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Aflaj's Irrigation Water Demand/Supply Ratio: Two Case Studies

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مقسوم الطلب على العرض لمياه الرى بالأفلاج

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الخلاصة: يعتمد الإنتاج الزراعي في سلطنة عمان بالكامل على الري ذلك لأن معظم المناطق المزروعة لا تتلقى أكثر من 100-200 ملم من الأمطار سنويا, حيث توفر الأفلاج أكثر من ثلث كمية المياه المستخدمة في الزراعة . يوجد في عمان 4112 فلجا، منها 3017 فلج حي تنتج كمية من الماء ما تقارب 680 مليون متر مكعب سنويا. ويعرف الفلج (مفرد أفلاج) على أنه نظام لتوفير الماء لمجموعة من المزارعين للاستخدام المدني والزراعي. كان الهدف الرئيسي من هذه الدراسة هو تقدير أداء الأفلاج كأنظمة ري. اختير فلجا الدريز والنجيد كعينة لهذه الدراسة حيث أنهما يقعان في بيئة شحيحة المياه وذات معدل بخر ونتح عاليين. استخدمت الدراسة طريقة يفترض فيها الفلج كوحدة واحدة كمؤشر لكفاءة الري. اختيرت النخيل التي تستخدم معظم مياه الري في التحليل. وأستعمل مقسوم الطلب على العرض لتقدير الأداء. في فلج الدريز، وحسب المعدل السنوي، لم تروى النخيل بما يكفي تماما من المياه. وحسب المعدل الشهري، فان مقسوم الطلب على العرض كان أقل من 0.6 شتاء وأعلى من 1.0 في الصيف. كان فلج النجيد يوفر ماء أكثر بكثير من الطلب على مدار العام حيث أن مقسوم الطلب على العرض بلغ 0.25 فقط شتاء ولم يزد عن 1.0 صيفا.

ABSTRACT: Due to the geographical location of Oman in an arid zone, agricultural production depends fully on irrigation. The traditional irrigation systems (*Aflaj,* sing. *falaj*) supply more than one third of water for agriculture. *Falaj* is defined in the context of this paper as a canal system which provides water for domestic and agricultural uses. Oman has 3,107 active *Aflaj* producing about 680 Mm^3 of water per year. The main objective of this study was to estimate the irrigation performance of *Aflaj* in Oman. *Falaj* al-Dariz and al-Nujaid were chosen as case studies. Both *Aflaj* are located in an extremely arid environment, where the rainfall is low and evapotranspiration is high. The study utilized an approach to estimate the irrigation performance of *Aflaj* by considering the *falaj* as a single unit of irrigation. The irrigation demand/supply ratio (D/S) was used in the analysis as a tool of evaluation. Date palm, the dominant crop irrigated by *Aflaj,* was selected for the analysis. In *falaj* al-Dariz the date palms were slightly under irrigated on a yearly basis. On a monthly basis, in winter, the D/S was below 0.6 and in summer it was above 1.0. On the other hand, *falaj* al-Nujaid was supplying too much water than the date palms needed all round the year. In winter the D/S ratio was as low as 0.25. Even in summer, the D/S ratio did not much exceed 1.0.

Keywords: *Aflaj*, traditional irrigation, irrigation demand/supply ratio, efficiency, Athar, Oman.

Introduction

Agriculture in Oman is fully dependent on irrigation because most crop production areas receive only 100 to 200 mm of rainfall annually. Oman has 4,112 *falaj,* of which 3,017 are live *Aflaj*(افلاج) , supplying about 680 Mm^3 /year of water, of which 410 Mm^3 are utilized by *Aflaj* users for domestic and agriculture. These *Aflaj* irrigate some 26,500 hectares (The Ministry

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of Regional Municipalities, Environment and Water Resources, 2001). The *falaj* (فلج) (singular of *Aflaj*) is defined as, a canal system, which provides water for a community of farmers for domestic and agricultural use. The term *falaj* is derived from an ancient Semitic root, which has the meaning "*to divide*", since the water shares in *Aflaj* are divided between the owners (Al-Ghafri, 2005). The local nomenclature of the *falaj* implies the system as a whole, including the collection and distribution areas. *Aflaj* in Oman can be classified into three types, depending on their source of water: *Ghaili* (غيلي), *Daudi* (داؤودي) , and *Aini* (عيني). However, the methods of administration and management are very similar. Only the *Daudi* type is similar to the *Qanat* irrigation system of Iran (Al-Ghafri *et al*., 2000).

The traditional way of irrigation scheduling varies from one *falaj* to another. Several methods are adapted for distributing water among farmers. The most common method is to divide the irrigation rotation (*dawran*دوران) over 4 to 20 days, depending on the *falaj* flow and the type of soil; each full day is divided to 48 *athars,* or 30 minutes, each *athar* is then divided to smaller divisions. Traditionally, farmers have used sundials in the daytime, and stars at night for timing their water shares in the field (Al-Ghafri *et al*., 2003).

Previous studies have considered water management on the farm scale within the *falaj* system (Norman *et al*., 1998a, 1998b, 2001). However, this study aims to analyze the overall irrigation performance of the *falaj* system, by considering the whole *falaj* as a single farming system unit, hence all the lands of the *falaj* are assumed to be irrigated during a fixed period (*dawran*). This paper illustrates a method for an estimation of *falaj* irrigation performance using irrigation demand over supply ratio (D/S).

Site Description for the Study Area

The villages of al-Dariz الدريز (N23˚ 19´ - E56˚ 47´) and al-Nujaid النجيد (N23˚ 28´ – E56˚ 47´) are located in the Ibri (ولاية عبري) district in the Dhahirah (الظاهرة) region in northern Oman. Ibri has 363 *falaj*, which is the second largest number of *Aflaj* among the 60 *wilayats* (districts) of Oman. These villages are located close to one of the world's driest deserts, *Ar Rub' al Khali* (الربع الخالي) known also as the "Empty Quarter". They have a negligible amount of rainfall.

There is no rain gauge installed in al-Dariz. However, there are rain gauges in two places in the same district at Ibri and Tanam (تنعم). From these two places, rainfall data have been collected by MRMEWR for 25 years (1975 - 1999). The average annual rainfall for these 25 years is 88 mm y^{-1} (Ibri) and 85 mm y^{-1} (Tanam). The maximum and minimum rainfall data are not available. The average annual rainfall for the period 1991 - 1998 was 133 mm y^{-1} in al-Nujaid. Data for the period of study (May 2002 to April 2003) were collected by installing a rain gauge in the research area of al-Dariz.

Falaj al-Dariz is a large *Daudi falaj* (chain of wells) with a total channel length of 6,503 m, of which 5,880 m is a tunnel. One of the two mother-wells of *falaj* al-Dariz has dried up. This *falaj* has good water quality. According to the MRMEWR (2001), water quality tests show an electrical conductivity (EC) of 480 µS cm^{-1} and pH of 8.0. *Falaj* al-Nujaid, on the other hand, is a medium size *Daudi falaj* located about 25 km upstream and north of *falaj* al-Dariz. *Falaj* al-Nujaid has one mother well located in the wadi bed of Wadi al-Kabir, 2.2 Km m from the first opening of the tunnel. *Falaj* al-Nujaid has a higher EC (749 µS cm^{-1}) and similar pH (8.0) as *falaj* al-Dariz (MRMEWR, 2001).

Date palms (*Phoenix dactylifera*) occupy more than 90% of the cropping area of *falaj* al-Dariz and *falaj* al-Nujaid. Other crops cover negligible areas in these two *aflaj* and are planted seasonally. Winter crops, such as wheat, barely and garlic, are planted between October and November and harvested between March and April. Summer crops, such as onion, beans and corn, are planted between February and April, and harvested between June and September. However, these crops occupy a small portion of land and water compared with date palms.

Materials and Methods

Irrigation Water Demand/Supply (D/S) ratio

The ratio of crop water demand to irrigation supply (Demand over Supply ratio, D/S) was used for this study as suggested by Norman *et al.* (1998 a, b and 2001). A D/S ratio greater than 1.0 indicates that farmers are applying less water than plant require. A D/S ratio smaller than 1.0 indicates that farmers are over-irrigating. A minimum ratio of 0.6 is accepted for surface irrigation (Norman *et al.,* 1998a).

The average daily water requirements (demand) for each month in the year were obtained from published official literature by the Ministry of Agriculture and Fisheries Wealth (Al-Nadi, 2003). A calibrated water level was used to determine the flow rate. The area was obtained from maps published by MRMEWR (2001). The quantity of water supplied per area (S) was calculated from the flow rate, time of application and area.

Data collection

Data were collected by direct fieldwork, interviews and a review of the literature. Rain data and field observations (such as sudden rise of water flow, unusual behavior of irrigators, etc.) were recorded during the course of this study. Contact with the *falaj* community and with members of the *falaj* administration was maintained throughout the study. Soil textural analyses and field capacity measurements were done in the laboratories of Sultan Qaboos University, Oman.

Crop water requirements for date palm

The data for the water requirements (ETc) for the date palm was retrieved from Al-Nadi (2003). The calculation was made for a plant density of 1 date palm per 15 m^2. The estimation of ETc was based on the Penman-Monteith method (Richard *et al.*, 1998).

Water level

Two data loggers were installed in *falaj* al-Dariz and *falaj* al-Nujaid on 25 May 2002. Solid-state high-duty loggers were used (STS model DL/N). Readings were recorded every hour. The last data were downloaded from the loggers on 25 April 2003 and 11 months data were successfully retrieved.

Flow rate

The flow rate was measured as close as possible to the demand area, to avoid errors created by water losses in the conveyance system. It was observed four times during the 11 months of water level reading, using a solid-state current meter (model: VALPORT.LTD VEM003). The average of three readings was taken at three different locations. The *falaj* width and depth of the water were also measured and recorded in every observation.

Soil sampling

Soil samples were taken from three farms, in the head, center and tail end of each *falaj* cropping area. In each farm, samples were taken from three locations at depths of 15, 30 and 45 cm. Samples were analyzed for soil texture using a hydrometer and bulk density using core sampling method. The samples for determining the field capacity were collected from the field after 24 hours of full irrigation, and then the water content was obtained using the gravimetric method.

Results and Discussion

Area

According to MRMEWR (2001), the cropped area of *falaj* al-Dariz is 255.4 ha and 21.3 ha for *falaj* al-Nujaid. The area was estimated using GIS system after GPS land survey.

Rainfall

The effective rainfall during the study period was 44.1 mm. *Falaj* al-Nujaid is located about 25 km up stream of al-Dariz, therefore the same rainfall data was used for al-Nujaid case study.

Flow rate calibration

By linear regression the following calibration equation was obtained for calculating the flow rate of *falaj* al-Dariz:

$$Q = 99.1\ H^{0.22} \quad (R^2 = 0.66)$$

Q = the flow rate ($l\ s^{-1}$)
H = the logger measured head (cm)

Figure 1 shows the hydrograph of *falaj* al-Dariz. The trend shows that the *falaj* flow was in the process of recession, since there was little rainfall during that period. An abnormal rise and recession in the flow rate occurred between September and October 2002. This was due to the *falaj* tunnel collapse.

The calibration equation for *falaj* al-Nujaid was:

$$Q = 2.22\ H^{1.79} \quad (R^2 = 0.85)$$

Figure 2 shows the hydrograph of *falaj* al-Nujaid, with two adonolies. The hydrograph shows two adonolies in the flow rate. The first was observed in September 2002 and the second in April 2003. During this period, the upstream catchments of the wadi that feed the *falaj* experienced heavy rainfall. The tunnel of *falaj* al-Nujaid passes through a wadi bed, but it is not totally sealed. There are places where surface water can percolate into the tunnel. So, the high flows

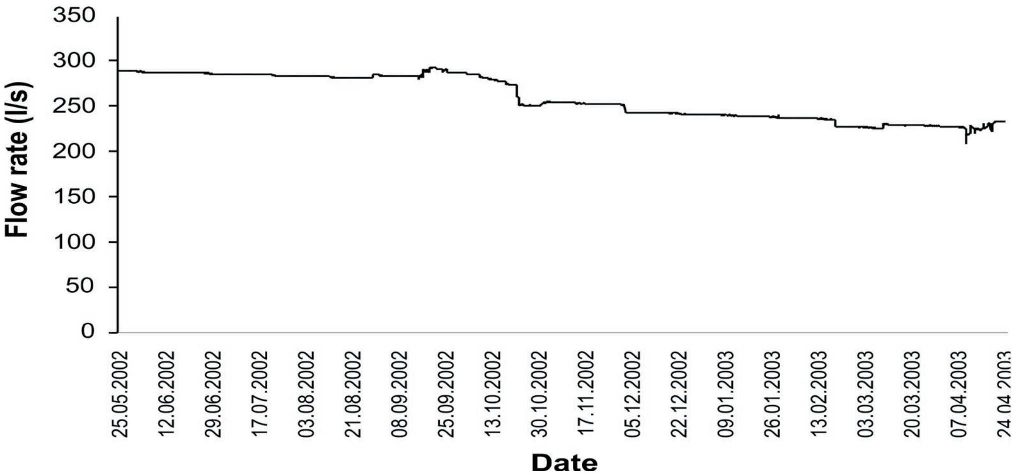

Figure 1. Hydrograph of *falaj* al-Dariz.

in September and April are not from groundwater but a temporary intrusion of surface flow. Local people said that it takes 6 months for the *falaj* flow rate to increase to high flow after heavy rain, then it remains with a steady flow for 4 to 5 years, even without any other heavy rain. However, the recent data are insufficient to verify this fact. Collection of hydrological data is needed for a longer period. In both flow rate calculations (of September and April), it should be noted that the high flow rate was obtained by extrapolating the regression curve. Thus, these values may include a large error. However, these high flows occur in short periods in few times, the overall error is insignificant.

Soil analysis

The soil texture of al-Dariz is dominated by clay loam with a bulk density of 1.43g cm^{-3} and field capacity of 22 % by volume. *Falaj* al-Nujaid has a sandy loam soil mixed with small gravels with a bulk density of 1.72 g cm^{-3} and a field capacity of 16.4 % by volume. These results indicate that *falaj* al-Dariz has a finer

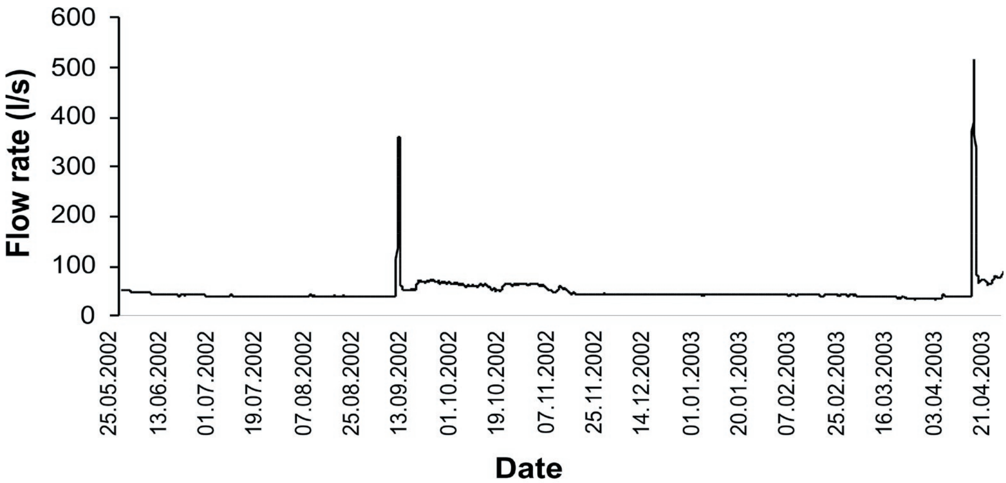

Figure 2. Hydrograph of *falaj* al-Nujaid.

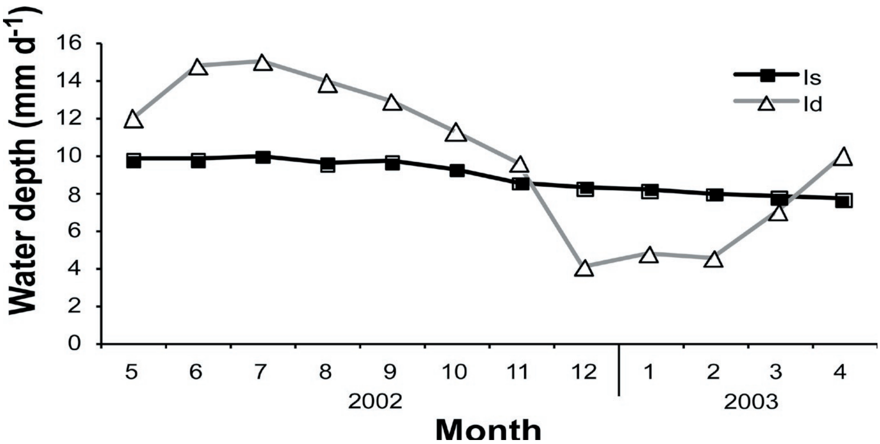

Figure 3. Monthly average irrigation demand and supply for *falaj* al-Dariz, 2002-2003.

soil texture with higher field capacity than *falaj* al-Nujaid. Hence, the *dawran* of *falaj* al-Dariz (19 days) is designed to be longer than the *dawran* of *falaj* al-Nujaid (10 days).

Irrigation Water Demand/Supply (D/S) ratio for falaj al-Dariz

a) Annual D/S

The logger started the first reading of the water head in the channel of *falaj* al-Dariz on 25 May 2002. The last reading retrieved from the logger was on 26 April 2003. For calculations, this period is called T_p and the complete year period T_y. The total time during the period of observation T_p was 8,047 hours. The total volume of water delivered to the field during T_p was 7.487 Mm^3 and the total volume for the whole year was 8.151 Mm^3 with a yearly depth (volume/area) of 3,191 mm. The total supplied water to the field including the effective rainfall was 3,235 mm.

Based on Al-Nadi (2003) the total annual demand for date palms, ETc = 3,620 mm y^{-1}, and the annual D/S can be calculated as:

$$D/S = 3,620 / 3,235 = 1.12 \text{ or } 112\%$$

This result indicates that the date palms in al-Dariz are under irrigated as demand is higher than supply by 12% on a yearly basis.

b) Monthly D/S

The same criterion was used to calculate D/S on a monthly basis. For each month, the average daily water delivered was calculated. This calculation includes the rainfall of April 2003.

From Figure 3, it can be seen that the patterns of demand and supply are not matched. While the water demand is higher in summer and lower in winter, the supplied water follows the hydrograph of the *falaj*. It is clear from the figure that the water supply of *falaj* al-Dariz was decreasing at the period of measurement.

From Figure 4, it is clear that the D/S was changing every month. From April to November, the *falaj* did not supply enough water to meet the crop water requirement, while in December, January and February, the *falaj* supplied more water than demanded. Only in March, was the D/S (0.90) is within the accepted range (0.6 – 1.0). This means that the plants were stressed in summer and over-irrigated in winter. The highest D/S was in June (1.52) and the lowest was in December (0.49).

Irrigation Water Demand/Supply ratio (D/S) for falaj al-Nujaid

a) Annual D/S

The logger started the first reading of the water level in the channel of *falaj* al-Nujaid on 25 May 2002. The last reading retrieved from the logger was on 25 April 2003. For calculations, this period is T_p and a complete one-year period T_y. The total time during the period of observation T_p was 8,054 hours. Assuming that the flow rate of the 12th month will be same as the average of previous 11 months, the total volume of water delivered to the field at T_p was 1.315 Mm^3. The

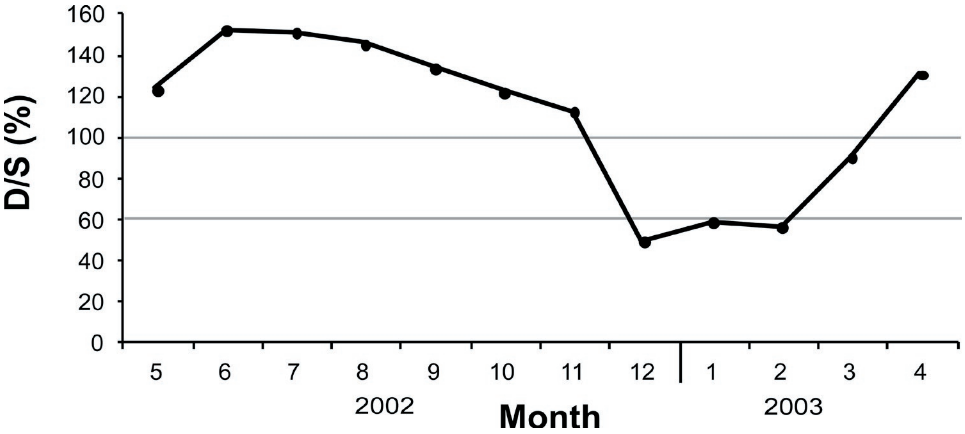

Figure 4. Monthly D/S for *falaj* al-Dariz, 2002-2003.

annual volume was 1.431 Mm^3 with a yearly depth of 6,723 mm. The total supplied water to the field including the effective rainfall was 6,767 mm.

The annual demand for date palm is ETc = 3,620 mm y^{-1} and the annual demand/supply can be calculated as:

$$D/S = 3{,}620 / 6{,}767 = 0.53 \text{ or } 53\ \%$$

This result indicates that the demand area of *falaj* al-Nujaid is over irrigated on a yearly basis.

b) Monthly D/S

For each month, the average daily supply was calculated including the rainfall of April 2003. The supply of water peaked on September 2002 and April 2003, when the surface water entered the canal after rainfall (Figure 5). Over the whole year, *falaj* al-Nujaid supplied more water than the crops demanded. Compared with *falaj* al-Dariz, this *falaj* has light soil with relatively low field capacity. Generally, more water needs to be applied to the soil in al-Nujaid than in al-Dariz.

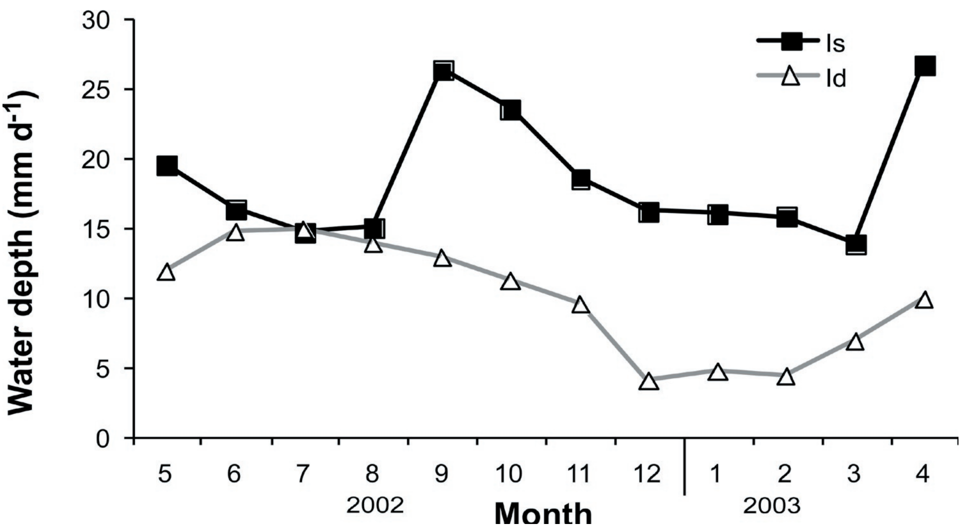

Figure 5. Monthly average irrigation demand and supply for *falaj* al-Nujaid, 2002-2003.

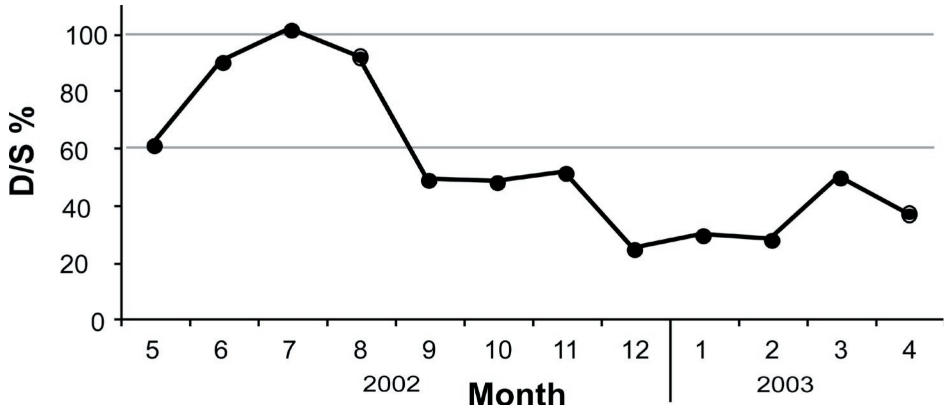

Figure 6. Monthly D/S for *falaj* al-Nujaid, 2002-2003.

From Figure 6, it can be seen that *falaj* al-Nujaid supplied water more in winter than it did in summer. From May 2002 to August 2002, the *falaj* performed well, with D/S values between 0.6 and 1.0. However, from September 2002 to April 2003, the *falaj* wasted tremendous amounts of water, with a minimum D/S value in December 2002 (0.25).

Conclusion

In *falaj* al-Dariz the date palms were slightly under irrigated on a yearly basis. On a monthly basis, the performance of the *falaj* irrigation system was different. In winter, the D/S was below 0.6 and in summer it was above 1.0. This means that *falaj* al-Dariz wasted water in winter but the plants were stressed in summer. On the other hand, *falaj* al-Nujaid was supplying more water than the date palms needed all year round. In winter the D/S ratio was as low as 0.25. Even in summer, the D/S ratio did not much exceed 1.0. Probably, the reason for the low D/S in this *falaj* is because it has a lighter soil that needs more water to be applied. In this *falaj*, farmers are irrigating more frequently than in *falaj* al-Dariz.

The data obtained from this study was adequate to meet the objective of roughly estimating the irrigation performance of *aflaj*. However, further research is needed to precisely evaluate the hydrological and agricultural systems of *aflaj*. This requires measuring more parameters for longer periods. For *falaj* hydrological studies, rainfall, flow rate and wadi flood records are necessary. For detailed irrigation performance evaluation, on-field weather data should be obtained with real-time soil moisture content in the soil, within and below the root zone. For measuring areas of land use, high-resolution satellite images can be used, capturing each cropping season every year. A complete understanding of the *falaj* water management may not be attained unless further measurements on water and soil quality are made, as well as, economical evaluation of the input and output of the *falaj* system related to irrigation.

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