Phyton-International Journal of Experimental Botany
DOI:10.32604/phyton.2020.09142
Article

Sub-Surface Drip Irrigation in Associated with H_2O_2 Improved the Productivity of Maize under Clay-Rich Soil of Adana, Turkey

Alhan Sariyev[1], Celaleddin Barutcular[2,*], Mert Acar[1], Akbar Hossain[3] and Ayman EL Sabagh[2,4,5,*]

[1]Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Cukurova University, Adana, 01330, Turkey
[2]Department of Field Crops, Faculty of Agriculture, Cukurova University, Adana, 01330, Turkey
[3]Bangladesh Wheat and Maize Research Institute, Dinajpur, 5200, Bangladesh
[4]Department of Field Crops, Faculty of Agriculture, Siirt University, Kezer Campus, Siirt, 56100, Turkey
[5]Department of Agronomy, Faculty of Agriculture, Kafrelsheikh University, Kafrelsheikh, 33156, Egypt
*Corresponding Authors: Celaleddin Barutcular. Email: cebar@cu.edu.tr; Ayman EL Sabagh. Email: ayman.elsabagh@agr.kfs.edu.eg
Received: 14 November 2019; Accepted: 03 January 2020

Abstract: Maize being sub-tropical crop is sensitive to water deficit during the early growth stages; particularly clay-rich soil, due to the compaction of the soil. It is well-documented that potential sub-surface drip irrigation (SDI) (Full irrigation; SDIFull (100% field capacity (FC)), Deficit irrigation; SDIDeficit (70% FC)) improves water use efficiency, which leads to increased crop productivity; since it has a constraint that SDI excludes soil air around the root-zone during irrigation events, which alter the root function and crop performance. Additionally, in clay-rich soils, the root system of plants generally suffers the limitation of oxygen, particularly the temporal hypoxia, and occasionally from root anoxia; while SDI system accomplishes with the aerating stream of irrigation in the rhizosphere could provide oxygen root environment. The oxygen can be introduced into the irrigation stream of SDI through two ways: the venturi principle, or by using solutions of hydrogen peroxide through the air injection system. Therefore, the application of hydrogen peroxide (H_2O_2; HP) can mitigate the adverse effect of soil compactness and also lead to improving the growth, yield and yield attributes of maize in clay-rich soil. Considering the burning issue, a field study was conducted in consecutive two seasons of 2017 and 2018; where hybrid maize was cultivated as a second crop, to evaluate the effect of liquid-injection of H_2O_2 (HP) into the irrigation stream of SDI on the performance of maize in a clay-rich soil field of Adana, Turkey. When soil water content decreased in 50% of available water, irrigation was performed. The amount of water applied to reach the soil water content to the field capacity is SDIFull (100% FC) and 70% FC of this water is SDIDeficit (70% FC). In the irrigation program, hydrogen peroxide (HP) was applied at intervals of 7 days on average according to available water with and without HP: SDIFull (100% FC) + 0 ppm HP with full SDI irrigation; SDIFull (100% FC) + 250 ppm HP with deficit SDI irrigation; SDIDeficit (70% FC) + 0 ppm HP, SDIDeficit (70% FC) + 250 ppm HP and SDIDeficit (70% FC) + 500 ppm HP. Deficit irrigation (SDIDeficit (70% FC)) program was started from tasseling stage and continued up to the physiological maturity stage with sub-soil drip irrigation. H_2O_2 was applied 3 times during the growing season. Two years' results revealed that the liquid-injection of H_2O_2 into the irrigation stream of SDI improved the growth and yield-related attributes and grain yield of maize. Based on the obtained results, during the extreme climatic condition in the year 2017, SDIFull (100% FC) + 250 ppm HP was more effective than SDIFull (100% FC) + 0 ppm HP on all traits for relative to full irrigation. While, during the favourable climatic condition in the 2018 season, SDIFull (100% FC) + 250 ppm HP was more effective than full irrigation with SDIFull (100% FC) + 0 ppm HP for the grain yield, grains, and SPAD value. Accordingly, the most effective treatment was SDIFull (100% FC) + 250 ppm HP, as it gave the highest growth and yield-related attributes and grain yield of maize followed by SDIDeficit (70% FC) + 250 ppm HP. Therefore, SDIFull with 250 ppm H_2O_2 using as liquid-injection may be recommended to mitigate the adverse effect of soil compactness particularly water-deficit stress in clay-rich soil for the sustainability of maize production.

Keywords: Sub-surface drip irrigation; water-deficit stress; H_2O_2; air injection; maize

1 Introduction

Maize is an important food crop in the world [1–3]. It is a warm-season crop and grown under extremely divergent climatic environments ranging from tropical to temperate [4,5]. Maize might be successfully grown in locations where the night temperature does not go below 15°C as crop stops growing below this rate [6]. As a C_4 plant, maize is able to grow diverse agro-climatic zones extending from sub-tropical to cooler temperate regions. However, enough supply of soil water is essential for the growth and development of the maize [5]. Since it can survive under various abiotic stress than other crops as a C_4 crop; however, excess or deficit soil moisture stress [5,7–9] due to erratic rainfall as well as a heavy soil texture are the most important constraints for the sustainability of maize production in worldwide [10]. Additionally, in clay-rich soils, due to soil compactness, or when sub-surface drainage is impeded, an inadequate oxygen rate in the root zone could adversely impact on the biological functioning of plants including maize [11,12]. Therefore, to ensure adequate yield and grain quality, proper irrigation management is very essential, particularly in clay-rich soils.

In recent years, sub-surface drip irrigation (SDI) systems have increased substantially. The SDI is a potential irrigation system for the sustainability of crop production systems through improving the water use efficiency than other forms of irrigation systems; particularly in the soils where water is deficit/limited [13]. Since, SDI has a negative impact around the crop rhizosphere (root-zone of crops) through disregarding the soil air (oxygen in the root-zone); which is responsible to reduce root function, finally alter the physio-biochemical process of the plant. Besides these, lack of soil oxygen content in the root-zone leads to damage to the root tissue, altering the growth and development of vegetative and reproductive organs, changes in plant internal cell structure [12,14–16]. Positively, oxygation in the root-zone assures the ideal root function, also provides molecular oxygen for aerobic metabolism of microorganisms [12,17,18] availability of nutrients and improves water use efficiency that ultimately leads to boost the growth and development of plant process finally yield [19]. However, to ensure the oxygen readiness in SDI system and also to improve the water use efficiency, SDI system should be accomplished with the oxygen (aerating) in the rhizosphere of the crop.

For providing available oxygen around the crop roots under the SDI system, it is important to accomplish the oxygen with the stream of applied SDI water which suffers from the progressive hypoxia, and periodically from the anoxia. Earlier studies recommended that the oxygen can be introduced into the irrigation stream of SDI through the way of the venturi principle, or by using solutions of HP through the air injection system [19,20]. The H_2O_2 (HP) has been effectively used as an oxygen source for in situ remediations in a saturated aquifer [12,17]. Therefore, to ensure the molecular oxygen in the crop root-zone of clay-rich soil under SDI system, a field study was conducted in a clay-rich soil field of Adana, Turkey to evaluate the effect of liquid-injection of H_2O_2 (HP) into the irrigation stream of sub-surface drip irrigation (SDI) to mitigate the adverse effect of soil compactness particularly water-deficit stress in clay-rich soil for the sustainability of maize production.

2 Materials and Methods

2.1 Location of the Study

The present research was conducted in consecutive two years during the year 2017 and 2018 as hybrid maize was grown as a second crop in the experimental field trial area of Cukurova University, Adana, Turkey.

2.2 The Soil of the Experimental Field

The physical and chemical properties of experimental soils are presented in Tab. 1.

Table 1: Some characteristics of the study area soil at 0–30 cm depth

Sand	Silt	Clay	pH	EC (μmhos.cm^{-1})	$CaCO_3$ (g kg^{-1})	Organic Matter	Field Capacity	Permanent Wilting Point
g kg^{-1}						%		
363	267	370	7.6	144	359	1.2	33.4	23.3

EC: Electrical conductivity, $CaCO_3$: Lime

2.3 Experimental Treatments and Design

Hybrid maize ('72May80') was sown on July 7, 2017, and on May 28, 2018, in the first and the second year respectively. Inter-row spacing was between 70 cm (row to row) and 17 cm (plant to plant). Each plot was established with 10 m long and 6 rows. Irrigation was performed when the soil water content was decreased by 50% of available water in the research area. Soil water content was monitored by TDR (Time Domain Reflectometry, Soil Moisture 6050X3K1B-MiniTrase Kit) during the growing season. The amount of water applied to reach the soil water content to the field capacity (FC) is SDIFull (100% FC) and 70% FC of this water is SDIDeficit (70% FC). In the irrigation program, hydrogen peroxide (H_2O_2; (HP)) was applied at 7 days intervals on an average according to available water with and without HP: with full SDI irrigation, SDIFull (100% FC) + 0 ppm HP and SDIFull (100% FC) + 250 ppm HP; with deficit SDI irrigation, SDIDeficit (70% FC) + 0 ppm HP, SDIDeficit (70% FC) + 250 ppm HP and SDIDeficit (70% FC) + 500 ppm HP. HP was applied 3 times during the growing season. Deficit irrigation (SDIDeficit (70% FC)) program was started from tasseling stage and continued up to the physiological maturity stage with sub-soil drip irrigation. All treatments were arranged in a randomized completely block design with four replications.

2.4 Fertilizer Management

The fertilizers N-P-K were applied at 75 kg ha^{-1} and 45 kg N ha^{-1} (Urea, 45%) were applied at the sowing time and an additional 13 kg of N (Ammonium Sulphate, 21%) was given per hectare at the V6-growth stage.

2.5 Data Collection and Procedure

Data on the plant biomass (g m^{-2}), grain weight (mg), grains m^{-2} (no.) and test weight and harvest index (HI %), were recorded randomly for each plot. Harvested grain samples were cleaned to record grain weight (mg), grains m^{-2} (no.), single grain weight (GW; mg) and grain yield (GY; t ha^{-1}). The biological yield (BY) was estimated as the total ground dry matter of each plot and converted into t ha^{-1}. Harvest index (HI%) was determined as a ratio of grain yield to biological yield and was expressed in the percentage. At the time of harvesting, the parameters were determined after the separation of kernels and measuring the humidity content of grains by grain moisture meter (Model: Dicky John). The grain weight includes a moisture content of 12%.

The chlorophyll content, hereafter referred to as SPAD value, was measured on 10 randomly selected plants in each plot, using a portable chlorophyll meter (Minolta SPAD-502, Osaka, Japan). Grain yield was determined based on the harvested plot in all trials. Grain yields were obtained after physiological ripening from one square meter in the two middle rows of each plot.

2.6 Statistical Analysis

Data were analyzed by using 'analysis of variance' (ANOVA) with the help of computer package MSTAT-C and the mean differences among the treatments were adjusted with the Least Significant Test ($LSD_{0.05}$) [21].

3 Results and Discussion

The results indicated that application of sub-soil irrigation with injecting HP increased the yield-related properties and grain yield of maize (Tab. 2). The positive effect of the addition of HP to the irrigation water, even if under full irrigation was performed in maize, was caused by an increased in the number of seeds. The most effective treatments were SDIFull (100% FC%) + 250 ppm HP and SDIFull (100% FC%) + 0 ppm HP as these treatments gave the highest and statistically similar growth parameters followed by SDIDeficit (70% FC) + 250 ppm HP in both years (Tab. 2). The findings indicated that the growth of plants could be improved by the application of HP at the injury level. The study also depicted that the application of HP, improved the SPAD and yield-related characteristics of maize which was visible through improved chlorophyll contents, increased grain weight, more grain number and increased yield.

The results of the present study also supported by the findings of Logan et al. [22] and Neill et al. [23], who also found that application of HP improved the seedling growth, morphology, biochemical and yield-related traits and grain yield of maize under stress condition (low-temperature stress), due to the amelioration of the chilling injury. Neill et al. [23] revealed that HP at low rate as a signal molecule in cells in plants.

Data presented in Fig. 1, demonstrated that SDI_{full} irrigation with 250 ppm HP treatments caused a significant increase in yield of crop relative to control plants. Under adverse climatic condition (in 2017 season) 250 ppm HP was more effected to recover to water stress reduction on all traits for relative to SDI_{full} irrigation. At the same time, 250 ppm HP was positively influenced by full irrigation. While, under normal climate condition (in 2018 season), only SDI_{full} irrigation with 250 ppm HP was positively recovered all traits than deficit irrigation with HP application for relative to full irrigation. It is due to the increasing the oxygen content through the injection of HP in the SDI system improved the root metabolism which leads to increase the most of traits. The assumption is also supported by earlier findings, since for different crops: Goorahoo et al. [24] injecting air into SDI system improved the oxygen concentration in the rhizosphere of pepper, and also increased the N-fixation, which lead to increase fruit weight about 39%. Similarly, Bhattarai et al. [19] found that injecting air into SDI system under clay-rich soils improved the growth, fruit weight and also water productivity of several field crops such as soybean (*Glycine max* (L.) Merr.), cotton (*Gossypium hirsutum* L.) and zucchini (*Cucurbita pepo* L. subsp. *pepo*).

This study also predicted that $SDI_{Deficit}$ (70% FC) + 250 ppm HP, improved grain yield in maize (Fig. 2). In the 2017, under extreme climatic condition, $SDI_{Deficit}$ (70% FC) + 250 ppm HP ppm was more effective than $SDI_{Deficit}$ (75% FC) + 500 ppm HP on all traits for relative to deficit irrigation ($SDI_{Deficit}$ (70% FC) +

Table 2: Yield attributes of maize are influenced by the application of H_2O_2 with sub-surface drip irrigation stream in clay-rich soil in Adana, Turkey

SDI × HP	Biomass (gm^{-2})	Grain yield (gm^{-2})	Harvest index (%)	Grain weight (mg)	Grains (no. m^{-2})	Test weight (kg hL^{-1})	SPAD value
	In the year 2017						
$SDI_{Deficit}$ (70% FC) + 0 ppm HP	1386c	644c	45.0b	237b	2708b	68.3	50.7
$SDI_{Deficit}$ (70% FC) + 500 ppm HP	1710b	973b	56.9a	266a	3667a	69.5	52.7
$SDI_{Deficit}$ (70% FC) + 250 ppm HP	1894ab	1127ab	59.5a	268a	4234a	67.8	54.5
SDI_{Full} (100% FC) + 250 ppm HP	2043a	1200a	58.8a	277a	4328a	65.6	54.4
SDI_{Full} (100% FC) + 0 ppm HP	1991a	1115ab	56.0a	272a	4105a	66.5	52.5
$LSD_{0.05}$	243.6	200.1	7.51	23.9	911.1	NS	NS
	In the year 2018						
$SDI_{Deficit}$ (70% FC) + 0 ppm HP	2106a	631e	30.0bc	221e	2871c	68.9	39.7d
$SDI_{Deficit}$ (70% FC) + 500 ppm HP	2506a	677c	27.1c	231d	2933c	69.1	48.8b
$SDI_{Deficit}$ (70% FC) + 250 ppm HP	2040a	653d	32.1b	236c	2774c	68.1	44.3c
SDI_{Full} (100% FC) + 250 ppm HP	2611b	1035a	39.7a	253b	4115a	71.3	55.2a
SDI_{Full} (100% FC) + 0 ppm HP	2603b	974b	37.4a	274a	3554b	70.1	54.1a
$LSD_{0.05}$	206.0	6.5	3.29	4.09	421.3	NS	1.36

SDI, Sub-surface drip irrigation; $SDI_{Deficit}$, Deficit irrigation under sub-surface drip irrigation system; SDI_{Full}, Full irrigation under sub-surface drip irrigation system; HP, H_2O_2; NS, non-significant.
$SDI_{Full\ irrigation}$ (100% FC) + 0 ppm HP with full SDI irrigation; $SDI_{Full\ irrigation}$ (100% FC) + 250 ppm HP with deficit SDI irrigation; $SDI_{Deficit\ irrigation}$ (70% FC) + 0 ppm HP, $SDI_{Deficit\ irrigation}$ (70% FC) + 250 ppm HP and $SDI_{Deficit\ irrigation}$ (70% FC) + 500 ppm HP.

0 ppm HP). While, under normal climatic condition (in 2018 season), $SDI_{Deficit}$ (70% FC) + 500 ppm HP was more effective than $SDI_{Deficit}$ (70% FC) + 250 ppm HP on the biomass, grain yield, grains and SPAD value for relative to deficit irrigation ($SDI_{Deficit}$ (70% FC) + 0 ppm HP).

Earlier, it is stated that activities of antioxidant enzymes increase with application of HP [25], in several cereal crops. Several new reports also stated that antioxidant activity was improved with the application of HP at a low rate under stressful environment [26]. Hybrid maize was irrigated with added HP was improved to grain yield. These positive effects were similar to seed priming or foliar sprayed with HP [27]. The injecting HP through the irrigation system into a clay-rich soil, which was saturated or at field capacity, improved the biomass and yield of several crops after treatments of 1, 3, and 4 months, respectively [19].

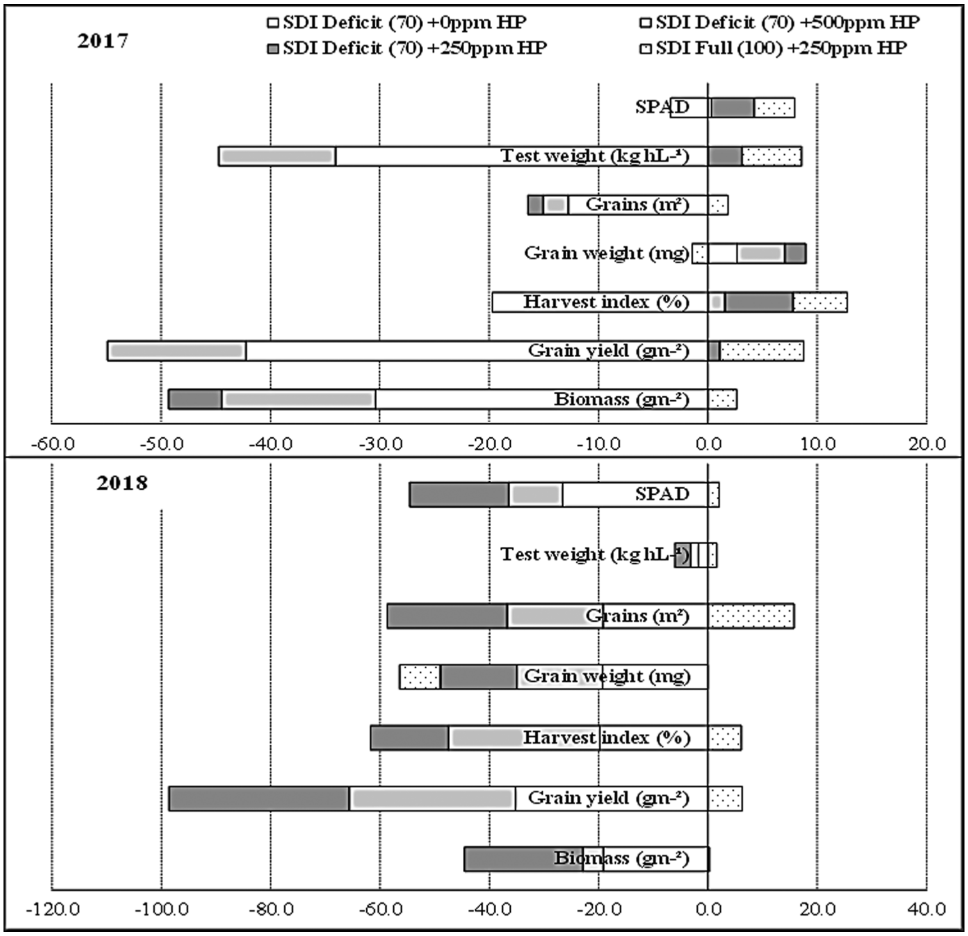

Figure 1: Increased/decreased of different parameters of maize (%) due to both full and deficit SDI irrigation in combination with different levels of HP as compared to control treatment (SDI Full (100% FC) + 0 ppm HP). SDI, Sub-surface drip irrigation; $SDI_{Deficit}$, Deficit irrigation under sub-surface drip irrigation system; SDI_{Full}, Full irrigation under sub-surface drip irrigation system; HP, H_2O_2; $SDI_{Full\ irrigation}$ (100% FC) + 0 ppm HP with full SDI irrigation; $SDI_{Full\ irrigation}$ (100% FC) + 250 ppm HP with deficit SDI irrigation; $SDI_{Deficit\ irrigation}$ (70% FC) + 0 ppm HP, $SDI_{Deficit\ irrigation}$ (70% FC) + 250 ppm HP and $SDI_{Deficit\ irrigation}$ (70% FC) + 500 ppm HP

Moreover, maximum grain yield and grain m^2 were recorded when SDI_{Full} (100% FC) + 250 ppm HP were applied as, while it was minimum in grain weight (Fig. 3). It is well documented that applied HP improved yield attributes under stressful conditions. Under drastic climatic condition (in 2017 season) SDI_{Full} (100% FC) + 250 ppm HP was more effective than SDI_{Full} (100% FC) + 0 ppm HP on all traits for relative to full irrigation (SDI_{Full} (100% FC) + 0 ppm HP). While, under normal climatic condition (in 2018 season) SDI_{Full} (100% FC) + 250 ppm HP was more effective than SDI_{Full} (100% FC) + 0 ppm HP on the grain yield, grains and SPAD value for relative to full irrigation (SDI_{Full} (100% FC) + 0 ppm HP).

Similar results were also identified for maize, where a significant improvement of biomass was found due to HP treatment to soil exhibiting excellent structure and adequate the levels of irrigation [28,29]. Whereas the fine-textured soils have a greater water retention capacity which leads to continuous anaerobic conditions in the root zone [11,29].

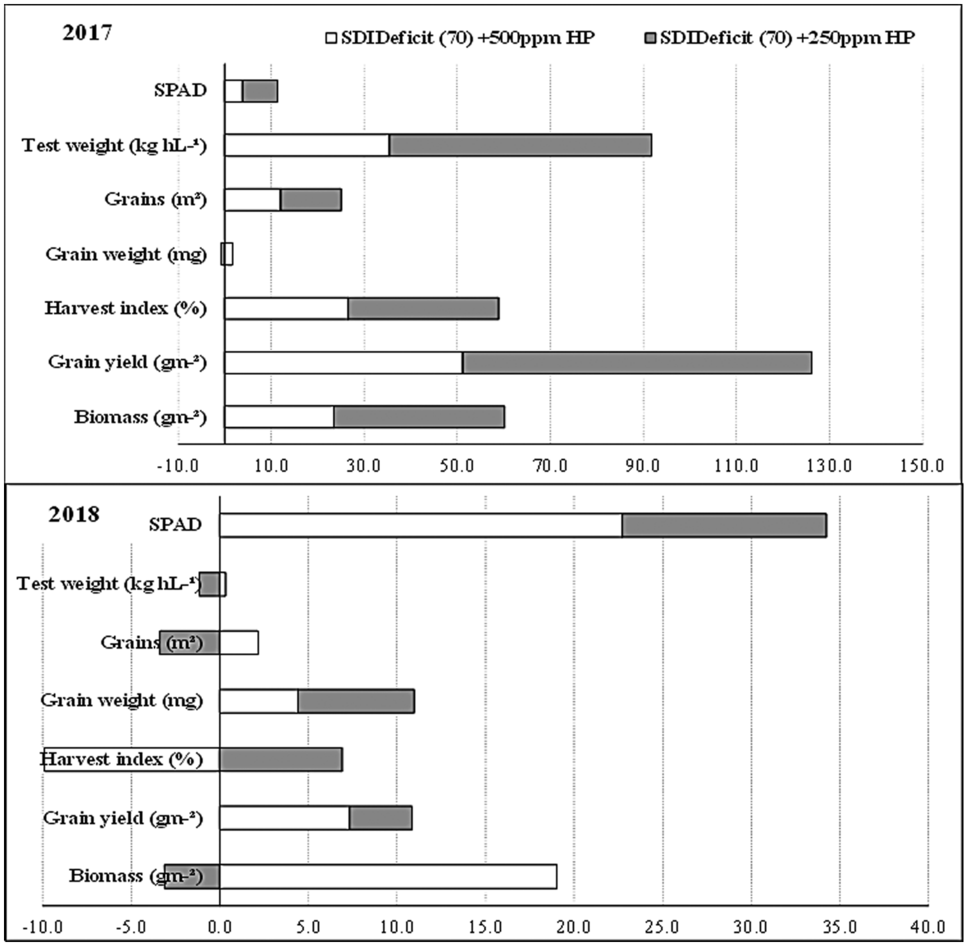

Figure 2: Increased/decreased of different parameters of maize (%) due to Deficit SDI in combination with different levels of HP as compared with control ($SDI_{Deficit}$ (70% FC) + 250 ppm HP). SDI, Sub-surface drip irrigation; $SDI_{Deficit}$, Deficit irrigation under sub-surface drip irrigation system; SDI_{Full}, Full irrigation under sub-surface drip irrigation system; HP, H_2O_2; NS, non-significant. $SDI_{Full\ irrigation}$ (100% FC) + 0 ppm HP with full SDI irrigation; $SDI_{Full\ irrigation}$ (100% FC) + 250 ppm HP with deficit SDI irrigation; $SDI_{Deficit\ irrigation}$ (70% FC) + 0 ppm HP, $SDI_{Deficit\ irrigation}$ (70% FC) + 250 ppm HP and $SDI_{Deficit\ irrigation}$ (70% FC) + 500 ppm HP

Several researchers [12,30] revealed that injecting HP into the soil through irrigation system, significantly increased the water use efficiency, finally growth and development of plants; whereas, plants in low-oxygen soils exhibit a decrease in the xylem/phloem ratio which ultimately alters the physiological process of the plant [12,16,31] found that soil injection HP through SDI system increased the oxygen content in the crop rhizosphere which leads to increase xylem/phloem ratio in plants.

4 Conclusion

Of special interest in the potential application of this injection of HP trough the SDI system, mitigated the adversities of water deficit stress of maize by improving growth. These positive changes eventually resulted in improved maize yield. Injecting different levels of HP through the SDI system into the experimental soil (clay-rich soil) with low air content, significantly improved the yield and yield attributes and also water use efficiency of maize under clay-rich soil. During the adverse condition

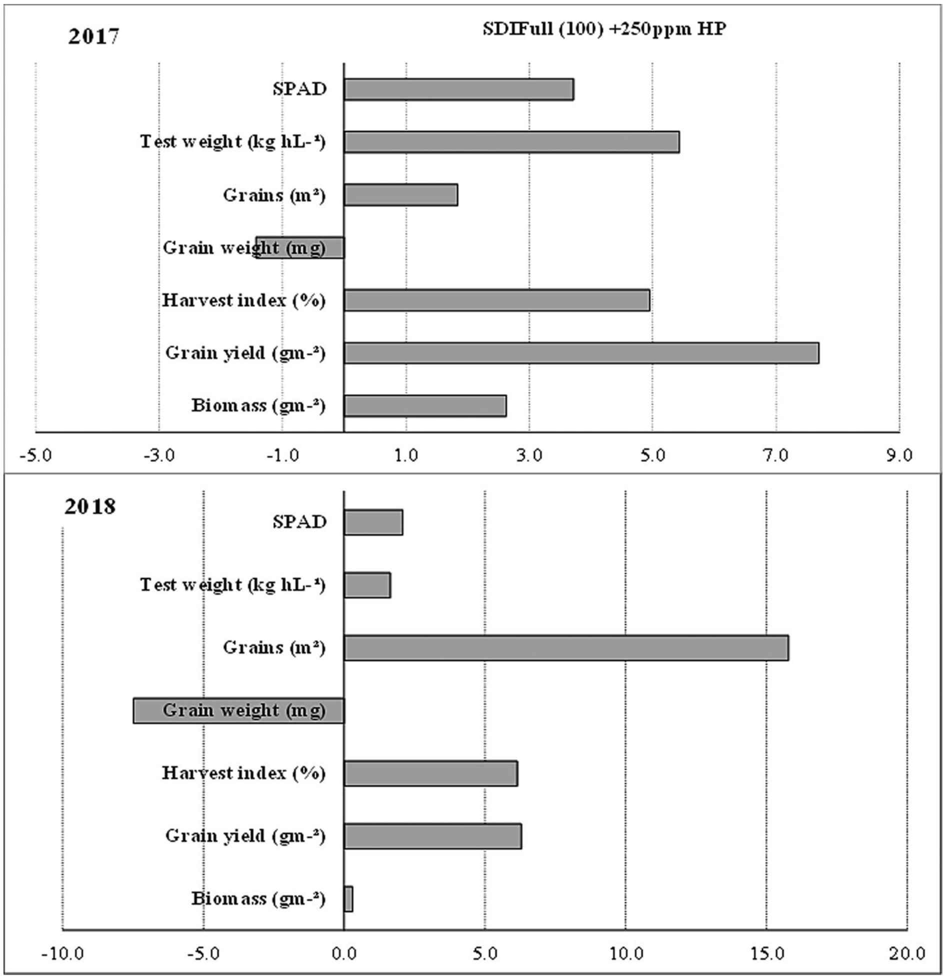

Figure 3: Increased/decreased of different parameters of maize (%) due to the application of full SDI in combination with 250 ppm HP. SDI, Sub-surface drip irrigation; $SDI_{Deficit}$, Deficit irrigation under sub-surface drip irrigation system; SDI_{Full}, Full irrigation under sub-surface drip irrigation system; HP, H_2O_2. $SDI_{Full\ irrigation}$ (100% FC) + 0 ppm HP with full SDI irrigation; $SDI_{Full\ irrigation}$ (100% FC) + 250 ppm HP with deficit SDI irrigation; $SDI_{Deficit\ irrigation}$ (70% FC) + 0 ppm HP, $SDI_{Deficit\ irrigation}$ (70% FC) + 250 ppm HP and $SDI_{Deficit\ irrigation}$ (70% FC) + 500 ppm HP

(in 2017 season) SDI_{Full} (100% FC) + 250 ppm HP was more effective than SDI_{Full} (100% FC) + 0 ppm HP on all traits for relative to full irrigation (SDI_{Full} (100% FC) + 0 ppm HP). While, during the normal climatic condition (in 2018 season) SDI_{Full} (100% FC) + 250 ppm HP was more effective than SDI_{Full} (100% FC) + 0 ppm HP on the grain yield, grains and SPAD value for relative to full irrigation (SDI_{Full} (100% FC) + 0 ppm HP). Thus, the improvement in growth and productivity of crop through injecting HP through the SDI system into clay-rich soils might have great potential as a method for improving soil oxygen content in clay-rich soil.

Acknowledgement: The authors thank for the financial support offered by the Research Foundation of the Cukurova University, Adana, Turkey.

Funding Statement: This publication was supported by Award Number (BAP, FÖA-2016-6152) from the Research Foundation of the Cukurova University, Adana, Turkey and Principal Investigator, Prof. Dr. Alhan Sariyev "https://bap.cu.edu.tr/."

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

1. EL Sabagh, A., Barutçular, C., Hossain, A., Islam, M. S. (2018). Response of maize hybrids to drought tolerance indices in relation to grain weight. *Fresenius Environmental Bulletin, 27(4),* 2476–2482.
2. Abdelaal, K. A., Hafez, Y. M., El Sabagh, A., Saneoka, H. (2017). Ameliorative effects of Abscisic acid and yeast on morpho-physiological and yield characteristics of maize plant (*Zea mays* L.) under water deficit conditions. *Fresenius Environmental Bulletin, 26(12),* 7372–7383.
3. Murad, K. F. I., Hossain, A., Fakir, O. A., Biswas, S. K., Sarker, K. K. et al. (2018). Conjunctive use of saline and fresh water increases the productivity of maize in saline coastal region of Bangladesh. *Agricultural Water Management, 204,* 262–270. DOI 10.1016/j.agwat.2018.04.019.
4. Ahmad, I., Basra, S. M. A., Wahid, A. (2014). Exogenous application of ascorbic acid, salicylic acid and hydrogen peroxide improves the productivity of hybrid maize at low temperature stress. *International Journal of Agriculture and Biology, 16,* 825–830.
5. Molla, M. S. H., Nakasathien, S., Ali, M. A., Khan, A. S. M. M. R., Alam, M. R. et al. (2019). Influence of nitrogen application on dry biomass allocation and translocation in two maize varieties under short pre-anthesis and prolonged bracketing flowering periods of drought. *Archives of Agronomy and Soil Science, 65(7),* 928–944. DOI 10.1080/03650340.2018.1538557.
6. Agrisnet (2012). Maize: climatic requirement. *http://sikkimagrisnet.org/General/en/Maize_Climatic_Requirement.aspx*.
7. Majid, M. A., Islam, M. S., Sabagh, E. L., Hasan, A., Barutcular, M. K. et al. (2017). Evaluation of growth and yield traits in corn under irrigation regimes in sub-tropical climate. *Journal of Experimental Biology and Agricultural Sciences, 5(2),* 143–150. DOI 10.18006/2017.5(2).143.150.
8. EL Sabagh, A., Hossain, A., Barutçular, C., Khaled, A. A. A., Fahad, S. et al. (2018b). Sustainable maize (*Zea mays* L.) production under drought stress by understanding its adverse effect, survival mechanism and drought tolerance indices. *Journal of Experimental Biology and Agricultural Sciences, 6(2),* 282–295. DOI 10.18006/2018.6(2).282.295.
9. EL Sabagh, A., Barutcular, C., Islam, M. S. (2017). Relationships between stomatal conductance and yield under deficit irrigation in maize (*Zea mays* L.). *Journal of Experimental Biology and Agricultural Sciences, 5,* 15–21. DOI 10.18006/2017.5(Spl-1-SAFSAW).S15.S32.
10. Lone, A. A., Warsi, M. Z. K. (2009). Response of maize (Zea mays L). To excess soil moisture (esm) tolerance at different stages of life cycle. *Botany Research International, 2(3),* 211–217.
11. Letey, J. (1961). Aeration, compaction and drainage. *California Turfgrass Culture, 11,* 17–21.
12. Gil, M. P. M., Ferreyra, E. R., Barrera, M. C., Zúñiga, E. C., Gurovich, R. L. (2009). Effect of injecting hydrogen peroxide into heavy clay loam soil on plant water status, net CO_2 assimilation, biomass, and vascular anatomy of avocado trees. *Chilean Journal of Agricultural Research, 69(1),* 97–106.
13. Sarker, K. K., Hossain, A., Murad, K. F. I., Biswas, S. K., Akter, F. et al. (2019). Development and evaluation of an emitter with a low-pressure drip-irrigation system for sustainable eggplant production. *AgriEngineering, 1(3),* 376–390. DOI 10.3390/agriengineering1030028.
14. Schaffer, B., Anderson, P. C., Ploetz, R. C. (1992). Responses of fruit trees to flooding. *Horticultural Reviews, 13,* 257–313.
15. Drew, M. C. (1997). Oxygen deficiency and root metabolism: injury and acclimation under hypoxia and anoxia. *Annual Review of Plant Physiology and Plant Molecular Biology, 48(1),* 223–250. DOI 10.1146/annurev.arplant.48.1.223.
16. Kozlowski, T. T. (1997). Response of woody plants to flooding and salinity. *Tree Physiology. Monograph, 1,* 1–29.

17. Zappi, M., White, K., Hwang, H. M., Bajpai, R., Qasim, M. (2000). The fate of hydrogen peroxide as an oxygen source for bioremediation activities within saturated aquifer systems. *Journal of the Air & Waste Management Association, 50(10),* 1818–1830. DOI 10.1080/10473289.2000.10464207.
18. Petigara, B., Blough, N., Mignerey, A. (2002). Mechanism of hydrogen peroxide decomposition in soils. *Environmental Science & Technology, 36(4),* 639–645. DOI 10.1021/es001726y.
19. Bhattarai, S. P., Huber, S., Midmore, D. J. (2004). Aerated subsurface irrigation water gives growth and yield benefits to zucchini, vegetable soybean and cotton in heavy clay soils. *Annals of Applied Biology, 2004(144),* 285–298. DOI 10.1111/j.1744-7348.2004.tb00344.x.
20. Abuarab, M. E., Mostafa, E., Ibrahim, M. M. (2012). Effect of air injection under subsurface trickle irrigation on yield and water use efficiency of corn in a sandy clay loam soil. *Journal of Advanced Research, 4(6),* 493–499. DOI 10.1016/j.jare.2012.08.009.
21. Fisher, R. A. (1935a). *The design of experiments*. New York: Hafner Publishing Company.
22. Logan, B. A., Kornyeyev, D., Hardison, J., Holaday, A. D. (2006). The role of antioxidant enzymes in photoprotection. *Photosynthesis Research, 88(2),* 119–132. DOI 10.1007/s11120-006-9043-2.
23. Neill, S. J., Desikan, R., Clarke, A., Hurst, R. D., Hancock, J. T. (2002). Hydrogen peroxide and nitric oxide as signaling molecules in plants. *Journal of Experimental Botany, 53(372),* 1237–1247. DOI 10.1093/jexbot/53.372.1237.
24. Goorahoo, D., Carstensen, G., Zoldoske, D. F., Norum, E., Mazzei, A. (2001). Using air in subsurface drip irrigation (SDI) to increase yields in bell pepper. *Proceedings of Irrigation Association Technical Conference*, *San Antonio, Texas, USA*, 95–102.
25. Gong, M., Chen, B., Li, Z. G., Gou, L. H. (2001). Heat-shock-induced cross adaptation to heat, chilling, drought and salt in maize seedlings and involvement of H_2O_2. *Journal of Plant Physiology, 158(9),* 1125–1130. DOI 10.1078/0176-1617-00327.
26. Appu, M., Muthukrishnan, S. (2014). Foliar application of salicylic acid stimulates flowering and induce defense related proteins in finger millet plants. *Universal Journal of Plant Science, 2,* 14–18.
27. Ahmad, I., Basra, S. M. A., Afzal, I., Farooq, M., Wahid, A. (2013). Growth improvement in spring maize through exogenous application of ascorbic acid, salicylic acid and hydrogen peroxide. *International Journal of Agriculture and Biology, 15,* 95–100.
28. Melsted, S. W., Kurtz, T., Brady, R. (1949). Hydrogenperoxide as an oxygen fertilizer. *Agronomy Journal, 41(2),* 79. DOI 10.2134/agronj1949.00021962004100020011x.
29. Blokhina, O., Virolainen, E., Fagerstedt, K. V. (2003). Antioxidants, oxidative damage and oxygen deprivation stress: a review. *Annals of Botany, 91(2),* 179–194. DOI 10.1093/aob/mcf118.
30. Schaffer, B., Whiley, A. W. (2002). Environmental physiology. In: Whiley, A. W., Schaffer, B., Wolstenholme, B. N. (eds.) *Avocado: Botany, Production and Uses*. pp. 135–160. Wallingford, UK: CABI Publishing.
31. Hsu, Y., Tseng, M., Lin, C. (1999). The fluctuation of carbohydrates and nitrogen compounds in flooded wax-apple trees. *Botanical Bulletin of Academia Sinica, 40,* 193–198.