JURNAL UPI

ASEAN Journal of Science and Engineering

AJSE ASEAN Journal of Science and Engineering

Journal homepage: http://ejournal.upi.edu/index.php/AJSE/

Effects of Sustained Deficit Irrigation on Vegetative Growth and Yield of Plum Trees Under the Semi-Arid Conditions: Experiments and Review with Bibliometric Analysis

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ABSTRACT

This study evaluated sustained deficit irrigation on the production and quality of plum trees under the semi-arid conditions of the Saïs plain, with four water regimes: T0 (dose practiced by the farmer which may be equal to or greater than 100% ETc), T1 (100% ETc), T2 (80%ETc) and T3 (60%ETc) during the agricultural year 2017/2018. The results of the study showed a significant influence of the irrigation dose on vegetative parameters such as shoot diameter and length, physiological parameters such as leaf temperature, production parameters such as fruit yield per tree and fruit number per tree, and quality parameters such as acidity and sugar content. The fruits grown on T3 (60 %ETc)-treated trees had the highest sugar content. The total acidity of the fruit juice decreased with the increase in sugar content. In summary, the main parameters of vegetative growth, production, and quality were significantly affected by the reduction in irrigation dose. The findings also suggested that a 20% reduction in irrigation dose is feasible without significantly affecting the yield. A bibliometric analysis is conducted on the collected papers on Scopus on sustainable deficit irrigation and its impact on vegetative growth from 1999 to 2023.

ARTICLE INFO

Article History:
Submitted/Received 10 Aug 2023
First Revised 29 Sep 2023
Accepted 26 Nov 2023
First Available online 27 Nov 2023
Publication Date 01 Sep 2024

Keyword:
Bibliometric analysis,
Growth parameters,
Plum tree,
Sais plain,
SDI,
Water regime.

1. INTRODUCTION

The rosaceous fruit sector in Morocco is composed of three subgroups, namely the pome fruits (apple, pear, and quince), the stone fruits (apricot, plum, peach-nectarine, cherry, and medlar), and the dry fruits (almond, walnut, pistachio, and pecan).

The production depends on crop and seasonal weather conditions. Water is the key determinant of the tree's growth and development. Osmosis allows the tree to absorb the water it requires, while transpiration causes it to lose it at the same time. Solar energy acts as the driver of the transfer. Stonefruit is one of the most important irrigated crops in the world. Their ability to survive in different environments indicates that they have somewhat different water requirements (Wu *et al*., 1999).

The annual rainfall in Morocco is about 140 billion cubic meters (BCM), but most of it evaporates or is used by plants, leaving only 22 BCM of natural water resources. This means that each person in Morocco has access to only 700 m3 of water per year, which is much lower than the global average. Out of the 22 BCM, 18 BCM comes from rivers and lakes, and 4 BCM comes from underground sources. However, not all this water can be used easily or cheaply. A series of severe drought cycles have had a devastating impact on the country's economy and environment, particularly in agriculture. Irrigation is necessary because stone fruit species require a lot of water, especially in areas that experience repeated droughts, as is the case in Morocco (Stour & Agoumi, 2008). This shows the limitations and challenges of water management in Morocco, and the need for an integrated approach.

Irrigated agriculture remains one of the largest and least efficient uses of water, a resource that is becoming increasingly scarce throughout the world. Growers need to implement innovative irrigation and farming strategies that use water more wisely due to low water use efficiency (WUE) and rising competition for water resources with other sectors (such as tourism or industrial). Drip irrigation and sheltered cultivation have improved WUE in areas with dry and hot climates, mainly by reducing runoff and evapotranspiration losses. However, further methods are still needed to increase WUE in irrigated agriculture. By allowing crops to tolerate mild water stress with no or minimal irrigation, deficit irrigation techniques like managed deficit irrigation or partial root drying have emerged as possible ways to enhance water savings in agriculture (Costa *et al*., 2007).

Water scarcity will continue to pose a challenge for irrigated agriculture in the present and the future. The management of irrigation systems will shift from emphasizing yield per unit of land to maximizing yield per unit of water used or improving water productivity. Insufficient water availability for irrigation will become the norm rather than the exception (Fereres & Soriano, 2007). In this situation, it is necessary to implement innovative irrigation strategies like sustained deficit irrigation (SDI), which is one of the methods to ensure irrigation water savings with little to no impact on production. SDI is the application of less than 100% of the crop's evapotranspiration, with the deficit increasing as the crop matures (since the crop's water demand rises with crop development). If irrigation is not properly managed, it could, nevertheless, have detrimental effects on the environment. The SDI strategy involves providing the tree with less water than it requires to meet its total water demand while accepting a minor decrease in yield. As a result, water productivity per unit of water will rise (Rowland *et al*., 2018).

Numerous studies have also examined various irrigation methods, including the use of regulated deficit irrigation (RDI) during specific stages of the tree and fruit development cycle, to increase water use efficiency and fruit quality (Boland *et al*., 2000a; Boland *et al*., 2000b). The main goal of the technique is to subject the plant to water stress at a predetermined time (unlike SDI) (Chenafi *et al*., 1964). The effects of crop load and RDI on the Japanese plum, Prunus salicina Lindell, were investigated. RDI applied during stage II of fruit growth and post-harvest was compared to irrigation to match total crop evapotranspiration. The combination of medium crop load and RDI shifted fruit mass distribution towards the low-value categories. As a result, the economic returns under the RDI treatment with a low crop level were comparable to or higher than those with a medium crop level. In addition, both crop levels and RDI increased fruit total soluble solids (TSS) concentration, so fruit under RDI and low crop levels had the highest values of TSS (Instrigliolo & Castel, 2010).

Four-year-old P. salicina cv. "Black-Gold" trees in Valencia, Spain, were subjected to drought, and the effects on tree water status, growth, yield, and fruit size were assessed. Water was limited to replace 33% or 66% of the tree's evapotranspiration (ETc) during stages II and III of fruit growth, or after harvest, or for both periods at 66% of ETc. Average fruit weight was reduced by water deficit during fruit growth, and there was a negative relationship between fruit size and integrated midday stem water potential. On the other hand, drought after harvest had no immediate effect on blooming, fruit set, fruit growth, or yield. However, there was a 10% decrease in yield compared to control plots in the last year of the trial (Intrigliolo & Castel, 2005). Ten-year-old apricot, P. armeniaca L., cv. "Blida", trees were subjected to three different drip irrigation regimes throughout four growing seasons: (1) a control treatment, which received irrigation at 100% of seasonal crop evapotranspiration (ETc); (2) a continuous deficit irrigation (DI) treatment, which received irrigation at 50% of the control treatment; and (3) a RDI treatment (Pérez-Pastor *et al*., 2009).

Numerous studies that examined SDI in different species have demonstrated its benefits on fruit yield and quality. According to Rowland *et al*., (2018), a 2014 study using drip irrigation on three melon cultivars (100% and 50% ETc), using deficit irrigation, could save 37 to 45% on irrigation costs with only a slight decrease in economic production. It also decreased yield without increasing water use efficiency. Walso mentioned a study on spearmint that demonstrated how uniform oil content could be maintained while biomass was reduced by lowering watering levels (Rowland *et al*., 2018). Results on pomegranate, Punica granatum L., plants have been very significant by Intrigliolo *et al*., (2013), showing that similar yield values were achieved in SDI and control trees irrigated at 100% ETc even after three seasons of water restriction. This was due to a compensating increase of 28% in the number of fruits harvested per tree that offset a 22% decrease in average fresh fruit weight observed in the SDI treatment (Intrigliolo *et al*., 2013).

This paper aims to evaluate sustained deficit irrigation on the production and quality of plum trees under the semi-arid conditions of the Saïs Plain, Morocco, and consolidated by a comprehensive bibliometric analysis of global research from 1999 to 2023 based on the keywords of “Sustained deficit irrigation” AND “vegetative growth” AND “Semi-arid conditions”. Bibliometric is one of the best methods to understand the research trend. Previous studies on bibliometrics are presented in **Table 1**.

Table 1. Previous studies on bibliometric.

No	Title	Reference
1	Involving Particle Technology in Computational Fluid Dynamics Research: A Bibliometric Analysis	Nandiyanto *et al.* (2023a)
2	Bibliometric Computational Mapping Analysis of Trend Metaverse in Education using VOSviewer	Muktiarni *et al.* (2023)
3	The Use of Information Technology and Lifestyle: An Evaluation of Digital Technology Intervention for Improving Physical Activity and Eating Behavior	Rahayu *et al.* (2023)

Table 1 (continue). Previous studies on bibliometric.

No	Title	Reference
4	Strategies in language education to improve science student understanding during practicum in laboratory: Review and computational bibliometric analysis	Fauziah *et al*. (2021)
5	How language and technology can improve student learning quality in engineering? definition, factors for enhancing students' comprehension, and computational bibliometric analysis	Al Husaeni *et al*. (2022)
6	Mapping of nanotechnology research in animal science: Scientometric analysis	Kumar (2021)
7	Scientific research trends of flooding stress in plant science and agriculture subject areas (1962-2021)	Nurrahman *et al*. (2023)
8	Introducing ASEAN Journal of Science and Engineering: A bibliometric analysis study	Nandiyanto *et al*. (2023b)
9	A bibliometric analysis of chemical engineering research using VOSviewer and its correlation with Covid-19 pandemic condition	Nandiyanto *et al*. (2021)
10	A bibliometric analysis of materials research in Indonesian journal using VOSviewer	Nandiyanto and Al Husaeni (2021)
11	Bibliometric analysis of engineering research using Vosviewer indexed by google scholar	Nandiyanto and Al Husaeni (2022)
12	Bibliometric computational mapping analysis of publications on mechanical engineering education using VOSviewer	Al Husaeni and Nandiyanto (2022)
13	Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis	Nandiyanto *et al*. (2023c)
14	Domestic waste (eggshells and banana peels particles) as sustainable and renewable resources for improving resin-based brakepad performance: Bibliometric literature review, techno-economic analysis, dual-sized reinforcing experiments, to comparison with commercial product	Nandiyanto *et al*. (2022)
15	Bibliometric analysis of educational research in 2017 to 2021 using VOSviewer: Google scholar indexed research	Al Husaeni *et al*. (2023a)
16	Bibliometric analysis of high school keyword using VOSviewer indexed by google scholar	Al Husaeni and Nandiyanto (2023b)
17	Bibliometric analysis of special needs education keyword using VOSviewer indexed by google scholar	Al Husaeni *et al*. (2023b)
18	Bibliometric analysis for understanding the correlation between chemistry and special needs education using vosviewer indexed by google	Bilad (2022)

2. MATERIALS AND METHODS

2.1. Site of study and plant resources

The current study was carried out during the 2017–2018 agricultural season, in an orchard located 14 km from Meknes and 21 km from Ain Jemaa, at an altitude of 488 m, a latitude of N: 33°54 '46.5 and longitude of W: 5°39'26.5 in the Sais plain (Fez-Meknes region). The uniform plum, P. salicina Lindell. cv. "Angelino", trees were grafted on Myrobolan rootstocks. The plum orchard was planted in 2014. The orchard was planted in 2014; the management adopted a double Y goblet, with a density of 666 trees/ha corresponding to a spacing of 3 m between trees and 5 m between rows. The study involved 60 plum trees spread over four rows of plantations. For each row, one of the four doses of irrigation was applied. But only nine trees were monitored. Localized drip irrigation was the method of choice (two drippers per tree, uniformly spaced one meter apart on the lateral line), with a flow rate of 8 l/h per dripper. Each planting row also included a polyethylene lateral line.

Four water regimes: T0 (dose practiced by the farmer which may be equal to or greater than 100% ETc), T1 (100% ETc), T2 (80%ETc), and T3 (60%ETc) during the agricultural year 2017/2018. Treatments T1, T2, and T3 were defined by reference to the crop reference evapotranspiration (ETo) provided by the nearest meteorological station (National School of Agriculture meteorological station). Once ETo is known, the water demand of the tree was calculated (ETc) with an adjustment to take into account the vegetative state of the tree and the characteristics of the irrigation system used (Allen *et al*., 2006; Chen *et al*., 2005).

To compensate for trace element deficiencies, fertilization was used with major element inputs (N, P, and K) in addition to foliar inputs (Radi *et al*., 2003; Odell, 2020; Meyer & Nalepa, 1991). Based on the findings of the water and soil analyses, the fertigation schedule was designed. Ammonium nitrate, potassium sulfate, and phosphate were the fertilizers used. An equal amount of fertilizer; 150 kg-ha-1 of N, 100 kg-ha-1 of P, and 160 kg-ha-1 of K; was applied to all trees. In addition to mechanical weeding between rows and two chemical treatments based on glyphosate and paraquat in the inter-rows, weed management was carried out (Bussi *et al*., 2015; Odell, 2020). Two types of pruning were carried out, winter pruning during the vegetative rest in November, and green pruning during June.

The phytosanitary treatments were carried out according to the target pest and the active ingredient (with different treatment times for each pest):

(i) White oil was applied to manage the cochineal insect target populations in Winter (January);
(ii) Ziram and Thiram were applied to control candidiasis, cankers, and dieback diseases during the Flowering stage (Lalancette *et al*., 2017);
(iii) Abamectin was applied to yellow mites during the Flowering stage (Marčić *et al*., 2009);
(iv) Imidacloprid was applied against aphids and thrips during the blooming period (Dutcher *et al*., 2005);
(v) Copper-based treatments were applied to control viral diseases (three applications after harvest);

2.2. Irrigation treatments

The assessment of the plant's water demand and the identification of the available water resources served as the basis for irrigation management. The demand, which is mostly determined by the climate, is intended to be met by the available water resources. Calculating potential evapotranspiration allows for the quantitative assessment of demand (Subedi & Chávez, 2015; Marsal *et al*., 2015).

Rosaceous plants that bear fruit depend on smart watering for their best growth and productivity. The amount of water needed for good production varies depending on the climate, soil type, planting method, species, and rootstock (Mirás-Avalos *et al*., 2017).

In this study, we examined SDI, also referred to as "CDI" continuous deficit irrigation, which is based on the application of water restrictions throughout the tree's growth cycle. The implementation of appropriate water limits for stone fruits could increase water use efficiency and fruit quality without having a significant influence on yield levels.

2.3. Experimental design

The trial was carried out using a completely randomized design with three replications, with the water regime serving as the treatment factor. Sixty trees, or 15 trees per row, were planted in four rows. One of four watering rates was used for each row of trees.

Irrigation control for the experiment aimed to regulate water amounts based on the water balance using tensiometer or capacitive probes, tools that provide more precise knowledge

DOI: https://doi.org/10.17509/ajse.v4i2.64600
p- ISSN 2776-6098 e- ISSN 2776-5938

of the soil's water status, and observations of the tree behavior (vigor, fruit size, emergence of suckers or early growth, etc.) to adjust the irrigation water determined for each treatment.

The water balance approach involves computing the irrigation water requirement (IWR), which is the difference between ETc and effective rainfall (Eff rain), as shown in equations 1, 2, and 3 below. Effective rainfall is the amount of rain that a crop uses after surface runoff and deep percolation have lost some of it. This parameter was calculated using the Food and Agriculture Organization (FAO)'s recommended method, "Eff rain (mm) = 0.8 x Rainfall".

The efficiency of the irrigation system (Esys) [The efficiency of the drip irrigation system used is of the order of 1 (for the three trials)] and the cultural coefficient (Kc) (crop coefficient), which varies depending on the species and phenological stage, of a plant were considered. Additionally, the area that the foliage covers (Kr) [The reduction coefficient (Kr) used to account for the rate at which the foliage covers the soil]. Using the Penman-Monteith model, the ETo (mm) was calculated. All agrometeorological factors were necessary for this model (see Equation 1 and 2).

IWR (mm) = ETc (mm) – Eff rain (mm) [1]

Etc = Kr x Kc xETo/Esys [2]

According to the equation below, applications were made based on the irrigation duration once the irrigation dose had been determined. Management of irrigation is carried out logically. Daily ETo measurements were gathered from a meteorological station that was not more than 20 km away from the orchard where the experiments were set up. According to ETc, irrigation time was determined. Throughout the growth stages (June through September), three water regimes (100% ETc, 80% ETc, and 60% ETc) were tested (see Equation 3) (Dbara *et al*., 2016).

Duration (h) = [Dose (mm) x Area occupied by the tree (m2)] / [Flow rate per tree (l/h)] [3]

2.4. Measurement of qualitative and quantitative parameters

After each harvest, fruit samples were chosen per treatment to study the following parameters:

(i) Yield: the yield of each tree is determined by the weight of the fruits at harvest time (end of June) and the number of fruits harvested (Kg/tree).
(ii) Quality of the peaches: 20 fruits (corresponding to each treatment) were chosen randomly at the time of harvest to determine the quality of the peaches by analyzing the following parameters, in the Pomology Laboratory of Fruit Trees, Olive Growing and Viticulture Department, National School of Agriculture of Meknes, Morocco:
    a. Physical parameters: Fruit weight (FW), fruit length (FL), fruit diameters (FD), flesh weight (FW), and core weight (CW).
    b. Chemical parameters: Chlorophyll content (Chl) measured by a SPAD meter, total soluble sugars (TSS) expressed as °Brix from the reading of the juice refractometer of the samples studied, titratable acidity (TA) of the juice by titration of 0.01 mol/l at pH 8.2 and expressed as malic acid content which is most dominant in peaches and sugar/acid ratio (RSA).

Statistical analysis of the 2017 and 2018 data was carried out using the Statistical Package for the Social Sciences (SPSS) program, and the resulting data were subjected to an ANOVA (Analysis of Variance). The significance of mean differences at a 5% threshold was assessed using the Student, Newman, and Keuls (SNK) multiple comparisons test of the means.

DOI: https://doi.org/10.17509/ajse.v4i2.64600
p- ISSN 2776-6098 e- ISSN 2776-5938

2.5. Bibliometric analysis

Bibliometric analysis requires an extensive collection of databases on the topic of studies on the effects of high temperature and drought stress on plants. Developed by Elsevier Publishing Co., Scopus covers the various journals published from 1900 to the present. We used the database of SCOPUS (https://www.scopus.com/search) to construct a bibliographic database on the topic of plant responses to sustained deficit irrigation and its impact on vegetative growth studies. SCOPUS is broadly accepted by scholars and has been used as a helpful tool to do bibliometric analysis in most recent research. Specifically, according to the "Advanced Search" option in SCOPUS, we searched fields and information based on Boolean operators, using the terms of "Sustained deficit irrigation" AND "vegetative growth" AND "Semi-arid conditions", and conducted a literature search from January 1999 to November 2023. The search was carried out for "All Fields" in SCOPUS. The search was limited to English-language publications, and the time frame was set as mentioned before. Finally, we utilized manual filtering of search results to remove irrelevant articles and then analyzed results by VOSviewer (**Figure 1**).

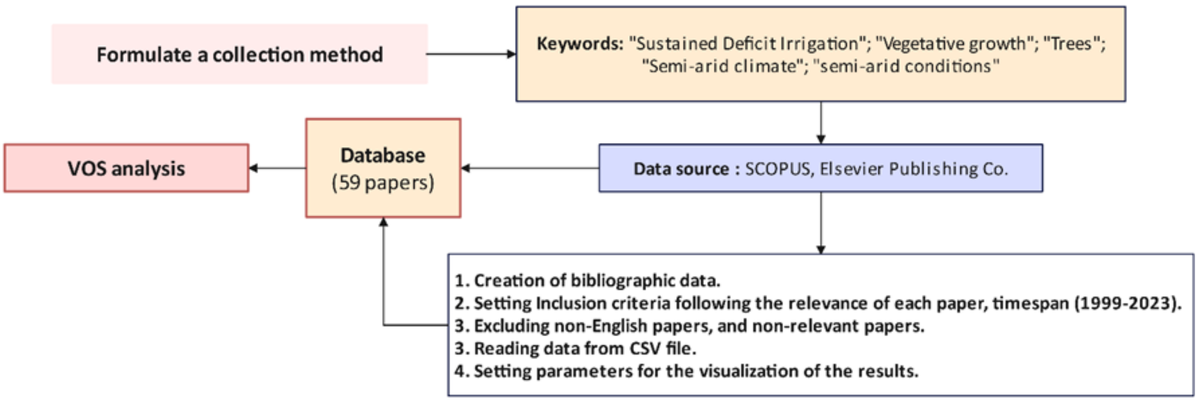

Figure 1. VOSviewer bibliometric analysis flowchart. This flowchart is modified from the literature (Cui *et al.* (2022)).

VOSviewer, a sophisticated software tool for literature analysis and knowledge visualization, was innovatively crafted by the academic minds at Leiden University in the Netherlands, as pioneered by van Eck and Waltman in 2010 (Van Eck & Waltman, 2010). This bibliometric analysis and knowledge visualization tool offered as a free resource, emerges as an indispensable asset for scholars and researchers seeking to unravel the intricacies of diverse research problems (N'diaye *et al.*, 2022). Its functionality extends to providing insightful perspectives through clustering views, label views, and density views, offering a comprehensive toolkit for navigating the complex landscape of scholarly literature. VOSviewer excels particularly in the analysis of keywords, cluster structures, subject words, and authorship details. The application of VOSviewer in our study involved the creation of a database sourced from SCOPUS, specifically targeting research related to sustained deficit irrigation and vegetative growth. This rich dataset, meticulously organized and stored as a CSV file, served as the foundation for our subsequent bibliometric analysis, as illustrated in **Figure 1**. This process allowed us to harness the power of VOSviewer in exploring and visualizing the intricate web of connections within the body of literature, shedding light on key themes, and thematic clusters.

3. RESULTS AND DISCUSSION

3.1. Measurements of vegetative parameters

3.1.1. Annual shoot diameter

This parameter depicted the impact of the water regime on the increase in the annual shoot diameter during the trial period in 2017 (the initial and second measurements were taken on May 5 and September 17, 2017, respectively). There was a substantial difference between the four treatments, according to the analysis of variance. The statistical analysis indicated that the water deficit, which resulted in the smallest increase for the T3 treatment (60% ETc) with an average of 0.77 mm, reduced the growth of the annual shoot diameter (**Table 2**). The T0 treatment, on the other hand, had the largest increase with an average of 1.59 mm. This treatment used a dose that was equal to or higher than the 100% ETc dose. The SNK test identified two homogeneous groups at the 5% significant level. The first group consisted of the T0 treatment (producer), which has an average thickness of 1.59 mm, and the second group consisted of the T3 treatment (60% ETc), which has an average thickness of 0.77 mm. The T1 (100% ETc) and T2 (80% ETc) irrigation doses could belong to either group.

Table 2. Effect of sustained deficit irrigation on vegetative parameters of plum trees (Agricultural year 2017-2018).

Treatment	SD (mm)		SL (cm)		LA (cm^2)	
	2017	2018	2017	2018	2017	2018
T0	1.59^{a}	7.56^{ab}	1.39^{a}	52.86^{a}	2692.30^{a}	2256.60^{b}
T1	1.24^{ab}	8.17^{a}	1.33^{a}	39.17^{b}	2681.00^{b}	2896.40^{a}
T2	1.03^{ab}	7.82^{ab}	1.12^{ab}	33.03^{c}	2345.00^{b}	2363.70^{b}
T3	0.77^{b}	6.82^{b}	0.76^{b}	22.14^{d}	2173.47^{b}	2169.10^{b}

SD: Shoot diameter, SL: Shoot length, and LA: Leaf area. T0: Control (farmer/producer), T1: 100% of crop evapotranspiration (ETc), T2: 80% of ETc, and T3: 60% of ETc. In each column and for each year the values followed by the same letter are not significantly different at 5% probability according to the test SNk.

In 2018, the deficit irrigation affected the vegetative vigor. Indeed, the analysis of variance showed a significant effect of water regimes on the increase in the annual shoot diameter. Data in **Table 2** showed the effect of the water regime on the increase of the annual shoot diameter during the trial period in 2018 (the first and second measurements were taken on May 7 and September 17, 2018, respectively). The SNK test revealed two homogeneous groups. The first group included treatments T1, T2, and T0 with mean values of 8.17, 7.82, and 7.56 mm, respectively for these three treatments, and the second group included the three treatments T2, T0, and T3 with mean values of 7.82, 7.56, and 6.82 mm respectively.

3.1.1. Annual shoot diameter

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p- ISSN 2776-6098 e- ISSN 2776-5938

the second group consisted of the T3 treatment (60% ETc), which has an average thickness of 0.77 mm. The T1 (100% ETc) and T2 (80% ETc) irrigation doses could belong to either group.

3.1.2. Annual shoot length

In 2017, the trees that received irrigation dosage T0 had the longest shoot growth compared to the other treatments. The T3 treatment had the smallest increase in length (average of 0.76 mm) among treatments T1, T2, and T3, with a maximum value of 1.39 mm (**Table 2**). This treatment inhibited the shoot growth. Additionally, the statistical analysis showed that the irrigation dose had a substantial impact on this parameter.

The SNK test at the 5% significance level identified two homogeneous groups. The first group consisted of the T0 treatment, which had an average of 1.39 mm, and the second group consisted of the T3 treatment, which had an average of 0.76 mm. The T1 (average of 1.33 mm) and T2 (average of 1.12 mm) irrigation doses could belong to either group.

In 2018, the statistical analysis distinguished four distinct groups. The first group was represented by the T0 treatment with an average shoot length of 52.86 cm, the second group included the T1 treatment with an average of 39.17 cm, the third group was represented by the T2 treatment with an average of 33.03 cm, and the fourth group contained the T3 treatment with an average of 22.14 cm.

3.1.3. Leaf area

In 2017, the leaf area values ranged from a minimum of 2173.47 mm2 measured on the tree leaves that were irrigated using a 60% ETc irrigation dose (T3) to a maximum of 2692.28 mm2 measured on the tree leaves that had been given the dose practiced by the farmer (**Table 2**). Additionally, the analysis of variance showed that the irrigation regime had a significant impact on the leaf area. Two homogenous groups were detected by the SNK test: T1 > T2, T0, and T3. Thus, the reduced leaf area was caused by the water shortage.

In 2018, the statistical analysis of the effect of the water regime on the leaf area showed that the values of the leaf area varied between a minimum of 2169.11 mm2 measured on the tree leaves irrigated at 60% ETc and a maximum of 2896.42 mm2 measured on the tree leaves that received the 100% ETc dose. The values recorded on the trees of the different treatments showed a significant effect with the reduction of the irrigation dose. Indeed, the SNK test at the 5% t significance level revealed two homogeneous groups. The first group was represented by the treatment T1 and the second group included the treatments T0, T2, and T3.

3.2. Measurements of physiological indicators

3.2.1. Chlorophyll content

The chlorophyll content measurements showed a significant difference between the water treatments. The values of this parameter in 2017 ranged from a minimum of 43.13 CCI (Chlorophyll Context Index) measured on the plum leaves irrigated with 60% ETc to a maximum of 45.48 CCI measured on the tree leaves that received 100% ETc (**Table 3**). This illustrates the effect of the water regime on the chlorophyll content of plum tree leaves. The SNK test of mean comparison identified three homogeneous groups: T0, and T1>T2>T3. The analysis of variance of the 2018 data revealed no significant effect between the treatments, with a maximum average of 14.46 CCI in treatment T1, and a minimum average of 12.97 CCI in treatment T3 (60%) (**Table 3**).

DOI: https://doi.org/10.17509/ajse.v4i2.64600
p- ISSN 2776-6098 e- ISSN 2776-5938

Table 3. Effect of sustained deficit irrigation on physiological indicators of plum trees in 2017 and 2018.

Treatment	Chl (CCI)		FT (°C)	
	2017	2018	2017	2018
T0	45.34[a]	14.30[a]	2.75[a]	3.59[a]
T1	45.50[a]	14.46[a]	2.60[a]	4.30[a]
T2	44.40[ab]	14.21[a]	0.92[b]	1.53[b]
T3	43.13[b]	12.97[a]	-0.08[c]	-0.24[c]

Chl: Chlorophyll content, FT: Foliage temperature, T0: Control (farmer/producer), T1: 100% of crop evapotranspiration (ETc), T2: 80% of ETc, and T3: 60% of ETc. In each column and for each year the values followed by the same letter are not significantly different at 5% probability according to the test SNk.

3.2.2. Temperature difference (T_{air} - $T_{foliage}$)

The analysis of variance revealed a highly significant effect on the temperature difference in 2017, which allowed us to assess the impact of the irrigation regime on the temperature difference between air and foliage. The findings showed that the severity of the water deficit applied to the plums caused a decrease in the temperature difference between the air and the foliage. Treatment T0 had the highest average temperature difference of 2.75 °C, while treatment T3 recorded the lowest average temperature difference of -0,8 °C. The SNK test formed three homogeneous groups: the irrigation doses T0 and T1, which had average temperature differences of 2.75 °C and 2.57 °C, respectively, belonged to the first group. Treatment T2, which belonged to the second group, had an average temperature difference of 0.91 °C. The irrigation dose T3, which had an average temperature difference of -0.8 °C, belongs to the third group.

By examining the data in 2018, we noticed that the temperature difference between the air and the foliage decreased with the severity of the water deficit applied to plums. Treatment T3 recorded the lowest average temperature difference of -0.24 °C, while treatment T0 had the highest average temperature of 4.3°C. The SNK test at the 5% threshold revealed three homogeneous groups: the first consisted of T0 and T1 with the respective means of 3.59 °C and 4.3 °C, the second group consisted of T2 with an average of 1.53 °C, and the third group consisted of T3 with an average of -0.24 °C.

3.3. Measurements of production parameters

3.3.1. Total number of fruits per tree

The number of fruits per tree is a very important component of yield, as it directly affects production. The analysis of variance revealed a significant effect of irrigation on the total number of fruits. In 2017, number of fruits per tree varied between a minimum of 185 fruits measured on plums irrigated according to the dose practiced in the T0 treatment and a maximum of 350 fruits measured on plums having received a regime of 100% ETc (**Table 4**).

The SNK test results indicated that the 100% ETc regime was superior to the other three irrigation variants. It revealed two homogeneous groups. The first group was represented by the T1 treatment with an average of 350 fruits per tree. The second group was represented by the T0 treatment with an average of 185 fruits per tree. The 80% ETc and 60% ETc irrigation doses belonged to both groups at the same time.

In 2018, the water regime also influenced the total number of fruits per tree. Indeed, the statistical analysis revealed a significant effect between the three treatments, and the SNK test at the 5% threshold distinguished two homogeneous groups: the first group included

DOI: https://doi.org/10.17509/ajse.v4i2.64600
p- ISSN 2776-6098 e- ISSN 2776-5938

treatment T1 with an average of 994 fruits per tree and T2 with an average of 922 fruits per tree, and the second group included T0 and T3 treatments with averages of with an average of 786 and 675 fruits per tree, respectively (**Table 4**).

Table 4. Effect of sustained deficit irrigation on production parameters of plum trees in 2017 and 2018.

Treatment	FN/tree	FD (mm)	FL (mm)	FW (g)	FFW/tree (g)	FCW (g)	FY/tree (kg/tree)
	Year 2017						
T0	185.00[b]	45.03[a]	39.13[a]	50.36[b]	49.09[ab]	1.11[a]	15.65[a]
T1	350.00[a]	45.96[a]	40.68[a]	55.91[a]	49.08[a]	1.22[a]	15.61[a]
T2	264.00[ab]	44.47[a]	38.64[a]	48.39[b]	46.96[bc]	1.18[a]	13.27[ab]
T3	264.00[ab]	42.25[b]	36.67[b]	43.81[b]	42.36[c]	1.21[a]	11.97[b]
	Year 2018						
T0	786.22[b]	55.26[ab]	55.31[ab]	103.50[ab]	95.96[a]	2.04[a]	108.21[ab]
T1	994.11[a]	55.27[a]	57.97[a]	115.84[a]	111.78[a]	2.52[a]	136.49[a]
T2	922.00[a]	54.58[ab]	56.67[a]	94.50[b]	102.89[a]	3.11[a]	104.81[ab]
T3	675.67[b]	53.86[b]	53.47[b]	93.53[b]	96.33[a]	2.19[a]	76.03[b]

FN: Fruit number, FD: Fruit diameter, FL: Fruit length, FW: Fruit weight at harvest, FFW: Fruit flesh weight, FCW: Fuit core weight, and FY: Fruit yield. T0: Control (farmer/producer), T1: 100% of crop evapotranspiration (ETc), T2: 80% of ETc, and T3: 60% of ETc. In each column and for each year the values followed by the same letter are not significantly different at 5% probability according to the test SNk.

3.3.2. Fruit diameter

The average diameter of the fruit at harvest in 2017 varied between a minimum of 42.25 mm measured on plums irrigated with 60% ETc and a maximum of 45.96 mm measured on plums that received 100% ETc (**Table 4**). Moreover, the analysis of variance revealed a highly significant effect of the irrigation regime on the fruit diameter at harvest. The SNK test revealed two homogeneous groups. The first group consisted of treatments T0, T1, and T2 with averages of 45.03; 45.96, and 44.47 mm, respectively. The second group was represented by the T3 treatment with a mean of 42.25 mm.

In 2018, the results obtained from the different treatments also showed a significant effect with the reduction of the irrigation dose. The SNK test at the 5% threshold revealed two homogeneous groups, the first group consisted of the treatments T0, T1, and T2 with respective means of 55. 26, 55.27, and 54.58 mm. The second group was represented by treatments T0, T2, and T3 with means of 55.26, 54.58, and 53.86 mm, respectively (**Table 4**).

3.3.3. Fruit length at harvest

The average length of the fruit in 2017 varied between a minimum of 36.67 mm measured on plums irrigated with 60% ETc and a maximum of 40.68 mm measured on plums that received 100% ETc (**Table 4**). Analysis of variance revealed a highly significant effect of the irrigation regime on fruit length. The SNK test revealed two homogeneous groups: T1, T0, and T2 > T3. On the other hand, in 2018, the average length of the fruit varied between a minimum of 53.47 mm measured on plums irrigated 60% ETc and a maximum of 57.97 mm measured on plums that received 100% ETc (**Table 4**). Analysis of variance revealed a highly significant effect of the irrigation regime on fruit length. The SNK test classified the treatments into two homogeneous groups: the first group was represented by the treatments T0, T1, and T2 with

DOI: https://doi.org/10.17509/ajse.v4i2.64600
p- ISSN 2776-6098 e- ISSN 2776-5938

respective means of 55.31, 57.97, and 56.67 mm, and the second was represented by the treatments T0 and T3 with means of 55.31 and 53.47 mm, respectively.

3.3.4. Fruit weight at harvest

Fruit weight at harvest is a very important component of yield. The data recorded in this trial in 2017 showed that this parameter varied between a minimum of 43.81 g for plums irrigated with 60% ETc and a maximum of 55.91 g for plums that received 00% ETc (**Table 4**). In addition, the analysis of variance revealed a highly significant effect of the irrigation regime on fruit weight at harvest. The SNK test indicated that the T1 treatment was superior to the three other irrigation variants (T0, T2, and T3). The data recorded in 2018 also showed that the deficit irrigation affected the average fruit weight per tree. Indeed, the analysis of variance revealed a significant difference between the four water regimes, and the SNK test indicated two homogeneous groups. The first group comprised treatments T1 and T0 which recorded the highest value with an average weight per fruit of 115.84 g followed by treatment with an average value of 103.5 g, and the second group included treatments T0, T2, and T3 with an average weight per fruit values of 103.5, 94.5, and 93.53 g, respectively.

3.3.5. Fruit flesh weight

The analysis of the variance of the average fruit flesh weight in 2017 showed that the effect of water restrictions was significant for the plum tree. Indeed, the SNK test showed three homogeneous groups. The first group consisted of treatment T1 which recorded an average fruit flesh weight of a plum fruit of 54.46 g (**Table 4**). The second group consisted of the treatments T0 and T2 which reported respective values of 49.09 and 46.96 g. The third group consisted of the T3 treatment that induced an average fruit flesh weight of 42.36 g.

However, the results of the analysis of variance revealed a non-significant effect of irrigation on this parameter in 2018. The SNK test revealed a single homogeneous group concerning the flesh weight parameter, which included the treatments T0, T1, T2, and T3 with average fruit flesh weights of 95.96, 111.78, 102.89, and 96.33 g, respectively.

3.3.6. Fruit core weight

The analysis of variance showed that in 2017 there was no significant difference between the different treatments T0, T1, T2, and T3, which had the average fruit core weight values of 1.11, 1.22, 1.18, and 1.21 g, respectively. However, in 2018, the average fruit core weight was higher in the trees that received the T2 treatment compared to the other three treatments. Moreover, the statistical analysis revealed a non-significant effect of the irrigation dose on the fruit core weight.

3.3.7. Fruit yield per tree

The results obtained from the average fruit yield per tree showed a significant effect of the irrigation regime on the fruit yield per tree, in 2017. These results showed that deficit irrigation reduced the average fruit yield per tree, which went from 15.65 Kg/tree for T0 to 11.97 kg/tree for T3 treatment. There were two homogeneous groups according to the SNK test. The first group was represented by T0 and T1 with respective average fruit yields of 15.66 and 15.61 kg/tree. The second group consisted of the T3 treatment with an average fruit yield of 11.97 kg/tree. However, the T2 treatment, with an average fruit yield of 13.27 kg/tree, belonged to both groups at the same time.

In 2018, the results showed that T1 treatment significantly improved the average fruit yield per tree. Indeed, this treatment had an increase of 20.71% compared to the T0 treatment and

DOI: https://doi.org/10.17509/ajse.v4i2.64600
p- ISSN 2776-6098 e- ISSN 2776-5938

44.29% compared to the T3 treatment (**Table 4**). The improvement in yield achieved by the T1 treatment was explained both by the yield components' average weight per fruit and the average number of fruits per tree that were higher for this treatment. It should also be noted that there was a significant effect between the treatments on the average yield per tree and according to the SNK test, there were two homogeneous groups. The first group was represented by treatments T0, T1, and T2 with averages of 108.21, 136.49, and 104.81 kg, respectively. However, the second group was represented by the treatments T0, T2, and T3 with the respective means of 108.21, 104.81, and 76.03 kg.

3.3.8. Fruit color

Figure 1 shows the evolution of the coloration of the plum fruit in 2017 as a function of treatment. The color of the fruits was not affected by water stress, as most fruits were harvested at color stages C5 and C4 in 2017 and at color stages C3 and C2 in 2018 for all the treatments (**Table 5**).

Figure 1. Color stages of plum fruits after harvest (2017) (*C1: Greenish purple; C2: Light purple; C3: Dark purple; C4: Bluish purple; C5: Dark blue*).

Table 5. Effect of sustained deficit irrigation on plum color in 2017 and 2018.

Treatment	FC (%)	
	2017	2018
T0	C4 (40)	C3 (44)
T1	C4 (44)	C3 (44)
T2	C5 (43)	C3 (43)
T3	C5 (38)	C2 (44)

FC: Fruit color, T0: Control (farmer/producer), T1: 100% of crop evapotranspiration (ETc), T2: 80% of ETc, and T3: 60% of ETc. In each column and for each year the values followed by the same letter are not significantly different at 5% probability according to the test SNk.

3.4. Measurements of plum fruit quality parameters

3.4.1. Sugar content

The sugar content is the parameter that most determines the fruit quality and its appreciation by the consumer. In 2017, the sugar content varied between a minimum of 19.56 °Bx obtained by the 100% ETc dose and a maximum of 20.91 °Bx obtained by the 80% ETc dose (**Table 6**). Moreover, the analysis of variance revealed a highly significant effect of the irrigation dose on the sugar content. According to the SNK test, the trees irrigated with the 80 and 60% ETc regimes produced plums richer in sugars than those that received the 100% ETc regime. So, in this case, the sugar level increased with the water deficit.

The values of the sugar content showed a significant variation according to the treatments. Indeed, the results showed that the T3 treatment significantly improved the sugar content of the fruit. This was confirmed by the SNK, test which distinguished three distinct groups. The

DOI: https://doi.org/10.17509/ajse.v4i2.64600
p- ISSN 2776-6098 e- ISSN 2776-5938

first group included the T3 treatment with the highest mean value of 17.11 °Bx. The second group consisted of the T2 treatment, which recorded a mean value of 16.33 °Bx. The third group included the treatments (T1 and T0) with 15.67 and 15.06 °Bx, respectively.

Table 6. Effect of sustained deficit irrigation on qualitative parameters of plums in 2017 and 2018.

Treatment	SS (°Brix)		TA (g/l)		SAR		pH		JC (%)	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
T0	20.13[ab]	15.06[c]	4.06[b]	5.51[b]	49.86[a]	27.79[a]	3.13[a]	3.68[a]	49.52[a]	69.31[a]
T1	19.56[b]	15.67[c]	4.53[a]	6.12[b]	43.46[b]	26.04[a]	3.12[a]	3.70[a]	53.67[a]	73.35[a]
T2	20.91[a]	16.33[b]	4.28[ab]	8.44[a]	49.00[a]	19.58[b]	3.16[a]	3.61[b]	53.10[a]	67.11[a]
T3	20.85[a]	17.11[a]	4.28[ab]	8.00[a]	46.10[ab]	21.84[b]	3.05[b]	3.56[c]	40.80[b]	62.08[a]

SS: Soluble sugar, TA: Titratable acidity, SAR: Sugar/acid ratio, and JC: Juice Content. T0: Control (farmer/producer), T1: 100% of crop evapotranspiration (ETc), T2: 80% of ETc, and T3: 60% of ETc. In each column and for each year the values followed by the same letter are not significantly different at 5% probability according to the test SNk.

3.4.2. Total acidity

The analysis of the variance of 2017 data revealed a significant effect of the irrigation regime on total acidity (g malic acid/liter of juice), which varied between a minimum of 4.06 g/l recorded on the juice of the plums irrigated with the T0 treatment and a maximum of 4.53 g/l measured on the juice of the plums who that received the T1 treatment (**Table 6**). In addition, the SNK test showed that the total acidity of the juice from the plums that received the 100% ETc was greater than that obtained in the trees irrigated with the 80 or 60% ETc dose. In 2018, the acidity values also showed a significant variation depending on the treatments, which was confirmed by the SNK test. The latter distinguished two distinct groups. The first group included treatments T2 and T3 with average total acidity values of 8.44 and 7.99 g/l, respectively, and the second group included both T0 and T1 treatments with 5.51 and 6.12 g/l, respectively.

3.4.3. Sugar/acid ratio

As for the two other quality parameters, in particular sugar content and total acidity, the analysis of variance revealed a highly significant effect of the irrigation regime on the sugar/acid ratio in 2017. This parameter varied between a minimum of 43.45 recorded on plums irrigated with the T1 treatment and a maximum of 49.85 measured on plums that received the T0 treatment (**Table 6**). In 2018, according to the SNK test, there were two homogeneous groups concerning the parameter of the sugar/acidity ratio. The first group was represented by treatments T0 and T1 with means of 27.79 and 26.04, respectively. The second group was represented by treatments T2 and T3 with means of 19.58 and 21.8.

3.4.5. pH measurement

Data recorded in 2017 showed that the pH parameter ranged from a minimum of 3.04 recorded on plums irrigated with a 60% ETc dose to a maximum of 55.91 g measured on the plums that received an 80% ETc regime (**Table 6**). In addition, analysis of variance revealed a highly significant effect of the irrigation regime on the fruit juice pH. The SNK test revealed two homogeneous groups: T0, T1, and T2>T3. The results in 2018 showed that decreasing the irrigation dose tends to decrease the pH of plum juice. This observation was approved by the results of the statistical analysis, which showed a significant difference in the pH of plum juice

DOI: https://doi.org/10.17509/ajse.v4i2.64600
p- ISSN 2776-6098 e- ISSN 2776-5938

and three homogeneous groups by the SNK test. The first group included treatments T0 and T1 with pH averages of 3.68 and 3.70, respectively, the second group included the T2 treatment with an average of 3.61, and the third group included the T3 treatment with an average of 3.56.

3.4.6. Fruit juice content

In 2017, the fruit juice content average values were: 53.66, 53.09, 49.52, and 40.80% for treatments T1, T2, T0, and T3, respectively (**Table 6**). Analysis of variance revealed a highly significant effect of irrigation dose on juice content. The data, corresponding to this parameter in 2018, showed that deficit irrigation did not affect the juice content, as the analysis of variance did not show any significant difference between the four water regimes. However, the T1 treatment recorded the highest value with an average of 73.35%, followed by the T0 with an average of 69.31%, then the T2 treatment with an average of 67.11%, and the T3 treatment with an average of 62.08%.

The results of this study conducted over two years (2017 and 2018) reflected a significant effect of water stress on the physiological and morphological processes of the plum tree (Razouk *et al*., 2016), in line with the results of Bryla *et al*. (2005) and Sampiero *et al*., (2015).

For some varieties of rosacea with nuclei, Faghih *et al*., (2019) found that irrigation deficiency had a significant impact on the annual shoot diameter. However, on a morphological level, there was a change in one vegetative parameter after another. Similarly, the shoot length was impacted by deficit irrigation. Regarding the leaf area, the findings demonstrated a very noticeable effect of water stress (Faghih *et al*., 2019).

On the physiological level, the water deficit induced a reduction in the temperature difference (T_{air}-$T_{foliage}$) and could reach -0.24 °C under the T3 treatment (60%). This corroborates the results found by Messaoudi and El Fellah, (2004) who showed that the application of a water deficit generates a concomitant closure of the stomata thus reducing the gas exchanges between the plant and the air, which resulted in an accumulation of heat in the leaves.

In terms of production, the number of fruits per tree was affected by deficit irrigation, which differs from the results obtained by Samperio *et al*. (2015a) who showed that the water restriction regime did not induce any significant difference in the total number of fruits per tree for the 'Angeleno' Japanese plum variety (Samperio *et al*., 2015b).

Likewise, a decrease in average fruit flesh weight was observed when water restriction became more severe. These findings support those made by Maatalla *et al*., (2015), who demonstrated a reduction in mean fruit flesh weight in two plum varieties when a 50% ETC irrigation was used during the fruit growth period. Our results also support the findings of Juan and Intrigliolo (2010), who demonstrated a reduction in flesh fruit weight of 11% when a water restriction regime was used in conjunction with two levels of medium and low tree stocking during phase II of fruit growth.

On the other hand, the results of the present study showed that it is possible to reduce the irrigation dose by 20% without significantly affecting the yield of the plum tree. Similar findings were made by Razouk and Kajji (2015), who demonstrated that the water regime of 50% ETc was the only one where peach tree yield was considerably lowered.

Deficit irrigation enhanced fruit quality qualitatively by raising sugar content and lowering the overall acidity of fruit juice. These findings are consistent with earlier findings in the literature, including those of Faghih *et al*., (2019) and Girona *et al*., (2003). The development of the mechanism of resistance to water restriction, namely the accumulation of sugar, could be used to explain this. The accumulation of soluble sugars is a strategy used by plants under

DOI: https://doi.org/10.17509/ajse.v4i2.64600
p- ISSN 2776-6098 e- ISSN 2776-5938

stress to withstand environmental restrictions, which explains the noticeably higher sugar content in fruits (Maatallah *et al*., 2015).

3.5. The principal information about the collected data

From the years 1999 to 2023, a comprehensive analysis of scholarly publications reveals a noteworthy surge in research dedicated to understanding the impact of sustained deficit irrigation on the vegetative growth of trees in semi-arid conditions. This investigation encompasses a total of 59 papers sourced from 35 different outlets. Among these publications, 74.57% constitute articles, 13.56% are review papers, 10.16% are book chapters, and 1.7% are conference proceedings. Intriguingly, a substantial 84.74% of these papers emerged within the last decade, showcasing a recent intensification of interest in this particular research domain. The quantity of papers, as a quantitative metric, serves as a barometer for the growing popularity and significance of this field. Diving deeper into the collaborative landscape, more than 57 authors actively contributed to the exploration of sustained deficit irrigation's impact on tree vegetative growth in semi-arid conditions. This collective effort yielded a compilation of 507 keywords (refer to **Figure 2A),** highlighting the multidimensional aspects under investigation. Consequently, the exploration of plant responses to water deficit and drought has become a focal point for publishers, various geographic regions, academic institutions, and researchers alike. Notably, the temporal evolution of scholarly contributions in this field is marked by distinct phases. In the period from 1999 to 2011, a modest count of 6 papers, constituting 10.17% of the total, addressed vegetative growth responses to sustained deficit irrigation. The subsequent years, from 2011 to 2017, witnessed a substantial upswing with 18 papers, representing 30.51% of the total output. This growth is further underscored by the average annual publication rate, which escalated from 0.5 papers during 1999-2011 to 3.6 papers during 2011-2015. The most remarkable surge occurred between 2016 and 2023, with an exponential rise resulting in the publication of 40 papers, accounting for an impressive 67.8% of the total corpus (see **Figure 2B**). In the last six years alone, the quantity of publications has surpassed the combined output of the preceding 14 years, indicative of a burgeoning scientific and societal interest in the pertinent issues addressed within this research niche. Examining the impact and dissemination of these research findings, the data reveals a substantial global citation count, with the pinnacle reaching 247 citations by November 11, 2023 (refer to **Figure 2C**). This underscores not only the quantity but also the influence of the research, affirming its significance within the broader scientific community. In summary, the analysis of publication trends and citation metrics indicates a burgeoning interest and recognition of the effects of sustained deficit irrigation on tree vegetative growth in semi-arid conditions, marking a substantial and impactful contribution to the scientific discourse.

3.6. Most relevant sources of information

The table provides a comprehensive snapshot of the key sources shaping the discourse on sustainable deficit irrigation and its impact on vegetative growth from 1999 to 2023. Topping the list is "Agricultural Water Management," exhibiting noteworthy influence with 11 papers, 23,940 total citations, and an impressive H-index of 152 (**Figure 3, Table 7**.). Following closely is "Agronomy," contributing significantly with 6 papers and an extensive total citation count of 44,161. "Scientia Horticulturae" and "Plants" also make substantial contributions, with 4 and 2 papers, respectively, each boasting considerable citation counts and H-indices. Notably, journals such as "Plant Physiology and Biochemistry" and "Water" underscore their impact through high H-indices of 146 and 85, respectively. The table reflects the prominence of

DOI: https://doi.org/10.17509/ajse.v4i2.64600
p- ISSN 2776-6098 e- ISSN 2776-5938

specific journals in shaping the scholarly landscape of sustainable deficit irrigation, offering valuable insights into the key sources driving research and discussions in this critical domain.

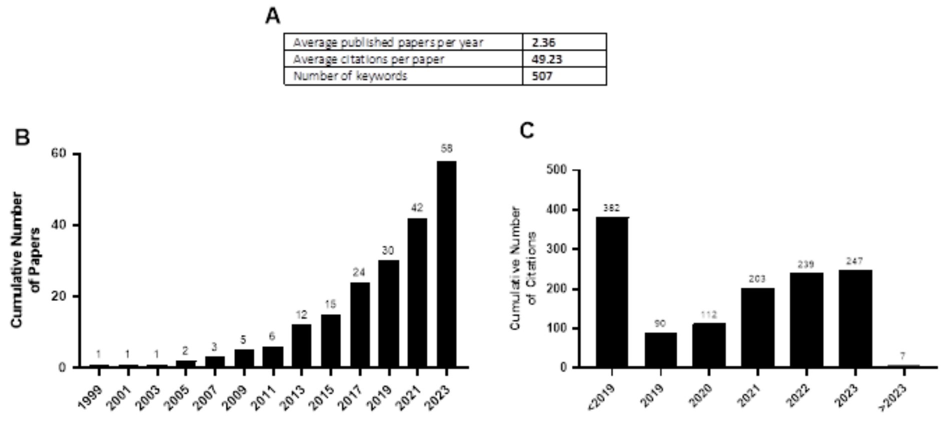

Figure 2. Information based on 1999-2023 studies on plant responses to sustained deficit irrigation, including **(A)** comprehensive information on the collected papers; **(B)** cumulative number of papers in 1999-2023; **(C)** cumulative number of citations during the study interval (1999-2023).

Figure 3. Co-occurrence of the most relevant source of the retrieved publication (1999-2023).

Table 7. The most relevant source information between 1999-2023 in papers relating to sustainable deficit irrigation and its impact on vegetative growth

Rank	Sources	NP	TC (2019-2022)	TP (2019-2022)	H-index	IF (2022)
1	Agricultural Water Management	11	23 940	2 229	152	6.7
2	Agronomy	6	44 161	8 545	67	3.7
3	Scientia Horticulturae	4	26 696	3 195	134	4.3
4	Plants	2	47 082	8 698	67	4.5
5	Plant Physiology and Biochemistry	2	19 802	1 931	146	6.5
6	Irrigation Science	2	1 339	203	80	3.0
7	International Journal of Fruit Science	2	1 377	386	26	2.4
8	Fruits	2	113	117	36	-
9	Water	2	74 947	13 633	85	3.4
10	Plant Archives	2	253	2 146	18	-
-	Others	24	-	-	-	-

3.7. Most Cited Papers and References

Traditionally, the quantity of citations for papers serves as a direct indicator of the global or local quality and impact of those papers. In this investigation, we have assembled a list of the top 20 most cited papers in the realm of research on plant responses to high temperature and drought, as detailed in **Table 8.**

Table 8. The most cited references for research papers on plant vegetative growth in response to deficit irrigation in semi-arid conditions from 1999 to 2023. DOI: Digital Object Identifier; TC: Total citations.

Rank	Author/date - Title	DOI	TC
1	Fernández *et al*. (2020) "Water use indicators and economic analysis for on-farm irrigation decision: A case study of a super high-density olive tree orchard"	10.1016/j.agwat.2020.106074	243
2	Fernández and Morino (1999) "Water use by the Olive tree"	10.1300/J144v02n02_05	162
3	Galindo *et al*. (2018) "Deficit irrigation and emerging fruit crops as a strategy to save water in Mediterranean semiarid agrosystems"	10.1016/j.agwat.2017.08.015	110
4	Chedlia *et al*. (2007) "Effects of water deficit on olive trees cv. Chemlali under field conditions in Arid region in Tunisia"	10.1016/j.scienta.2007.03.020	99
5	Jordi *et al*. (2008) "Evaluation of partial root-zone drying for potential field use as a deficit irrigation technique in commercial vineyards according to two different pipeline layouts"	10.1007/s00271-007-0098-4	68

Table 8 enumerates the most influential references in research papers centered on the vegetative growth of plants in response to deficit irrigation within semi-arid conditions, spanning the years 1999 to 2023. The top-cited papers, as identified by their Total Citations (TC), showcase the significant contributions in this field. Topping the list is Fernández *et al.* (2020), paper titled "Water use indicators and economic analysis for on-farm irrigation decision: A case study of a super high-density olive tree orchard" with a remarkable TC of 243, in which the authors advocate for a judicious application of the water productivity approach, addressing both biophysical and economic dimensions. Despite the increasing adoption of the water footprint approach, their examination underscores its limited advantage over the water productivity approach in evaluating on-farm water use. The study concludes with a case analysis of a super high-density olive orchard, demonstrating the use of economic water productivity indicators for improved decision-making (Fernández *et al.*, 2020). Following closely is Fernández and Morino's 1999 work, "Water Use by the Olive Tree" accumulating 162 citations, in which Fernández and Morino discussed the use of water efficiently by the olive tree, and advocated the notion of deficit irrigation. Other noteworthy contributions include Galindo *et al.* (2018) study, on "Deficit irrigation and emerging fruit crops as a strategy to save water in Mediterranean semiarid agrosystems" with 110 citations, in their work, the authors attempted to summarize the strengths and the weaknesses of adopting advanced deficit irrigation strategies, and discussed the response of some important emerging fruit crops, namely, jujube (*Zizyphus jujuba* Mill.), loquat (*Eriobotrya japonica* Lindl.), pistachio (*Pistacia vera* L.), and pomegranate (*Punica granatum* L.). Ben Ahmed *et al.* (2007), research on the "Effects of water deficit on olive trees Chemlali under field conditions in an Arid region in Tunisia" garnered 99 citations, and Marsal *et al.* (2008), evaluation of "Partial root-zone drying for potential field use as a deficit irrigation technique in commercial vineyards according to two different pipeline layouts" with 68 citations. This comprehensive

DOI: https://doi.org/10.17509/ajse.v4i2.64600
p- ISSN 2776-6098 e- ISSN 2776-5938

compilation serves as a valuable resource for researchers seeking to delve into pivotal studies shaping the discourse on plant vegetative growth in water-deficient environments.

3.8. Most Used Keywords

Keywords not only signify the trajectory of research but also reflect shifts in associated hotspots. In this investigation, we identified the 50 most frequently occurring keywords in studies on plant responses to elevated temperature and drought spanning the years 1999 to 2023 (refer to **Figure 4**). All keywords were clustered into 5 types in the co-occurrence network (**Figure 4**). From the bibliometric analysis, it was found that the top 50 keywords, were clustered into 6 clusters. There were 14 keywords in the red cluster, mainly including tree physiology, fruit growth, irrigation management, evapotranspiration, phenology, water use efficiency, and water use productivity. Thus, the red cluster's main research focus was on tree physiology under irrigation strategies, such as sustained deficit irrigation. The green cluster has 12 keywords (**Figure 4**), mainly including deficit irrigation, irrigation scheduling, regulated deficit irrigation, sustained deficit irrigation, phenols, anthocyanins, and water saving. Based on the cluster analysis, the strategies of irrigation became the main research goal, and researchers shifted their focus to plants' physiological and biochemical responses. Meanwhile, there were 10 keywords in the blue cluster: flowering, bud number, fruit set, proline content, shoot growth, soluble carbohydrates, etc. The clustering is concentrated in the context of the biochemical, and physiological responses of plants to different irrigation regimes. The yellow cluster had a total of 7 keywords, which mainly were drought stress, proline, underutilized crops, and partial root drying, among others. Finally, the remaining two clusters (purple, and light blue) clusters had a sum of 7 keywords of drip irrigation, water deficit, and yield.

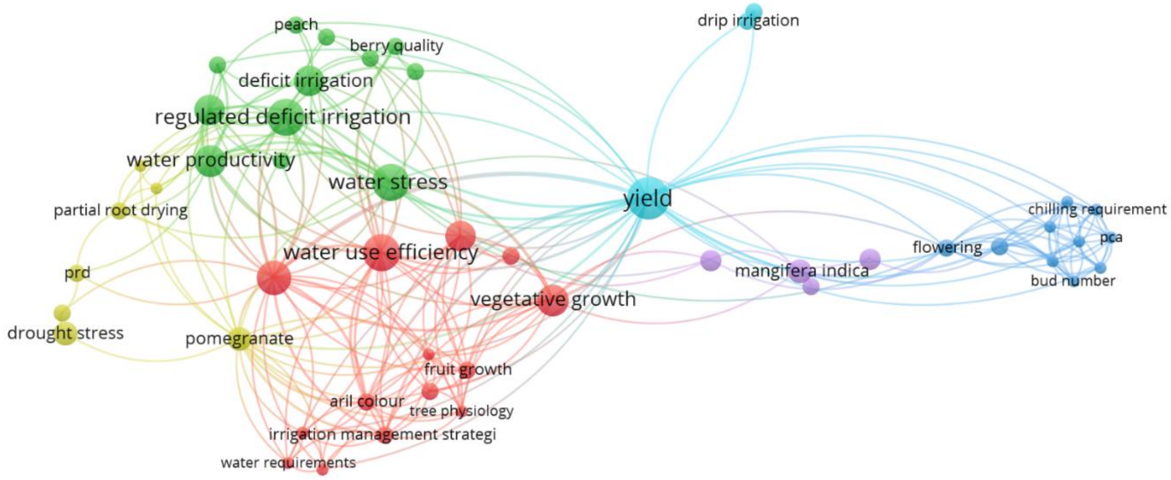

Figure 4. The examination of the top 50 keywords through a co-occurrence network analysis was conducted using the VOS clustering algorithm. Various clusters are distinguished by different colored regions, and connections between keywords are illustrated by red, blue, green, yellow, and purple lines. The magnitude of each node corresponds to the frequency with which the respective keyword appears in the articles.

4. CONCLUSION

Irrigation dose management is essential for regulating vegetative vigor and guiding both quantitative and qualitative production toward the optimal thresholds. We can conclude that the vegetative parameters significantly decreased as the level of water stress increased. Regarding the production metrics, there was a noticeable variation in the number of fruits, their average weight, and their yield per tree. When compared to the T0 control (producer), the yield for the T3 treatment (60% ETc) dropped by 44,09%. On the other hand, the quality parameter "sugar content" increased significantly in the event of water stress. However, this study also had some limitations that should be acknowledged and addressed in future research. First, the study was conducted over two years only, which may not be enough to capture the long-term effects of irrigation regimes on plum tree growth and productivity. Second, the study used only one plum variety, which may not be representative of other varieties with different responses to water stress. Third, the study did not measure other quality parameters such as firmness and flavor, which are also important for consumer preference and market value. Therefore, future research should extend the duration of the study, include more plum varieties, and evaluate more quality parameters to provide a more comprehensive and accurate assessment of the impact of irrigation regimes on plum tree performance and fruit quality. The bibliometric study provides quantitative and qualitative insights to deciders in the agriculture domain to evaluate the productivity and performance of the most productive countries.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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p- ISSN 2776-6098 e- ISSN 2776-5938