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Effect of Deficit Irrigation on Crop Yield and Water Productivity of Crop, a Synthesis Review

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Abstract

The use of agricultural water is the main among all uses of water. Water scarcity is one of the greatest challenges for crop production. In areas with water shortages, water savings in agricultural production is critical and essential. Improved irrigation management strategies and efficient use of irrigation water are the most cost-effective tools to address water conservation issues. Deficit irrigation is a method to increase water use efficiency, decrease water demand, and improve the yield of crops. In deficit irrigation practice, agricultural water productivity (yield per unit of water used) must be improved. Increasing water productivity is a vital element in improved water management for sustainability, health ecosystem functioning, and food security. Maximizing water productivity is better than land productivity for the dry agriculture system. Improving water productivity is impossible with water stress unless nutrient deficiencies, weeds, and diseases are removed. The general target of this review is to review the effect of deficit irrigation on crop yield and water productivity from the existing literature. The reviewed literature indicated that deficit irrigation approaches improve the yield of maize, onion, tomato and faba bean crops and the efficiency or water productivity of water use.

Keywords: Deficit irrigation • Crops • Water productivity • Water scarcity

Introduction

Water scarcity is the most challenge for crop production. Water scarcity and drought are driven by climate change. Present water shortages are one of the main global problems and are more critical in the future [1]. In areas with water shortages, water saving in agricultural production is critical and essential. Competition for water use for irrigation or agribusiness and other sectors increases as a result of water scarcity and an increase in drought. Agricultural water use is the main one among all water uses [2]. Water scarcity is not always the result of a physical lack of water but also due to inadequate institutional originations. Agriculture is forced to find new approaches to water scarcity by adopting sustainable water use issues. Innovations in water use in agriculture are required both by management and by water-saving practices. These innovations used to save agricultural water are practiced in irrigated agriculture (engineering, agronomical, management and institutional), system modernization, improved irrigation methods, farm irrigation scheduling, and controlled drainage system[3]. The use of limited water resources is more effective by manipulation of water transport through a soil-plant-atmosphere continuum, implementing actual distribution of irrigation water and increased focus on increasing water availability for yield increase [4].

Improved irrigation management and efficient use of irrigation water strategies are the most cost-effective tools to address water protection issues [5]. Deficit irrigation practice is one of the important methods for saving water to crop production. Deficit irrigation is a technique to reduce water demand, increase Water Use Efficiency (WUE), and optimize the yield of crops [6]. It is well-defined as the application of water below the full water requirement of the crop. Reduction in the water applied lowers evapotranspiration and crop growth rates by limiting their principal component, transpiration, and as a consequence, carbon assimilation [7]. Methods of applying deficit irrigation strategies can be regulated deficit irrigation, partial root-zone drying, and sustained deficit irrigation. In deficit irrigation practice, agricultural water productivity (yield per unit of water used) must be improved. It is a key technology because it helps to improve water use efficiency [8]. Deficit irrigation requires precise knowledge of crop response to drought stress for each growth stage since drought tolerance of crops varies by genotype and phonological stages [9]. It requires a detailed analysis and in-depth understanding of how given crops respond to water stress. In addition, it requires a more accurate and real-time allocation of agricultural water resources, especially in arid areas. In deficit irrigation water demand can be reduced, can be diverted for alternative uses, and to quantify the level of deficit irrigation it is first necessary to define the full crop evapotranspiration requirement [10]. Engineering, social, institutional,

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and cultural issues to determine the distribution and management of irrigation water are related to the economy of deficit irrigation.

Increasing water productivity is a vital element in improved water management for sustainability, health ecosystem functioning, and food security [11]. Water productivity is defined as the amount of agricultural output per unit of water depleted, grain yield per unit of water Evapotranspired (ETc), or grain yield per unit of total water input (irrigation plus rainfall) [12]. It is also described as crop yield per cubic meter of water consumption including green water (effective rainfall) and both green water and blue water (diverted water from water systems) for irrigation [13]. Adapted water stress tolerated crops, reducing water losses, and ensuring ideal agronomic conditions for crop production are opportunities for improving crop water productivity. Improving water productivity with water stress is possible if stresses such as nutrient deficiencies, weeds, and diseases are removed. Water productivity can be improved by improving field crop management; such as correct crop timing that will lead to a shorter crop season, proper supply of irrigation water, improved seeds, and correct application of water [14]. Maximization of yield per unit of water (water productivity) and not yield per unit of land (land productivity), is therefore a better strategy for dry farming systems [15]. Water productivity is a useful indicator for quantifying the impact of irrigation scheduling decisions concerning water management. To improve water productivity, techniques such as supplemental irrigation and water harvesting are required to optimize limited water resources. Improving water productivity in agriculture will reduce competition for scarce water resources, mitigate environmental degradation, and enhance food security with less water reward. In this review, the existing information on deficit irrigation and water productivity of crops for major crops is reviewed. As a methodology, different articles, papers from research gates, and journals were reviewed.

Literature Review

Effect of deficit irrigation on crops

Maize: Grain yield of maize and water use efficiency as affected by deficit irrigation. A combination of irrigation methods and deficit irrigation was affects the grain yield of maize crops ($p<0.05$) [16]. The water use efficiency was significantly influenced ($p<0.001$) by deficit irrigation in maize production. Water use efficiency was enhanced by deficit irrigation practices (Table 1).

Irrigation (as ETc)	Yield (kg/ha)	Water use efficiency (Kg/ha)
AFI at 100%	7942.8	1.72
AFI at 85%	7477.3	1.91
AFI at 70%	6657.0	2.06
AFI at 50%	4661.0	2.02
FFI at 100%	5968.3	1.2
FFI at 85%	5349.4	1.36
FFI at 70%	4122.1	1.27
FFI at 50%	3112.4	1.35
CFI at 100%	8412.9	0.912
CFI at 85%	7141.2	0.91
CFI at 70%	6077.7	0.94
CFI at 50%	5611.6	1.21
LSD 0.05	1556.1	0.526
CV	15.2	15.48

Table 1. Grain yield of maize and water use efficiency as affected by deficit irrigation.

Growth stages and yield components of maize were also affected by deficit irrigation. During the developmental stages, mid-season stage, and during all stages for a 75% deficit throughout the growing season, the yields of maize were significantly different at ($p<0.001$) from the rest of the treatment [17] (Table 2).

Treatment	Grain yield (ton/ha)	WUE (ton/ha)$^{*}10^{-3}$
Normal watering	7.11	1.04
75% Deficit in all stages	3.48	1.78
75% at the initial stages	7.03	1.12
75% at the development stages	6.738	1.16

75% at mid-stages	5.494	1.34
75% at late stages	6.986	1.14
50% at the initial stages	7.057	1.09
50% at the development stages	6.991	1.14
50% at mid-stages	6.139	1.23
50% at late stages	7.041	1.11
LSD	191.7	
CV	1.76	

Table 2. Growth stages and yield components of maize were also affected by deficit irrigation.

The Highest grain yield and lowest grain yield were recorded from full irrigation and 60% of full irrigation respectively. The 80% full irrigation had water use efficiency similar to full irrigation ($p<0.05$) and not between 60% of full irrigation (Figure 1) [18].

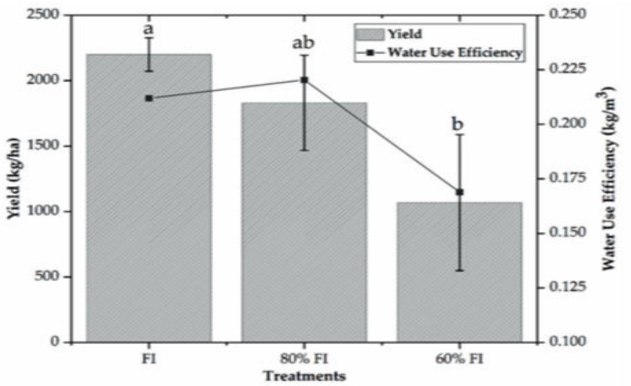

Figure 1. The highest grain yield and lowest grain yield were recorded from full irrigation and 60% of full irrigation respectively.

Onion: Onion crops were affected by deficit irrigation practices subjected to water stress and growing stages.

Application of a minimum amount of water (T_{80} to T_{50}) produces a reduction in onion yield versus applying a higher amount of water (T_{100} and T_{90}) (Table 3) [19].

Treatment						
	T_{100}	T_{90}	T_{80}	T_{70}	T_{60}	T_{50}
Replication 1	34	32	32	26	24	20
Replication 2	36	33	31	27	22	19
Replication 3	33	32	32	23	21	18
Mean	34.4	31.9	31.9	25.2	22.6	18.9
SD	1.11	0.64	0.64	1.7	1.7	1.11
CV	3.2	2	2	6.7	7.5	5.9
ANOVA for Yield						
F calculate		6.25	12.25	62.5	1025	294
F table		7.709	7.709	7.709	7.709	7.709
Comment		insignificant	significant	significant	significant	significant

Table 3. Onion crops were affected by deficit irrigation practices subjected to water stress and growing stages.

Onion crops were affected by deficit irrigation levels and growth stages. Marketable bulb yield was significantly ($p<0.01$) affected by the irrigation level [20]. Higher marketable bulb yields of onion (26.73t/ha) were gained from full irrigation (100% ETc) and followed by 80% and 60% irrigation levels with the value of 25.18 t/ha and 21.98 t/ha respectively. Water productivity was significantly ($p<0.01$) affected due to the application of deficit irrigation in different growth stages but not by irrigation level (Table 4).

Growth stages	Marketable yield (ton/ha)	Water productivity (kg/m^3)
Initial stages	25.99	7.83
Development stages	20.89	7.42
Bulb formation stages	21.52	7.43
Maturation stages	26.55	8.33
DMRT 5%		**
CV	8.15	7.3
Irrigation levels		
100%ETc	26.73	7.81
80%ETc	25.18	7.84
60%ETc	21.98	7.52
40%ETc	21.07	7.84
Mean	23.74	7.75
DMRT 5%	**	NS
CV	3.75	4.19

Table 4. Water productivity was significantly ($p<0.01$) affected due to the application of deficit irrigation in different growth stages but not by irrigation level.

Control treatment produces the highest marketable yield but it is not significantly different from no irrigation in the initial stages with a 75% deficit at development, mid and late stages, and no irrigation at mid stages with and a 75% deficit at initial, development and late stages [21]. No irrigating during a phonological stage and 50% ETc irrigation during the rest of the stages are characterized by poor performance in all yield components. Water productivity increase with the increase of water stress (Table 5).

Treatments		Marketable yield (ton/ha)	Water productivity (Kg/ m^3)
Trt. 1	Full irrigation all growth stages 100%ETc	42.6	7.7
Trt. 2	No irrigation in G_1 and 75% G_2, G_3, and G_4 Irrigation	39.1	10.8
Trt. 3	No irrigation in G_2 and 75% G_1, G_3, and G_4 Irrigation	33.3	10.4
Trt. 4	No irrigation in G_3 and 75% G_1, G_2, and G_4 Irrigation	26.9	10.6
Trt. 5	No irrigation in G_3 and 75% G_1, G_2, and G_4 Irrigation	35.0	13.1
Trt. 6	No irrigation in G_1 and 50% G_2, G_3, and G_4 Irrigation	28.4	12.3
Trt. 7	No irrigation in G_2 and 50% G_1, G_3, and G_4 Irrigation	23.7	11.7
Trt. 8	No irrigation in G_3 and 50% G_1, G_2, and G_4 Irrigation	20.9	12.9
Trt. 9	No irrigation in G_4 and 50% G_1, G_2, and G_3 Irrigation	25.3	14.9

Table 5. Control treatment produces the highest marketable yield.

Tomato: The total yield and marketable yield of tomatoes as affected by deficit irrigation levels mentioned that groundwater with 75% FC and recycled water with 100% FC produced the highest tomato yield relative to other treatments. The production loss (average) due to irrigation deficiency in groundwater treatment with 80% FC, groundwater with 70% FC, and groundwater with 60% FC was 7.7%, 25%, and 45%, respectively, compared to control treatment. Using recycled wastewater as an irrigation source, crop yield, and irrigation water use efficiency can be increased compared to mixed and conventional groundwater for tomato production at the same deficit irrigation level (Table 6) [22].

Treatment	Yield per plant (kg)	
	2017-2018	2018-2019
Groundwater with 100% FC	3.6 ± 0.05	3.98 ± 0.06
Groundwater with 80% FC	3.26 ± 0.03	3.79 ± 0.05
Groundwater with 70% FC	2.60 ± 0.03	3.54 ± 0.05
Groundwater with 60% FC	2.33 ± 0.03	32.93 ± 0.06
Recycled wastewater 100% FC	3.71 ± 0.05	4.05 ± 0.06
Recycled wastewater 80% FC	3.38 ± 0.05	3.94 ± 0.06
Recycled wastewater 70% FC	2.90 ± 0.05	3.72 ± 0.05
Recycled wastewater 60% FC	2.82± 0.05	3.00 ± 0.06
Mixed water 100% FC	3.52 ± 0.066	3.84 ± 0.06
Mixed water 80% FC	3.32 ± 0.06	3.77 ± 0.04
Mixed water 70% FC	2.80 ± 0.02	3.31 ± 0.05
Mixed water 60% FC	2.41 ± 0.03	2.96 ± 0.05

Table 6. The total yield and marketable yield of tomatoes as affected by deficit irrigation levels.

Tomato yield was affected by soil moisture level significantly ($p<0.001$). Lower moisture stress during fruit maturity stages than that applied during vegetative growth, fruit set, and fruit growing stages (Table 7).

Factors	Yield (kg/plant)	WUE (Kg/m^3)
Treatment stages	-	-
Vegetative growth stages	0.96	24.33
Flowering and fruit setting stages	0.94	23.64
Early fruit growth stages	0.95	23.78
Fruit development stages	0.90	23.16
Fruit maturity stages	0.81	20.28
Water level	-	-
60% FC-70% FC	0.78	21.37
70% FC-80% FC	0.93	23.39
80% FC-90% FC	1.02	24.23
Potassium fertilizer rate	ns	-
0 g K_2O	0.9	28.03
0.46 g K_2O	0.95	24.04
0.92 g K_2O	0.89	22.95
Stages* Water level	-	-
Stages* Potassium fertilizer rate	-	-
Water level * Potassium fertilizer rate	ns	ns
Stages *Water level * Potassium fertilizer rate	ns	ns
Note: ns- non significant		

Table 7. Tomato yield was affected by soil moisture level significantly ($p<0.001$).

The yield of tomatoes was reduced by too much water application but a higher yield was gained from zero deficit [23]. Applied irrigation water affects the marketable tomatoes yield.

A deficit irrigation strategy applied at 85%, 70% of crop water requirement gives relatively better fruit yield than 50% of crop water requirement (Table 8).

Treatment	Marketable yield (kg/ha)	Water use efficiency (kg/m^3)
Irrigation at 100% ETc	31.9	8.2
Irrigation at 85% ETc	25.0	12
Irrigation at 70% ETc	23.4	10.9
Irrigation at 50% ETc	22.8	11a
CV	14.9	19.1
LSD(0.05)	3.2	1.8

Table 8. Applied irrigation water affects the marketable tomatoes yield.

Feba bean: Feba bean dry grain yields were affected significantly by moisture stress [24]. They suggest that 50% full irrigation during the vegetative growth stages resulted in the highest dry grain yield. Rain-fed and 50% of full irrigation produce the highest and lowest water productivity during vegetative growth stages. The application of deficit irrigation using 50% during the vegetative growth stages saves 17% of the water quantity compared to deficit irrigation (Table 9).

Deficit irrigation strategies	Dry grain yield g/plant	Crop water requirement (kg/m^3)
Rainfed only	44.4	4.2
Full irrigation	101.6	2.9
75% during V.G and FI at rest of growing period	101.8	3.1
50% during V.G and FI at rest of growing period	105.7	3.6
25% during V.G and FI at rest of growing period	86.6	3.3
0% during V.G and FI at rest of growing period	66.6	2.9

Table 9. The application of deficit irrigation using 50% during the vegetative growth stages saves 17% of the water quantity compared to deficit irrigation.

Discussion

The growth and yield parameters of the Faba bean plants affected by different levels of irrigation water could be organized in the following descending order, 100%>80%>60% of the irrigation water requirement, respectively [25]. 100% of the irrigation requirement of the Faba bean gave the highest values of growth and yield parameters, while the lowest values were more pronounced when 60% of the irrigation requirement was applied. The increase in irrigation water levels is seen to significantly decrease water use efficiency. The effect of different levels of irrigation water on the efficiency of water use can be arranged in descending order as 60%>80%>100%. In general, irrigation plays a vital role in tomato yield formation, and the effect varies from stage to stage (Figures 2 and 3).

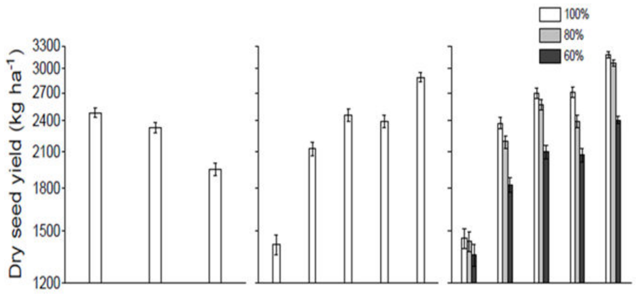

Figure 2. The growth and yield parameters of the Faba bean plants affected by different levels of irrigation water.

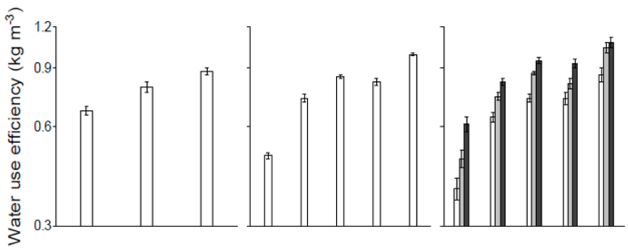

Figure 3. The increase in irrigation water levels is seen to significantly decrease water use efficiency

Conclusion

The overall aim of this review is to assess the effect of deficit irrigation on crop yield and water productivity from the existing literature. All reviewed literature above indicated that deficit irrigation approaches, improve the yield of maize, onion, tomato, and faba bean crops and the efficiency of water use. It can lead to certain yield loss which was compensated by saved water. Deficit irrigation can be used as a tactical measure to reduce irrigation water use when supply is limited. Production cost and leaching of nutrients are reduced by using deficit irrigation practices. In the water limited area, deficit irrigation is important to improve water productivity. The main advantage of deficit irrigation was it maximizes water productivity. In most of the reviewed literature, the permit for 60%-100% evapotranspiration of the irrigation level supply under deficit irrigation should be most important than the high level of water stress depending on the sensitivity of the crops to water stress. The interaction of growth stages and irrigation levels also affects crop yields and water productivity. The level of irrigation positively influenced the yield of the crops, with the yield of the crops decreasing as the level of water deficit increased.

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