

Sustainability of Rain-Fed Fig Production (*Ficus carica*) under Supplemental Irrigation in Semi-Arid Regions

Running title: Supplemental irrigation for rain-fed fig

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Abstract

In arid and semi-arid regions, inadequate rainfall necessitates supplemental irrigation to meet crop water requirements. Selecting the appropriate method is crucial for success. A two-years field experiment was conducted in Kharameh Region, Iran, to investigate the effect of different supplemental irrigation methods on fig tree yield, physiological response, and water productivity. Three irrigation methods including flood irrigation, subsurface drip irrigation, micro jet irrigation, and no supplemental irrigation (control) were applied as four treatments in five replications. Results showed that subsurface and micro jet irrigation significantly increased leaves width by 18.2%, shoot length by 27%, and shoot diameter by 13%. Micro jet irrigation also increased the amounts of chlorophyll in fig leaves by 14%, the average of total fruit numbers by 134% and the average of total fruit weight by 54% as compared to the other treatments. Furthermore, the highest levels of water efficiency were seen in micro jet irrigation techniques, while they dropped by 40% with subsurface drip irrigation. The practical implications of this study involve boosting fig yield, refining water management strategies, bolstering drought resistance, analyzing economic feasibility, gauging sustainability, and supporting the sharing of knowledge and skills for fig cultivation in semi-arid areas.

Keywords: subsurface irrigation, micro jet irrigation, water scarcity, fig fruit quality, water productivity, Kharameh.

1. Introduction

Water scarcity challenges in both quantity and quality are major problems for agricultural production in Iran (Amiri and Eslamian 2010; Amiri et al. 2015). Supplemental irrigation methods are necessary for the sustainability of agricultural systems, particularly for rain-fed

41 crops (Khozaei et al. 2020). Rain-fed fig orchards are common in arid and semi-arid regions
42 of Iran, producing a country level of approximately 75,910 tons of dry figs annually
43 (Abdolahipour et al. 2019). Despite fig plants' tolerance to water stress, prolonged drought
44 conditions can cause significant loss of yield (Abdolahipour et al. 2018; Karimi et al. 2012).
45 The prolonged drought condition led to soil salinity which has an adverse effect on quality
46 and quantity of rain fed fig (Abdolahipour et al. 2023). Severe drought causes leaf loss and
47 reduces fruit quality and quantity (Tehrani et al. 2016). Previous studies suggest that
48 supplemental irrigation and drought-resistant cultivars can improve water productivity in
49 plant production (Honar et al. 2020; Abdolahipour et al. 2019). Supplemental irrigation
50 effectively maintains soil moisture in the root zone, mitigating water deficit effects on crop
51 yield in arid regions (Moradi et al., 2023). Using the supplemental irrigation in fig orchards
52 has increased in semi-arid regions (Kamyab 2015; Sharifzadeh et al. 2012). Some Studies
53 show that supplemental irrigation improves yield and physiological traits of rain-fed fig trees
54 during drought (Honar and Sepaskhah 2015; Kamgar Haghighi and Sepaskhah 2015). Bagheri
55 and Sepaskhah (2014) recommend March supplemental irrigation for fig trees in low rainfall
56 years. Tapia et al. (2003) found that supplementing 220 mm of water in arid regions results
57 in economically viable fig yields. Al-Desouki et al. (2009) report increased yield and growth
58 of fig trees with supplemental irrigation. Khozaei et al. (2020) observed increased grapevine
59 yield with May supplemental irrigation. Choosing the right supplemental irrigation method
60 impacts rain-fed fig tree yield and morphology (Bouman et al., 2007). Flood irrigation
61 increases apple tree chlorophyll compared to drip and sprinkler irrigation (Chen et al. 2018).
62 Different irrigation methods affect root growth, soil enzyme activity, nutrient uptake, and
63 fruit quality (Wang et al. 2017). Furrow and trickle irrigation methods significantly influence
64 Squash fruit and seed yields (Amer et al., 2011).
65 Although there are some investigations on the effect of different supplemental irrigation
66 amounts on rain fed fig trees, but limited researches can be found on the effects of
67 supplemental irrigation methods on the quality and quantity of fig fruit and physiological
68 parameters of rain-fed fig trees. Therefore, this study aims to evaluate the impact of various

69 supplemental irrigation methods (flood, subsurface drip, micro jet, and no supplemental
70 irrigation) on soil moisture profile, fruit quality and quantity, and growth and physiological
71 parameters of fig trees (Sabz cultivar) in an arid region.

72 73 2. Material and Methods

74 2.1. Experimental Site

75 To investigate the effects of different supplemental irrigation methods on fig trees (Sabz
76 cultivar), two years of field experiments were conducted on 2017 and 2018 in Kharameh City,
77 Fars Province, Iran. The area is located on 29° 32"N, 53° 19" E, 1500 m above the sea level
78 has an arid climate with an average annual rainfall of 200 mm and mean annual temperature
79 of 20°C. The experimental site's soil properties are shown in Table 1.

80
81 **Table 1.** The soil properties of the experimental site.

Soil texture	Depth	Ph	Clay	Silt	Sand	Organic carbon	CaCo3	EC
	(cm)		(%)	(%)	(%)	(%)	(%)	(dS/m)
Loam	0-30	8	21.2	30	49.2	0.49	21	1.18
Sandy Clay loam	30-60	8.2	21.2	25.3	53.5	0.30	41	0.65
Sandy Clay loam	60-90	8.4	21.2	24.4	54.4	0.23	41	0.56
Sandy loam	90-120	8.4	19.3	19.6	61.1	0.21	40	0.54

86 Growing rain-fed figs require a warm climate with long, hot summers and mild winters,
87 preferably in Mediterranean or semi-arid regions. Figs thrive in well-drained soils with good
88 fertility and a pH level between 6.0 and 6.5 (Jafari and Eslami, 2022). Regular pruning, soil-
89 based fertilization, and pest management are essential for healthy growth and fruit production.
90 The Sabz fig variety used in this study is Iran's most important and expensive dried fig, known
91 for its unique traits, including drought tolerance, extensive roots, and adaptability to different
92 soils. Rain-fed fig orchards need three years of regular irrigation with rooted seedlings. After
93 three years, if rainfall exceeds 200 mm annually, irrigation can be stopped. However, in areas
94 with lower rainfall, supplementary irrigation may be needed for profitable crop production.
95 This combination of high price and low water consumption has led to a shift in regions like
96 Kharamah, Iran, to fig production (Jafari and Eslami, 2022).

2.2. Experimental Design and Field studies

The experimental design consisted of four treatments: 1: flood irrigation using a 10000m³ tanker for each tree, 2: subsurface drip irrigation using drip tape at 1m distance from the trunk and 50cm depth, 3: micro jet irrigation with one sprinkler per tree and 1.5m spraying radius, and 4: no supplemental irrigation (control), with five replications. Figure 1 shows the irrigation methods used. Measurements were taken on 5 trees with the same condition in each row. The trees were 3 years old and planted 8m×8m apart. Figure 2 shows the experimental treatments. Soil water content was monitored at depths of 0.3, 0.6, 0.9, and 1.2 using a Trime Hygrometer at a distance of 1m from each tree trunk from January to July each year. Based on Honar and Sepaskhah (2015), each tree received a total of 1500 L of supplemental irrigation in three applications (March, May, and August) with 500 L each time. The irrigation water properties are listed in Table (2).

Table 2. Irrigation water properties in the experimental site.

EC (ds/m)	PH	HCO (meq/L)	CL (meq/L)	SO4 ²⁻ (meq/L)	Ca (meq/L)	Mg (meq/L)	Na (meq/L)
1.2	7	4.6	120	1	31	43	51.9



(a)



(b)



(c)

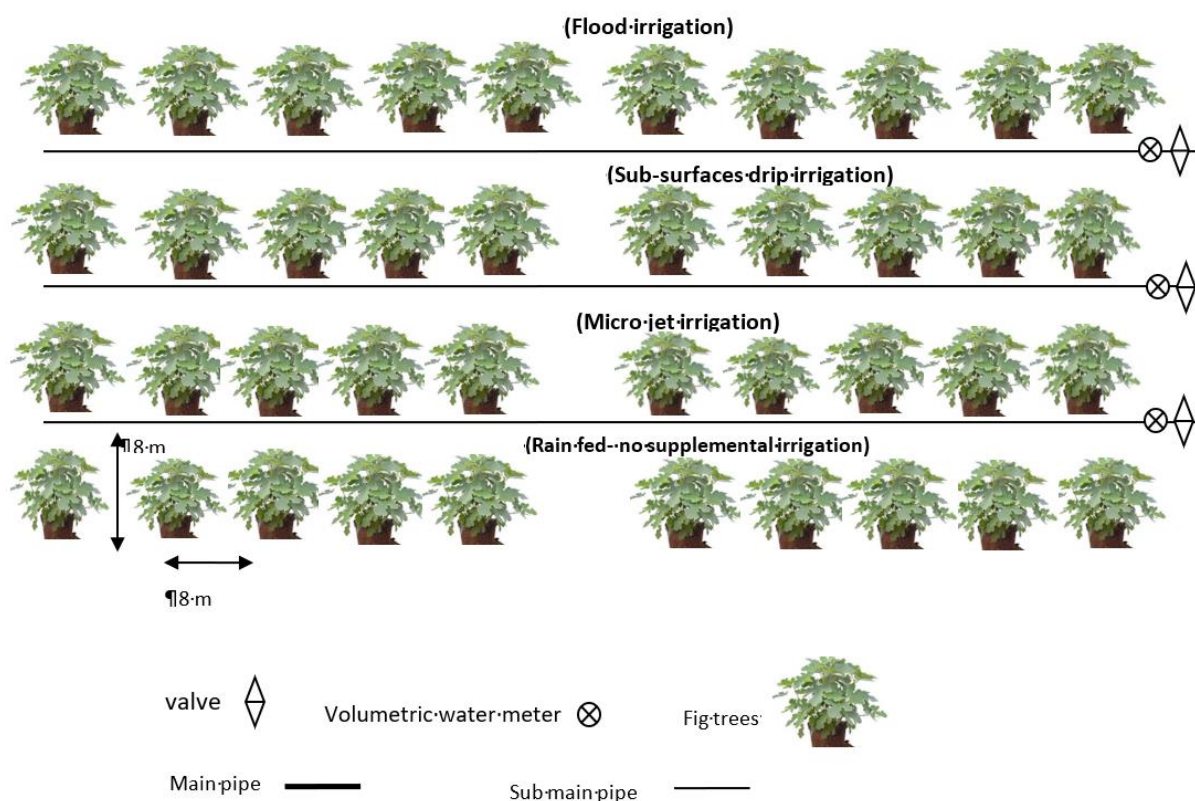


(d)

Figure 1. Irrigation treatments, control (a), subsurface drip (b), flood (c) and micro jet irrigation (d).

134 **2.3. Fig Orchard Properties**

135 Different fig cultivars have been planted in Kharameh region, with 'Sabz' being the most
136 common commercial variety (Jafari et al. 2012). Fig shoot growth occurs from mid-April to
137 mid-May, with maximum leaf area observed in May. Flowering and fruiting of fig trees
138 happen from April to July, with fruit maturation starting in August and ending in early
139 October. After this, fig leaves fall and the trees enter dormancy until the next growth period
140 in late October.



141 **Figure 2.** The schematic map of experimental treatments.

142 **2.4. Measurements and Calculations**

143 Growth parameters (shoot length, shoot diameter, node number, internode length, leaf width)
144 were measured in July for two years. Fig fruit number, weight, size, and color were
145 determined at harvest. Fruit size (diameter) was categorized as AA (>22mm), A (17-22mm),
146 and B (<17mm). Fruit color was categorized as **light yellow (best), brown (medium), and dark**
147 **brown (worst).**

148 **The irrigation water productivity (WP) as the total crop yield divided by the total irrigation**
149 **water, was determined for each treatment as follow, Fernández et al (2020):**

150 $WP = \frac{Y}{I}$

151 Where Y is the **fruit** yield (kg/ha), and I is the irrigation depth (m^3/ha).

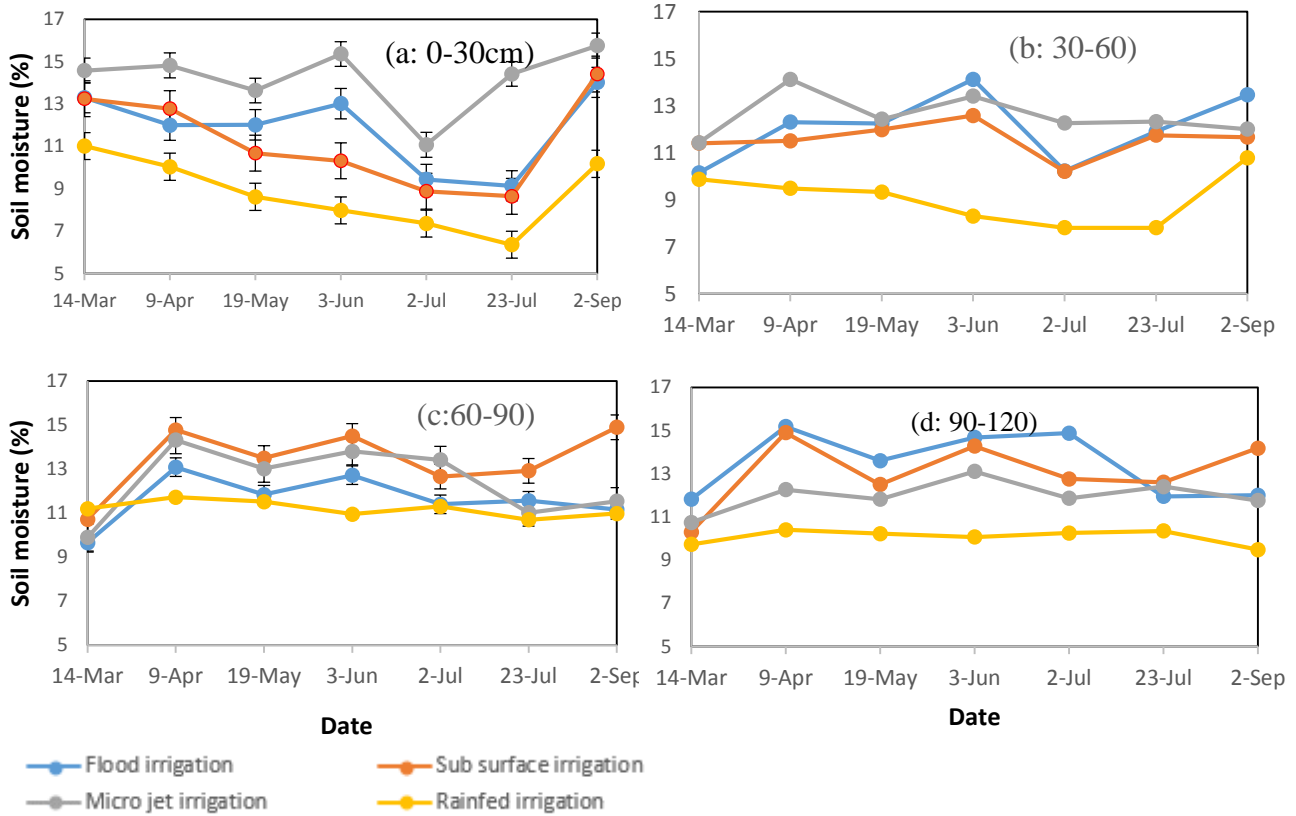
152 The content of total chlorophyll, chlorophyll (a), and chlorophyll (b) of the leaves were
153 measured using dimethyl sulfoxide (Hickox and Israelstam 1979) in the middle of August.
154 **Fresh and fully matured leaves were collected** from the tree at a fixed height and placed in
155 **plastic bags before the laboratory analysis. A number of 100** mg of leaf pieces (without veins)
156 were placed in an Erlenmeyer flask and 7 ml of dimethyl sulfoxide (DMSO) was poured on
157 it and kept in an incubator at 65 degrees Celsius for 60 minutes. **Then its volume was increased**
158 **to 10 ml with DMSO and the absorbance of the extract was read at 645 and 663 nono meter**
159 **wavelengths.**

160

161 **3. Results and Discussion**

162 **3.1. Soil Moisture**

163 The availability of water is a significant factor that can limit the growth and productivity of
164 plants (Liu et al., 2021). Soil moisture in different **depths and** irrigation methods during the
165 growing season is shown in Figure 3. Control treatment had lower moisture percentage than
166 other treatments in all soil layer. **The micro jet irrigation method maintained soil moisture at**
167 **high levels in the 0-30 cm and 30-60 cm soil layers, where the highest density of fig roots is**
168 **found (Abdolahipour et al., 2021), facilitating water absorption at these depths (Figures 3a and**
169 **3b). Also the most significant moisture change with a 5.4% increase, was observed at the 0-30**
170 **cm depth, primarily due to evaporation and water movement (Figure 3a). The highest soil**
171 **moisture in 60-90 cm and 90-120 cm depths were observed in subsurface drip irrigation and**
172 **flood irrigation, respectively.**



178 **Figure 3.** The average of volumetric soil moisture (%) in different supplemental irrigation
 179 methods for different soil depths; 0-30cm (a), 30-60cm (b), 60-90 cm (c) and 90-120cm (d)
 180 during the growing seasons (2018 & 2019).
 181

182 **3.2. Fig Trees Growth and Physiological Parameters**

183 Table 3 shows that the highest amounts of chlorophyll (a) was observed in the micro jet
 184 irrigation treatments (1.645 mg/g) followed by sub surface (1.582 mg/g), flood (1.302 mg/g)
 185 and control (1.251 mg/g). Supplementary irrigation had no significant effect on the amount
 186 of chlorophyll (b) in the leaves of fig trees. The amounts of total chlorophyll in the leaves of
 187 fig trees were affected significantly by supplementary irrigation, and the highest amounts
 188 were observed in the micro jet irrigation method (2.201) followed by subsurface, control and
 189 flood irrigation treatments (Table 3). These results indicate to the effect of water stress and
 190 irrigation system types on water relations parameters such as leaf chlorophyll (a), leaf
 191 chlorophyll (b), leaf proline, leaf cell sap osmotic pressure, opened stomata percentage, and
 192 leaf bound water content. Generally, leaf chlorophyll (a), leaf chlorophyll (b), as well as

193 opened stomata percentage parameters were increased when water amount increased
 194 (Trigueros et al. 2021). Anjum et al. (2011) and Shirbani et al. (2013) indicated that
 195 chlorophyll content is positively related to the rate of photosynthesis. Therefore, the decrease
 196 in chlorophyll content under drought stress conditions, as a common sign of oxidative stress,
 197 may be due to the photo-oxidation of pigments and chlorophyll decomposition. Ammar et al.
 198 (2020) found that the deficit irrigation decreased the chlorophyll content and increased the
 199 proline in fig plant leaves. Halo et al. (2018) observed higher chlorophyll content in crops
 200 resistant to oxidative stress and Chlorophyll (a) decreased more significantly than chlorophyll
 201 (b) under drought stress.

202 **Table 3.** Effect of supplemental irrigation on the two-year mean of some physiological traits
 203 of fig (*F. carica* cv. Sabz) in 2018 and 2019.

Supplemental Irrigation treatments	Chlorophyll-a	Chlorophyll-b	Total chlorophyll
	(mg/g)	(mg/g)	(mg/g)
Flood	1.302 b	0.438 a	1.740 b
Sub-surface Drip	1.582 a	0.480 a	2.062 ab
Micro jet	1.654 a	0.547 a	2.201 a
Control (Rain-fed)	1.251 b	0.525 a	1.776 b

204 Means with the same letters in each column are not significantly different using the Duncan test at $P \leq 0.05$.

205 Table 4 shows that supplemental irrigation significantly affected fig trees' growth parameters.
 206 As the results show the highest amounts of leaf width obtained in micro jet irrigation (12.81
 207 cm) with no significant difference by sub surface drip irrigation and decreased in average by
 208 about 12% in flood (11.71 cm) and control (10.82 cm) treatments. In this case Chen et al.
 209 (2018) found that drip irrigation increased leaf width and weight in apple trees.

210 Maximum shoot length was observed in flood irrigation (16.3 cm), with no significant
 211 difference by micro jet (15.48 cm) and sub-surface drip irrigation (15.14 cm), while the
 212 minimum one was observed in control treatment (12.3 cm). Leonel and Tecchio (2010) also
 213 showed supplemental irrigation increased shoot diameter and length in fig trees. Increasing
 214 irrigation rate caused promotions in many characteristics, which lead to an increment in both
 215 vegetative growth and fruiting and finally profitable yield in orange trees (Panigrahi 2023).
 216 Sub-surface drip irrigation had the maximum shoot diameter (8.75 cm) with no significant
 217 difference by flood (8.66 cm) and micro jet irrigation (8.58 cm), while the control treatment
 218 had the minimum shoot diameter (7.68 cm). The maximum number of nodes and internode

length were observed in micro jet irrigation followed by flood and subsurface drip irrigation and the minimum ones were observed in control treatment. These results demonstrate the importance of supplemental irrigation especially micro jet irrigation in improving fig trees' morphological conditions. Most studies show that supplemental irrigation improves vegetative growth compared to non-irrigated rain-fed plants (Varol et al., 2023). Andrade et al. (2014) found significant effects of supplemental irrigation on fig tree node number. Wang et al. (2017) reported significant effects of supplemental irrigation on root development and physiological parameters of trees. Abd-El-Rahman et al. (2017) found significant increases in vegetative growth and fig yield with supplemental irrigation. Moura et al. (2023) reported larger diameter, more branches, and longer internodes in irrigated fig trees. The findings of this study align with Wang et al. (2017), Abd-El-Rhman et al. (2017), and Moura et al. (2023).

Table 4. The average of growth parameters of fig trees under different supplemental irrigation treatments.

Supplemental irrigation treatments	Nod number	Internode length (cm)	Shoot length (cm)	Shoot diameter (cm)	Leaf width (cm)
Flood	10.59 a	6.12 a	16.3 a	8.66 ab	11.71 b
Sub-surface drip	10.49 a	5.93 a	15.14 ab	8.75 a	12.79 a
Micro jet	10.65 a	6.64 a	15.48 ab	8.58 ab	12.81 a
Control (Rain-fed)	9.00 b	4.76 b	12.3 b	7.68 b	10.82 b

The means with the same letters in each column are not significantly different using the Duncan test at $P \leq 0.05$.

3.3. Fig Fruits Quality and Quantity

Fig physiology and growth were affected by different irrigation methods. Quality and quantity of fig fruits can be affected by irrigation management for sustainable production (Si et al, 2023). In Table 5, fig fruit numbers were affected by supplemental irrigation. The number of Light yellow fig fruit increased by 102%, 52%, and 247% in micro jet irrigation as compared to flood, sub-surface drip, and control treatments, respectively. Important polyphenolic compounds in fig fruit are epicatechin, catechin, and chlorogenic acid, reaching peak levels during ripening. Polyphenol oxidase enzyme darkens fig skin by breaking down phenolic substances. Drought stress increases enzyme activity, darkening the fruit at ripening, while sufficient moisture brightens fruit skin (Sedaghat 2018).

244 The number of grade AA fig fruit increased by 455% and 317% in micro jet compared to
 245 flood and sub-surface drip irrigation, respectively, while control treatment had no grade AA
 246 fig fruit (Table 5).

247 Grade A fig fruit was highest in the control treatment, followed by micro jet irrigation, and
 248 the lowest number was found in flood irrigation, with no significant difference by sub-surface
 249 drip irrigation. The highest number of grade B fig fruit was obtained in control treatment and
 250 decreased by 31%, 26% and 22% in flood irrigation, micro jet irrigation and sub-surface drip
 251 irrigation, respectively (Table 5). According to Andrade et al. (2014), different supplemental
 252 irrigation methods significantly increased fig fruit numbers by about 27% to 47% as
 253 compared to control treatment. Sharifzadeh et al (2022) indicated that the supplemental
 254 irrigation leads to improve fig fruit yield and quality such as fruit size and color in Estahban
 255 city. Gunduz et al. (2011) found that supplemental irrigation increased peach fruit size and
 256 quality. Abdolahipour et al. (2019) reported that applying 2000 liters of supplemental
 257 irrigation per tree increased fig shoot growth and fruit number. The color and size of fig fruit
 258 depend on light intensity, temperature, pollination, fig formation, and soil moisture (Gunduz
 259 et al., 2011). Flashman (2016) stated that soil moisture and drought stress affect fig cell
 260 division, cell size, growth rate, and cracking. Micro-sprinkler supplemental irrigation
 261 increased apple fruit red color, anthocyanin content, firmness, size, and soluble solids
 262 concentration (Iglesias et al., 2002). Al-Desouki et al. (2009) observed increased nutrient
 263 absorption and improved photosynthetic capacity in rain-fed fig with supplemental irrigation.

264 **Table 5.** Effect of supplemental irrigation on the average number of fig fruits (*F. carica* cv.
 265 Sabz) in 2018 and 2019.

Supplemental irrigation treatments	grade AA (Size more than 23 mm)	grade A (Size 17–23 mm)	grade B (Size less than 17 mm)	Light yellow	Brown	Dark brown
Flood	1.8 b	15.4 c	84.4 c	29.2 b	42.3 c	29.4 a
Sub-surface drip	2.4 b	16.6 c	100.8 b	38.8 ab	65.8 b	37.4 a
Micro jet	10 a	25 b	97 b	59 a	44 c	33.4 a
Control (Rain-fed)	0 b	35 a	123 a	17 c	79 a	37.25 a

266 The means with the same letters in each column are not significantly different using the Duncan test at $P \leq 0.05$.

267 According to Table 6, supplemental irrigation significantly affected fig fruit weight. Light
 268 yellow fruits had the highest weight in micro jet irrigation, but significantly decreased by

269 about 53%, 35%, and 75% compared to flood, sub-surface drip, and control treatments,
 270 respectively. Brown fig fruit weight increased in average by about 55% in subsurface drip
 271 and control treatments as compared to micro jet and flood treatments, while there was no
 272 significant difference in the weight of dark brown fruits among all irrigation methods (Table
 273 6). Grade AA fig fruit weight was significantly increased in micro jet irrigation by about 78%
 274 and 75% compared to flood and sub-surface drip irrigation, respectively. There were no grade
 275 AA fig fruits in the control treatment, highlighting the importance of supplemental irrigation
 276 in improving fig fruit quality. Micro jet irrigation also significantly increased grade A fruit
 277 weight by about 53% and 56% compared to sub-surface drip and control, with no significant
 278 difference compared to flood irrigation. The control and sub-surface drip treatments had the
 279 highest weight for grade B fruits, while micro jet irrigation had the lowest one. These results
 280 demonstrate the effectiveness of micro jet irrigation in increasing both the quantity and quality
 281 of fig fruits. Honar et al. (2023) found that supplemental irrigation improved rain-fed fig yield
 282 in Estahban, Iran. Ntshidi et al. (2023) reported that water-saving irrigation methods like drip
 283 and micro jet are popular in orchards for abundant high-quality fruit. The finding of this study
 284 aligns with the results of Ntshidi et al. (2023).

285
 286 **Table 6.** Effect of supplemental irrigation on weight (gr) of fig fruits (*F. carica* cv. Sabz). In
 287 2018 and 2019).

Supplemental irrigation treatments	Grade AA (Size more than 23 mm)	Grade A (Size 17–23 mm)	Grade B (Size less than 17 mm)	Light yellow	Brown	Dark brown
Flood	11.5 b	70.78 a	341.28 b	122.2 b	171.34 b	96.02 a
Sub-surface drip	13.26 b	39.22 b	492.94 a	168.6 b	284.2 a	117.88 a
Micro jet	53.28 a	83.84 a	320.62 b	257.8 a	181.34 b	109.26 a
Control (Rain-fed)	0 b	36.1 b	492.67 a	64.25 c	260.9 a	109.92 a

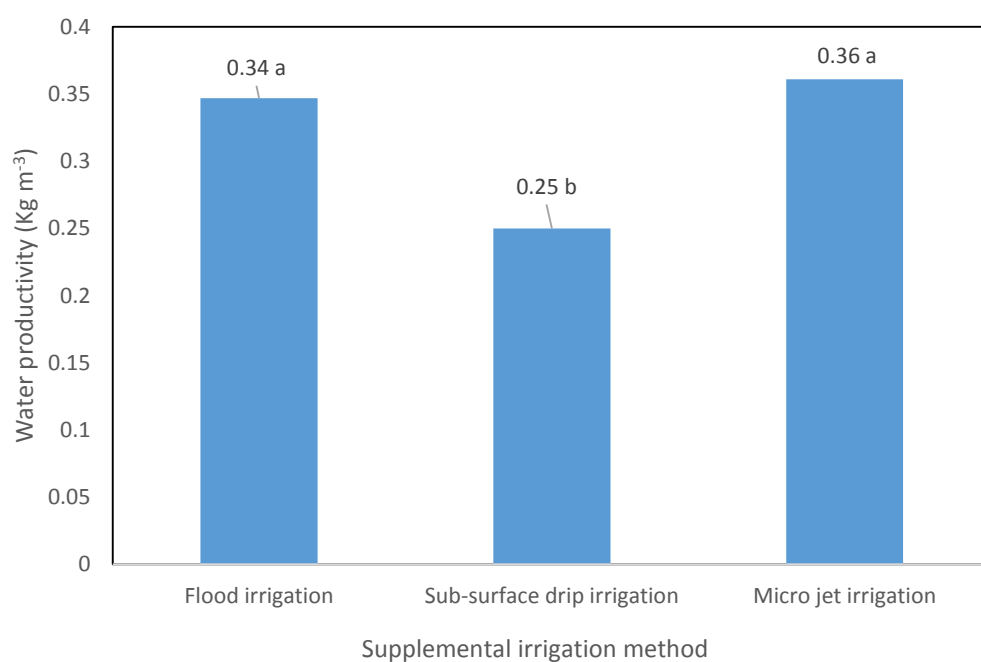
288 The means with the same letters in each column are not significantly different using the Duncan test at $P \leq 0.05$.

289 3.4. Water Productivity

290 The micro jet irrigation method demonstrated the highest water productivity compared to
 291 flood irrigation, with no significant difference observed between the two methods. Subsurface
 292 drip irrigation, on the other hand, showed a decrease in water productivity due to lower fig
 293 yield. However, this decrease may be compensated in future years as the roots can potentially
 294

295 reach the water source in sub surface irrigation more effectively. Further studies are needed
296 to explore this potential for improved water productivity with subsurface drip irrigation over
297 time.

298 Moursy et al. (2023) found that sprinkler and drip irrigation improve crop water productivity.
299 Cavalcante et al. (2022) and Sigua et al. (2020) reported the significant role of supplemental
300 irrigation in increasing yield and water productivity of rain-fed fig trees in semi-arid regions.
301 Allam et al. (2007) found a positive effect of supplemental irrigation on fig tree yield and
302 water productivity in Egypt. Supplemental irrigation provides benefits like higher water
303 productivity, lower crop failure risk, and stable yields (Filintas et al. 2021; Wang et al. 2021).
304 Zegbe and Servín-Palestina (2021) showed that implementing supplemental irrigation
305 maintains fruit yield, average mass, and marketable size at the same level as full irrigation,
306 while improving water use efficiency and productivity.



323

324 **Figure 4.** Water productivity in different supplemental irrigation methods.

325 4. Conclusions

326 Two years of field experiments in rain-fed fig orchards in the semi-arid Kherameh region
327 showed the effect of different supplemental irrigation methods on fig trees. The results
328 demonstrated that supplemental irrigation greatly affects the quality and quantity of fig fruit.
329

330 The highest amounts of total chlorophyll, leaf width, and internode length were observed in
331 micro jet irrigation, which promotes photosynthesis, leading to a significant increase in the
332 number and weight of high quality fig fruits (light yellow and grade AA fig fruit) compared
333 to other irrigation treatments. As the results showed micro jet irrigation resulted in the highest
334 quality, marketability, and water productivity, making it an effective supplemental irrigation
335 method for compensating rainfall deficiency in rain-fed fig cultivation. Future research should
336 focus on determining optimal irrigation levels and schedules for different crops and soils in
337 arid and semi-arid regions, as well as investigating the long-term impacts of irrigation
338 methods on soil health and ecosystem functioning. Assessing the economic aspects of
339 supplemental irrigation can warn policymakers and agricultural practitioners about the
340 potential benefits and trade-offs. These findings can facilitate the development of effective
341 water management, agricultural planning, and investment strategies in regions with
342 insufficient rainfall for rain-fed agriculture

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344 **References**

- 345 - Abdolahipour, M., Kamgar-Haghighi, A. A., Golkar, G., & Kamali, H. R. (2023). Evaluation
346 of the Effect of Supplemental Irrigation with Saline Water on Quality and Quantity of Rainfed
347 Fig Fruit. *Water and Irrig. Manag*, 12(4), 695-711.
- 348 - Abdolahipour, M.; Kamgar-Haghighi, A. A.; Sepaskhah, A. R. Time and amount of
349 supplemental irrigation at different distances from tree trunks influence on soil water
350 distribution, evaporation and evapotranspiration in rainfed fig orchards. *Agric. Water Manag.*
351 **2018**, 203, 322-332.
- 352 - Abdolahipour, M.; Kamgar-Haghighi, A. A.; Sepaskhah, A.R.; Zand-Parsa, S.; Honar, T.;
353 Razzaghi, F. Time and amount of supplemental irrigation at different distances from tree
354 trunks influence on morphological characteristics and physiological responses of rainfed fig
355 trees under drought conditions. *Sci. Hortic.* **2019**, 253, 241-254.
- 356 - Abdolahipour, M.; Kamgar-Haghighi, A. A.; Sepaskhah, A. R.; Dalir, N.; Shabani, A.; Honar,
357 T.; Jafari, M. Supplemental irrigation and pruning influence on growth characteristics and
358 yield of rainfed fig trees under drought conditions. *Fruits.* **2019**, 74, 282-293.

- 359 - Abdolahipour, M.; Kamgar-Haghighi, A. A.; Sepaskhah, A. R.; Zand-Parsa, S.; Honar, T.
360 Root length density of rainfed fig trees under different times, amounts, and positions of
361 supplemental irrigation. *J. Agric. Sci. Tech.* **2020**, 22(4), 1137–1150.
- 362 - Al-Desouki, M. A.; Abd El Rhman, I. E.; Sahar, A. F. Effect of some anti-transparent and
363 supplemental irrigation on growth, yield and fruit quality of Sultani fig (*Ficus carica*) grown
364 in the Egyptian western coastal zone under rainfed conditions. *Res. J. Agric and Bio. Sci.*
365 **2009**, 5, 899-908.
- 366 - Al-Ghzawi, A.L.A.; Khalaf, Y.B.; Al-Ajlouni, Z.I.; AL-Quraan, N.A.; Musallam, I.; Hani,
367 N.B. The effect of supplemental irrigation on canopy temperature depression, chlorophyll
368 content, and water use efficiency in three wheat (*Triticum aestivum* L. and *T. durum* Desf.)
369 varieties grown in dry regions of Jordan. *Agriculture.* **2018**, 8, 67.
370 <https://doi.org/10.3390/agriculture8050067>
- 371 - Allam, K.; Adly, M.; Mourad, M. Effect of supplemental irrigation and intercropping
372 treatments on the productivity of fig trees and lentil crop in the Northwest Coast. *Misr J.*
373 *Agric. Eng (MJAE).* **2007**, 24, 88-102.
- 374 - Ammar, A.; Aissa IB.; Mars, M.; Gouiaa, M. Comparative physiological behavior of fig
375 (*Ficus carica* L.) cultivars in response to water stress and recovery. *Sci Hortic.* **2020**,
376 260,1081. <https://doi.org/10.1016/j.scienta.2019.108881>
- 377 - Amer, K. H. Effects of irrigation method and quantity on squash yield and quality. *Agric.*
378 *Water Manag.* **2011**, 98, 1197–1206.
- 379 - Amiri, M.J.; Eslamian, S. Investigation of climate change in Iran. *J. Environ. Sci. Technol.*
380 **2010**, 3, 208–216.
- 381 - Amiri, M.J.; Eslamian, S.; Arshadi, M.; Khozaei, M. Water recycling and community. In
382 *Urban Water Reuse Handbook*; Eslamian, S., Ed.; CRC Press: Boca Raton, FL, USA, 2015,
383 pp. 261–273.
- 384 - Anjum, S. A.; Xie, X. Y.; Wang, L. C.; Saleem, M. F.; Man, C.; Lei, W. Morphological,
385 physiological and biochemical responses of plants to drought stress. *Afr. J. Agric. Res.* **2011**,
386 6, 2026-2032.

- 387 - Andrade, I. P. D. S.; Carvalho, D. F. D.; de Almeida, W. S.; Silva, J. B. G.; da Silva, L. D.
388 Water requirement and yield of fig trees under different drip irrigation management.
389 *Engenharia Agrícola*. **2014**, 34, 17-27.
- 390 - Bagheri, E.; Sepaskhah, A. R. Rain-fed figs yield as affected by rainfall distribution. *Theor.*
391 *Appl. Climatol.* **2014**, 117, 433-439.
- 392 - Bouman, B. A conceptual framework for the improvement of crop water productivity at
393 different spatial scales. *Agric. Syst.* **2007**, 93, 43–60.
- 394 - Cavalcante, E. S.; Lacerda, C. F.; Mesquita, R. O.; de Melo, A. S.; da Silva Ferreira, J. F.; dos
395 Santos Teixeira, A.; Lima, S. C. R. V.; da Silva Sales, J. R.; de Souza Silva, J.; Gheyi, H. R.
396 Supplemental irrigation with brackish water improves carbon assimilation and water use
397 efficiency in maize under tropical dryland conditions. *Agriculture*. **2022**, 12, 544.
398 <https://doi.org/10.3390/agriculture12040544>
- 399 - Chen, R.; Huang, Y.; Ji, X.; Xu, Y.; Xue, X.; Wang, J. Effects of different irrigation methods
400 on growth, fruit quality and yield of apple trees. *Asian J. Agric. Res.* **2018**, 10, 54-58.
- 401 - Danielescu, S.; MacQuarrie, K. T. B.; Zebarth, B.; Nyiraneza, J.; Grimmett, M.; Levesque, M.
402 Crop water deficit and supplemental irrigation requirements for potato production in a temperate
403 humid region (Prince Edward Island, Canada). *Water*. **2022**, 14, 2748.
404 <https://doi.org/10.3390/w14172748>
- 405 - Eslami, A.; and Jafari, M. Applying different supplementary irrigation methods in rainfed fig
406 orchards. Agricultural Engineering Research Institute, *Technical instructions registration* 2022,
407 No: 62021.
- 408 - Fernández, J. E.; Alcon, F.; Diaz-Espejo, A.; Hernandez-Santana, V.; Cuevas. M. V. Water use
409 indicators and economic analysis for on-farm irrigation decision: A case study of a super high
410 density olive tree orchard. *Agric. Water Manag.* **2020**, 237, 106074.
- 411 - Filintas, A.; Nteskou, A.; Katsoulidi, P.; Paraskebioti, A.; Parasidou, M. Rainfed and
412 supplemental irrigation modelling 2D GIS moisture rootzone mapping on yield and seed oil of
413 cotton (*Gossypium hirsutum*) using precision agriculture and remote sensing. *Eng. Proc.* **2021**,
414 9, 37. <https://doi.org/10.3390/engproc2021009037>

- 415 - Flashman, E. Catalytic strategies of the non-heme iron-dependent oxygenases and their roles in
416 plant biology. *Curr. Opin. Struct. Biol.* **2016**, 31, pp.126-135.
- 417 - Fox, P.; Rockstrom, J. Supplemental irrigation for dry-spell mitigation of rainfed agriculture in
418 the Sahel. *Agric. Water Manage.* **2003**, 61, 29–50.
- 419 - Gholami, M.; Rahemi, M.; Rastegar, S. Use of rapid screening methods for detecting drought
420 tolerant cultivars of fig (*Ficus carica L.*). *Sci. Hort.* **2012**, 143, 7-14.
- 421 - Gunduz, M.; Korkmaz, N.; Asik, S.; Unal, H. B.; Avci, M. U. H. Effects of various irrigation
422 regimes on soil water balance, yield, and fruit quality of drip-irrigated peach trees. *J. Irrig. Drain.
423 Eng.* **2011**, 137(7), 426-434.
- 424 - Halo, BA.; Al-Yahyai, RA.; Al-Sadi, AM. An endophytic *Talaromyces omanensis* enhances
425 reproductive, physiological and anatomical characteristics of drought-stressed tomato. *J. Plant
426 Physiol.* **2020** ,1, 249:153163.
- 427 - Hiscox, J. D.; Israelstam, G. F. A method for extraction of chlorophyll from leaf tissue without
428 maceration. *Canad. J. Bot.* **1979**, 57, 1332-1334.
- 429 - Honar, T.; Shabani, A.; Abdolahipour-Haghighi, M.; Dalir, N.; Sepaskhah, A. R.; Kamgar-
430 Haghighi, A.; Jafari, M. Effect of supplemental irrigation timing and potassium fertilizer on rain-
431 fed fig in micro-catchment: yield and yield quality. *Iran Agric Res.* **2020**, 39, 29-36.
- 432 - Honar, T.; Shabani, A.; Abdolahipour, M.; Dalir, N.; Sepaskhah, A.R.; Haghighi, A.A.; Jafari,
433 M. Rain-fed fig trees response to supplemental irrigation timing and potassium fertiliser in micro-
434 catchment. *J. Hortic. Sci. Biotechnol.* **2021**, 96, 738–749.
- 435 - Honar, T.; Sepaskhah, A. R. Effect of Using Potassium on Increasing Resistance of Fig Trees
436 to Drought. National Drought Research Institute, Shiraz, Iran, 2015, 113 pp.
- 437 - Iglesias, I.; Salvia, J.; Torguet, L.; Cabús, C. Orchard cooling with over tree micro sprinkler
438 irrigation to improve fruit colour and quality of ‘Topred Delicious’ apples. *Sci. Hortic.* **2002**, 93,
439 39–51 .
- 440 - Jafari, M.; Eslami, A. The reaction of young fig trees of Sabz variety to different supplementary
441 irrigation methods. *J of Hortic Sci Technol.* **2022**, 32(2). p. 236-225.

- 442 - Kamgar-Haghighi, A. A.; Sepaskhah, A. R. Effects of Different Levels of Supplementary
443 Irrigation and Pruning Times on Rain fed Fig Trees in Wet and Dry Years. National Drought
444 Research Institute, Shiraz, Iran, 2015, 102 pp.
- 445 - Kamyab, S. Evaluation of Possibility of Supplemental Irrigation Application in Rainfed Fig
446 Orchards of Fars Province. Research report, Shiraz University, Shiraz, Iran, 2015, 95 pp. (in
447 Persian).
- 448 - Karimi, S.; Hojati, S.; Eshghi, S.; Nazary Moghaddam, R.; Jandoust, S. Magnetic exposure
449 improves tolerance of fig 'Sabz' explants to drought stress induced in vitro. *Sci.Hort.* **2012**, 137,
450 95-99.
- 451 - Khozaei, M.; Kamgar-Haghighi, A. A.; Sepaskhah, A. R.; Zand-Parsa S.; Razzaghi, F.; Karami,
452 M. J. Supplemental irrigation management of rainfed grapevines under drought conditions using
453 the CropSyst model. *Span. J. Agric. Res.* **2020**, 18(2), e12032.
- 454 - Leonel, S.; Tecchio, M. A. Épocas de poda e uso da irrigação em figueira'Roxo de Valinhos' na
455 região de Botucatu, SP. *Bragantia.* 2010, 69, 571-580.
- 456 - Liao, Z.; Zeng, H.; Fan, J.; Lai, Z.; Zhang, C.; Zhang, F.; Wang, H.; Cheng, M.; Guo, J.; Li, Z.;
457 Wu, P. Effects of plant density, nitrogen rate and supplemental irrigation on photosynthesis, root
458 growth, seed yield and water-nitrogen use efficiency of soybean under ridge-furrow plastic
459 mulching. *Agric. Water Manag.* **2022**, 268, 107688.
- 460 - Liu, X., Zhang, Q., Song, M., Wang, N., Fan, P., Wu, P., et al. (2021). Physiological responses
461 of Robinia pseudoacacia and Quercus acutissima seedlings to repeated drought-rewatering under
462 different planting methods. *Front. Plant Sci.*
- 463 - Moradi, L.; Siosemardeh, A.; Sohrabi, Y.; Bahramnejad, B.; Hosseinpanahi, F. Physiological
464 and biochemical responses in five wheat cultivars to supplemental irrigation. *J. Agric. Sci.*
465 *Technol.* **2023**; 25, 125-138.
- 466 - Moura, E.A.; Mendonça, V.; Figueirêdo, V.B.; Oliveira, L.M.; Melo, M.F.; Irineu, T.H.S.;
467 Andrade, A.D.M.; Chagas, E.A.; Chagas, P.C.; Ferreira, E.S.; et al. Irrigation Depth and
468 Potassium Doses Affect Fruit Yield and Quality of Figs (*Ficus carica* L.). *Agriculture.* **2023**, 13,
469 640. <https://doi.org/10.3390/agriculture13030640>

- 470 - Moursy M.; ElFetyany M.; Meleha A, El-Bialy MA. Productivity and profitability of modern
471 irrigation methods through the application of on-farm drip irrigation on some crops in the
472 northern Nile Delta of Egypt. *Alex Eng J.* 2023, 62, 349–356
- 473 - Ntshidi, Z.; Dzikiti, S.; Mazvimavi, D.; Mobe, N.T. Effect of Different Irrigation Systems on
474 Water Use Partitioning and Plant Water Relations of Apple Trees Growing on Deep Sandy Soils
475 in the Mediterranean Climatic Conditions, South Africa. *Sci. Hortic.* **2023**, 317, 112066.
- 476 - Panigrahi, P. Impact of deficit irrigation on citrus production under a sub-humid climate: a case
477 study. *Water Supply.* **2023**, 23(3):1177. <https://doi.org/10.2166/ws.2023.074>
- 478 - Pastori, G. M.; Trippi, V. S. Oxidative stress induces high rate of glutathione reductase
479 synthesis in a drought-resistant maize strain. *Plant Cell Physiol.* **1992**, 33, 957–961.
- 480 - Sharifzadeh, M.; Kamgar-Haghighi, A. A.; Sepaskhah, A. R.; Honar, T.; Abdolahipour, M.;
481 Kamyab, S.; Khosrozadeh, M. Factors Contributing to Application of Supplemental Irrigation
482 Technique in Fig Production: Evidence from a Survey in Iran. National Drought Research
483 Institute, Shiraz, Iran, 2012, 73 pp. (in Persian).
- 484 - Sharifzadeh, M.; Kamgar-Haghighi, A. A.; Sepaskhah, A. R.; Honar, T.; Ahmadvand, M.;
485 Abdolahipour, M. Shadow spaces for water stress adaptation: Supplemental irrigation application
486 in rainfed fig production. *Water Resour. Res.*, **2022**, 58, e2022WR033327. <https://doi.org/10.1029/2022WR033327>
- 487
- 488 - Shirbani, S.; Abdolahi Pour Haghighi, J.; Jafari, M.; Davarynejad, G. H. Physiological and
489 biochemical responses of four edible fig cultivars to water stress condition. *J. Agric. Sci.* **2013**,
490 3, 473-479.
- 491 - Sedaghat, S. Evaluation of Bud and Fruit Development and Chemical Changes of 'Sabz' Cultivar
492 (*Ficus carica* L.) Under Rain-Fed Condition. Ph.D. Dissertation. Shiraz. Iran. 2018, 171 pp, (In
493 Persian).
- 494 - Si, Z.; Qin, A.; Liang, Y.; Duan, A.; Gao, Y. A review on regulation of irrigation management
495 on wheat physiology, grain yield, and quality. *Plants.* **2023**, 12, 692.
496 <https://doi.org/10.3390/plants12040692>

- 497 - Sigua, G. C.; Stone, K. C.; Bauer, P. J.; Szogi, A. A. Efficacy of supplemental irrigation and
498 nitrogen management on enhancing nitrogen availability and urease activity in soils with sorghum
499 production. *Sustainability*. **2020**, 12, 8358. <https://doi.org/10.3390/su12208358>
- 500 - Tapia, R.; Botti, C.; Carrasco, O.; Prat, L.; Franck, N. 2003. Effect of four irrigation rates on
501 growth of six fig tree varieties. *Acta Hortic*. **2003**, 605, 113-118.
- 502 - Tehrani, M. M.; Kamgar-Haghighi, A. A.; Razzaghi, F.; Sepaskhah, A. R.; Zand-Parsa, S.;
503 Eshghi, S. Physiological and yield responses of rainfed grapevine under different supplemental
504 irrigation regimes in Fars province, Iran. *Sci. Hort*. **2016**, 202, 133-141.
- 505 - Trigueros, CR; Gambín, JMB; Tortosa, PAN; Cabañero, JJA; Nicolás, EN. Isohydrlicity of two
506 different citrus species under deficit irrigation and reclaimed water conditions. *Plants*. **2021**, 10
507 (2121),1–19.
- 508 - Varol, IS.; Kirnak, H.; Irik, HA.; Ozaktan, H. Effects of Supplementary Drip Irrigations Applied
509 in Different Growth Stages on Yield and Yield Components of Chickpea Plants Grown Under
510 Semiarid Climate Conditions. *Gesunde Pflanzen*. **2023**, 75(4),1307-14.
- 511 - Wang, C.; Liu, W.; Li, Q.; Ma, D.; Lu, H.; Feng, W.; Xie, Y.; Zhu, Y.; Guo, T. Effects of
512 different irrigation and nitrogen regimes on root growth and its correlation with above-ground
513 plant parts in high-yielding wheat under field conditions. *Field Crop Res*. **2014**, 165, 138–149.
- 514 - Wang, G.-Y.; Hu, Y.-X.; Liu, Y.-X.; Ahmad, S.; Zhou, X.-B. Effects of supplement irrigation
515 and nitrogen application levels on soil carbon–nitrogen content and yield of one-year double
516 cropping maize in subtropical region. *Water*. **2021**, 13, 1180. <https://doi.org/10.3390/w13091180>
- 517 - Wang, J.; Niu, W.; Zhang, M.; Li, Y.; Effect of alternate partial root-zone drip irrigation on soil
518 bacterial communities and tomato yield. *Appl. Soil Ecol*. **2017**, 119, 250-259.
- 519 - Wang, Y.; Xie, Z. K.; Li, F.; Zhang, Z. The effect of supplemental irrigation on watermelon
520 (*Citrullus lanatus*) production in gravel and sand mulched fields in the Loess Plateau of northwest
521 China. *Agric. Water Manage*. **2004**, 69(1), 29–41. <https://doi.org/10.1016/j.agwat.2004.03.007>
- 522 - Zegbe, J. A., & Servín-Palestina, M. (2021). Supplemental irrigation to save water while
523 growing cactus pear in semi-arid regions. *Irrig. Drain*, 70(2), 269-280.

524 - Zhou, S.; Hu, X.; Zhou, Z.; Wang, W.; Ran, H. Improving water use efficiency of spring maize
525 by adopting limited supplemental irrigation following sufficient pre-sowing irrigation in
526 northwest China. *Water*. 2019, 11, 802. <https://doi.org/10.3390/w11040802>.

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528 پایداری تولید انجیر دیم (*Ficus carica*) تحت آبیاری تکمیلی در مناطق نیمه خشک

529 امیر اسلامی، مسلم جعفری، و مریم خزاعی

530

چکیده

531 در مناطق خشک و نیمه خشک، بارندگی ناکافی نیاز به آبیاری تکمیلی برای برآوردن نیاز آبی محصول دارد. انتخاب
532 روش مناسب برای موفقیت بسیار مهم است. یک آزمایش مزرعه ای دو ساله در منطقه خرامه ایران به منظور بررسی
533 تأثیر روش های مختلف آبیاری تکمیلی بر عملکرد درخت انجیر، پاسخ فیزیولوژیکی و بهره وری آب انجام شد. سه روش
534 آبیاری غرقابی، آبیاری قطره ای زیرسطحی، آبیاری میکرو جت و بدون آبیاری تکمیلی (شاهد) به عنوان چهار تیمار در
535 پنج تکرار اعمال شد. نتایج نشان داد که آبیاری زیرسطحی و میکرو جت به طور معنی داری باعث افزایش 18.2 درصدی
536 عرض برگ، 27 درصدی طول شاخساره و 13 درصدی قطر شاخساره شد. همچنین آبیاری میکرو جت باعث افزایش
537 14 درصدی کلروفیل برگ انجیر، 134 درصد میانگین تعداد میوه و 54 درصد میانگین وزن کل میوه نسبت به سایر
538 تیمارها شد. علاوه بر این، بالاترین سطوح راندمان آب در روش های آبیاری میکرو جت مشاهده شد، در حالی که با آبیاری
539 قطره ای زیرسطحی 40 درصد کاهش یافت. پیامدهای عملی این مطالعه شامل افزایش عملکرد انجیر، پالایش
540 استراتژی های مدیریت آب، تقویت مقاومت به خشکی، تجزیه و تحلیل امکان سنجی اقتصادی، سنجش پایداری، و حمایت
541 از اشتراک دانش و مهارت ها برای کشت انجیر در مناطق نیمه خشک است.

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