Alternate Furrow Irrigation with Different Irrigation Intervals for Maize (Zea mays L.)

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Abstract: This research was conducted to determine the yield and water-use efficiency of maize under fixed and variable alternate furrow irrigation (fixed AFI, variable AFI) and every furrow irrigation (EFI) at different irrigation intervals in areas with shallow and deep groundwater. In variable AFI, water was applied to the furrow, which was dry in the previous irrigation cycle. The results indicated that even at 4-day irrigation intervals the water needs of maize on a fine textured soil in both areas (with deep and shallow water table) are not met by AFI. The decrease in grain yield due to water stress was mainly due to the decrease in the number of grains per cob and to a lesser extent to the decrease in 1000-grain weight. At the Kooshkak site with shallow groundwater (between 1.31 and 1.67 m), grain yields in AFI at 4- and 7-day intervals were comparable to those obtained in EFI at 7- and 10-day intervals, respectively. This might be due to the contribution of groundwater to the water use of the plant (about 5-10%). In the Badjgah area, with deep water depth, grain yield in AFI at 7-day intervals was statistically lower than that obtained in EFI at 10-day interval. In AFI, a shorter irrigation interval (4-day) may alleviate the water stress and result in no yield reduction compared with that in EFI at 7-day intervals even though water application was reduced. Furthermore, in the area with a shallow water table, AFI at 7-day intervals may be superior to EFI at 10-day irrigation intervals. When seasonal irrigation water is less than 700 mm, it may be preferable to use AFI at 10-day intervals to increase water-use efficiency, especially in areas with shallow groundwater. In general, when water was insufficient for full irrigation, the relative grain yield (yield per unit water applied) of maize under AFI was higher than those under EFI.

Key words: Deficit irrigation, Groundwater contribution, Water conservation, Water use efficiency.

Crop production during the summer months in the semi-arid Mediterranean-type environments mainly relies on irrigation. Shortage of water in arid and semi-arid regions of Islamic Republic (I.R.) of Iran is an important limiting factor in crop production. This is true for Fars Province in southern part of I.R. of Iran where annual rainfall is less than 400 mm with negligible amount of rain during growing season of summer crops.

Agricultural water-use efficiency can be improved in different ways. Many investigators (e.g. Grimes et al., 1968; Fischbach and Mulliner, 1974; Stewart et al., 1981; Musick and Dusek, 1982; Samadi and Sepaskhah, 1984; Crabtree et al., 1985; Hodges et al., 1989; Graterol et al., 1993; Stone and Nofziger, 1993; Sepaskhah and Kamgar-Haghighi, 1997) have used wide-spaced furrow irrigation or skipped crop rows (alternate furrow irrigation, AFI) as a means to improve water-use efficiency (WUE). In AFI, some furrows are irrigated, while adjacent furrows are not, and WUE is increased mainly by reduced evaporation from the soil surface, as in the case of drip irrigation.

In general, the use of such methods of irrigation results in a lower yield in spite of a higher WUE. The experiments of New (1971) with sorghum and Samadi and Sepaskhah (1984) with dry bean (7-day irrigation intervals) indicated a significant yield reduction in AFI. The reduction was attributed to a smaller amount of applied water and an apparently imposed soil moisture stress, especially at the reproductive stage of growth. AFI combined with an exceptional every furrow irrigation (EFI) at the pod filling stage produced the highest bean yield with a smaller amount of water compared with the EFI (Samadi and Sepaskhah, 1984). AFI at 10-day intervals resulted in a 34% reduction of applied irrigation water, but only 18% reduction of sugarbeet yield on the average (Sepaskhah and Kamgar-Haghighi, 1997).

However, there is evidence that more frequent irrigation with a larger amount of water may increase crop yield. Grain yield of finger millet under surface irrigation was increased by shorter irrigation intervals (8-11 days) (Vanangamudi et al., 1990). The sorghum forage yield increased by shorter irrigation intervals (7-10 days) (Abdel-Magid et al., 1982; Boobathi and Singh, 1984). The optimum irrigation interval for sorghum grain yield under surface irrigation was reported to be 12-18 days (Done et al., 1984; Myers et al., 1984). Wheat yield was also increased by frequent irrigation as reported by English and Nakamura (1989). Similarly, Lyle and Bordovsky (1995) obtained the highest grain yield using low-energy precision
application (LEPA) irrigation at 3- and 6-day intervals. Thus, it is postulated that the water stress effects of AFI on yield may be alleviated by shorter irrigation intervals. The amount of applied water in AFI at shorter intervals is almost equal to or even less than that applied in EFI at longer intervals. Furthermore, crop yield may be increased by using proper irrigation scheduling. The grain yield of finger millet was increased by a shorter irrigation interval (Vanangamudi et al., 1990). The proper irrigation interval of the maize in the southern region of I.R. of Iran is usually seven days. The root yield of sugarbeet under AFI at 6-day interval was similar to that under EFI at 10-day intervals, while water was saved by 23% on the average (Sepaskhah and Kamgar-Haghighi, 1997).

As water is scarce in arid and semi-arid regions, the use of shallow groundwater developed in many areas plays an important role in crop water supply. Studies in California and Texas (USA) showed that salt-tolerant crops (cotton, alfalfa and barley) are capable of extracting significant quantities of water from a saline groundwater (reported by Ayars and Schoneman, 1986; Hutmacher et al., 1996; Ayars et al., 1999; Ayars et al., 2003). Grismer and Gates (1988) reported that under arid conditions, ground water can supply as much as 60-70% of a crop’s water requirement. Wallender et al. (1979) found that cotton extracted up to 69% of its evapotranspiration (ET) from a saline (6 dS m$^{-1}$) groundwater. Ayars and Schoneman (1986) reported that cotton extracted up to 49% of ET from saline (10 dS m$^{-1}$) groundwater depending on the amounts of non-saline water applied. The amount of water extracted from groundwater depends on the irrigation water application and scheduling (Sepaskhah et al., 2003). The maximum use of saline groundwater was observed when only one irrigation was applied after pre-plant irrigation for cotton as reported by Ayars and Schoneman (1986).

The objective of this research was to test the aforementioned hypothesis for maize under AFI and EFI at different intervals (shorter and longer than the common interval in the study region) under deep and shallow groundwater conditions.

**Materials and Methods**

1. **Badjgah experiment**

The experiment on a clay loam soil (Fine, mixed, mesic, Typic Calcixerepts) with a deep water table was conducted at the Badjgah Agriculture Experiment Station of Shiraz University located 16 km north of Shiraz (29º, 36' N, 52º, 32' E, 1810 m MSL). Table 1 shows some physical properties of the soils. Volumetric water contents at field capacity and permanent wilting point of the soil at depths of 0-30 cm were 0.335 and 0.168 cm$^{3}$ cm$^{-3}$, respectively. These values for the soil depths of 30-90 cm were 0.39 and 0.157 cm$^{3}$ cm$^{-3}$, respectively. The mean air temperature during the growing period was 20.2 ºC.

The design of the experiment at each site was a randomized split plot with four replications and consisted of three irrigation intervals (4-, 7-, and 10-day) as main plots (each with net area of 157.5 m$^{2}$).

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### Table 1. Selected physical properties of soils in two experimental areas.

| Depth cm | Particle size distribution | Sand % | Silt % | Clay % | Organic matter % | CaCO$_3$ % | Texture |
|----------|---------------------------|--------|--------|--------|------------------|------------|---------|
| 0-30     | Badjgah*                  | 35     | 35     | 30     | 2.0              | 17.0       | cl***   |
| 30-54    | 23                        | 39     | 39     | -      | 19.6             | 28.0       | c       |
| 54-112   | 21                        | 39     | 40     | 0.70   | 30.4             | silc      |
| 112-158  | 19                        | 46     | 25     | -      | 37.5             | sil       |
| 158-180  | 33                        | 51     | 16     | 0.5    | 37.5             | silc      |
| 0-25     | Kooshkak**                | 19     | 36     | 45     | 1.83             | 37.5       | c       |
| 25-42    | 21                        | 29     | 50     | 1.28   | 44.0             | c         |
| 42-70    | 16                        | 32     | 52     | 0.98   | 44.5             | c         |
| 70-100   | 21                        | 21     | 58     | 0.84   | 39.0             | c         |
| 100-120  | 13                        | 34     | 53     | 0.70   | 44.5             | c         |
| 120-160  | 12                        | 35     | 53     | 0.60   | 44.7             | c         |

* Abtahi et al. (1991)
** Mahjoory (1975)
*** cl= clay loam, silc = silty clay loam, sil= silt loam, c=clay
Table 2. Average top biomass yield (t ha\(^{-1}\)) under different irrigation treatments and the standard error of mean.

| Location     | Irrigation methods | Irrigation interval (days) |
|--------------|--------------------|---------------------------|
|              |                    | 4 | 7 | 10 |
| Badjgah      | Every furrow       | 13.36 (1.14)* | 10.81 (1.07) | 9.32 (0.56) |
|              | Variable alternate | 10.28 (0.25) | 8.81 (0.41)   | 7.61 (0.41)  |
|              | Fixed alternate    | 10.62 (0.41) | 8.98 (0.29)   | 6.76 (0.51)  |
|              | Mean               | 11.42 | 9.53 | 7.68 |
|              | s.e.               | 0.68 | 0.45 | 0.44 |
| Kooshkak     | Every furrow       | 15.20 (1.04) | 11.45 (0.47) | 9.87 (0.70) |
|              | Variable alternate | 12.59 (0.92) | 8.79 (0.90)   | 8.70 (0.42)  |
|              | Fixed alternate    | 12.34 (0.70) | 9.32 (0.68)   | 8.79 (1.05)  |
|              | Mean               | 13.38 | 9.85 | 9.12 |
|              | s.e.               | 0.61 | 0.51 | 0.43 |

* Figures in parenthesis are standard error of means.

and three furrow irrigation methods (sub-plots, each with net area of 52.5 m\(^2\)). The irrigation methods were: (i) fixed alternate-furrow irrigation (FAFI) in which water was applied to alternate furrows throughout the growing season; (ii) variable alternate-furrow irrigation (VAFI) which was similar to FAFI, but water was applied to the furrow which was dry in the previous irrigation cycle; and (iii) every furrow irrigation ( EFI) in which water was applied to every furrow. Irrigation water was obtained from a well with an electrical capacity, based upon before-irrigation soil moisture measurements. The soil water content in the root zone at 1.05 m depth before irrigation was measured with a neutron probe. The neutron tubes were placed in the middle of each sub-plot in two replications. In EFI, one neutron access tube was placed between the furrow and the top of the bed, and in AFI, two neutron tubes were installed, one at the bottom of furrow and the other on the top of the bed. Neutron probe readings were taken at depths of 0.3, 0.6 and 0.9 m from the furrow bottom and from the top of the bed. Soil water content at a depth of 0-15 cm was 75% of that at a depth of 30 cm.

The crop evapotranspiration at different irrigation intervals (ET, mm) was estimated from the water balance in the root zone, which increased during the growing season as the root depth was increased. The following equation was used for the water balance (Jensen, 1973):

\[
ET = I + P - D + \left( \sum \Delta \theta_1 - \sum \Delta \theta_{n} \right)
\]

Where I is irrigation amount (mm), P is precipitation (mm), D is percolation deeper than the bottom of root zone (mm), n is the number of layers examined, \(\Delta \theta_1\) is the thickness of each soil layer (mm) and \(\theta_1\) and \(\theta_n\) are volumetric soil water contents (cm\(^3\) cm\(^{-3}\)) before two consecutive irrigations. The value of D was estimated from soil unsaturated hydraulic conductivity (K) equation on the assumption of unit hydraulic gradient at the bottom of root zone. The soil water content measured at different soil depths indicated that it is relatively constant at depths lower than the depth of maximum root activity, i.e., 60 cm. Similar results were reported for sugarbeet by Sepaskhah and Kangar-Haghghi (1997). The K(\(\theta\)) equation was determined by the internal drainage method at a depth of 0-70 cm by measuring soil water content profile on a representative point inside the field (Hillel et al., 1972; Kashefpour and Sepaskhah, 1995). The equation of K (mm d\(^{-1}\)) for the field soils are K(\(\theta\))=2.72×10\(^{-6}\)Exp(110 \(\theta\)).
The maize was harvested from sub-plots (7.5 m\(^2\)) on October 13 and grain yield (at 14% moisture content) and top biomass yield were measured. The number of grains in each cob and the 1000-grain weight were determined in the sample from each sub-plot.

2. Kooshkak experiment

The experiment on a clay loam soil (Fine, carbonatic, mesic, Aquic Calciixererts) with shallow water table was conducted at the Kooshkak Agricultural Experiment Station of Shiraz University located 75 km north of Shiraz (30º 4’ N, 52 º ,35’ E, 1609 m MSL). Table 1 shows some physical properties of the soil. Volumetric soil water contents at field capacity and permanent wilting point of the soil at a depth of 0-30 cm were 0.39 and 0.213 cm\(^3\) cm\(^{-3}\), respectively. These values at depths of 30-90 cm were 0.42 and 0.282 cm\(^3\) cm\(^{-3}\), respectively. The mean air temperature during the growing period was 22.2°C.

No rainfall occurred during the growing season. The depth of water table in this area varied between 1.67 m at the sowing time and 1.31m at the end of irrigation treatments. Electrical conductivity of the groundwater was 1.2 dS m\(^{-1}\).

For estimation of groundwater contribution to plant water use, the soil water balance equation during a given period can be written as (Sepaskhah et al., 2003):

\[ \Delta R = P + V_z + I + G_c - ET - D \]

Where, \( R \) is the soil water variation in the root zone (mm). The water entering the system during the given period is made up of: \( P \), precipitation (mm); \( V_z \), the water stored (mm) in the deeper layer of thickness \( Z \) explored by the roots after equivalent root growth; \( I \), irrigation water depth (mm); \( G_c \), groundwater contribution (mm). The water leaving the system, for the same period, consists of: \( ET \), actual crop evapotranspiration (mm); and \( D \), deep percolation loss (mm). \( G_c \) is computed from the

| Table 3. Average grain yield (t ha\(^{-1}\)) with 14% moisture content (dry basis) under different irrigation treatments and the standard error of mean. |
|-----------------|-----------------|---|---|---|
| Location | Irrigation methods | 4 | 7 | 10 |
| Badgah | Every furrow | 8.28 (1.26)* | 6.88 (0.94) | 5.84 (0.39) |
| | Variable alternate | 6.50 (0.35) | 4.85 (0.25) | 3.59 (0.16) |
| | Fixed alternate | 6.51 (0.54) | 5.24 (0.11) | 3.57 (0.21) |
| | Mean | 7.10 | 5.66 | 4.33 |
| | s.e. | 0.50 | 0.40 | 0.35 |
| Kooshkak | Every furrow | 10.94 (0.93) | 7.89 (0.55) | 6.23 (0.48) |
| | Variable alternate | 8.18 (0.99) | 5.79 (0.52) | 5.30 (0.26) |
| | Fixed alternate | 8.54 (0.55) | 6.39 (0.69) | 5.41 (0.83) |
| | Mean | 9.22 | 6.69 | 5.65 |
| | s.e. | 0.54 | 0.39 | 0.33 |

* Figures in parentheses are standard error of means.

| Table 4. Average number of grains per cob under different irrigation treatments and the standard error of mean. |
|-----------------|-----------------|---|---|---|
| Location | Irrigation methods | 4 | 7 | 10 |
| Badgah | Every furrow | 624 (87.5)* | 538 (45.6) | 457 (27.0) |
| | Variable alternate | 500 (24.5) | 418 (18.7) | 392 (10.7) |
| | Fixed alternate | 498 (19.3) | 399 (7.5) | 301 (14.3) |
| | Mean | 541 | 452 | 353 |
| | s.e. | 33.6 | 24.0 | 24.2 |
| Kooshkak | Every furrow | 720 (9.3) | 640 (33.5) | 521 (27.4) |
| | Variable alternate | 673 (16.9) | 570 (38.7) | 472 (47.6) |
| | Fixed alternate | 645 (20.0) | 523 (30.0) | 470 (20.4) |
| | Mean | 679 | 578 | 488 |
| | s.e. | 12.5 | 23.0 | 19.1 |

* Figures in parentheses are standard error of means.
potential capillary rise, $G$ (mm) as follows:

$$ G_c = G - \frac{G}{R_{\text{min}}} R $$  \hspace{1cm} (3)

Where, $G$ is the potential contribution from the groundwater, $R$ is the difference between soil water content at root depth before irrigation (mm) and soil water content at permanent wilting point (mm). $R_{\text{min}}$ is calculated as:

$$ R_{\text{min}} = (1 - p) R_{\text{max}} $$  \hspace{1cm} (4)

Where, $p$ is the water depletion fraction (dimensionless) and $R_{\text{max}}$ can be calculated as follows:

$$ R_{\text{max}} = (\theta_{\text{fc}} - \theta_{\text{pwp}}) d $$  \hspace{1cm} (5)

Where $\theta_{\text{fc}}$ and $\theta_{\text{pwp}}$ are volumetric soil water content (cm$^3$ cm$^{-3}$) at field capacity and permanent wilting point, respectively, and $d$ is the root depth (mm). $D$ was estimated by Darcy equation, assuming a unit hydraulic gradient (Sepaskhah and Kashefi pour, 1995) as $K(\theta)$ (unsaturated hydraulic conductivity, mm d$^{-1}$) as follows:

$$ K(\theta) = 6.78 \times 10^{-11} \exp(60\theta) $$  \hspace{1cm} (6)

Where, $\theta$ is the volumetric water content of soil (cm$^3$ cm$^{-3}$). The reason for using a unit hydraulic gradient for estimation of $D$ was similar to that for Badjgah experiment. The value of $G$ was determined by the depth of groundwater below the root zone according to procedure presented by Sepaskhah et al. (2003).

The experimental procedure was similar to that for Badjgah area, except that the planting was in the fourth week of May, 1995 and harvest date was October 16, 1995. The total amount of pre-treatment irrigation water was 153 mm. The experimental treatment was started on June 15. Electrical conductivity of irrigation water was 0.6 dS m$^{-1}$.

The analysis of variance and Duncan multiple range test (DMRT) were used to analyze the data.

## Results and Discussion

1. **Yield**

   In the Badjgah experiment, in general, grain and top biomass yields (grain plus stover) were higher under irrigation at 4-day intervals than at 7- and 10-day intervals, and decreased significantly as the irrigation interval increased (Tables 2 and 3). Grain and top biomass yields under every furrow irrigation (EFI) were significantly higher than those under alternate furrow irrigation (AFI) (Tables 2 and 3) due to higher amounts of applied water and crop evapotranspiration. However, grain and top dry yields were not statistically different between the plants under a variable AFI (VAFI) and fixed AFI (FAFI) due to similar amounts of applied water and crop evapotranspiration. The interactive effects of irrigation intervals and irrigation methods for grain and top dry yields were not significant at the 5% level of probability.

   In the Kooshkak experiment, the effects of irrigation at 4-day and 10-day intervals on grain and top biomass yields were similar to those in the Badjgah experiment (Tables 2 and 3). However, the interactive effect of irrigation intervals and irrigation methods on grain yield was statistically significant at the 5% level of probability. The grain yield was not significantly different under irrigation at 7- and 10-day intervals. Furthermore, the top dry yield under irrigation at 10-day intervals was not significantly influenced by the irrigation method.

   In general, the grain and top biomass yields in Kooshkak experiment were higher (about 26% higher for grain, and 13% higher for top) than those in Badjgah experiment. This may be due to the higher evaporative demand, which results in application of more irrigation water and also due to upward flow of water from shallow groundwater at a depth of 1.31-1.67 m.

2. **Yield component**

   The effects of the irrigation method and interval on the number of grains per cob were similar to those on the grain yield (Table 4). Therefore, the main cause of grain reduction is attributed to the decrease in number of grains per cob (Table 4).
The 1000-grain weight decreased as irrigation interval increased at both experimental sites; however, irrigation method did not influence the 1000-grain weight significantly, except at a 7-day interval in the Kooshkak area (Table 5).

In general, the main cause of grain yield reduction at longer intervals was attributed to a decrease in grain number per cob and 1000-grain weight, while the reduction in grain yield by the irrigation method (AFI) was mainly caused by decreased number of grains per cob.

3. Evapotranspiration (ET)

In general, ET decreased at longer irrigation intervals and in AFI (Table 6). ET was higher at the Kooshkak location probably due to higher mean seasonal air temperature and shallow groundwater. The relationship between grain yield reduction \((1−y/y_m)\) and ET reduction is shown as follows:

\[
(1−y/y_m)=a(1−ET/ET_m), \quad r^2=0.92 \tag{7}
\]

where, \(a=1.16\), s.e. 0.056, \(y\) and \(y_m\) are the actual and maximum grain yield, respectively, and \(ET\) and \(ET_m\) are the actual and maximum evapotranspiration, respectively. The coefficient of yield response in this equation is lower than the reference value reported by Doorenbos and Kassam (1979), for maize (1.25).

4. Actual capillary rise

Using Eqs. (2-5), the actual capillary rise \((G_c)\) at each irrigation interval in the Kooshkak area was estimated and the values were summed up to determine the seasonal \(G_c\). The ratio of \(G_c\) to ET (Table 6) was also calculated. The results are presented in Table 7. The values of \(G_c\) and \(G_c/ET\) were negligible under EFI at 4-day intervals since the soil water content before irrigation was not below the critical soil water content and plant was not under stress. The highest values of \(G_c\) and \(G_c/ET\) (77.6 mm and 10%, respectively) were obtained in VAFI at 10-day intervals due to irrigation deficit and imposed water stress. These values were obtained where water depths varied between 1.67 m at sowing time and 1.31 m at the end of irrigation treatments. It is obvious that the shallower the water table and the larger the irrigation intervals, the greater may be their contribution to the plant water use.

5. Deep percolation

In general, deep percolation (percolation deeper than the root zone) was reduced in AFI drastically. This may be due to the more lateral movement of water in the soil in AFI (Table 6). Deep percolation also decreased at longer irrigation intervals. This may be due to the lower water content of the lower layers.
of the root zone in irrigation treatments at longer intervals. Further, deep percolation at the Kooshkak location was higher than that at the Badjgah location due to higher groundwater and consequently higher soil water content of the soil below the root depth. In general, AFI reduced the deep percolation by 79.2% and 78.2% compared with EFI at the Badjgah and Kooshkak locations, respectively. The ratio of deep percolation to ET was very low (5% or less) except for EFI at the Kooshkak location, which was about 15-18% due to higher water table.

6. Water use efficiency

Water use efficiency (WUE) was regarded as the weight of the harvested portion production (grain) per unit of water consumed. The difference between the amounts of water applied in EFI and AFI was larger at 4- and 7-day intervals than at 10-day intervals (Table 8). This is probably because more frequent irrigation under EFI resulted in higher evaporation from soil surface, especially during the early part of the growing season with incomplete ground cover. Thus, it is possible to design an experiment where both irrigation interval and water quantities are variable. WUE at the Badjgah site was not significantly influenced by the irrigation method or interval (Table 9). This means that when available water is scarce (about 500 mm) fixed AFI at 10-day intervals is equally efficient as EFI at 10-day intervals which required more than 800 mm of applied water. WUE at the Kooshkak site was higher than that at Badjgah, especially in AFI at 10-day intervals. At Kooshkak, WUE in AFI at 10-day intervals and that in fixed AFI at 7-day intervals was higher than those in other treatments. Therefore, when available water is less than 700 mm, AFI at 10-day intervals is more efficient than EFI at 10-day intervals, which required 960 mm of applied water.

7. Yield and water relationship

The relationships between relative applied water (amount of water relative to that applied for maximum grain yield in EFI at 4-day intervals, %), x, and relative grain yield (relative to the maximum grain yield, %), y, combined for both sites in EFI and AFI were as follows (Fig. 1):

\[ y = a + bx, \quad r^2 = 0.74 \quad \text{in EFI} \]  
\[ y = c + dx, \quad r^2 = 0.97 \quad \text{in AFI} \]

where, \( a \) =1.37, s.e. 14.7, \( b \) =0.96, s.e. 0.177, \( c \) =8.2, s.e. 3.81, and \( d \) =0.92, s.e. 0.049. Since there was no statistically significant difference between yields in fixed and variable AFI, these data were included in AFI in Eq. (9). The relative grain yield in AFI (Eq. 9) was higher than that in EFI (Eq. 8). The slope of the regression lines in Fig. 1 was considered to show the efficiency of applied water (Stone and Nofziger, 1993; Sepaskhah and Kamgar-Haghighi, 1997). The slope of Eq. (8) is slightly (4.3%) steeper than that of AFI (Eq. 9) though not significant. The y intercept of Eq. (8) was 1.37 which is much smaller than that in Eq. (9), i.e., 8.2. Therefore, the yield with a given amount of applied water in AFI is slightly higher than that in EFI. Fig. 1 may be used to estimate the yield expected from a given amount of water.

The results of Stone and Nofziger (1993) indicated

| Location | Irrigation methods       | Irrigation intervals (days) |
|----------|--------------------------|-----------------------------|
|          |                          | 4   | 7   | 10  |
| Badjgah  | Every furrow             | 1316| 1093| 813 |
|          | Variable alternate       | 1006| 755 | 545 |
|          | Fixed alternate          | 961 | 770 | 508 |
| Kooshkak | Every furrow             | 1503| 1223| 958 |
|          | Variable alternate       | 1163| 848 | 698 |
|          | Fixed alternate          | 1204| 836 | 682 |

| Location | Irrigation methods       | Irrigation intervals (days) |
|----------|--------------------------|-----------------------------|
|          |                          | 4   | 7   | 10  |
| Badjgah  | Every furrow             | 0.63| 0.63| 0.72|
|          | Variable alternate       | 0.65| 0.64| 0.66|
|          | Fixed alternate          | 0.68| 0.68| 0.70|
| Kooshkak | Every furrow             | 0.70| 0.65| 0.65|
|          | Variable alternate       | 0.72| 0.68| 0.76|
|          | Fixed alternate          | 0.71| 0.76| 0.79|
that wide-spaced furrow irrigation was about 13% more efficient than EFI in use of applied water, which was similar to the results obtained by Ghasemi and Sepaskhah (2003) in grain sorghum. However, Sepaskhah and Kamgar-Haghighi (1997) reported the slope in linear equation for AFI to that for EFI to be 1.26 for root yield of sugarbeet, which is a vegetative yield.

Under full irrigation (relative applied water of 100%), EFI and AFI resulted in a similar relative yield (100%, Fig. 1). However, under reduced irrigation water (relative applied water less than 100%), AFI resulted in a higher relative grain yield. At relative applied water of 50%, AFI led to 16% higher grain yield than EFI. Under 67% relative applied water in EFI and AFI, the relative maize grain yields were 63% and 70%, respectively, while with the same amount of relative applied water Kang et al. (2000) obtained 82% and 97% relative yield in EFI and AFI, respectively, showing a greater difference from that obtained in this study. This may due to the difference in seasonal rainfall and the use of plastic film cover in the field in the Kang et al. (2000) experiment.

Similar relationships between top biomass weight (relative to the maximum top dry weight, %), \( y \), and relative applied water (relative to the water applied for maximum top biomass weight, %), \( x \), in EFI and AFI are shown as follows (Fig. 2):

\[
y = e + fx, \quad r^2 = 0.93 \text{ in EFI} \\
y = g + hx, \quad r^2 = 0.95 \text{ in AFI}
\]

where, \( e=11.0, \ s.e.\ 9.2, f=0.87, \ s.e.\ 0.111, g=25.1, \ s.e.\ 4.44, \) and \( h=0.75, \ s.e.\ 0.058. \) Since there was no statistically significant difference between yields in fixed and variable AFI, their data were included in AFI Eq. (11). The equation in AFI (Eq. 11) showed a greater relative top dry weight than that in EFI. At relative applied water of 50%, AFI would result in 15% greater top dry weight than EFI.

The results of other investigators suggests that the bulk of the water savings is due to reduction of evaporation from the soil surface (Tsegaye et al., 1993), as may be the case in the present study.

**Conclusions**

Although the present experiments were conducted for only one year, the results at multiple sites were analyzed. The results indicated that even at 4-day irrigation intervals the full water needs of maize on a fine textured soil were not met by AFI at both sites (with deep and shallow groundwater). The decrease in grain yield due to water stress in AFI was mainly due to the decrease in the number of grains per cob and to a lesser extent to the decrease in 1000-grain weight. At the Kooshkak site with shallow water table (between 1.31 and 1.67 m), grain yields in AFI at 4- and 7-day intervals were comparable with those in EFI at 7- and 10-day intervals, respectively. This might be due to the groundwater contribution to plant water use (about 5-10%) and reduced evaporation from soil surface. In the Badjgah area with deep water depth, grain yield in AFI at 7-day intervals was significantly lower than that in EFI at 10-day intervals. It may be concluded that in AFI, shorter irrigation intervals (4-day) may alleviate the water stress and result in no yield reduction compared with that in EFI at 7-day intervals, even though water application was reduced. Furthermore, in areas with shallow groundwater, AFI at 7-day intervals may be superior to EFI at 10-day intervals. When seasonal irrigation water is scarce (less than 700 mm), it may be preferable to use AFI at 10-day intervals to obtain higher water-use efficiency, especially in areas with shallow groundwater. In general, when the amount of applied water was less
than that for full irrigation, the grain yield of maize in AFI was higher than that in EFI.

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* In Persian.