	50	50
Operating Pressure (kPa)	110	280	350	350	150	150	300	150	180	200
System Age (years)	7	2	5	5	6	1	3	1	1	3
Water Supply	Deep well	Deep well	Canal	Canal	Canal	Canal	Deep well	Canal	Canal	Deep well
Irrigation Water (EC)	0.714	0.512	1.286	1.286	0.455	0.455	0.843	0.500	0.650	0.923
Irrigation Water (pH)	7.22	8.25	7.70	7.70	7.92	7.92	6.87	7.98	8.03	6.91

Orchard No/Properties	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}	P_{17}	P_{18}
Area (ha)	1.3	6.3	1.2	1.8	1.1	1.3	2.0	1.7
Tree age (years)	4	6	4	4	4	4	10	5
Plant Row Spacing (m)	5	5	5	5	5	5	5	5
Plant Row (m)	3	3	3	3	3	3	3	3
Filter type	Hydrosyclone + Disc	Hydrosyclone+ Sand gravel+	Hydrosyclone+ Sand gravel+ Disc	Hydrosyclone+ Sand gravel+ Disc	Hydrosyclone+ Sand gravel+ Disc	Hydrosyclone+ Sand gravel+	Sand gravel+ Disc	Hydrosyclone+ Sand gravel+ Disc

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		Disc				Disc		
Main Pipe Material	PVC-PE	PVC-PE	PVC-PE	PVC-PE	PVC-PE	PVC-PE	PVC-PE	PVC-PE
Main Pipe Diameter (mm)	110	110	110	90	110	90	110	125
Main Pipe Length (m)	100	210	170	147	170	147	220	200
Manifold Pipe Material	PE	PE	PE	PE	PE	PE	PE	PE
Manifold Diameter (mm)	50	75-63	75-63	90-75-63	75-63	90-75-63	75-63	90-75-63
Manifold length (m)	105	60	70	125	70	110	50	90
Lateral Pipe Diameter (mm)	16	20	20	20	20	20	20	20
Lateral Pipe Length (m)	100	140	171	110	159	120	114	75
Lateral Spacing (m)	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Emitter Flow (L h^{-1})	2	2	2	2	2	2	2	2
Measured Avg. Emitter Flow Rate (L h^{-1})	2.34	1.53	2.50	2.11	2.45	2.16	2.25	2.91
Measured Avg. Emitter Pressure (bar)	1.63	0.78	0.91	1.48	1.25	1.65	2.07	1.46
Emitter spacing (cm)	50	40	33	50	33	50	50	60
Operating Pressure (kPa)	200	180	200	300	250	280	270	250
System Age (years)	3	5	3	3	3	3	9	4
Water Supply	Deep well	Canal	Canal	Canal	Canal	Canal	Deep well	Deep well
Irrigation Water (EC)	0.905	0.370	0.486	0.456	0.486	0.456	0.343	0.650
Irrigation Water (pH)	6.87	8.37	8.09	8.10	8.09	8.10	7.84	8.03

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