

SUSTAINABLE WATER SAVING AND WATER PRODUCTIVITY USING DIFFERENT IRRIGATION SYSTEMS FOR COTTON PRODUCTION

Oner Cetin¹

ABSTRACT

In this article, different irrigation systems/methods (furrow, sprinkler, surface drip irrigation (SDI) and subsurface drip irrigation (SSDI) used for cotton irrigation in South-eastern Region of Turkey were evaluated on water use efficiency, water and yield relationships and water productivity. According to a study carried out in this region, the sprinkler irrigation method resulted in a lower yield than that of both the drip and furrow method. Considering the optimum yields, SDI resulted in 21 % more seed-cotton yield than yield obtained by the furrow irrigation, and 30 % more than the sprinkler irrigation. Irrigation water use efficiency (IWUE) or water physical productivity (WPP) proved to be 0.49, 0.39 and 0.24 kg/m³ for SDI, furrow and sprinkler, respectively. The net return of US\$989 /ha per land area could be obtained using 10000 m³/ha of irrigation water for the furrow irrigation method. Whereas the same net return was obtained using 8000 m³/ha of irrigation water for the SDI. The water economic productivity (WEP) for furrow irrigation and SDI were US\$0.099 /m³ and US\$0.124 /m³, respectively. According to another study, the maximum WPP (0.84 kg/m³) occurred in the SSDI system at a soil depth of 40 cm. The net return was US\$1109.9 /ha at the same treatment using irrigation water of 551 mm. The reason of differences on WPP for two different studies of SDI could be attributed to different irrigation scheduling based on different methods and cotton variety. The use of the SDI technique in arid and semi-arid areas and the evaporation rate from the soil surface increased considerably due to high air temperature and low relative humidity, as in those study areas. Having higher water use efficiency and saving water are dependent on decreasing the evaporation from the soil and an appropriate irrigation management. Thus, the use of SSDI is one of the main methods of saving water. Water productivity can vary according to the crop, climate conditions, agronomic practices and agricultural technologies. Better agronomic practices and water management can, thus, improve the yield and water productivity of irrigated crops.

Keywords: water productivity, water saving, cotton, surface and subsurface drip irrigation.

1. INTRODUCTION

The main user of the fresh water is globally agriculture sector. Because irrigation can maximize the crop yield and/or irrigation water use efficiency (IWUE) or water productivity and maximize the farmer's economic returns. However, increasing water demand for industrial and domestic use and for environmental sustainability create a pressure on irrigated agricultural sector.

On the other hand, irrigation in Turkey has increased the crop yield from once through five times depending on climate and soil conditions and agricultural techniques. The rainfed agriculture enables only US\$489 /ha of gross income in average however the irrigated agriculture provides US\$3201/ha (DSI, 2016). Irrigation is, thus, vital important for crop production and farmers' incomes.

¹ Department of Agricultural Structures and Irrigation, Agricultural Faculty, Dicle University, Diyarbakır, Turkey; E-mail. onercetin@dicle.edu.tr, oner_cetin@yahoo.com

Food demand and food security will increase and those will be more complex. Increasing temperatures depending on climate change will increase water demand, and where rainfall declines in the future. Thus, more irrigation to ensure food security and maintain livelihoods will be needed. Connecting this issues, the effects of mitigation on irrigation water requirements will be significant in near future and the larger overall water savings should be considered both globally and regionally (Turral et al., 2011).

Cotton provides mainly raw material for textile industry and seeds of cotton contain 17-26 % of fat and protein of 19-30 (Swern, 1982). In Turkey, the seed-cotton of 2,57 milyon tonnes has been producing in the area of 519 000 ha. Average yield is about 4950 kg/ha. Turkey has got a proportion of 4 % and 9th range in the world. Cotton is grown in Eagen, Mediterranean and Southest regions of Turkey. However, the Souteheast Region has been producing more than 50 % of total country production (TUIK, 2018).

Even if all the agricultural practices and inputs such as soil plough, fertilization, control of diseases and insects, sowing time etc for cotton production are important. However, economical cotton growing is not possible without irrigation. Thus, irrigation is the main input and dominates the cotton production. On the other hand, comparing to the other field crops with cotton, it needs much more amount of irrigation water because the irrigation period is long and it consumes much more water. The many studies of water consumptive use, irrigation scheduling, comparing different irrigation systems, deficit irrigation and fertigation on cotton have been carried out in Turkey (Tekinel and Kanber, 1979; Yalçuk and Özkara, 1984; Karaata, 1985; Baştuğ, 1987; Kanber et al., 1991; Yavuz, 1993; Cetin and Bilgel, 2002, Yazar et al., 2002; Dağdelen et al., 2005; Üzen and Çetin, 2016).

There are many different irrigation systems/methods or/and way to deliver irrigation water to the cotton fields. These could be sprinkler, surface irrigation, surface and subsurface drip irrigation. Each irrigation system/method is specific considering field characteristics, operation and management issues. However, surface and subsurface drip irrigation provides to be an economical method of water application for row crops such as cotton (Cetin and Bilgel, 2002; Cetin et al., 2018).

All irrigation systems and/or methods have been using for cotton irrigation in the world and Turkey. However each irrigation system/method has got some advantages and limitations in terms of water consumptive use, water use efficiency or water physical productivity, water uniformity, total amount of irrigation water applied, evaporation loss, labor and system cost and use convenience of the systems etc.

For this, surface irrigation (furrow), sprinkler and drip irrigation, some moving irrigation systems (center pivot, linear moving systems) might be used for cotton irrigation considering soil, climate and crop characteristics and farmers conditions.

In this article, different irrigation systems/methods (furrow, sprinkler, surface drip (SDI) and subsurface drip irrigation (SSDI) used for cotton irrigation in Southeastern Region of Turkey were compared in terms of water use, water and yield relationships and water productivity.

1. ASSESSMENT OF FURROW, SPRINKLER AND DRIP IRRIGATION ON COTTON YIELD AND WATER USE EFFICIENCY

Surface irrigation is defined as application of water to the furrows or basin by means gravity along the soil surface. The investment and operation cost are lower compared to the other pressurized irrigation systems. Furrow irrigation is preferred for row crops

such as cotton. Furrow irrigation can able to provide maximum benefit in terms of water use in case appropriate operation.

Surface irrigation (furrow) has still been commonly using for cotton irrigation in Turkey. Land levelling, convenient furrow length and water discharge depending on soil characteristics should be taken into consideration for an appropriate furrow irrigation. Otherwise, the redundant and over irrigation water might be used. This could cause soil salinity, erosion and drainage problems.

On the other hand, the requirement of irrigation water for cotton irrigated by surface irrigation could differ from the region to another region in Turkey (Table 1).

Table 1. Amount of irrigation water and numbers for cotton irrigation under surface irrigation in different regions of Turkey (Çetin and Bilgel, 1996)

Region name	Amount of irrigation water (mm)	Amount of irrigation water (m ³ /ha)	Irrigation number	Source
Iğdır	350	3500	3	(İstanbuluoğlu, 1995)
K.Maraş	650	6500	7	(Kanber et al., 1986)
Ege (Menemen)	450	4500	5 – 6	(Yalçuk and Özkara, 1984)
Ege (Nazilli)	350	3500	4	(Yalçuk and Özkara, 1984)
Çukurova	670	6700	5	(Kanber and Derviş, 1978)
Harran	900-1000	9000-10000	8 - 10	(Çetin and Bilgel, 2002)

According to the results of the study carried out by Çetin and Bilgel (2002), the seed-cotton yields increased with increasing water amounts for all irrigation methods (furrow, sprinkler and SDI). However, the cotton yields decreased with excessive irrigation. The lower yield was obtained with using of sprinkler irrigation method than that of both the drip and furrow irrigation method (Table 2, Figure 1a). The yield differences among the irrigation methods were statistically significant. Taking into account optimum yields (4380, 3380 and 3630 kg/ha for SDI, sprinkler and furrow irrigation methods, respectively) according to the averaged yields for 4 experimental years, drip irrigation provided 21 % more seed-cotton yield than the furrow method, and 30 % more than the sprinkler method. IWUE was computed also to be 0.49, 0.39 and 0.24 kg/m³ for SDI, furrow and sprinkler, respectively (Figure 1b). Hence, SDI resulted in both higher cotton yield and also significantly water savings. Thus, the lowest IWUE was computed in sprinkler-irrigated plots and the highest in drip-irrigated plots.

The reasons of the lower cotton yield using sprinkler irrigation in this study region might be climatic condition such as high temperature (up to 46.8 °C), very low relative humidity (15-30 %) and higher wind speed in summer. Because, irrigation events realized during the day time and the negative impacts of sprinkler drops on both the flowers and leaves of the plants might be specified. Thus, dry wind and higher temperature during the irrigation season resulted in increased evaporation. All these conditions might be main reasons on the lower yield using sprinkler irrigation in this study (Çetin and Bilgel, 2002).

Considering all the circumstances, net return per land area, net return per unit of water, and water-saving drip irrigation were more appropriate for sustainability (Kumar et al., 2008; Çetin and Uzen, 2016). The net return of US\$989 ha⁻¹ per land area could be obtained using 10000 m³/ha of irrigation water for the furrow irrigation method, whereas the same net return was obtained using 8000 m³/ha of irrigation water for the drip irrigation method. The physical and economic productivity for furrow irrigation and SDI were 0.39 kg/m³, US\$0.099/ m³, and 0.49 kg/m³ and US\$0.124/m³, respectively (Çetin and Uzen, 2016b).

Table 2. The cotton yields (lint + seed) obtained according to different irrigation methods (Çetin and Bilgel, 2002).

Furrow		Sprinkler		Drip	
Irrigation water (mm)	Yield (kg/ha)	Irrigation water (mm)	Yield (kg/ha)	Irrigation water (mm)	Yield (kg/ha)
624	2610 b	31	850 d	341	2070 c
937	3630 a	328	2160 c	619	3460 b
1248	3850 a	735	2910 b	898	4380 a
		1106	3280 ab	1144	4890 a
		1432	3380 a		

All values represent the average of over the four years of the research. The vules of means according to the experiment years by the same letter are not significantly different (0.01>P) according to a Duncan's multiple range test.

On the other hand, the relationships between cotton yield and amount of water applied and WPP are shown in Figure 2. According to the different irrigation methods, the intersection point in the curves of WPP and water-yield could be considered appropriate point in terms of amount of water applied. At the next right side of this intersection point, the applied water could be non-benefit. However, this consideration might not be valid for some cases considering WEP or other conditions.

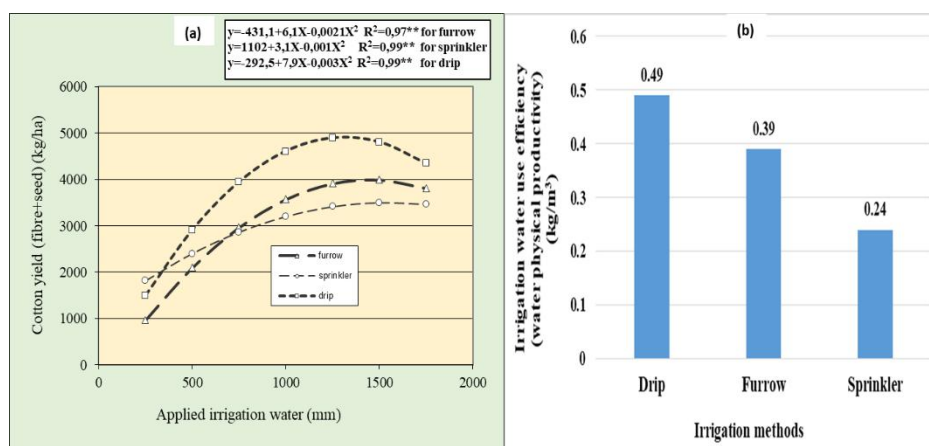


Figure 1. The relationships between seed-cotton yield and amount of irrigation water applied (a) and water physical productivity (b) according to the furrow, srinkler and surafce drin irrigation (Adanted

2. EFFECTS OF SURFACE AND SUBSURFACE DRIP IRRIGATION ON COTTON YIELD and WATER PRODUCTIVITY

Considering the results of the study (Çetin et al., 2018), it was concluded that the SSDI method at 1.0 ET_c was proven to be optimum and resulted in recording higher seed-cotton yield and water saving in comparison to the SDI method. SSDI resulted in much more seed cotton yield compared to SDI in every case (Figure 3). Thus, there were significant seed cotton yield differences, as much as 18% (657 kg/ha), between SSDI (the lateral depth of 40 cm, which is recommendable) (4323 kg/ha) and SDI (3667 kg/ha). The relationship between the amount of irrigation water applied and seed-cotton yield was defined as $Y = 2502.8 + 3.42 X$ ($R^2 = 0.98^{**}$) using linear regression. Thus, the seasonal actual evapotranspiration and amount of irrigation water were 589 and 552 mm, respectively. Comparing the previous studies using traditional and/or surface irrigations, SSDI enables water saving up to about 40%. On the other hand, the use of 30 cm at the lateral depth for SSDI has created some soil plough problems in terms of

damaging the system; thus, this lateral depth should not be used for SSDI construction for cotton irrigation.

Agricultural water productivity (AWP) vary considering field and farm scale, country and basin level. The main purpose of AWP in the field scale is to maximize the biophysical AWP for a specific crop or product (for instance: cotton or silage corn). However, the AWP in farm level is aimed to maximize the economic return from the whole farm involving one or multiple crops or products. The AWP for the country level is to improve for food security and exports. The competition between sectors, equity issues and conflicts may be taken into account for AWP in the basin scale (Molden et al. 2010).

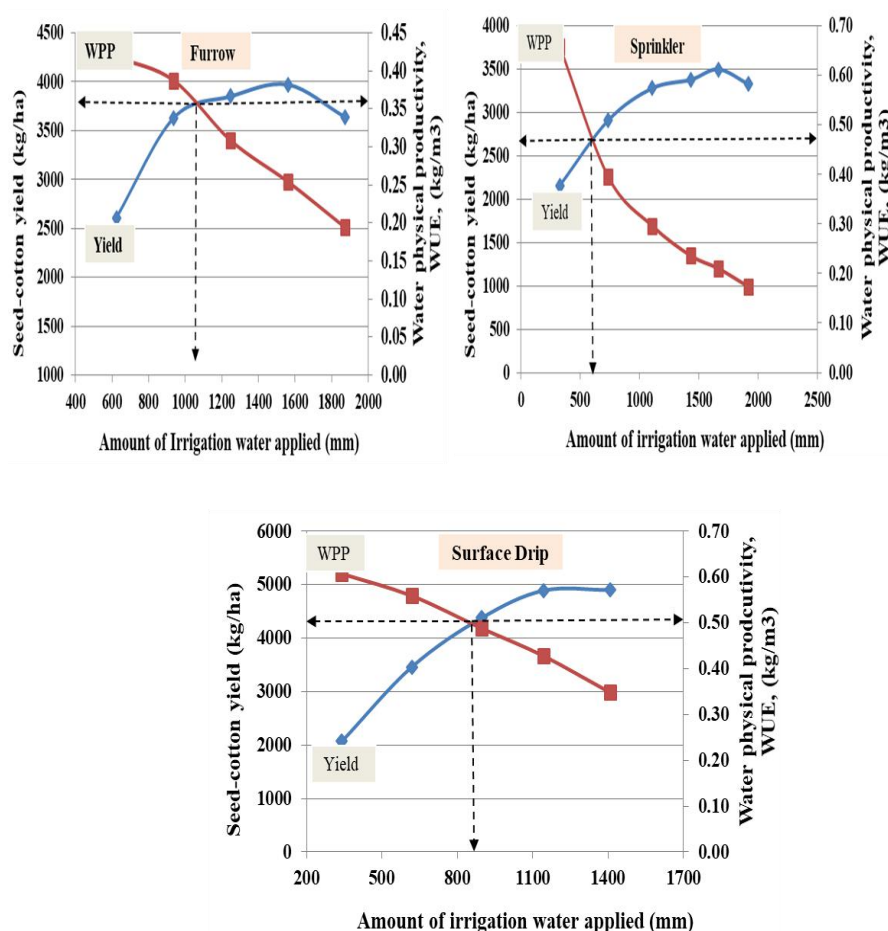


Figure 2. Relationships between irrigation water, seed-cotton yield and water use efficiency according to the different irrigation methods (Adapted from Cetin and Bilgel, 2002)

Water use efficiency (WUE) can be increased by use of efficient water use that is, increasing water absorption and water transport in the stems of plants (Chen et al., 2018). Water physical productivity (WPP) and WUE are often used interchangeably but have different meanings. WUE specifically could be defined as the ratio of biomass (total dry matter) produced per unit of irrigation water used, i.e. consumptive water use or the sum of transpiration by the crop and evaporation from the soil. On the contrary,

WP means the ratio of above-ground biomass per unit of water transpired by the crop. Both terms are related to farmers' economic goals. WUE is concerned mainly the irrigation schemes, management agencies and water districts. However, WP interests more farmers and research community (Levidow et al., 2014).

According to the study results (Çetin et al., 2018), the maximum WEP (US\$ 0.84/m³) occurred in the SSDI system at a soil depth of 40 cm (Figure 4). Furthermore, WPP, in general, decreased as long as the amount of water applied increased. The net return (US\$1109.9/ha) in which the irrigation application (551.3 mm) had a calculated ET_c of 1.00 times based on FAO-56 PM and SSDI at a soil depth of 40 cm was found to be more applicable in terms of farmer practices. The maximum WEP in terms of volumetric unit of water (US\$0.17/m³) occurred under the treatment in which both the irrigation applications had a calculated ET_c of 1.25 times based on FAO-56 PM and SSDI at a soil depth 30 cm and the treatment with evapotranspiration of 1.00 times based on FAO-56 PM and SSDI at a soil depth of 40 cm (Figure 5). As a result, SSDI-40 cm resulted in saving water and greater water productivity using amount of irrigation water based on 1.0xET_c.

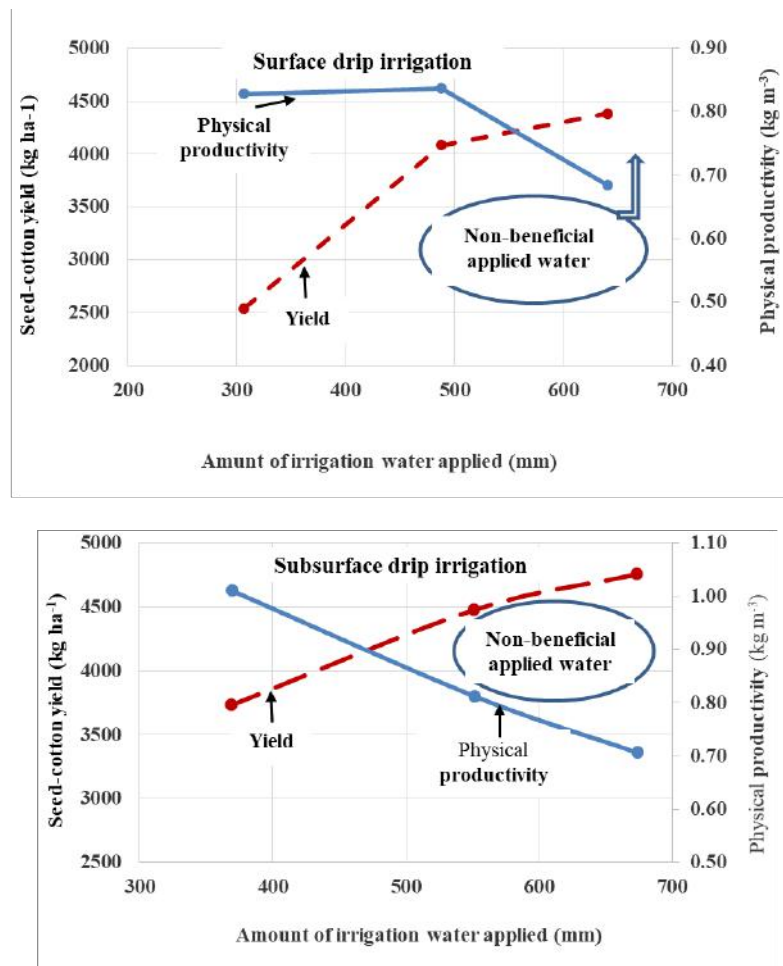


Figure 3. Comparison of physical productivity and seed-cotton yield according to the amount of irrigation water applied, surface and subsurface drip

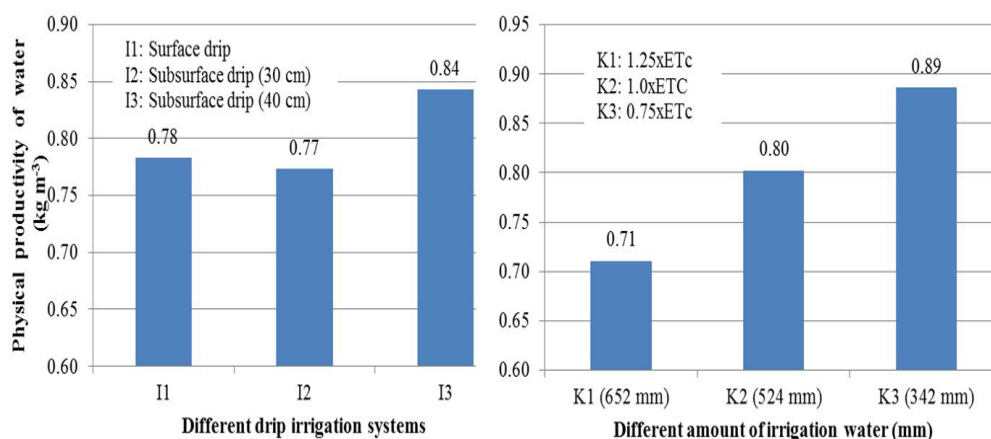


Figure 4. Physical productivity of water according to different drip irrigation systems and different amount of irrigation water

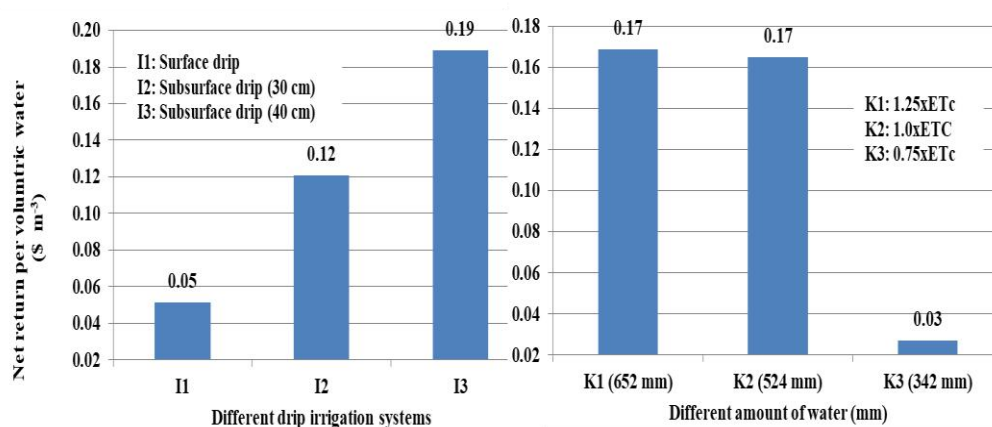


Figure 5. Net return per volumetric water according to different drip irrigation systems and different amount of irrigation water

3. CONCLUSION

Water productivity in terms of WPP (WUE) and WEP (economic productivity based on unit area and volumetric water) are the main indexes to compare and evaluate different irrigation systems and irrigation scheduling. Thus, farmers, irrigators, irrigation scientists, managers of irrigation schemes, and decision-makers should consider these indicators for efficient irrigation and more economic net return and water saving. Thus, there are two main ways of improving the physical productivity of water used in irrigated agriculture. One is to decrease consumptive water use for a certain production, and the second is to increase crop yield or production.

Water productivity can vary according to the crop, irrigation source (surface water, well water, etc.), climate conditions, agronomic practices, and agricultural technologies.

Thus, better agronomic practices and water management can, thus, improve the yield and water productivity of irrigated crops.

Conventional irrigation methods such as surface irrigation are still the most widely used method for cotton cultivation in Turkey. However, the pressurized irrigation systems, such as drip and sprinkler, have increased year after year, and these systems ensured a lot of importance due to their ability to achieve higher irrigation efficiency and uniformity when compared to traditional surface systems. For this, the Turkish government has subsidized 50% of the total cost of pressurized irrigation systems for the farmers who want to use them.

The use of the SDI technique in arid and semi-arid areas and the evaporation rate from the soil surface increased considerably due to high air temperature and low relative humidity, as in those study areas. This reduced water use efficiency, and to overcome this situation, the SSDI system could be used. Having higher water use efficiency and saving water are dependent on decreasing the evaporation from the soil in addition to appropriate irrigation management. The use of SSDI is one of the main methods of saving water and water productivity.

ACKNOWLEDGEMENT

Some of data in this article are provided from a part of “Project Final Report” (TUBITAK 115O600) carried out by the author of this article. Thus, the author would like to thank to the Scientific and Technological Research Council of TURKEY (TUBITAK) for providing financial support.

REFERENCES

- Baştuğ, R., 1987 A study on water-yield relationships of cotton under the Çukurova conditions. Ph.D Thesis, Çukurova University, Institute of Applied Sciences, Adana, Turkey. (with English abstract in Turkish).
- Cetin, O. & Bilgel, L. 1996 The General Rules of Cotton Irrigation and Irrigation Applications in Harran Plain. The National Society of Agricultural Engineering, TOPRAKSU 1996/3 Ankara, 2-5 (in Turkish)
- Çetin, Ö. & Bilgel, L. 2002 Effects of Different Irrigation Methods on Shedding and Yield of Cotton. Agricultural Water Management, Volume 54/1, 1-15.
- Çetin, Ö. & Üzen, N. 2016 Raising Water Productivity Levels and Ensuring Sustainability of Irrigation For High Water Using Crops. 2nd World Irrigation Forum, 6-8 November 2016, Chiang Mai, Thailand. W.3.1.01
- Çetin, Ö., Üzen, N., Temiz, M.G. & Başbağ, S. 2018 Comparison of surface and sub-surface drip irrigation and real-time irrigation scheduling based on FAO-56-Penman-Monteith for cotton. Final Project Report, (TUBITAK-1001, 115O600) (with English abstract in Turkish). (This Project was financially supported by Scientific and Technological Research Council of Turkey-TUBITAK).
- Chena, Z., Xia, J., Ma, H., Wang, Y., Gao, H., Kong, X. & Honghai Luo, H. 2018 Presowing fertigation effects on soil moisture absorption and consumption of cotton in arid regions. Agricultural Water Management 210, 130–139.
- Dağdelen, N., Yılmaz, E., Sezgin, F., Gürbüz, T. & Akçay, S. 2005 Effects of Different Trickle Irrigation Regimes on Cotton (*Gossypium hirsutum* L.) yield in Western Turkey. Pakistan of Biological Sciences, Vol. 8, IS-10, PS. 1387–1391
- DSI, 2016 Soil and water resources in Turkey. State Hydraulic Works, www.dsi.gov.tr Access date: 26.03.2018 (in Turkish)
- İstanbuluoğlu, A. 1995 Water consumptive use and last irrigation time of cotton in Iğdır Plain. Research Institute of Rural Affairs in Erzurum. Publication No: 49/45. (with English abstract in Turkish)

- Kanber, R. & Derviş, Ö. 1978 Water consumptive use of cotton in Çukurova conditions. Regional Research Institute of Soil-Water in Tarsus. Publication No: 90/40. (with English abstract in Turkish)
- Kanber, R., Eylon M., Yüksek, G., Demiröz C., 1986. Water consumptive use of cotton under Kahramanmaraş conditions. Research Institute of Rural Affairs in Tarsus. Publication No: 113/63. (with English abstract in Turkish)
- Kanber, R., Tekinel, O., Baytorun, N., Kumova, Y. & Alagoz, T. 1991 Use of Class A Pan on Water Consumptive Use and Irrigation Intervals. Southeastern Anatolia Project, Regional Development Administration, Project Report, GAP Publication No: 44, Adana
- Karaata, H. 1985 Water consumptive use of cotton in the Harran Plain. Research Institute of Rural Affairs. Publication number No: 24/45. Şanlıurfa, Turkey. (with English abstract in Turkish).
- Levidow, L., Zaccaria, D., Maia, R., Vivas, E., Todorovic, M. & Scardigno, A. 2014 Improving water-efficient irrigation: Prospects and difficulties of innovative practices. Agricultural Water Management, Volume 146, December 2014, Pages 84-94
- Molden, D., Oweis, T., Steduto, P., Bidraban, P., Hanjra, M.A. & Kijne, J. 2010 Improving agricultural water productivity: Between optimism and caution. Agricultural Water Management 97: 528-535.
- Swern, D. 1982 Bailey's Industrial Oil and Fat Products. A Wiley Interscience Publication, Vol. 2, 1-69. USA.
- Tekinel, O. & Kanber, R. 1979 Water consumptive use and yield under the limited irrigation strategies in Çukurova Region of Turkey for cotton. Tarsus Regional Research Institute of Soil and Water. Publication No: 94. Tarsus, Turkey (with English abstract in Turkish)
- TUIK, 2018 Data of Crop Production in Turkey. Turkish Statistical Institute, www.tuik.gov.tr, Access date: 26.03.2018. (in Turkish)
- Turrall, H., Burke, J. & Faurès, J.M. 2011 Climate change, water and food security. Food And Agriculture Organization Of The United Nations, Rome.
- Üzen, N. & Çetin, Ö. 2016 Effects of nitrogen fertigation frequency on yield and nitrogen retention in drip-irrigated cotton. J. of Plant Nutrition, Vol. 39, No. 14, 2126–2135.
- Üzen, N. & Çetin, Ö. 2016 Effects of nitrogen fertigation frequency on yield and nitrogen retention in drip-irrigated cotton. J. of Plant Nutrition, Vol. 39, No. 14, 2126–2135.
- Yalçuk H. & Özkara M. 1984 The effects of limited irrigation levels on cotton yield under the Aegean Region of Turkey. Menemen Regional Research Institute of Soil and Water. Publication No: 107/70. (with English abstract in Turkish).
- Yavuz, M.Y. 1993 The effects of different irrigation methods on cotton yield. Ph.D Thesis, Çukurova University, Institute of Applied Sciences, Adana, Turkey. (with English abstract in Turkish).
- Yazar, A., Sezen, S.M. & Sesveren, S. 2002 LEPA and Trickle Irrigation of Cotton in the Southeast Anatolia Project (GAP) Area in Turkey. Agricultural Water Management, Vol. 54, Number 3, 189-203