Science Arena Publications
Specialty Journal of Agricultural Sciences
Available online at www.sciarena.com
2017, Vol, 3 (2): 14-18

The Effects of Drought Stress and Plant Density on Forage Yield of Artichoke (*Cynara scolymus* L.)

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Abstract: *In order to study the effect of drought stress and plant density on the forage yield of Artichoke, a study was carried out in the Research Farm of the Agriculture School, Islamic Azad University, Maybod, in April 2015. This experimental study was performed as a split plot in randomized complete block design with three replications. The factor of water stress was applied at three levels consisting of 4, 8 and 12 cm using class A evaporation pan and the factor of plant density was considered 8, 10 and 12 plants/m² (with the distances of 30, 40 and 50 cm in a row and the distance between the rows were 50 cm). The characteristics of fresh weight, dry weight, percentage of protein, RWC, LWP and WUE are studied. The results show that the effects of drought stress are significant on fresh weight, dry weight and LWP and the effects of plant density have importance on percentage of protein, fresh weight and LWP. The interaction between drought stress and plant density plays a major role just on the percentage of protein. Increased water stress causes reduction in the fresh weight, dry weight, percentage of protein, RWC and LWP and increase in WUE. Among the treatments, the highest yield is related to the control irrigation and 10 plant/m² .*

Keywords: *Artichoke, Cynara scolymus, water stress, plant density, forage yield.*

INTRODUCTION

In Iran, total area of the ranges is estimated about 90 million hectares by which 10 million tons of forage is annually produced. Production of livestock products directly depends on cultivation of forage plants and their production and it is necessary to develop an accurate and principal plan for production of forage. The yield of such plants enhances through increasing in the cultivation area and using breeding methods [1]. Artichoke (*Cynara scolymus* L.) belongs to *Compositae* and its perennial plant. It is sensitive to cold and is native to the South Europe and the Mediterranean region [2]. Water stress is the lack of sufficient moisture to grow the plant naturally and complete the life cycle. Water stress reduces agricultural products and this decreased yield can be due to reduced moisture of the soil and air. Severity of water stress is a criterion to assess the amount of stress entered into a plant canopy because of an adverse environmental factor, based on the amount of damage to yield [3]. Desirable plant density is a density in which all environmental factors (water, air, light and soil) are completely used while the competition between and within the plants is minimal. At lower density, maximum levels of environmental factors are not used such as light, moisture, and nutrition; and at higher density, strong competition decreases the total yield [4]. Jafari and Jalali [3] studied the effects of water stress and plant density on the yield and its components of maize and found that water stress and plant density have significant effects on the yield and yield components. In terms of seed yield, the density of 75000 plants/ha was the best density. The lowest seed yield was related to the stress treatment at flowering stage. In a research, effects of drought stress and number of harvesting on some of the yield indicators of *Cynara scolymys* were investigated [5]. The results showed that during the vegetative stage, the effect of stress was significant only

on leaf number, including that the *Cynara scolymus* may have better resistance to drought stress during the vegetative stage. Biglari et al. [6] reported that with increasing plant density, seedling growth of *Cynara scolymus* increases, as a result, this plant requires higher densities and higher densities have an effective effect on other growth factors. Emam and Ranjbar [7] reported that severe drought stress caused a significant reduction in seed yield and high density resulting in a significant increase in seed yield of maize. Daneshian and Jabari [8] studied the effects of limited irrigation and plant density on morphological characteristics and seed yield in sunflower hybrid. Maximum seed yield was obtained after 50 mm evaporation and at various irrigation levels, maximum grain yield was obtained from the density of 12 plant/m^2. Khalili et al. [9] examined the effects of plant density on the qualitative and quantitative yield of forage Sorghum hybrids and found that the highest fresh and dry forage yield and leaf/stem ratio were obtained at the density of 350000 plants/ha. Plant density had no significant effect on the percentage of protein.

The purpose of the present study was to evaluate optimum plant density and drought stress on forage yield and protein percentage of *Cynara scolymus* in Maybod, Iran.

Materials and Methods

In order to study the effects of water stress and plant density on the forage yield of Artichoke, a study was conducted in the Research Farm of the School of Agriculture, Islamic Azad University, Maybod Branch, in the crop year 2015. The farm lies at latitude 54° 2' 10" N and longitude 32° 14' 45" E and elevation of 1120 m. This experimental study was carried out as a split plot in randomized complete block design with three replications. Drought stress was applied as the main factor at three levels consisting of 4 (control), 8 (mild stress) and 12 (severe stress) cm using class A evaporation pan and plant density, as the secondary factor, was considered 8, 10 and 12 plants/m^2 (with the distances of 30, 40 and 50 cm in a row and the distance between the rows was considered 50 cm). Drought stress was applied after 5-leaf stage. Before land preparation to determine the amount of required fertilizer, a specimen derived from soil was analyzed (Table1) and according to the recommendation of the Soil and Water Institute, the required fertilizer was added.

Table1. Physicochemical characteristics of soil

Soil texture	Silt	Clay	Sand	K(ppm)	P(ppm)	Total N %	Organic Carbon%	pH	E.C. dS/m
Sandy loam	24.6	19.6	55.8	245	13	0.009	0.35	7.37	6.68

According to weather data, low and irregular rainfall and extreme fluctuations, temperature, high evaporation, low relative humidity and long period of heat, Maybod City is considered as arid region (Table 2).

Table2. Climatic characteristics of the research site

Month	Total monthly precipitation (mm)	Relative humidity (%)	Evaporation (mm)
April	15.7	23	217.7
May	0.7	18	318.2
June	0	13	454.7
July	0	13	495.9
August	0	14	420.6
September	0	14	411.4

After plowing, leveling and ridging operations, based on soil test, in each plot, 200 kg/ha of urea fertilizer was used in two times (plating time and mid-vegetation growth (100kg/ha in each time)). The planting date was April 19th. Each experimental plot was 6 m^2 and included 4 sowing lines. In order to measure fresh and dry weights, 7 plants were randomly selected from each plot. 7 plants were selected from each plot and the leaf's relative water content (RWC) and its water potential (LWP) were determined by dipping in solutions with different potentials. In this test, water-use efficiency was obtained by dividing the biological yield to the volume of consumed water. The percentage of leaf protein was determined using Kjeldahl method. Finally, experiment data were analyzed by MSTAT-C software and the mean values were compared by the Duncan test.

Results

Fresh and dry weight

According to the results of variance analysis (table3), the effects of different treatments of water stress and density were meaningful on the fresh weight while interactions were not remarkable. According to table 4, the lowest fresh weight (26.2 ton/ha) was related to the treatment of severe drought stress and the highest fresh weight (68.3 ton/ha) was related to control. Compared to control, in the treatment of the mild water stress, the yield decreased by %23.91. Different plant densities had different effects on fresh weight and the differences between them were significant. The lowest fresh weight (41.4 ton/ha) was related to 12 plant/m^2 and the highest fresh weight (51.3 ton/ha) was related to 8 plant/m^2.

The influence of drought stress was effective on the dry weight although the effect of density was not significant (Table3). According to table 4, the highest dry weight was related to the control irrigation and the density of 12 plant/m^2 (8.8 and 6.5 ton/ha, respectively) and the lowest dry weight was related to severe drought stress and 8 plant/m^2 (3.5 and 5.2 ton/ha, respectively).

Table3. Variance analysis of studied characteristics of Artichoke

Variable	df	Fresh weight	Dry weight	RWC	WUE	LWP	Protein%
Rep.	2	104.625	1.314	64.124	0.315	0.013	0.172
Water stress	2	4016.20*	64.815**	618.93*	$0.326^{n.s}$	3.202**	$4.65^{n.s}$
Main error	4	101.07	3.971	86.993	0.027	0.056	0.92
Density	2	220.20*	$3.664^{n.s}$	$34.65^{n.s}$	$0.184^{n.s}$	0.231*	65.22**
water stress × density	4	$13.05^{n.s}$	$0.288^{n.s}$	$8.326^{n.s}$	$0.010^{n.s}$	$0.019^{n.s}$	10.80**
Secondary error	12	50.14	1.059	25.877	0.063	0.044	0.63
CV (%)		15.31	17.45	7.38	19.19	10.32	6.35

* and **: it is meaningful at significance level of %5 and %1, respectively.
n.s.: it is not meaningful

Leaf's Relative Water Content

The results of variance analysis showed that the effects of water stress were significant on the RWC while the effect of density was not crucial on it (Table3). According to table 4, the lowest RWC (%60.20) was related to the severe drought stress and the highest RWC (%76.71) was also related to control, the lowest RWC (%66.64) was related to the density of 12 plant/m^2 and the highest RWC (%70.20) was related to the density of 8 plant/m^2.

Leaf Water Potential (LWP)

The results of variance analysis showed that the effects of water stress were meaningful on the leaf water potential at the significance level of %1 while the effect of density was important on it at the significance level of %5 (Table3). According to table 4, the least LWP (1.478 MPa) was related to the severe water stress, the greatest LWP (2.661MPa) related to control, and also, the least LWP (1.876 MPa) related to the density of 12 plant/m^2 and the highest LWP (2.194 MPa) related to the density of 8 plant/m^2.

Water-use efficiency

The results of variance analysis showed that the treatments of water stress, plant density and the interaction between them had no significant effects of the water-use efficiency of the plant (Table3).

Protein

According to the results of variance analysis (Table 3), the effects of water stress were not significant on the percentage of protein while the effects of plant density were dominant on it. The interaction effect was prominent. According to Table4, the lowest (%11.82) and highest (%13.25) percentages of protein were related to the treatments of severe and mild water stress, respectively. Also, the lowest (%10.89) and highest (%15.64) percentages of protein were related to the densities of 12 and 8 plant/m^2, respectively.

Table4. Mean comparison of the main effects and interaction effect of drought stress×density on the studied characteristics of Artichoke

drought stress(cm from evaporation pan)							
Treatment		Fresh weight ton/ha	Dry weight ton/ha	RWC%	WUE Kg/m^3	LWP Mpa	Protein%
4		68.3a	8.8a	76.71a	1.103a	2.661a	12.52ab
8		44.4b	5.3b	69.79b	1.327a	1.939b	13.25a
12		26.2c	3.6b	60.20c	1.481a	1.478c	11.82b
plant density (plant/m^2)							
12		51.3a	6.5a	66.64a	1.450a	1.876b	10.89b
10		46.1ab	5.9ab	69.86a	1.296ab	2.008ab	15.64a
8		41.4b	5.2b	70.20a	1.165b	2.194a	11.07b
drought stress×density							
4	12	73.1a	9.6a	74.47ab	1.19abc	2.53a	9.36f
	10	68.1a	9.0a	77.66a	1.12bc	2.54a	15.98a
	8	64.2ab	9.9a	78.01a	0.98c	2.90a	12.32d
8	12	50.9bc	6.0b	69.44b	1.50ab	1.77bcd	13.96c
	10	45.1cd	5.4bc	69.65b	1.34abc	1.95bc	15.98a
	8	37.0de	4.5bcd	70.27b	1.13bc	2.09b	9.91f
12	12	29.9e	4.0cd	56.02d	1.65a	1.32e	9.35f
	10	24.7e	3.4d	62.26c	1.41abc	1.52de	15.04b
	8	23.8e	3.3d	62.32c	1.37abc	1.58cde	11.06e

Note: There is no significant difference between those means with the same letter.

Discussion

Drought stress had significant effect on fresh and dry forage yield of *Cynara scolymus* so that increasing drought stress reduced the fresh and dry forage weight. The effects of different densities had various influences on fresh weight and the differences between them were significant. In lower density, accessing to the water is higher and therefore, the fresh weight becomes greater. In cases where aerial parts are economically important, dense cultivation and creation of large leaf area can be effective in increasing dry weight. In the present study, plant density were not effective on dry yield. Jalini and Zarehpour [10] illustrated significant differences between different levels of irrigation in terms of yield.

The highest leaf RWC was obtained from the control treatment. Increasing irrigation rate surged the osmotic potential and because of this, the plant absorbed more water [11]. In wheat genotype, increasing drought stress declined the leaf chlorophyll content and its relative water content. In wheat, the first and most sensitive reaction to drought stress was reduction in cellular turgesence and decline in growth (especially elongation).

The effects of drought stress were not remarkable on water use efficiency. Decreasing water content of irrigation increased water use efficiency. Alizadeh [12], Jalini and Zarehpour [10] asserted that the treatments of irrigation had significant effects on water use efficiency and their results were not consistent with the result of the present study.

The results illustrated a correlation between irrigation and LWP. Increasing irrigation rate rose the leaf potential. The results are consistent with Shoban et al. results [13]. There are remarkable differences between various irrigation regimes in terms of leaf water potential at the significance level of %1. Studying the trees under drought stress shows that LWP reduces under drought stress.

In addition to reduced dry matter yield, drought stress changes the percentage of protein which plays an important role in the quality of forage. In a plant like millet, drought stress reduces production and storage of photosynthetic materials. These results show that the response of crop yield extremely depends on the severity of stress, plant species and developmental stages. In the millet, the effects of different irrigation regimes are not effective on percentage of nitrogen in leaf. In the maize, it was observed that water stress affects the metabolism of protein and reduces the growth of seedling. Due to the temporary stress, photosynthetic materials were reduced and this caused to low accumulation of soluble materials [14].

Conclusion

According to the results of interaction effects, the highest forage yield and percentage of protein were obtained from 10 plant/m² and 4 cm evaporation out of evaporation pot. In this treatment, protein yield is 1.43 ton/ha. It's highest protein yield from all of treatments.

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