Deficit Irrigation Effect on Water Use Efficiency of Crops in Arid and Semi-Arid Regions

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Abstract

Irrigation is necessarily prerequisites resulting major contribution of food supplies worldwide and almost 70% of fresh water resources have been used in agriculture. Efficiently water usage in irrigation is great interests in water shortage regions. Deficit irrigation, DI, is one of ways leading water savings particularly in those climates. The procedure of DI is allowing certain amount of water deficiency in the crop zone for improvement of water use efficiency of crop. In this paper, some study findings of DI obtained from the field researches were assessed with detail. In accordance of evaluations, upper limit of the water deficiency not resulting notable yield reduction is 25%. Crop critical stages are very important for determination of crop response to water stress. Therefore, water deficiency should be at none critical stages of crops. Development of new crop cultivars that are tolerant to the water deficiency and education of farmers about efficient water use in farm levels are highly advisable especially in water-limited regions.

Key Words: Irrigation, deficit irrigation, sustainable water use, water productivity.

Introduction

Irrigation has great contributions on improvement of agro-production especially at water scant regions (Topak *et al.* 2009). In such regions, current water resources should be well managed for maximum yield. In arid and semi-arid regions such as Konya basin of Turkey, it is almost impossible to get economical yield under none-irrigated conditions (Yavuz *et al.* 2019). Recently, there is large fluctuation in amount and distribution of precipitation e.g. drought conditions have witnessed and even winter cereals are also irrigated in critical time at Konya province of Turkey.

Water shortage is major problem in sustainable agriculture in most parts of the world due to the having arid and semi-arid environments. Groundwater has used plenty due to the lack of surface water resources in such regions. There is urgent effort resulting better water saving in the agriculture. As mentioned above, irrigation has used plenty water supplies so water saving should be started firstly in irrigation. Efficient water management is needed for maximum water productivity. The adequate design, installation and use of modern irrigation systems are very important for maximum profit from those technologies. The other possible solution is application of deficit irrigation, DI, programs with different irrigation systems.

In water scant regions of the world, the main issue is to get maximum benefit from unit water use or water savings especially in agricultural activities. Improvement of water use efficiency crop is prior issue in deficit irrigation practices. Water efficiency, WE, sometimes is used as water productivity, WP, is explained as gain from the unit water use.

Irrigated agriculture is the main support of the food security. Modern irrigation systems are great interests due to causing better water use efficiency since around 70% of fresh water resources have been used in irrigation globally (Shreedhar *et al.* 2015) and greater than 80% in developing countries (FAO, 2002). In that regard, agriculture is maximum water user among the all sectors at present. Yavuz *et al.* (2016) added that groundwater supplies have been used plenty in arid or semi-arid climates due to availability of insufficient surface water resources. Environmental problems can be associated from over water extractions from the groundwater reservoir. Much taking water from such resources may lead to rising of irrigation energy cost such as it has maximum share within all production costs in agro-production in Konya basin of Turkey. In that case, high cost of irrigation energy results low income, sometimes no gain, of farmers. Therefore, water resources must be used efficiently for minimizing irrigation cost as well as sustainable use of water supplies particularly in water scant environments.

DI is possibly one of procedures to increase WP and can be defined as amount of water application lower than full crop water requirements (Chai *et al.* 2016). Fereres and Soriano (2007) also described DI as ‘application of water to the crops that is less than full need’s of crops during growing season. In accordance of their long experiences, DI is viable solution for maximizing the farmer’s income from unit water use in irrigation.

Acar *et al.* (2014) recommended drip irrigation system use, if possible, in deficit irrigation program for field crop production. In accordance of their previous research findings, 25% deficiency in applied water had no significant yield reduction.

In the literature, there are two deficit irrigation techniques namely DI based on the growth stages of plants and partial root drying (PRD). In DI based on the growth stages of plants, full irrigation is performed at the critical stages and water stress is allowed at none-critical stages. In PRD, half of the root systems are full irrigated while the other half part is exposing the dry conditions. PRD is with two types: (1) Alternate Partial Root Drying, APRD: irrigated and partially dried parts of the crop zone are interchanging in subsequent irrigation processes. (2)

Fixed Partial Root Drying, FPRD: half of root areas are fully irrigated while the other half part is exposing permanent dry conditions (Chai *et al.* 2016).

Seymen *et al.* (2019) suggested that one of the most important strategies for using water resources more productive in arid and semi-arid climates is farming of crop cultivars such as pumpkin that are highly adaptable for those types of regions. That crop is also very tolerance to certain amount of water deficiency in root zone.

In water shortage regions, surface irrigation systems are far from the current interests due to the declines in water supplies as well as increasing the impact of climate change. In that case, DI seems realistic solution for improvement water savings. Studies relevant to the DI should focus on accurate determination of critical stages of crops to the water deficiency to obtain maximum benefits in different irrigation techniques (Du *et al.* 2015).

In this study, findings some researches in both Turkey and world relevant to the DI by different irrigation systems were assessed. In that regard, DI applications for common field crops were examined in better understanding of water saving importance for water shortage environments.

Assessment of DI Studies

Yavuz *et al.* (2017) studied deficit irrigation effect on seed yield of pumpkin plant in Konya province of Turkey during the periods 2013-2014. They used irrigation regimes as full irrigation (I_{100}), 75% of I_{100} (I_{75}) 50% of I_{100} (I_{50}), 25% of I_{100} (I_{25}) and 0% of I_{100} (I_o). In assessment of combine two-year, crop water use or evapotranspiration (ETc) varied from 194 mm to 521 mm depending on the irrigation regimes.

Table 1. Applied water, evapotranspiration, yield and water productivities

Years	**Irrigation treatments**	**Applied water (mm)**	**ETc (mm)**	**Seed yield (Kg/ha)**	**Water use efficiency (WUE)**	**Irrigation water use efficiency (IWUE)**
2013	I_{100}	370	521	**860**	0.17	0.23
	I_{75}	298	453	**734**	0.16	0.25
	I_{50}	226	378	715	0.19	0.32
	I_{25}	153	309	612	0.20	0.40
	I_o	33	194	484	**0.25**	**1.47**
2014	I_{100}	336	495	**839**	0.17	0.25
	I_{75}	270	434	**782**	**0.18**	0.29
	I_{50}	204	376	445	0.12	0.22
	I_{25}	138	315	335	0.11	0.24
	I_o	42	209	234	0.11	**0.56**

The seed yields were found as 860 kg/ha and 234 kg/ha for I_{100} and I_o, respectively (Table 1). In examine 2014 yield difference between I_{100} and I_{75} was less than 10% although 25% deficit irrigation was performed at I_{75} treatment. IWUE was found maximum as 1.47 and 0.56 for 2013 and 2014, respectively at I_o treatment. It is obvious that deficit irrigation has positive contribution on both WUE and IWUE. In addition, crop water use is low in pumpkin plant by comparison to the common field crops such as sugar beet and corn in region. In that regard, this plant is very favorable for sustainable use of water resources especially in regions with water scarcity such as Konya province of Turkey.

Yavuz *et al.* (2018) performed field research about growth stages affect on yield and water use of drip irrigated sunflower plant under Middle Anatolian, Turkey. The physical components of soil in research site is clay-loam (CL) having available water capacity, AWC, of 153 mm / 0.90 m. They used irrigation water from the deep well. The oil sunflower variety of *Sirena* was used in research. The irrigation treatments were namely irrigation at only one growth of stages of vegetative development (V), Flowering (F), and Pod Filling (PF) and irrigation in all three stages (VFPF). The VFPF treatment was considered as control and phenologic observations were performed in VFPF treatment (Table 2).

Table 2. Details of Irrigation treatments

Treatments	Plant development stages		
	(V)	(F)	(PF)
VFPF	+	+	+
V	+	-	-
F	-	+	-
PF	-	-	+

+: Irrigation performed
-: None irrigation performed

In result, maximum applied water as 530 mm was obtained from VFPF treatment. The highest crop water use as about 662 mm was found from VFPF treatment. Maximum seed yield was obtained as 4911 kg/ha from irrigation at VFPF treatment. In examine irrigation at only one growth stage; the maximum seed yield of 3060 kg/ha was obtained from irrigation at flowering stage. The WUE and IWUE, varied from 0.85 to 0.46, and from 1.51 to 0.84 kg/m^3, respectively. The maximum WUE and IWUE were found from the F treatment (Table 3).

Table 3. Applied water, Evapotranspiration, water use efficiency, WUE, and irrigation water use efficiency, IWUE

Treatments	Number of irrigation	Applied water (mm)*	Seasonal Evapotranspiration (mm)	Seed yield (kg ha^{-1})	WUE kg m^{-3}	IWUE kg m^{-3}
VFPF	6	530	661.6	4911	0.74	0.93
V	2	164	326.0	2448	0.75	1.49
F	2	202	358.7	3060	0.85	1.51
PF	2	204	375.7	1711	0.46	0.84

Al-Ghobari and Dewidar (2018) conducted 2-year field research about different deficit irrigation program affect on yield response of surface (SDI) and subsurface (SSDI) drip irrigated tomato plant in Saudi Arabia. Soil is sandy (S) and average bulk density of about 1.61 g/cm^3 for 0-60 cm soil depth. They considered following irrigation regimes: Full Irrigation (FI): replenishment of whole water deficiency in root zone depth; FI_{80}: replenishment of 80% water deficiency in root zone depth; FI_{60}: replenishment of 60% water deficiency in root zone depth. In result, they found the maximum fruit yield as 89 t/ha and 75 t/ha from SSDI-FI and SSDI-FI_{80} treatments, respectively (Table 4). They calculated yield response factor, ky, for determination whether tomato plant is tolerant to deficit irrigation or not. The ky values were 0.95 and 1.05 for SSDI and SDI, respectively. Ky value is lower than 1.0 in SSDI so tomato plant is tolerant to the deficit irrigation. In result, deficit irrigation via SSDI system is highly advisable for tomato farming in water scant regions. In Table 4, maximum fruit yields of 70 t/ha and 89 t/ha were obtained from the FI treatment for SDI and SSDI respectively. In water rich region, FI is highly advisable for maximum outcome from unit irrigation area. In water shortage environments, FI_{80} can be suggested for more agro-production with same amount of water application.

Table 4. Fruit yield of tomato for 2015 and 2016 growing seasons

	Irrigation regimes	**Fruit yield (t/ha)**
SDI	FI	70
	FI_{80}	58
	FI_{60}	40
SSDI	FI	89
	FI_{80}	75
	FI_{60}	55

Himanshu *et al.* (2019) performed field study in Texas High Plain to determine the effect of DI on yield under different cotton growth stages in semi-arid climate conditions. They stated that little yield reduction was found water deficiency especially at a) and e) stages. d) stage is very critical so none-deficiency could be done especially in this stage for maximum yield (Table 5).

Table 5. Growth stages of cotton for irrigation scheduling

Cotton Growth Stages	**Days After Planting**	**Water Requirement**
a) Germination and leading emergence	3 to 12	Low
b) Squaring	32 to 51	Low
c) Flower initiation	52 to 76	Moderate
d) Peak bloom	77 to 106	High
e) Cutout, late bloom and ball opening	108 to 132	Moderate

Conclusion

Deficit irrigation is a good alternative for better water saving particularly in water shortage regions. It can be applicable for different crop growth stages since water stress in soil profile can be allowed in none-critical stages. In that regard, precise determination of the critical stages of crops is very important role to play in success of the DI program. This irrigation strategy is friendship for environment since less amount of water has applied by comparison to full irrigation program. Less amount of water application from the groundwater resources means less energy use or minimizing energy cost in whole crop production costs in using the pressurized irrigation systems. It has led to sustainable use of water resources in areas where the water shortage is very serious problems in agriculture. The application of DI requires experiences about irrigation program. Therefore, farmers should be trained about the deficit irrigation management by specialist researchers. In accordance of our analysis, in addition to DI, cultivated lands of low water consuming crops such as sunflower and wheat should be replaced in water poor ecologies.

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