Asian Journal of Advances in Agricultural Research

12(3): 1-7, 2020; Article no.AJAAR.54498
ISSN: 2456-8864

The Effects of Regulated Deficit Irrigation on the Growth and Yield of Lettuce (*Lactuca sativa L.*) Grown in the Malkerns Area, a Region in the Kingdom of Eswatini (Southern Africa)

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Authors' contributions

This work was carried out in collaboration between both authors. Author MVD designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author SZ collected some of the data used in the study. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJAAR/2020/v12i330081
Editor(s):
(1) Dr. Tancredo Souza, Centre for Functional Ecology, University of Coimbra, Portugal.
Reviewers:
(1) Ana Maria Arambarri, National University of La Plata, Argentina.
(2) Bello Shehu Malami, Usmanu Danfodiyo University, Nigeria.
Complete Peer review History: http://www.sdiarticle4.com/review-history/54498

Original Research Article

Received 09 December 2019
Accepted 14 February 2020
Published 29 February 2020

ABSTRACT

Water is fast becoming an economically scarce resource in many areas of the world, including Eswatini, especially in arid and semi-arid regions. A study to test the response of lettuce (*Lactuca sativa L.*) to deficit irrigation was conducted in a field plot experiment at the Faculty of Agriculture at the Luyengo Campus of the University of Eswatini. The treatments were laid in a randomized block design. The experiment consisted of four treatments, each replicated three times. Treatment 1 (T1) was irrigated daily, treatment 2 (T2) irrigated after 2 days, treatment 3 (T3) irrigated after 3 days and treatment 4 (T4) irrigated after 4 days. A total of 30 lettuce plants were planted in each treatment. The lettuce was grown for a period of four weeks and then harvested whole. Yield parameters measured included the number of leaves, the plant height (cm), leaf area index (LAI), and the fresh and dry head mass (grams). Significant differences ($P < 0.01$) between treatments T3 and T4 were obtained for fresh and dry lettuce head mass. The highest water use efficiency and crop water productivity were obtained in treatment T3. It was concluded that irrigating lettuce every three days was the best option for the area under the conditions of the experiment.

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Keywords: Regulated Deficit Irrigation (RDI); Water Use Efficiency (WUE); lettuce; yield.

1. INTRODUCTION

Deficit irrigation (DI) is a well-accepted practice to optimize and or increase water use, thereby saving cost, by allowing crops to withstand mild water stress with no or only marginal decreases in yield and quality traits [1-3]. It is an optimization strategy whereby net returns are maximized by reducing the amount of irrigation water; crops are deliberately allowed to sustain some degree of water deficit and yield reduction. The deliberate restriction of irrigation water may be a legitimate management strategy to manipulate crop water use [4]. Regulated deficit irrigation (RDI) on the other hand is the application of irrigation water less than full crop water requirements [5]. It is an irrigation strategy based only on a reduction of irrigation amounts during certain plant cycle phases.

The application of less than full crop water requirement or skipping early vegetative stage irrigation has been shown to result in maximizing water use efficiency (WUE) in C_3 crops such as cotton (*Gossypium herbaceum*), wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) or C_4 crops such as maize (*Zea mays L.*) and sugarcane (*Saccharum officinarum* L.) [6] (Karam, et al. (2003); [7,8]. Many other researchers have reported beneficial effects of deficit irrigation on a variety of crops, grains, fruits and trees [9-11] vines (*Vitis sp.*) [12], rice (*Oryza sativa L.*) [13,14] citrus (*Citrus spp.*) [15] and trees [16].

According to Zhang and Owesis [17] crops under deficit irrigation showed comparable yields to that of well-watered crops due to the development of deep root system that maintains leaf water potential and reduced stomatal opening and transpiration during mid-day high temperatures. Proper application of this water-saving technique with better soil and nutrient management [18] also facilitate root system development, which is strongly linked with yield and consequently higher WUE.

With the increasing demand for water from other sectors, it is a must to improve WUE in agriculture [19]. The mix with climate change to this technology only intensifies the demands for efficient use of water in agriculture. According to Jat, et al. [19], climate change will burden currently irrigated areas and may even outstrip the current irrigation capacity due to general water shortages. Farmers with no or less access to irrigation water are clearly most vulnerable to climate change. Therefore, there is need for technologies and investments that improve WUE, access to irrigation water, or to find ways to improve income with less secure and more variable access to water. With dwindling water availability [20], a "deficit irrigation" strategy, in which irrigation is applied at the drought-sensitive growth stages of a crop, can make a substantial difference in the productivity of areas having limited access to irrigation water. Agriculture is the largest freshwater user on the planet, consuming more than two thirds of total withdrawals [21].

In a literature review by Capra, et al. [1] and Du, et al. [22], regulated deficit irrigation (RDI) has been identified as one of the key water-saving technologies in agriculture. The early-season partial root-zone irrigation resulted in better use of soil water reserves through improved root to shoot ratio [23], increased root biomass [24] and enhanced root activity [25]. However, there is a lack of detailed information on the definition, scientific principles, or specific practices of RDI [20]. Little is known about how this technology may be practiced effectively in real-world agriculture [26].

Lettuce (*Lactuca sativa L.)* is one of the most important salad vegetables of the world that is widely cultivated [27] due to the shortness of its vegetation time and its potential to return profit, nutritional value and production potential [28]. A fraction of the soil's readily available moisture (%RAM) was used as treatments, that is, the sustained deficit irrigation method [26] instead of targeting certain plant growth stages. The real challenge is to establish RDI on the basis of delivering sustained or increased crop productivity, while saving irrigation water and enhancing WUE. This would help conserve water and help increase the area irrigated in the rural areas of the country where water is a scarce resource.

The objective in this research was to determine the optimum reduced deficit irrigation strategy that would result in no significant differences in overall lettuce yield to the full irrigation strategy.

2. MATERIALS AND METHODS

In order to test the response of lettuce (*Lactuca sativa*) to deficit irrigation, a field plot experiment using a randomized block design was established in the Agricultural and Biosystems Engineering farm of the University of Eswatini at Luyengo campus (Southern Africa). The farm is located in the Middleveld of Eswatini at 21º34′S and 31º12′E at an altitude of about 730 m above sea level [29]. The experiment consisted of four treatments, each replicated three times in the open field conditions. The temperature was the same for all treatments. Treatment 1 (T1) was irrigated daily, treatment 2 (T2) irrigated after 2 days, treatment 3 (T3) irrigated after 3 days and treatment 4 (T4) irrigated after 4 days. A total of 30 lettuce plants were planted in each treatment.

The daily crop water requirements of lettuce were determined using the FAO 56 Penman – Monteith equation [30]. Drip irrigation was used as the best method for water application, with the gross amount of water applied being 4.8 mm per irrigation per day.

2.1 Transplanting

Seedlings were obtained from Vickery Seedlings, a local company that supply ready to be planted seedling located at Malkerns. The plants were spaced 30 cm apart along the drip line and the laterals were spaced 80 cm apart. The soils are dark loam to sandy loam and the average daily maximum temperatures are 30ºC and the minimum temperature is 14ºC. Basal fertilizer dressing was done using N:P:K; 2:3:2 (22) fertilizer at a rate of 15 g per seedling. Top dressing was done using limestone ammonium nitrate (LAN – 28% N) at a rate of 10 g per plant three weeks after transplanting. Weeding was done by hand using a hand hoe.

2.2 Water Management

Self-compensating, 16 mm dripper lines with emitter spacing of 0.30 m along the lateral were used each delivering 2.0 liters per hour. Irrigation was done twice a day, in the morning and in the afternoon for thirty minutes each.

2.3 Measured Parameters

Parameters measured included the number of leaves, the plant height (cm), the total amount of water applied (mm) and the lettuce fresh and oven dry mass (grams). The leaf area index (LAI) was calculated using the method described by Karam, et al. [31].

The water use efficiency (WUE) and the crop water productivity (CWP) were calculated from the lettuce yield and the water applied per treatment following the method described by Chai, et al. [20] and Senyigit and Kaplan [27].

3. RESULTS AND DISCUSSION

3.1 Number of Leaves, Plant Height and Leaf Area Index

Graphs showing the treatment effects on the measured parameters; the number of leaves, the plant height (cm) and the leaf area index (LAI) are shown in Fig. 1, Fig. 2 and in Fig. 3 respectively.

The treatment irrigated every three days (T3) consistently showed more leaves throughout the growing period compared to the other treatments. The stressed treatment (T4), irrigated every after four days, had the least number of leaves. Irrigating every day did not benefit the lettuce crop compared to having one or two days without irrigation.

The results for the plant height (cm) and the leaf area index (LAI) were similar to those of the average number of leaves.

3.2 Yield Parameters

Yield parameters measured included the lettuce fresh mass (grams), oven dry mass (grams) and the total amount of water applied (mm). Calculated from the lettuce yield and water applied, were the water use efficiency (WUE) and the crop water productivity (CWP).

The water use efficiency was calculated as the yield per millimeters of water applied and the crop water productivity as the yield per volume of water applied. The results are summarized in Table 1.

A test of significant differences was done on the fresh and dry weight of lettuce at harvest. There were highly significant differences ($P < 0.01$) between treatment T4 and the other treatments. The highest yield was obtained from treatment T3 which was larger than the other treatments. Treatment T4 had significant smaller yields than all the other treatments. These results were similar to those obtained by other researchers, [32,27,2], even though they had a slightly different research approach. Santosh, et al. [33] in their experiment observed that higher lettuce yields were obtained in treatments that were irrigated at 100% water requirement as compared to those that were either over irrigated and or under irrigated. Kirnak, et al. [4] also reported similar results on lettuce grown under an unheated greenhouse environment. The WUE results reported here are expressed in terms of yield and water application while, Ors and Suarez [34] found different WUE in spinach when they measured water consumption under stress conditions.

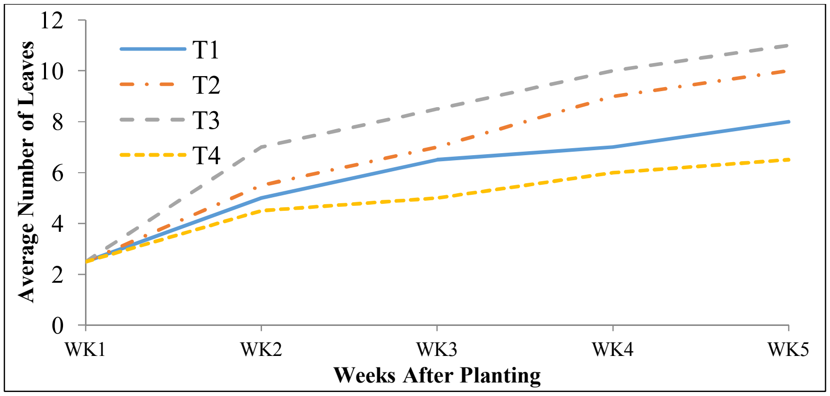

Fig. 1. The change in the average number of leaves of the lettuce plant with the weeks after planting

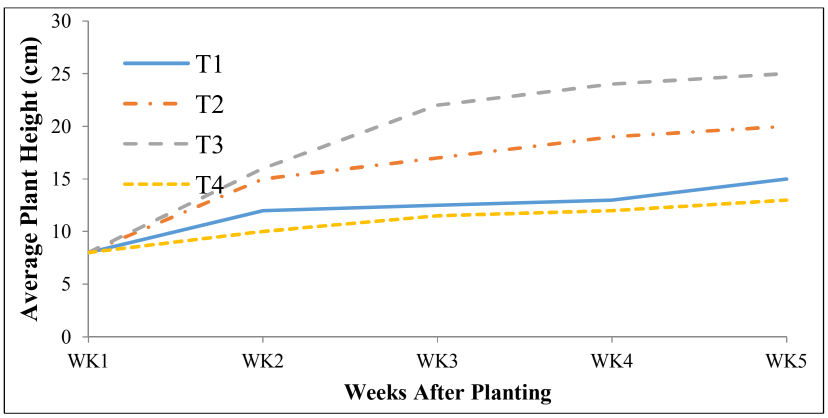

Fig. 2. The change in the average plant height (cm) of the lettuce plant with the weeks after planting

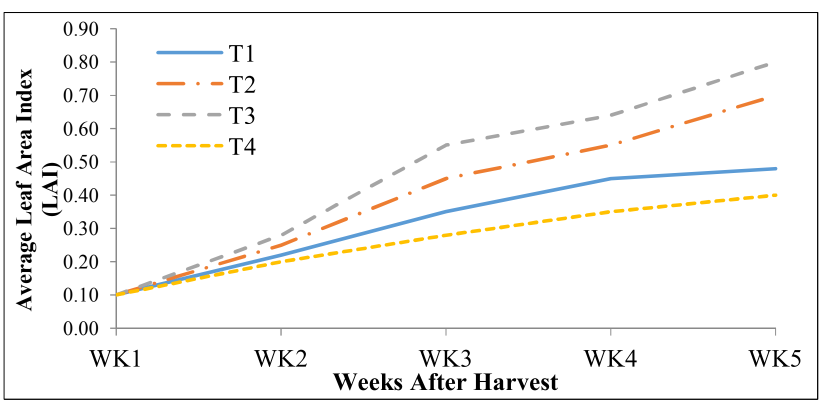

Fig. 3. The change in the average leaf area index (LAI) of the lettuce plant with the weeks after planting

Table 1. Average fresh and dry weight, irrigation water applied and calculated water use efficiency (WUE) and crop water productivity (CWP) for the different lettuce treatments

Treatment	Average fresh weight (g)	Average dry weight (g)	Irrigation water applied (mm)	WUE (g/mm)	CWP (g/m^3)
T1	239.2a	13.4a	303.6	0.79	0.079
T2	266.1a	13.4a	147.2	1.81	0.181
T3	319.6a	17.4a	82.2	3.89	0.389
T4	154.7b	8.8b	64.4	2.40	0.240
Significance	**	**			

4. CONCLUSION

It can be concluded from the findings of the research that where water is limiting, there is no need to irrigate lettuce every day or second day in the study area. Irrigating every three days would result in similar but optimum yields. However, irrigating every after four or more days would result in significantly lower yields than expected, which could be a loss to the farmer.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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