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# Performance Analysis of Collective Set-Move Lateral Sprinkler Irrigation Systems used in Central Anatolia

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**Abstract:** Performance assessment (PA) of irrigation and drainage systems has been an important area of research and debate in recent years. The present study was carried out to determine some performance parameters of sprinkler irrigation systems. Thirty-eight subunits (lateral) were monitored and assessed in the Konya Basin of Turkey. Sprinkler nozzle-pressure, flow rate, and their variations, and the amount of irrigation water were determined. Application and distribution uniformity, irrigation adequacy, and characteristics of system design and application were analyzed. Christensen Uniformity coefficient (CUC) and distribution uniformity (DU) values were between 41% and 88%, and between 18% and 81%, respectively. Variation in pressure and flow rates, and the use of different sprinkler parts in the same system were the main causes of the observed heterogeneity. It was concluded that by reducing lateral spacing the water distribution pattern, such as CUC and DU, could improve significantly and thus improve irrigation adequacy.

Key Words: Sprinkler system, Christensen uniformity coefficient, Distribution uniformity, Irrigation adequacy, Central Turkey

## İç Anadolu Bölgesindeki Yarı Hareketli Yağmurlama Sistemlerinin Performans Analizi

**Özet:** Bu çalışma yağmurlama sulama sistemlerinin bazı performans parametrelerinin belirlenmesi amacıyla, Konya ovasında 38 yağmurlama laterali izlenmiş ve değerlendirilmiştir. Yağmurlama başlık basınçları, debi ve başlık basınç değişimleri ile sulama suyu miktarları belirlenmiştir. Çalışmada optimum su kullanımını etkileyen bir çok faktör arasından uygulama ve dağılım üniformitesi, sulama yeterliliği ve tasarımlananla, uygulanan sistem karakteristikleri üzerinde yoğunlaşılmıştır. Christiansen Üniformitesi (CU) % 41-% 88 ve Dağılım Üniformitesi (DU) ve % 18-81 arasında bulunmuştur. Başlık basınçlarında ve akış debilerinde belirlenen yüksek değişkenliğin, aynı lateral üzerinde farklı başlıkların kullanılmasından ileri gelmesine yorumlanmıştır. Sonuçlar daha dar lateral aralıklarının su dağılım üniformitesini ve sulama yeterliliğini önemli düzeyde artıracağını göstermiştir.

Anahtar Sözcükler: Yağmurlama sistemi, Christian üniformitesi, Dağılım üniformitesi, Sulama yeterliliği, Orta Anadolu

## Introduction

Performance assessment (PA) of irrigation and drainage systems has been an important area of research and debate within the irrigation community in recent years (Vincent et al., 2001). This is recognized as the systematic observation, documentation, and interpretation of the management of an irrigation system (Bos et al., 2005). The management of water resources used for irrigation is fundamental to sustainable agriculture.

Water application uniformity affects crop yield and water use efficiency. Warrick and Gardner (1983) theoretically analyzed the effect of soil spatial variability and low irrigation uniformity. Letey et al. (1984) performed a similar analysis extended to crops with curvilinear yield functions. Montovani et al. (1995) simulated the effects on crop yield of sprinkler uniformity by using a linear crop water production function. Recently, Li (1998) presented a simulation model, including the effect of both sprinkler uniformity and

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water deficit on crop yield. All these studies showed that low uniformity in irrigation decreases average yield.

Uniformity of a sprinkler irrigation system is defined as the variation in the depth of water used in irrigation over an area (Branscheid and Williams, 1968; Vories and von Bernuth, 1986; Li and Kawano, 1996). Application uniformity of a sprinkler system is primarily influenced by sprinkler pressure and size, type of sprinkler irrigation package, and spacing (Vories and von Bernuth, 1986; Solomon, 1987).

Martinez et al. (2004) analyzed the influence of different design and performance factors, such as subunit arrangement, lateral spacing, working pressure, average application rate, and application efficiency of water application cost, in a permanent set sprinkler irrigation system. The results showed that the most important factor is sprinkler spacing.

Water application efficiency ($E_a$) was characterized as follows by Tarjuelo et al., (2000): 60%-70% (poor irrigation management), 80% (adequate management), and 90% (excellent management). Little et al. (1993) reported that SCS classifies uniformity of a sprinkler irrigation system as very good, good, poor, and worst if the Christensen uniformity coefficient (CUC) value is ≥ 90%, between 80% and 89%, between 70% and 79%, and > 69%, respectively.

One of the biggest problems for agriculture encountered in the Konya Basin is insufficient water resources. There is a need to develop effective irrigation systems for the region in order to irrigate a larger area with a limited amount of water. Farmers in central Turkey are familiar with sprinkler irrigation systems; however, due to high costs farmers tend to use old sprinkler parts on new systems and this creates some problems in the management of irrigation systems.

Tarı (1998) reported CUC and distribution uniformity ($DU_{lq}$) values between 58% and 82%, and between 37% and 82%, respectively, in the Konya-Ilgın Plain. In the present study pressure and discharge variations in system subunits were observed to be higher than expected.

New sprinkler irrigation system designs were generally not appreciated by the farmers in the area studied. Instead, they used old existing systems, which resulted in low irrigation efficiency; therefore, the present study was conducted in the Konya Plain to determine irrigation efficiency, uniformity, and adequacy, as well as to identify problems related to design and operation, and to offer necessary recommendations for improvement.

## Materials and Methods

The research was conducted in the Konya Closed Basin, which is at about 1000-1050 m asl in central Turkey, with irrigable land of approximately 1,900,000 ha (Figure 1). In this area about 1,653,000 ha are cultivated, and 1,008,000 ha are fallowed every year. Currently, 374,000 ha are irrigated (Çiftçi et. al., 2003).

The climate is considered to be typical semi-arid. Most of the precipitation occurs during the spring months and annual average precipitation, temperature, evaporation, and humidity are 326 mm, 11 °C, 1005 mm, and 64%, respectively (DMİ, 2003).


Figure 1. General view of the test areas and the Great Konya Plain.

Soil profiles in the study area have similar A and C horizons. Deep soils in the study area developed on young alluvial deposits. Others originated from lacustrine sediments and volcanic rocks. They have a heavy clay and silty clay texture, with high lime content. Some physical and chemical analyses of the soils were carried out in the local Ministry of Agriculture and Rural Affairs Soil and Water Resources Laboratory, using the methods described by Richards (1954) (Table 1).

### Properties of the Irrigation Systems

Field tests were conducted in the villages of Argıthanı, Orhaniye, Yukarıpınarbaşı, and Karaali on 38 set-move laterals in 2001, 2002, 2003, and 2004. These irrigation systems were designed and constructed in 1998, 1999, 1996, and 2001, respectively, by a government agency. The sprinkler irrigation systems used by farmers in the study area were operated every 10 days for 12 h $day^{-1}$. The laterals pipes were 75 mm in diameter. The longest lateral (380 m) was in Pınarbaşı and the shortest one (35 m) was in Karaali. Average lateral lengths were between 60 and 200 m. The irrigation systems were designed for a water application rate of between 6.1 and 32.0 mm $h^{-1}$ for different lateral spacing (Table 2). Nozzles were 4.8-4.6 in diameter and designed for a discharge rate of 1.8 $m^3$ $h^{-1}$ at 2.5 atm, but they were determined to be between 3.2-5.0 mm in diameter.

Irrigation water was supplied from wells and considered to be of good quality for irrigation, with no salinity problem. They covered 383-, 166-, 400-, and 112-ha areas with stream sizes of 220, 180, 100, and 75 l $s^{-1}$ in Argıthanı, Orhaniye, Yukarıpınarbaşı, and Karaali, respectively. All the systems were designed for the demand operation method, although all the farmers, except those in Pınarbaşı, applied the rotation method (Table 2).

### Methodology

Before conducting uniformity tests, lateral length, sprinkler spacing, size of test-field, distance to the water source, and soil infiltration capacity were determined (Table 2).

Each uniformity test was conducted on a single lateral (subunit), without overlapping, and the catch can pattern is shown in Figure 2. Lateral length was divided into 4 equal sections and 64 collectors were installed in 2 rows, 3 m apart and perpendicular to the lateral lines.

To determine the subunit uniformity in each system, the test lateral was divided into 4 equal sections and 16 catch cans were placed between the laterals of each section. The catch cans were 10.5 cm in diameter and 20 cm tall. The first row of catch cans was 1.5 m away from the lateral pipe and then the others were placed in a 3 × 3-m arrangement (Figure 2). The opening of each catch can was 30 cm above the soil surface and about 20 cm below the sprinkler head.

Table 1. Some physical and chemical properties of test area soils.

| Test site | Soil depth (cm) | Field capacity (dry weight %) | PWP (dry weight %) | Volume weight (g $cm^{-3}$) | Lime (%) | $EC_e$ ($dSm^{-1}$) | pH | Sand (%) | Clay (%) | Silt (%) | Texture |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Argıthanı | 0-30 | 32.30 | 17.69 | 1.29 | 23.71 | 0.68 | 8.0 | 13.05 | 70.52 | 17.52 | C |
| | 30-60 | 29.56 | 15.61 | 1.30 | 22.86 | 0.95 | 7.8 | 13.52 | 67.50 | 19.50 | C |
| | 60-90 | 30.55 | 17.14 | 1.31 | 27.89 | 0.69 | 7.9 | 11.43 | 69.50 | 19.08 | C |
| Orhaniye | 0-30 | 30.20 | 16.77 | 1.65 | 16.53 | 1.05 | 8.1 | 25.99 | 38.35 | 35.66 | CL |
| | 30-60 | 29.65 | 17.37 | 1.54 | 15.09 | 0.67 | 8.1 | 30.95 | 40.00 | 29.05 | CL |
| | 60-90 | 28.49 | 18.77 | 1.66 | 14.38 | 0.72 | 8.8 | 30.76 | 42.19 | 27.05 | CL |
| Y. Pınarbaşı | 0-30 | 28.20 | 17.70 | 1.25 | 34.26 | 0.62 | 8.1 | 15.35 | 60.57 | 24.08 | C |
| | 30-60 | 27.70 | 20.22 | 1.28 | 32.69 | 1.13 | 8.5 | 21.18 | 65.02 | 13.80 | C |
| | 60-90 | 27.44 | 19.84 | 1.38 | 33.05 | 2.50 | 8.3 | 17.00 | 70.97 | 12.03 | C |
| Karaali | 0-30 | 25.70 | 16.91 | 1.60 | 2.89 | 0.85 | 7.7 | 34.74 | 37.89 | 27.37 | CL |
| | 30-60 | 27.37 | 17.60 | 1.64 | 2.17 | 0.85 | 7.6 | 34.91 | 42.00 | 23.10 | C |
| | 60-90 | 28.96 | 18.43 | 1.53 | 2.17 | 0.85 | 7.6 | 34.67 | 42.15 | 23.18 | C |

Table 2. Design parameters of the sprinkler irrigation systems.

| Test site | Setting year | Test year | Test number | Area (ha) | Parcel number | Water source | Flow rate ($l\ s^{-1}$) | Method of operation designed for | Applied operation method | Infiltration rate ($mm\ h^{-1}$) | Application rate ($mm\ h^{-1}$) | | Lateral length (m) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Designed | Measured. | Max | Min | Common |
| Argıthanı | 1998 | 2001 | 11 | 383 | 208 | Well | 220 | Demand | Rotation | 25-40 | 8.0 | 14.2 | 210 | 40 | 150 |
| Orhaniye | 1999 | 2002 | 10 | 166 | 109 | Well | 100 | Demand | Rotation | 17-62 | 6.1 | 11.9 | 200 | 200 | 200 |
| Pınarbaşı | 1996 | 2003 | 9 | 400 | 210 | Well | 180 | Demand | Demand | 30-35 | 32.0 | 18.0 | 380 | 140 | 160 |
| Karaali | 2001 | 2004 | 8 | 112 | 367 | Well | 75 | Demand | Rotation | 20-23 | 5.7 | 17.9 | 130 | 35 | 60 |

*Runoff because S1 and S2 are very narrow spacings.

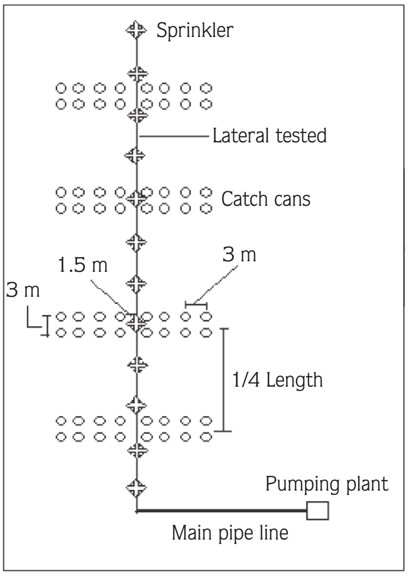



Figure 2. Layout of test area and view of the cans.

### Pressure and Discharge Variations

Sprinkler pressure was measured 3 times with a Venturi mounted manometer at each sprinkler. Pressure variation through the lateral pipe was calculated using the Merriam and Keller (1978) formula, as given below;

$$P_{var} = \frac{P_{max} - P_{min}}{P_{av}} \times 100 \quad (1)$$

where $P_{var}$ is pressure variation, $P_{max}$ is maximum measured pressure, $P_{min}$ is minimum pressure, and $P_{avg}$ is average pressure (atm)

Sprinkler discharge rates were measured with a flexible pipe inserted over the sprinkler head. Flow rate variation through the laterals was calculated using the following equation by Merriam and Keller (1978);

$$q_{var} = \frac{q_{max} - q_{min}}{q_{av}} \times 100 \quad (2)$$

where $q_{var}$ is flow rate variation, $q_{max}$ is maximum flow rate, $q_{min}$ is minimum flow rate (L $s^{-1}$), and $q_{avg}$ is average flow rate (l $s^{-1}$).

### Christensen Uniformity Coefficient (CUC)

The Christensen uniformity coefficient (CUC), distribution uniformity ($DU_{lq}$), and some other parameters were calculated using methods outlined by ASAE (2001). CUC was calculated using the equation developed by Christensen (1942);

$$CU = 100\left[1 - (\sum \left| \frac{x_i - x_{av}}{nx} \right|)\right] \quad (3)$$

where CUC is the Christensen uniformity coefficient, $x_i$ is individual measurements (mm), $x_{av}$ is the average of all measurements (mm), and n is the number of collectors.

### Distribution Uniformity (DU)

Distribution uniformity ($DU_{lq}$) was calculated using water depths measured at all the sections (1st, 2nd, 3rd, and 4th) of each sprinkler irrigation system, and was determined using the ASAE method (ASAE, 2001);

$$DU_{lq} = 100\left(\frac{X_{ilq}}{X}\right) \quad (4)$$

where $DU_{lq}$ is distribution uniformity, $X_{ilq}$ is average at low quarter (mm), and X is the average of all measurements (mm).

### Irrigation Adequacy

Irrigation adequacy was evaluated using a cumulative frequency distribution curve. The application adequacy ($A_a$) was determined by equation 5 (Cuenca, 1989; James, 1993);

$$A_a = \Delta D_{rz}/DRZ_{req} \quad (5)$$

where $\Delta D_{rz}$ is change of water in the root zone (mm) and $DRZ_{req}$ is the required amount of water in the effective root zone (mm).

Cumulative frequency distribution patterns were constructed by determining the depth of water caught at locations around the field and the percent of the total area represented by each catch can. In order to determine each test area's various water depth level percentages, the depths were arranged in descending order. In this way, deficient and excessive percentages could be determined. The depths were then arranged in descending order and the percentage of the field receiving each depth or more was computed.

### Different Lateral Spacing and Uniformity

To determine the effect of different lateral spacings on uniformity, water depths in the catch cans were superimposed by changing the lateral spacing with 3-m increments, for 9.0, 12.0, 15.0, and 18.0 m. CUC was calculated using equation 3 for each new lateral spacing. The effect of different lateral spacings on uniformity was determined using the T-statistic method (Eberhard and Russel, 1966).

## Results

The current study analyzed the influence of different irrigation system design and performance factors. According to the results, the most important factor was lateral spacing

### Properties of the Irrigation Systems

Field tests showed that the farmers used double nozzle impact sprinklers. Available sprinkler heads were fixed before conducting the uniformity tests. The sprinkler irrigation systems tested were very different than originally designed, in terms of the sprinkler heads, which resulted in different flow rates, lateral and head spacings, and numbers of heads used on each lateral. Almost all of the sprinkler heads had double nozzles, and over time the farmers replaced broken heads with the new ones made by different manufacturers. Gradually, this made the sprinkler irrigation systems much different than originally designed.

The lateral pipes in the study areas were usually either 5.0 or 6.0 m long and the sprinkler heads were placed between 2 or 3 pipes, making sprinkler head spacing 10-18 m. Operation time of the systems was between 10 and 12 h day$^{-1}$. In all the tested systems the laterals were 40-320 m long, but most often 200 m. The lateral pipes were 75 mm in diameter and were generally parallel to field slope, as suggested by the manufacturer.

### Water Applications and the Infiltration Rate

In most of the sprinkler irrigation systems the application rate was expected to be less than the infiltration capacity of the soil. Infiltration rates ranged from 17.0 to 62.0 mm h$^{-1}$ in all the fields we tested. The sprinkler irrigation systems were designed to apply 8-32 mm h$^{-1}$ to be on safe side and prevent surface runoff. The measured application values ranged between 11.9 and 18 mm h$^{-1}$, which was lower than the infiltration rate of the soils in the test areas (Table 2).

### Pressure and Flow Rate Change in the Laterals

Sprinkler pressure and flow rate of 38 irrigations events were evaluated during 4 different irrigation seasons. The pressure in all systems was designed to be 2.5 atm, whereas test results indicated that the pressure of the sprinkler systems ranged between 0.88 and 2.10 atm in Argıthanı in 2001, between 1.30 and 3.10 atm in Orhaniye in 2002, between 1.15 and 3.70 atm in Yukarıpınarbaşı in 2003, and between 0.4 and 2.60 atm in Karaali in 2003, for all the subunit areas. Sprinkler pressures were lower than what the systems were designed for (2.5 atm) in all the subunits, except T6 in Karali. In some irrigation events, the sprinkler pressure was observed to be less than 1.0 atm (Table 3). The pressure was determined to be higher than the system was designed for at only 1 test location (T6) in 2003 (Figure 3).

Mean sprinkler head pressure ranged from 0.4 to 3.7 atm. Sprinkler pressure was quite different in each irrigation system. Statistically significant linear correlations were noted between pipe length and sprinkler pressure during almost every test.

Mean head pressure variation along the subunits ranged between 20.69% and 31.20%. In general, they were above 20%, except during 3 tests (T3, T4, T10) in 2001, 1 test in 2002 (T4), 3 tests in 2003 (T1, T5, T8), and 1 test in 2004 (T2) (Table 3).

As expected, as the distance from the field to the water source shortened, overall sprinkler system pressure increased; however, higher sprinkler pressure was measured in the last section of the pipe, as compared to the first section, in 2001 at T1, T9, and T10, and in 2002 at T6.

Table 3. Sprinkler head pressure (P, atm) and its variation (%) measured in different locations and tests.

| Years | 2001 | | | 2002 | | | 2003 | | | 2004 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test Sites | | | | | | | | | | | |
| Test site | Argıthanı | | | Orhaniye | | | Yukarıpınarbaşı | | | Karaali | | |
| | $P_{max}$ | $P_{min}$ | $P_{var}$ | $P_{max}$ | $P_{min}$ | $P_{var}$ | $P_{max}$ | $P_{min}$ | $P_{var}$ | $P_{max}$ | $P_{min}$ | $P_{var}$ |
| $T_1$ | 1.69 | 1.25 | 30.9 | 3.00 | 2.40 | 26.4 | 1.40 | 1.20 | 16.13 | 2.10 | 1.70 | 20.9 |
| $T_2$ | 1.48 | 1.05 | 33.6 | 1.95 | 1.40 | 35.3 | 1.90 | 1.50 | 24.33 | 1.90 | 1.50 | 11.7 |
| $T_3$ | 1.50 | 1.45 | 3.4 | 2.40 | 1.90 | 24.2 | 2.40 | 2.00 | 18.68 | 2.60 | 1.80 | 32.2 |
| $T_4$ | 2.20 | 1.87 | 16.6 | 2.00 | 1.85 | 7.8 | 1.48 | 1.15 | 26.24 | 1.20 | 0.80 | 42.5 |
| $T_5$ | 1.40 | 1.01 | 30.7 | 3.00 | 2.08 | 39.8 | 2.10 | 1.70 | 21.75 | 1.50 | 1.10 | 31.2 |
| $T_6$ | 1.79 | 1.40 | 23.6 | 2.80 | 2.29 | 20.9 | 3.70 | 3.05 | 20.10 | 0.75 | 0.40 | 53.8 |
| $T_7$ | 1.28 | 1.00 | 25.8 | 2.90 | 2.10 | 33.1 | 2.10 | 1.65 | 23.10 | 1.70 | 1.20 | 32.7 |
| $T_8$ | 1.73 | 1.22 | 36.7 | 2.45 | 1.70 | 38.8 | 1.60 | 1.38 | 15.18 | 0.90 | 0.70 | 24.6 |
| $T_9$ | 1.08 | 0.88 | 20.6 | 1.90 | 1.30 | 41.1 | | | | 0.90 | 0.50 | 62.0 |
| $T_{10}$ | 1.90 | 1.82 | 3.7 | 2.30 | 1.80 | 25.8 | | | | | | |
| $T_{11}$ | 1.31 | 1.03 | 24.5 | | | | | | | | | |
| Mean | 1.58 | 1.27 | 22.7 | 2.48 | 1.88 | 29.31 | 2.09 | 1.70 | 20. 69 | 1.58 | 1.15 | 31.20 |

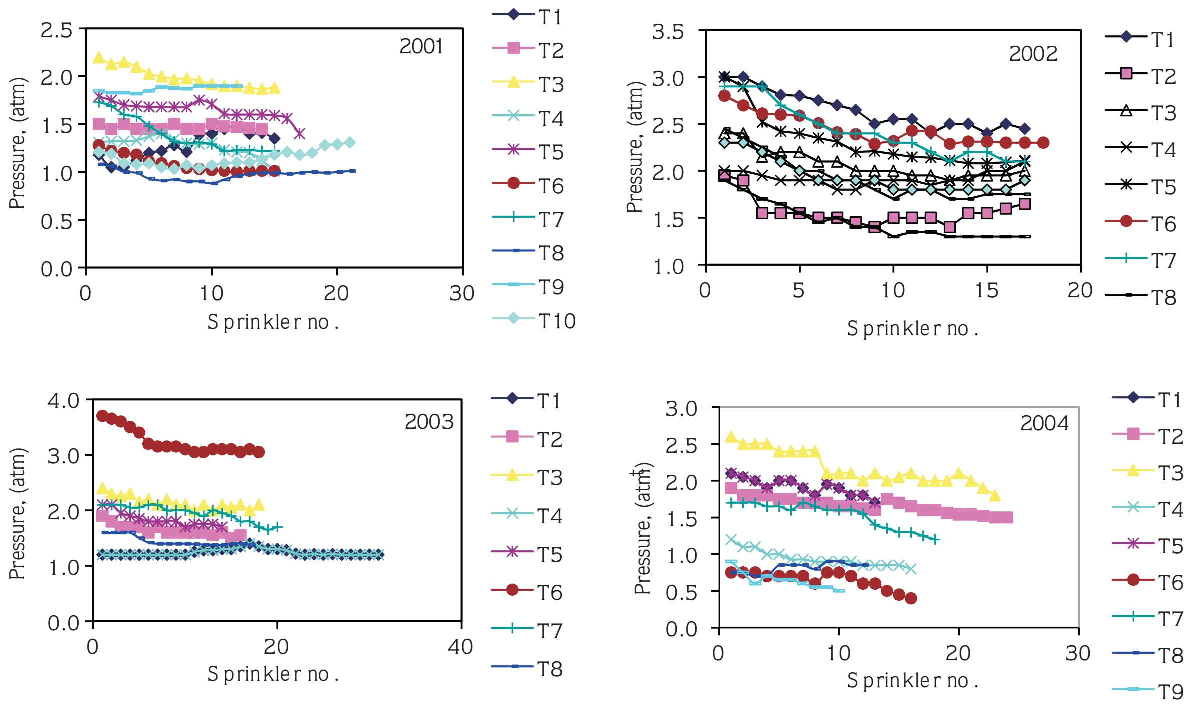



Figure 3. The pressure variation in sprinkler heads along the laterals for the different years and tests.

Sprinkler flow rates were between 0.461 and 0.687 l $s^{-1}$; however, mean sprinkler flow ranged between 0.6 and 0.7 l $s^{-1}$. The variation in mean flow rates was between 29% and 38%, and in general remained above 20%, except during 1 test each year (2001: T3; 2002: T4; 2003: T2; 2004: T2), (Table 4)

Flow rates fluctuated greatly along the pipes. A meaningful relationship between pipe length and flow rate was not observed (Figure 4), which was attributed not only to differences in pressure, but also to differences in sprinkler head type.

Table 4. Measured sprinkler flow rates (l/s) and their variation (%) for different locations and years.

| Years | 2001 | | | | 2002 | | | | 2003 | | | | 2004 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test site | $q_{max}$ | $q_{min}$ | $Q_{av}$ | $q_{var}$ | $q_{max}$ | $q_{min}$ | $q_{av}$ | $q_{var}$ | $q_{max}$ | $q_{min}$ | $q_{av}$ | $q_{var}$ | $q_{max}$ | $q_{min}$ | $q_{av.}$ | $q_{var}$ |
| T1 | 0.595 | 0.356 | 0.465 | 51 | 0.79 | 0.57 | 0.69 | 32 | 0.606 | 0.472 | 0.526 | 25 | 0.638 | 0.466 | 0.564 | 30 |
| T2 | 0.739 | 0.524 | 0.652 | 33 | 0.75 | 0.46 | 0.61 | 46 | 0.686 | 0.597 | 0.623 | 14 | 0.546 | 0.406 | 0.492 | 29 |
| T3 | 0.667 | 0.500 | 0.577 | 9 | 0.98 | 0.49 | 0.67 | 71 | 0.819 | 0.554 | 0.717 | 40 | 0.648 | 0.432 | 0.562 | 38 |
| T4 | 0.722 | 0.575 | 0.633 | 23 | 0.64 | 0.53 | 0.59 | 18 | 0.619 | 0.393 | 0.522 | 43 | 0.427 | 0.353 | 0.387 | 19 |
| T5 | 0.677 | 0.503 | 0.589 | 30 | 0.77 | 0.55 | 0.65 | 33 | 0.680 | 0.477 | 0.581 | 35 | 0.519 | 0.387 | 0.466 | 29 |
| T6 | 0.652 | 0.463 | 0.588 | 32 | 0.74 | 0.59 | 0.65 | 21 | 0.902 | 0.553 | 0.760 | 46 | 0.365 | 0.297 | 0.331 | 21 |
| T7 | 0.782 | 0.346 | 0.591 | 66 | 0.81 | 0.57 | 0.68 | 34 | 0.741 | 0.428 | 0.562 | 56 | 0.667 | 0.425 | 0.511 | 47 |
| T8 | 0.730 | 0.488 | 0.617 | 39 | 0.82 | 0.53 | 0.64 | 45 | 0.638 | 0.413 | 0.570 | 40 | 0.403 | 0.305 | 0.373 | 26 |
| T9 | 0.553 | 0.449 | 0.503 | 22 | 0.69 | 0.50 | 0.58 | 33 | | | | | 0.403 | 0.305 | 0.373 | 26 |
| T10 | 0.667 | 0.530 | 0.605 | 23 | 0.92 | 0.55 | 0.75 | 48 | | | | | | | | |
| T11 | 0.667 | 0.466 | 0.571 | 23 | | | | | | | | | | | | |
| Mean | 0.677 | 0.473 | 0.581 | $33.0^{ns}$ | 0.791 | 0.539 | 0.656 | $38^{ns}$ | 0.712 | 0.486 | 0.608 | $37^{ns}$ | 0.382 | 0.286 | 0.336 | $29^{ns}$ |

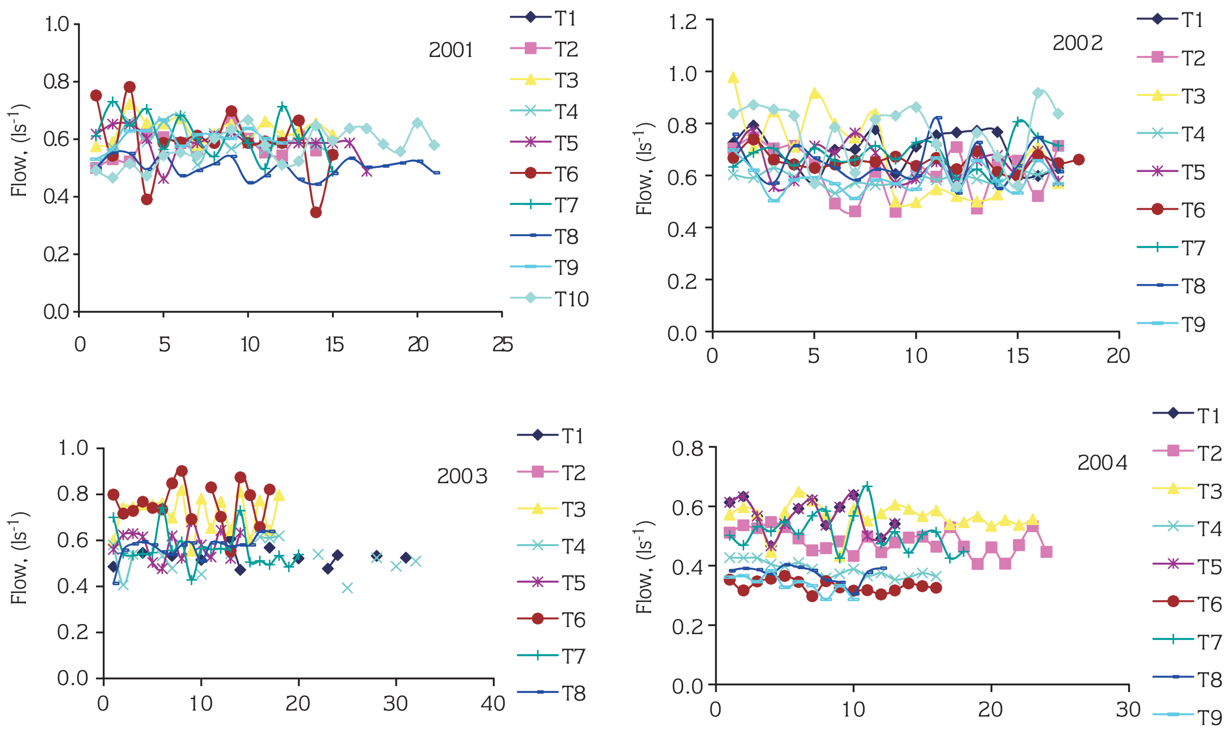



Figure 4. Flow variation in sprinkler heads along the laterals for the different years and tests.

Overall design of a sprinkler system should include a maximum flow rate variation of 10% (Merriam and Keller, 1978). Water discharge variation should not be more than 20% (Hansen et al., 1979); however, in the present study significant flow rate variation was observed in all tested subunits. Yet, during some tests, flow rate variation reached 71% (2001, $T_3$) (Table 4).

One subunit hydraulic design criterion is that maximum pressure variation should not exceed 20% of the mean working pressure of the sprinklers (Tarjuelo et al., 1999; Martinez et al., 2004)

Martinez et al. (2004) indicated that working pressure is very important for sprinkler irrigation systems. A decrease in pressure will result in a decrease in energy costs, although pipe diameter will need to increase. The higher the average application rate of a system, the higher the water application cost. This can be reduced by 40% when application efficiency increases from 60% to 90%.

A statistically significant negative correlation was observed between pressure variation and irrigation uniformity, except for the year 2002. Increasing the variation coefficient decreased uniformity in all the systems that were tested (Figure 5). This was also another cause of the observed reduction in irrigation efficiency.

### Irrigation Uniformity

Irrigation adequacy was evaluated using the cumulative frequency distribution curve of 38 irrigation events. In a well designed sprinkler irrigation system, water application depths between sprinkler heads should receive almost equal amounts of water, and due to friction losses through the lateral pipe, the amount of irrigation water may reduce linearly (Cuenca, 1989).

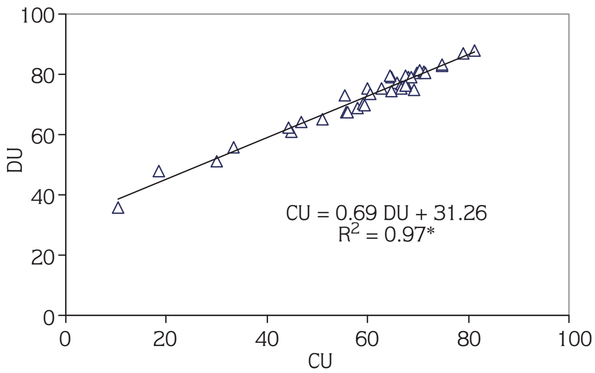



Figure 5. Relationships between the Christensen uniformity coefficient (CUC) and distribution uniformity (DU) for all years (2001-2004).

The present study showed that irrigation depths were not sufficiently uniform in all the test areas. In some laterals water depth was higher in the first quarter section and reduced toward the end of the lateral pipe; however, in some cases, the opposite was noted (Table 5). The cause of the irregularities in water depth was attributed to the use of different sprinkler heads and low pressure. In some cases water depth substantially differed and this was due to the wind-drift effect, from one side to the other side of the sprinkler system.

CUC for all the sites ranged between 48% and 88%, with a mean of 71%, 75%, 72%, and 69%, respectively, for all the test years. The lowest CUC value (61%) was measured in 2002 at test site $T_6$, while the lowest acceptable CUC value is reported to be 84% (Merriam and Keller, 1978; Kay, 1988; Keller and Bliesner, 1990).

DU ranged between 18% and 81%, averaging 61%, 63%, 66%, and 53%. Only 4 tests had a DU of about 75% or more with high uniformity. The others seemed to have very low DU values; therefore, in almost all the fields, sprinkler irrigation system uniformity was unacceptable, except for $T_6$ in 2002 (Table 5).

As expected, CUC values were higher than DU values. A linear relationship was noted between CUC and DU values, and the equation is as follows: CU = 0.69 DU + 31.26 and R2 = 0.97** (Figure 5, Table 5).

These low uniformity values in the subunits were attributed to the use of different sprinkler heads in almost every system and the use of non-original parts. Another reason might have been problems adjusting the water jets coming from sprinkler nozzles. Farmers usually inspect the sprinkler heads visually and adjust manually. Other causes of the low DU were wide pressure variation, wind speeds, and inappropriate lateral spacing (Figure 6).

### Irrigation Adequacy

Irrigation adequacy is the percentage of a field that receives a sufficient amount of water to maintain quantity and quality of crop production at a profitable level. Irrigation adequacy is generally defined as providing a satisfactory irrigation depth in the field (Cuenca, 1989; James, 1993).

Table 5. Some performance parameters (%) of the irrigation systems.

| | Years | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test site | 2001 | 2002 | 2003 | 2004 | 2001 | 2002 | 2003 | 2004 | 2001 | 2002 | 2003 | 2004 |
| | Christensen Uniformity Coefficient (CUC) | | | | Distribution Uniformity (DU) | | | | Irrigation Adequacy ($A_a$) | | | |
| T1 | 51 | 77 | 79 | 70 | 30 | 66 | 68 | 59 | 15 | 95 | 10 | 50 |
| T2 | 69 | 61 | 75 | 79 | 58 | 45 | 67 | 69 | 40 | 25 | 5 | 50 |
| T3 | 79 | 75 | 76 | 67 | 64 | 69 | 68 | 56 | 15 | 40 | 20 | 80 |
| T4 | 83 | 79 | 75 | 76 | 75 | 68 | 63 | 67 | 30 | 20 | 90 | 90 |
| T5 | 70 | 77 | 74 | 81 | 59 | 66 | 65 | 71 | 55 | 5 | 25 | 60 |
| T6 | 88 | 87 | 76 | 48 | 81 | 79 | 70 | 18 | 100 | 80 | 25 | 20 |
| T7 | 64 | 63 | 82 | 65 | 47 | 44 | 55 | 51 | 40 | 95 | 0 | 60 |
| T8 | 76 | 81 | 72 | 68 | 60 | 71 | 75 | 56 | 30 | 95 | 50 | 30 |
| T9 | 81 | 73 | | 56 | 70 | 60 | | 33 | 30 | 100 | | 20 |
| T10 | 77 | 80 | | | 67 | 64 | | | 100 | 100 | | |
| T11 | 59 | | | | 61 | | | | 50 | | | |
| Mean | 72 | 75 | 77 | 68 | 61 | 63 | 66 | 53 | 46 | 66 | 35 | 51 |

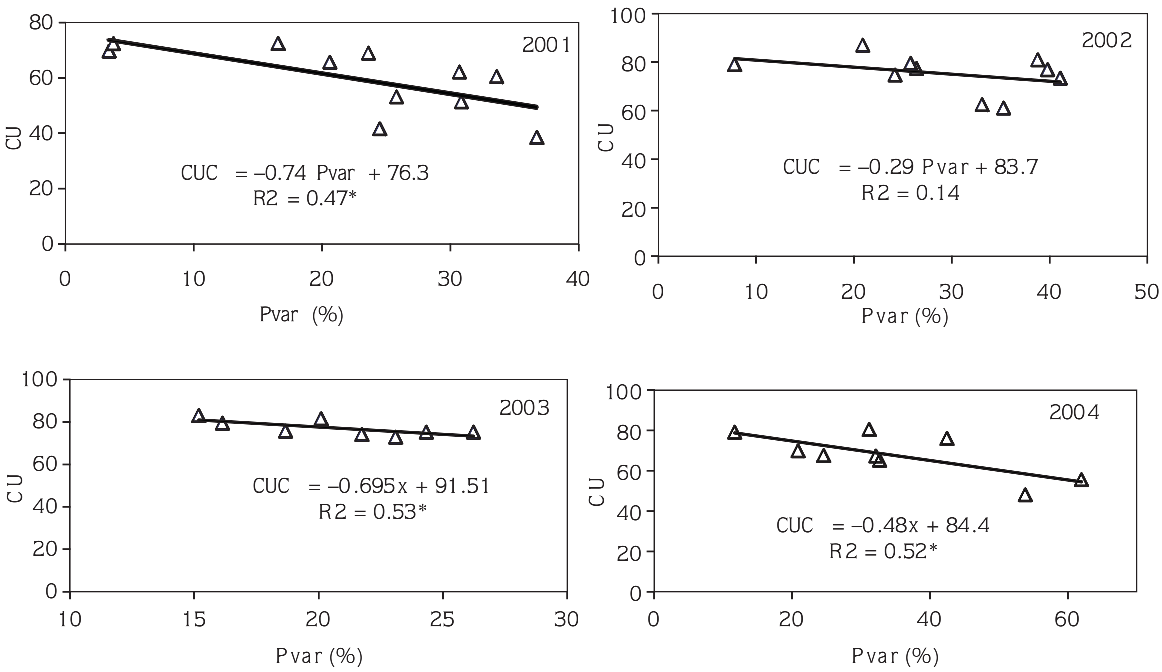



Figure 6. Relationships between the Christensen unifirmity coefficient (CUC) and pressure variation (Pvar) in lateral pipes.

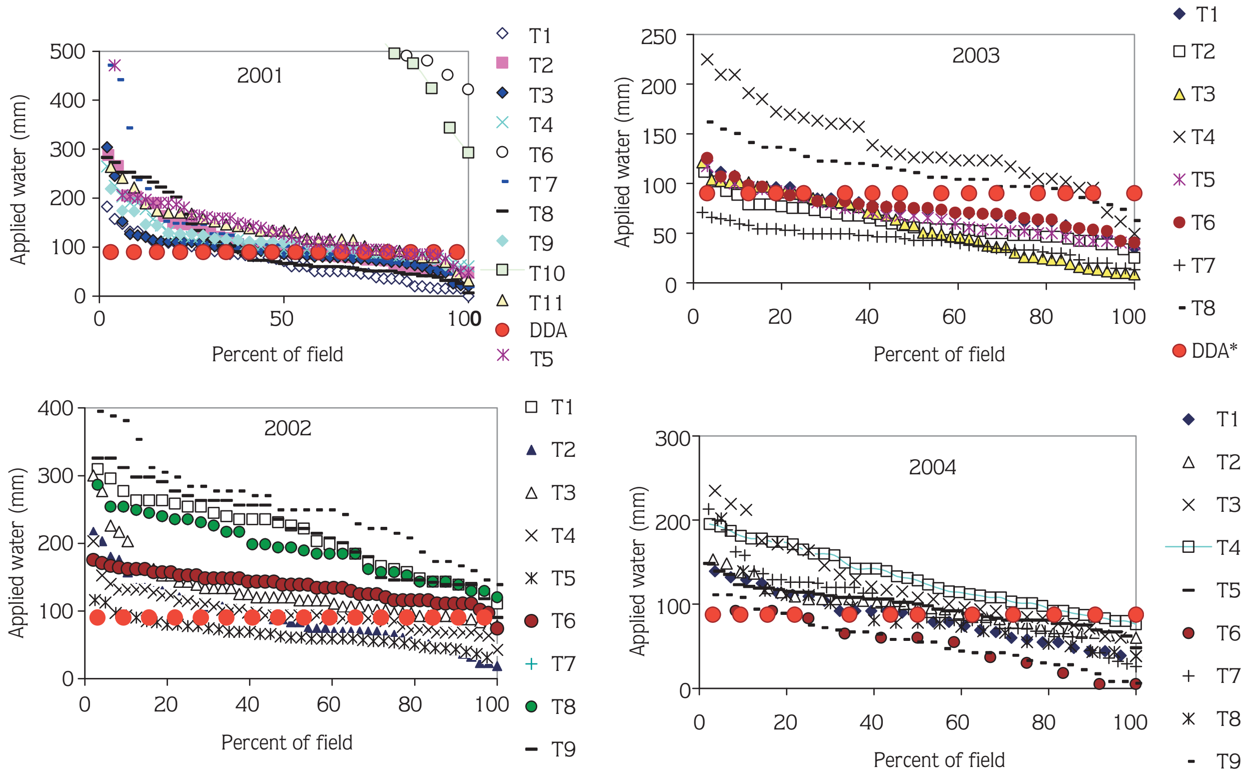
Irrigation adequacy can not be seen as a simple function of the area that reaches or passes a particular soil water content. It is a measure of the degree to which the soil water deficit over an entire field is met. Deficit, here, refers to the difference between the present soil water content and the target soil water content.

Adequate watering takes into account the water added to the effective root zone, but does not raise the soil water content to or above the target level. Although the irrigation systems were designed to apply, on average, 87.5 mm of water every 10 days, the farmers applied between 65 and 209 mm of water every 20 days. In full irrigation the soil is brought to field capacity.

The flatter slopes and smaller ranges of the infiltration depth curves indicated greater uniformity than for the steeper slopes. When uniformity was low more water was needed for full irrigation of the entire field. This resulted in the application of more water per irrigation application and increased water loss (Figure, 7).

Field irrigation adequacy values were 100% for 4 of the 38 irrigation events and, therefore, the majority was less than 100%. When the irrigation interval increased, available water in the root zone decreased by 70% and, therefore, it was necessary to apply more water during subsequent irrigation. Although the water depth applied was more than necessary, deficit irrigation was observed in some parts of the test area due to low distribution uniformity (Table 5, Figure 7).

Over-irrigation was observed in the entire field of some test areas (T6 and T10 in 2001, and T7 and T8 in 2002). In 2003 irrigation adequacy at test site T7 was zero; however, mean adequacy values were between 31% and 65% (Table 6). The values were lower than those recommended in the literature. It is suggested that a reasonable balance between irrigation uniformity and adequacy (A) is CUC = 80 and $A_a$ = 75 for field crops (Cuenca, 1989).




*DDA : Desired depth of application

Figure 7. Adequacy of irrigation in the test fields.

In general, the farmers had a tendency to use more water than was necessary. Both low uniformity and excessive water application increased deep percolation losses. Application efficiency can be improved by decreasing adequacy; however, this leads to an increase in the total under-irrigated area, reducing the quantity or quality of crops produced (James, 1993).

**Effect of Lateral Spacing on Uniformity of Irrigation**

When lateral spacing decreased, irrigation uniformity increased significantly (Table 6). In general, narrower lateral spacing resulted in increases in almost all irrigation uniformity values.

To determine the influence of lateral spacing, water application uniformity was compared between the different spacings of 38 laterals. The results showed that lateral spacing had a definite influence on water distribution uniformity; in contrast, greater spacing caused lower distribution uniformity. Statistical analysis showed that narrower spacing was a better choice ($P \leq 0.05$) for the sprinkler irrigation systems.

In 2001, CUC values of the 9   10-, 12   10-, and 15   10-m lateral spacings were significantly different ($P \leq 0.05$) than those of the 18   10-m lateral spacing ($P \leq 0.05$ and $P \leq 0.01$). Significant differences were not observed between spacings of 9   10 and 12   10 m, or between 15   10 and 12   10 m.

Table 6. Effect of different lateral spacings on CUC at the different test sites.

| Test site | Lateral Spacing (m) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 9 × 10 | 12 × 10 | 15 × 10 | 18 × 10 | 9 × 10 | 12 × 10 | 15 × 10 | 18 × 10 | 9 × 10 | 12 × 10 | 15 × 10 | 18 × 10 |
| | Argıthanı (2001) | | | | Orhaniye (2002) | | | | Pınarbaşı (2003) | | | |
| $T_1$ | 75.6 | 51.3 | 64.5 | 51.3 | 80.4 | 77.4 | 79.0 | 81.0 | 80.2 | 79.4 | 66.0 | 47.5 |
| $T_2$ | 77.8 | 68.9 | 59.5 | 60.5 | 69.6 | 74.2 | 75.5 | 61.0 | 83.5 | 76.2 | 75.2 | 68.0 |
| $T_3$ | 84.5 | 79.2 | 76.2 | 69.7 | 77.9 | 77.4 | 77.6 | 68.4 | 80.7 | 75.7 | 78.4 | 50.0 |
| $T_4$ | 85.6 | 83.0 | 79.5 | 72.5 | 83.8 | 75.3 | 70.7 | 79.0 | 77.4 | 75.2 | 59.9 | 42.5 |
| $T_5$ | 81.1 | 70.1 | 79.0 | 62.1 | 85.7 | 78.3 | 76.3 | 76.9 | 80.8 | 74.2 | 74.7 | 67.3 |
| $T_6$ | 84.5 | 87.8 | 80.5 | 75.5 | 90.1 | 89.1 | 72.9 | 91.1 | 79.9 | 81.5 | 81.3 | 69.2 |
| $T_7$ | 69.2 | 64.2 | 63 | 53.1 | 71.1 | 62.5 | 66.1 | 70.7 | 86.6 | 80.8 | 81.2 | 72.8 |
| $T_8$ | 43.7 | 75.5 | 40.8 | 38.5 | 82.7 | 81 | 78.5 | 81.6 | 84.4 | 83.1 | 80.4 | 65.7 |
| $T_9$ | 78.2 | 80.5 | 75.7 | 70.7 | 91.3 | 73.4 | 73.5 | 85.5 | | | | |
| $T_{10}$ | 88.1 | 77.3 | 81.8 | 72.4 | 73.1 | 79.5 | 73.3 | 75.9 | | | | |
| $T_{11}$ | 73.1 | 70.7 | 63.1 | 58.4 | | | | | | | | |
| Mean | 76.8 | 72.04 | 70.05 | 59.45 | 83.2 | 76.8 | 74.3 | 75.6 | 79.3 | 78.26 | 73.38 | 60.38 |

| Lateral Spacing (m) | 12 × 10 | 15 × 10 | 18 × 10 | Lateral Spacing (m) | 12 × 10 | 15 × 10 | 18 × 10 | Lateral Spacing (m) | 12 × 10 | 15 × 10 | 18 × 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | | | | P | | | | P | | |
| 9   10 | 0.409 | 0.259 | 0.004* | 9 × 10 | 0.256 | 0.034* | 0.357 | 9*10 | 0.047* | 0.031* | 0.0002** |
| 12 × 10 | | 0.731 | 0.025* | 12 × 10 | | 0.328 | 0.932 | 12 × 10 | | 0.247 | 0.001** |
| 15 × 10 | | | 0.004* | 15 × 10 | | | 0.372 | 15 × 10 | | | 0.012* |

*Significant difference at P = 0.05, **significant difference at P = 0.01 (not assessed in 2004 because the test parcels were very small).

In 2002 the CUC value of the 9 x 10-m lateral spacing was significantly different ($P \leq 0.05$) than that of the 15 x 10-m lateral spacing. Significant differences were not observed between the 9 x 10-m spacing and the other tests (Table 6).

In 2002 all CUC values of the 9   10-m lateral spacing were significantly higher than the other spacings ($P \leq 0.047$, $P \leq 0.031$, and $P \leq 0.0002$). The CUC value of the 12   10-m lateral spacing was significantly different than that of 18   10 m ($P \leq 0.001$), while there was no difference between 12   10- and 15   10-m lateral spacing ($P \leq 0.247$). Significant differences were not observed between 9   10-m lateral spacing and the other tests. The CUC value of the 15   10-m lateral spacing was significantly different than that of the 18   10-m lateral spacing ($P \leq 0.012$) (Table, 6).

In 2004 the test plots were very small, and lateral and sprinkler spacing were narrower than the systems were designed for; therefore, the effect of lateral spacing on CUC values could not be assessed.

When lateral spacing was 9 m, CUC values increased to > 80% at test sites T3, T4, T5, T6, and T10 in 2001, at T2, T4, T5, T8, and T9 in 2002, and at T2, T3, T4, T6, T7, and T8 in 2003 (Table, 6). Cuenca (1989) also reported that CUC values generally can increase when lateral spacing decreases, but results in increased capital costs. Vories and Bernuth (1986) claimed that reducing sprinkler irrigation lateral and sprinkler head spacing increases CUC.

## Discussion

Analysis of the data showed that the farmers in the region had poor water management practices. They usually used different numbers of sprinkler heads on a single lateral, with 12- to 18-m lateral spacing and 10-m sprinkler head spacing. The sprinkler heads had 2 nozzles on each side and nozzles sizes ranged from 3.2-5.0   4.5-5.5 mm (Table 7). With time the sprinkler heads were changed by the farmers for maintenance; therefore, they did not have uniform discharge rates.

Mean, maximum, and minimum pressures and flow rates, and their variation, were much higher than the systems were designed for. Irrigation intervals were longer than recommended and, therefore, the number of irrigations was somewhat lower than the systems were designed for.

Application of irrigation depths for the same crops varied widely from field to field. In all systems, considering CUC = 85% and DU = 75%, the pressure was supposed to be 2.5 atm, lateral length was supposed to be 200-250 m, and spacing was supposed to be 15   12 mm at Argıthanı and Orhaniye, and 15   15 m and 18   12 m at Karali. Nonetheless, lateral and head spacing used by the farmers were different than the systems were designed for at Orhaniye, Pınarbaşı, and Karaali, whereas they were as designed for at Argıthanı.

Three of the irrigation systems were designed for 15   12 m and one was designed for 18   18 m lateral and sprinkler head spacing, with an average pressure of 2.5 atm; however, the lateral and head spacings used were different. Irrigation interval, irrigation water depth, sprinkler size, and sprinkler discharge capacities were different from those the systems were designed for.

The availability of sprinkler parts and farming practices should be considered during the design of new sprinkler systems in the region. To obtain high uniformity values, the present sprinkler systems should be re-evaluated and non-uniform systems should be repaired.

Replacement parts in sprinkler systems should be the same as original and operating pressure should be uniform in order to obtain high performance. To increase irrigation uniformity in areas with high wind speed, narrower lateral spacing should be used, which will not increase capital costs.

The main variable related to water application uniformity in a set move sprinkler irrigation subunit is spacing; thus, the smaller the spacing, the higher the uniformity. The farmers in the study area were not knowledgeable enough to deal with the current irrigation systems efficiently. They had a tendency to operate the systems with common surface irrigation methods.

## Conclusions

Pressurized irrigation systems have been financially supported and constructed by the Turkish government, interest-free, to improve irrigation efficiency and crop yield. This program requires large quantities of labor and capital, but its success is unclear.

Our study showed that performance of the pressurized irrigation systems in the Konya region was much lower than expected, which was due to a lack of

Table 7. Some performance parameters of the sprinkler irrigation systems.

| Test site | Sprinkler head pressure (P. atm) | | | | Mean | | S1 × S2 | | CUC (%) | | | DU (%) | | | $A_a$ (%) | | Runoff |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Designed | Measured | | | | | | | | | | | | | | | |
| | | Max. | Mean | Min | $P_{var}$ | $Q_{va}$ | Designed | Applied | Max | Mean | Min | Max | Mean | Min | Max | Min | |
| Argıthanı | 2.5 | 2.10 | 1.41 | 0.88 | 22.7 | 33 | 15-12 | 18 × 12 | 88 | 74 | 51 | 81 | 62 | 30 | 100 | 46 | None |
| Orhaniye | 2.5 | 3.10 | 2.07 | 1.30 | 29.8 | 38 | 15 × 12 | 18 × 12<br>12 × 10 | 87 | 75 | 61 | 79 | 65 | 43 | 100 | 70 | None |
| Pınarbaşı | 2.5 | 3.7 | 1.84 | 1.15 | 20.7 | 37 | 15 × 15 | 18 × 10<br>15 × 10 | 83 | 72 | 36 | 75 | 59 | 10 | 90 | 0 | None |
| Karaali | 2.5 | 2.60 | 1.38 | 0.40 | 30.5 | 30 | 18 × 18 | 12 × 10<br>12 × 5<br>12 × 6 | 81 | 69 | 48 | 71 | 56 | 18 | 90 | 20 | Available |

Table 7. continued

| Test site | Crops | Et, (mm season$^{-1}$) | Et, (mm d$^{-1}$) | Irrigation number in season | | Irrigation interval (days) | | Irrigation depth (mm) | Nozzles size, (mm) | | Nozzles flow, (l s$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Designed | Applied | Designed | Applied | Applied | Designed | Applied | Designed | App. |
| Argıthanı | Sugar beet | 824.6 | 7.0 | 7 | 3-5 | 12 | 18 | 433-79 | 4.8 | 4.5 × 4.5 - 4.5 × 4.8<br>4.5 × 5.0 -5.0 × 5.5 | 0.383 | 0.581 |
| Orhaniye | Sugar beet<br>Pumpkin | 795.4<br>471.6 | 6.5<br>6.2 | 8<br>6 | 4<br>4 | 10<br>12 | 20<br>20 | 208-118<br>56-65 | 4.8 | 4.5 × 4.5 - 4.5 × 4.8<br>4.5 × 5.0 - 5.0 × 5.5 | 0.383 | 0.686 |
| Pınarbaşı | Sugar beet<br>Bean | 858.4<br>519.5 | 7.3<br>6.9 | 8<br>6 | 4<br>4 | 10<br>11 | 20<br>16 | 111-60<br>75-50 | 4.8 | 4.5 × 4.5 - 4.5 × 4.8<br>4.5 × 5.0 - 5.0 × 5.5 | 0.419 | 0.608 |
| Karaali | Sugar beet | 810..6 | 6.9 | 7 | 4 | 8 | 20 | 130-50 | 4.6 | 3.2 × 5.0 | 0.342 | 0.461 |

consideration of all the factors during preparation of the project, including farmers with limited knowledge, application of unsuitable irrigation schedules, local customs, and improper operation methods

Increasing irrigation efficiency will not be possible without solving the above-mentioned problems. It is, therefore, imperative that all the required parameters, such as climate, soil, water, crop, and social structure of the society be considered in great detail when designing pressurized irrigation systems. In addition, projects should include an operation schedule for irrigation, with respect to sustainable use and water resource management.

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