BRAZILIAN JOURNAL OF BIOLOGY®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Effect of deficit irrigation on yield and water use efficiency of onion (*Allium cepa* L.) in arid zones

Efeito da irrigação deficitária na produtividade e na eficiência do uso da água da cebola (*Allium cepa* L.) em zonas áridas

A. M. Alzoheiry[a,b]*

[a] Qassim University, College of Agriculture and Food, Department of Agricultural and Biosystems Engineering, Burydah, Saudi Arabia
[b] Damanhur University, Faculty of Agriculture, Department of Natural Resources and Agricultural Engineering, Damanhour, Egypt

Abstract

Onion is considered a major vegetable crops all over the world. In arid zones water deficit can affect the yield of crops such as onion. Through this research, four levels of irrigation were used (100% of the calculated crop evapotranspiration ***ET100***, 80% of the calculated crop evapotranspiration ***ET80***, 70% of the calculated crop evapotranspiration ***ET70***, and 60% of the calculated crop evapotranspiration ***ET60***) in combination with two levels of fertilization (100% of the recommended fertilization ***NPK100*** and 75% of the recommended fertilization ***NPK75***). The total yield (fresh weight) of each experimental unit were harvested, weighed, and then sorted into marketable and unmarketable and both the overall and the marketable water use efficiency were calculated. The results were statically analyzed using the ANOVA analysis and the means were compared using the Duncan LSD method. Principle Component Analysis (PCA) was used to classify the treatments into clusters. Results used indicated that the water use efficiency of onion increase if a mild drought stress (85% of the calculated crop evapotranspiration) were exerted on the plants at 100% of the recommended fertilization level. The availability of fertilizers helps the plant manage the drought stress while keeping an adequate level of yield. The lack of fertilizers combined with the drought stress resulted in rapid decrease in the yield thus decreasing the water use efficiency. The recommended water deficit level under these circumstances would be 88.9% of the plant water requirements.

Keywords: deficit irrigation, onion, water use efficiency.

Resumo

A cebola é considerada uma das principais hortaliças em todo o mundo. Nas zonas áridas, o déficit hídrico pode afetar o rendimento de culturas como a cebola. Nesta pesquisa foram utilizados quatro níveis de irrigação (100% da evapotranspiração calculada da cultura ET100, 80% da evapotranspiração calculada da cultura ET80, 70% da evapotranspiração calculada da cultura ET70 e 60% da evapotranspiração calculada da cultura ET60) em combinação com dois níveis de adubação (100% da adubação recomendada NPK100 e 75% da adubação recomendada NPK75). A produção total (peso fresco) de cada unidade experimental foi colhida, pesada e, em seguida, classificada em comercializável e não comercializável e calculada a eficiência geral e a comercializável do uso da água. Os resultados foram analisados estatisticamente pela análise ANOVA, e as médias foram comparadas pelo método Duncan LSD. A Análise de Componentes Principais (PCA) foi utilizada para classificar os tratamentos em clusters. Os resultados utilizados indicaram que a eficiência do uso da água pela cebola aumenta se um leve estresse hídrico (85% da evapotranspiração calculada da cultura) for exercido sobre as plantas a 100% do nível de fertilização recomendado. A disponibilidade de fertilizantes ajuda a planta a gerir o estresse hídrico, mantendo um nível adequado de rendimento. A falta de fertilizantes, combinada com o estresse hídrico, resultou numa rápida diminuição do rendimento, diminuindo assim a eficiência do uso da água. O nível de déficit hídrico recomendado nestas circunstâncias seria de 88,9% das necessidades hídricas da planta.

Palavras-chave: déficit hídrico, cebola, eficiência no uso da água.

1. Introduction

Onion a major vegetable crops and consumed all over the world. The annual onion production worldwide is about 75,000,000 metric tons. Egypt is the fourth top onion producing country with total onion cultivated area of 105,000 ha and an annual production of 2,200,000 metric tons (Sen Nag, 2017). Onion yield is sensitive to water deficit in soil. Semida et al. (2017) emphasised the sensitivity of onion production to water

*e-mail: a.ezoheiry@qu.edu.sa; alzoheiry@gmail.com
Received: December 28, 2023 – Accepted: March 13, 2024

deficit they used salicylic acid to enhance the ability of plant to cope with the drought stress. Bekele et al. (2023) studied the effect of drought on onion yield they found the drought stress in the final stages of growth to reduce the yield by forcing early maturation of the onions. Bertino et al. (2022) concluded that fertilization plays a role in the amount of total yield produced by onion plant under different conditions. Abouabdillah et al. (2022) studied the effect of deficit irrigation on vegetative, Eco physiological and yield parameters of onion under Mediterranean conditions they reported significant effects of irrigation level on the ecophysiological parameters, such as Proline content, stomatal conductance and leaf temperature. Zaky, et al. (2022) said that injection with the nano NPK rate (23.81 L ha^{-1}) and the mineral NPK (75% NPK and 100% NPK) achieved the highest values of total bulb yield (52.36 and 52.02) ton ha^{-1}. El-Desuki et al. (2006) found that the reduction of the NPK fertilization from 100% of the recommended to 40% of the recommended decreased both the amount and the quality of onion bulbs. Naghdyzadegan Jahromi et al. (2023) examined the water use efficiency of plants at different levels of irrigation. He found that the highest water use efficiency was achieved at 75% from the plant water requirement. Abdelkhalik et al. (2019) recommended 75% of the fully irrigation requirements as a successful irrigation management strategy for onion production under Mediterranean conditions. Kumar et al. (2007) pointed out the lack of information about onion irrigation management in semi-arid climates and different types of irrigation systems. He also reported that the irrigation management should vary according to the soil-agro-climatic conditions. Thus, the aim of this work is to determine the effect of 4 levels of irrigation and two levels of fertilization on the onion yield, marketable yield, and water use efficiency under arid zones conditions.

2. Materials and methods

2.1. Plantation and management

Pegou onion was grown for two years at the same season each year. The experimental farm had a clay loam soil with a bulk density of 1300 kg m^{-3}. Some of the soil physical properties are shown in Table 1.

The seeds of onion were sown in the end of April for the two consecutive years of the study. When the average height of the plants was about 15 cm. The plants were transplanted to the permanent field. Plants were spaced 15 cm in between in the same row with row spacing of 50 cm. the drip irrigation line was 16 mm in diameter with 4 l h^{-1} pressure compensating inline emitters. The experimental design was a randomized complete block design with 4 levels of irrigation as the blocks (100% of the calculated crop evapotranspiration *ET100*, 80% of the calculated crop evapotranspiration *ET80*, 70% of the calculated crop evapotranspiration *ET70*, and 60% of the calculated crop evapotranspiration *ET60*), and two fertilization level under each block (100% of the recommended fertilization *NPK100 (250 Kg ha^{-1})* and 75% of the recommended fertilization *NPK75 (187.5 Kg ha^{-1})*). Each combination of irrigation and fertilization were replicated three times. The total number of experimental units were 24. The length of each experimental unit was 16 m and a separating distance of 1.5 m was left blank between the experimental units. The crop evapotranspiration was calculated using the crop coefficient and the lengths of the growing stages recommendations of the *FAO Penman-Monteith* paper (FAO 56 - Allen et al., 1998) & *CROPWAT* software. The total crop evapotranspiration *ETc* was then calculated as m^3 ha^{-1}. Table 2 shows the average monthly weather data for the location of the experimental field. The seasonal amounts of water added to the experimental units are shown in Table 3.

Table 1. Some physical properties of the experimental field soil.

Depth, cm	Particle size distribution, %			Texture class	FC, %	PWP, %
	Sand	Silt	Clay			
0-30	28.2	34.1	37.7	Clay loam	35.2	21.1
30-60	22.3	38.0	39.7	Clay loam	37.5	22.2

Table 2. Monthly climatic data of the experimental field zone.

Climatic parameters	Months				
	May	Jun.	Jul.	Aug.	Sep.
T_{min}, ºC	13.6	16.6	18.8	19	17.8
T_{max}, ºC	24.0	27.2	28.1	28.1	26.3
RH, %	59.0	58.9	61.3	62.3	62.3
Wind speed, m s^{-1}	3.8	4.16	4.57	4.38	2.52
Sunshine, h	10	12	12	12	10

Table 3. Seasonal amounts of irrigation water, m^3 ha^{-1}.

Years No.	*ET100*	*ET80*	*ET70*	*ET60*
One	5640	4512	3948	3384
Two	5820	4656	4074	3492

2.2. Measurements and calculated parameters

2.2.1. The total yield (Y)

The total yield (fresh weight) of each experimental unit were harvested, weighed, and then sorted into marketable and unmarketable. The sorting of the marketable and unmarketable yield was done according to the criteria described by Tolossa (2021). The total yield and each category were then scaled to the hectare level.

2.2.2. Water use efficiency (WUE), Tolossa (2021)

The water use efficiency (*WUE*) was calculated as in Equation 1:

$$WUE = \frac{Y}{IRR} \quad (1)$$

where: *WUE* = water use efficiency, kg m^{-3}; *Y* = total yield, kg; *IRR* = total amount of irrigation applied, m^3.

2.2.3. Marketable water use efficiency (MWUE) Tolossa (2021)

The marketable water use efficiency (*MWUE*) was calculated from Equation 2

$$MWUE = \frac{MY}{IRR} \quad (2)$$

where: *MWUE* = The marketable water use efficiency, kg m^{-3}; *MY* = The total fresh weight of the marketable yield, kg.

2.3. Statistical analysis

The results were statically analyzed using the ANOVA analysis and the means were compared using the Duncan LSD method. Multiple regression analysis was performed to determine the effect of the treatments and the PCA was performed using XLSTAT software version 2019.2.2.59614, Addinsoft (2019), Boston, MA, USA. PCA is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components (PCs). Kaiser-Meyer-Olkin (KMO) Principal component analysis was used to categorize the treatments into clusters. It was used to determine if the PCA can be used or not (data sets with KMO higher than 0.5 can be analyzed using PCA Shrestha (2021))

3. Results and discussion

3.1. The total yield

The values of the total yield are summarized in Table 4. It can be seen that the total yield of onion decreased with the increase of water deficit for all levels of deficit and under all the tested levels of fertilization. The total yield decreased from 27.73ton ha for the $ET_{100}NPK_{100}$ treatment to 12.82ton ha^{-1} for the treatment $ET_{60}NPK_{100}$ in the first year of the experiment. The same trend was found in the second year.

For the second level of fertilization (NPK_{75}), the onion yields also decreased with the increase of water deficit for both the two years of the experiment. The ANOVA analysis showed that both the irrigation treatments and the interaction between the irrigation and the fertilization had a significant effect on the total yield while the fertilization treatments effect was not significant. The results are similar to what Gelu et al. (2021) reported. They found a decrease in the onion yield with the increase of irrigation deficit level but the decrease was not significant between 100% ET and 85% ET.

3.2. The marketable yield

The fresh marketable weights of the yield are summarized in Table 5. It can be seen that the marketable yield of onion decreased with the increase of water deficit for all levels of deficit and under all the tested levels of fertilization. The marketable yield decreased from 25.41ton ha^{-1} for the $ET_{100}NPK_{100}$ treatment to 7.91ton ha^{-1} for the treatment $ET_{60}NPK_{100}$ in the first year of the experiment. The same trend of decrease in yield with the increase of water deficit continued in the second year.

For the second level of fertilization (NPK_{75}), the marketable yield also decreased with the increase of water deficit for both the two years of the experiment. The ANOVA analysis showed that the both the irrigation treatments and the interaction between the irrigation and the fertilization had a significant effect on the marketable yield while the fertilization treatments effect was not significant.

3.3. Water use efficiency (WUE)

The effect of water deficit and the two levels of the fertilization on the water use efficiency of onion crop are shown in Figure 1. From the figure it's clear that the water use efficiency (*WUE*) of the onion crop increased from 4.92 kg $m^{-3}$to 5.01 kg m^{-3} when the water supplied were decreased from 100% of the water requirements to 80% of the water requirements then it started to decrease after that for all water deficit levels tested.

For the second tested level of the fertilization, the water use efficiency decreased as the water deficit increased for all the levels of water deficit tested. The same trend continued in the second year of the experiment where the water use efficiency of the onion increased from 4.5 kg m^{-3} to 5.09 kg m^{-3} when the water supplied were decreased from 100% of the water requirements to 80%

Table 4. Total yield (fresh weight).

Treatments	Total yield, ton ha^{-1}		Average, ton ha^{-1}
	First year	Second year	
$ET_{100}NPK_{100}$	27.73^{a}	26.18^{a}	26.96
$ET_{100}NPK_{75}$	26.98^{a}	25.69^{a}	26.34
$ET_{80}NPK_{100}$	22.60^{abc}	23.68^{a}	22.76
$ET_{80}NPK_{75}$	18.84^{abcd}	16.17^{abc}	17.51
$ET_{70}NPK_{100}$	13.64^{bcd}	11.78^{bc}	12.71
$ET_{70}NPK_{75}$	13.73^{bcd}	10.76^{bc}	12.25
$ET_{60}NPK_{100}$	12.82^{bcd}	10.80^{bc}	11.81
$ET_{60}NPK_{75}$	9.39^{d}	8.13^{c}	8.76
F-test *ET NPK* Interaction	* NS *	* NS *	

Means with the same letter are not significantly different than each other. NS: not significant. *Significant at p>0.05.

Table 5. Marketable yield (fresh weight).

Treatments	Total marketable yield, ton ha^{-1}		Average, ton ha^{-1}
	First year	Second year	
$ET_{100}NPK_{100}$	25.41^{a}	24.13^{a}	26.96
$ET_{100}NPK_{75}$	24.81^{a}	23.49^{a}	26.34
$ET_{80}NPK_{100}$	22.52^{abc}	17.02^{a}	22.76
$ET_{80}NPK_{75}$	18.19^{abcd}	15.47^{abc}	17.51
$ET_{70}NPK_{100}$	11.55^{bcd}	11.94^{bc}	12.71
$ET_{70}NPK_{75}$	9.61^{bcd}	9.04^{bc}	12.25
$ET_{60}NPK_{100}$	7.91^{bcd}	6.26^{bc}	11.81
$ET_{60}NPK_{75}$	7.11^{d}	4.42^{c}	8.76
F-test *ET NPK* Interaction	* NS *	* NS *	

Means with the same letter are not significantly different than each other. NS: not significant. *Significant at p>0.05.

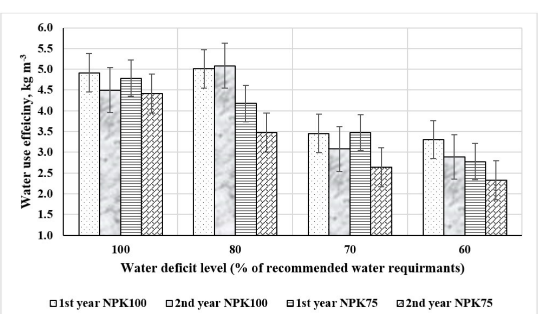

Figure 1. The response of water use efficiency to the water deficit level.

of the water requirements then it started to decrease after that for all water deficit levels tested. For the second tested levels of the fertilization the water use efficiency decreased as the water deficit increased for all levels of water deficit tested. The ANOVA test showed that the effect of the irrigation, fertilization and the interaction between them were all significant for P= 0.05.

The equation that describe the relation between the level of water deficit and the water use efficiency was a second-degree polynomial in the form:

$WUE = -0.0019ET^2 + 0.3463ET - 11.207$ with an $R^2 = 0.74$ (in the range from 100% of the water requirements (ET=100%) to 60% of the water requirements (ET=60%)). This equation agrees with the finding of Hassan (2013). He reported a second-degree polynomial relation between the *WUE* and the level of irrigation of onion plants, this polynomial could be used to determine the best irrigation strategy to achieve the maximum *WUE*

3.4. Marketable water use efficiency (MWUE)

The average values of marketable water use efficiency (*MWUE*) are shown in Figure 2. It is clear that the marketable water use efficiency decreased for all levels of water deficit at all levels of fertilization. The results of ANOVA test showed that the effect of the irrigation, fertilization and the interaction between them were all significant for P= 0.05.

The regression analysis indicated that the treatment attributes to 91% of the variation in the results and the effects were highly significant with ***P*** level <0.01. There was positive correlation between the irrigation levels and the measured properties. Also there was positive correlation between the fertilization levels and the measured properties. The results of PCA resulted in KMO value equal to 0.66; and the results indicated three different clusters of the treatment combination with $\boldsymbol{ET_{100}NPK_{100}}$, $\boldsymbol{ET_{100}NPK_{75}}$, and $\boldsymbol{ET_{80}NPK_{100}}$ as one cluster. The treatment combination $\boldsymbol{ET_{80}NPK_{75}}$ was in the second cluster by itself and the rest of the treatment combinations were the third cluster Figure 3. The PCA biplot Figure 4 shows that the first cluster treatments $\boldsymbol{ET_{100}NPK_{100}}$, $\boldsymbol{ET_{100}NPK_{75}}$, and $\boldsymbol{ET_{80}NPK_{100}}$ had positive effects on principle components. While the second cluster treatment combination showed a negative effect of the second Principle Component and the rest of the treatment combinations had negative effect on the two Principle Components.

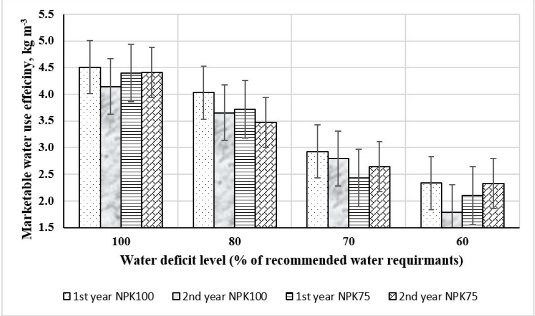

Figure 2. The response of marketable water use efficiency to the water deficit level.

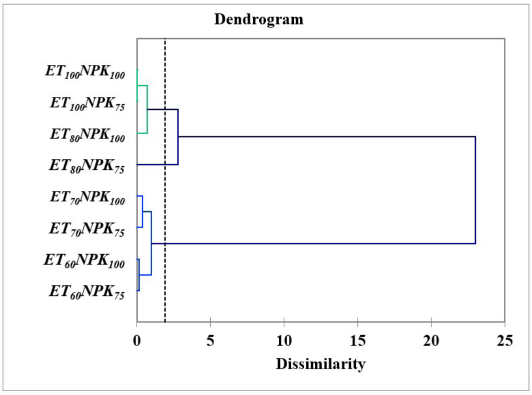

Figure 3. Dendrogram for Agglomerative hierarchical clustering.

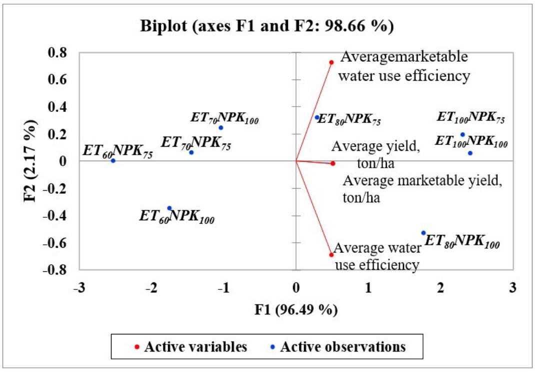

Figure 4. PCA biplot (PC1 vs. PC2) of the different treatment combinations.

4. Discussion

The results show a decrease in the total and marketable yield as the water deficit increase. In fact, according to Gedam et al. (2021), onion bulb yield depends on the amount of water supply, since this crop requires high water quantities. These authors performed a screening on 100 onion genotypes for drought tolerance and found positive correlation between bulb yield and the ability of plants to maintain leaf area, water status, cell membrane integrity, chlorophyll content, and antioxidant enzyme activities under water deficit conditions. Anyia and Herzog (2004) explained also the decrease in biomass production of cowpea genotypes under drought conditions by the effect of the stress on leaf area and gas exchange. These two parameters depend in turn on cell membrane integrity in leaves which is an important criteria of drought tolerance (Dhanda et al., 2004).

The decrease in both total and marketable yield of onion by water deficit was more obvious under fertilization deficiency, which may be attributed to the fact that under drought stress, plants need more osmolytes (in particular potassium) for osmotic adjustment to take up water at lower levels of soil moisture. Potassium plays a major role in osmotic adjustment at the cell level in plants. The lack of Potassium in the NPK_{75} level of fertilization limits the plant ability to control the osmotic adjustment thus limiting the plant ability to extract water from the soil. These results suggest that the presence of Potassium enhance the ability of plants to withstand drought. Similar results were reported by Ibrahim et al. (2020) they refereed Potassium enhancement of leaf water content under stress conditions to the maintenance of turgor potential and enhancing the integrity of cell membranes. In addition, the lack of nitrogen would result in less vegetation growth that would result in less yield both total and marketable. This is similar to what Yadav et al. (2005) reported about onion being a crop with high nitrogen demand and that lack of nitrogen would affect the yield of onion both total and marketable.

Also, Figure 1 illustrates that the recommended fertilization helped the plants withstand the mild drought stress in the first level of the water deficit (ET_{80}) then the water use efficiency decreased as the drought stress increased. At 75% of the recommended fertilization, the water use efficiency decreased directly when the drought stress increased. Similar results were found by Hassan (2013) who reported a decrease in the total production and the WUE of onion as the water deficit level increased under less than full fertilization.

Using the resulting equation to predict the maximum water use efficiency at this level of fertilization resulted in a water use efficiency equal 5.12 kg m^{-3} with a water deficit level of 88.9% of the of the water requirements. This result also implies that even though the total water use efficiency were increased with mild water deficit the Marketable water use efficiency decreased this means that the water deficit affected the quality of the onion crop and if the production was for fresh consumption of the onion it is better to maintain the recommended level of irrigation but if the production was for the purposes of onion processing then a lower level of irrigation water regime should be adapted.

5. Conclusion

Water deficit is an important factor that can affect the yield of onion in arid zones. The water use efficiency of onion would increase if a mild water stress were exerted on the plants at 100% of the recommended fertilization level. The availability of fertilizers helps the plant mange the drought stress while keeping an adequate level of yield. The lack of fertilizers combined with the drought stress resulted in rapid decrease in the yield that resulted in a decrease in the water use efficiency. The recommended water deficit level under these circumstances would be 88.9% of the plant water requirements.

Acknowledgements

The researcher(s) would like to thank the Deanship of Scientific Research, Qassim University for funding the publication of this project

References

ABDELKHALIK, A., PASCUAL, B., NÁJERA, I., BAIXAULI, C. and PASCUAL-SEVA, N., 2019. Regulated deficit irrigation as a water-saving strategy for onion cultivation in mediterranean conditions. *Agronomy*, vol. 9, no. 9, pp. 521. http://dx.doi.org/10.3390/agronomy9090521.

ABOUABDILLAH, A., EL BERGUI, O., BOUABID, R., BOURIOUG, M., BROUZIYNE, Y., EL JAOUHARI, N. and BOUAZIZ, A., 2022. Investigation of the Response of onion (Allium Cepa L.) to continuous deficit irrigation as smart approaches to crop irrigation under Mediterranean conditions. In: *Proceedings of the E3S Web of Conferences*, 2022, Les Ulis, France. Les Ulis, France: EDP Sciences, vol. 337, pp. 04001.

ADDINSOFT, 2019. *XLSTAT: statistical and data analysis solution*. Boston: Addinsoft.

ALLEN, R. G., PEREIRA, L.S., RAES, D. and SMITH, M., 1998. *Crop Evapotranspiration-Guidelines for computing crop water requirements*. Rome: FAO. FAO Irrigation and Drainage Paper, no. 56.

ANYIA, A.O. and HERZOG, H., 2004. Water-use efficiency, leaf area and leaf gas exchange of cowpeas under mid-season drought. *European Journal of Agronomy*, vol. 20, no. 4, pp. 327-339. http://dx.doi.org/10.1016/S1161-0301(03)00038-8.

BEKELE, T., ASSEFA, S. and TEKLEAB, S., 2023. Effect of deficit irrigation levels at different growth stages on yield and water productivity of furrow irrigation on onion (*Allium cepa* L.) in Silte Zone, Ethiopia. *Journal of Science & Development*, vol. 11, no. 1, pp. 12-25.

BERTINO, N.M., GRANGEIRO, L.C., DA COSTA, J.P., COSTA, R., LACERDA, R.R.D.A. and GOMES, V.E.D.V., 2022. Growth, nutrient accumulation and yield of onion as a function of micronutrient fertilization. *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 26, no. 2, pp. 126-134. http://dx.doi.org/10.1590/1807-1929/agriambi.v26n2p126-134.

DHANDA, S.S., SETHI, G.S. and BEHL, R.K., 2004. Indices of drought tolerance in wheat genotypes at early stages of plant growth. *Journal Agronomy & Crop Science*, vol. 190, no. 1, pp. 6-12. http://dx.doi.org/10.1111/j.1439-037X.2004.00592.x.

EL-DESUKI, M., MAHMOUD, A.R. and HAFIZ, M.M., 2006. Response of onion plants to minerals and bio-fertilizers application. *Research Journal of Agriculture and Biological Sciences*, vol. 2, no. 6, pp. 292-298.

GEDAM, P.A., THANGASAMY, A., SHIRSAT, D.V., GHOSH, S., BHAGAT, K.P., SOGAM, O.A., GUPTA, A.J., MAHAJAN, V., SOUMIA, P.S., SALUNKHE, V.N., KHADE, Y.P., GAWANDE, S.J., HANJAGI, P.S., RAMAKRISHNAN, R.S. and SINGH, M., 2021. Screening of onion (*Allium cepa* L.) genotypes for drought tolerance using physiological and yield based indices through multivariate analysis. *Frontiers in Plant Science*, vol. 12, pp. 600371. http://dx.doi.org/10.3389/fpls.2021.600371. PMid:33633759.

GELU, G., HABTEWOLD, M. and BERGENE, A., 2021. The effect of deficit irrigation on Onion yield and water use efficiency: concerning moisture stress areas of Arba Minch, Southern Ethiopia. *Ethiopian Journal of Water Science and Technology*, vol. 4, pp. 1-14. http://dx.doi.org/10.59122/1351926.

HASSAN, A.M., 2013. Response of onion to different levels of irrigation water and fertilization: (ii) biomass, yield, size classes, quality, and water use. *Misr Journal of Agricultural Engineering*, vol. 30, no. 3, pp. 885-906. http://dx.doi.org/10.21608/mjae.2013.102032.

IBRAHIM, M.F., ABD EL-SAMAD, G., ASHOUR, H., EL-SAWY, A.M., HIKAL, M., ELKELISH, A. and FARAG, R., 2020. Regulation of agronomic traits, nutrient uptake, osmolytes and antioxidants of maize as influenced by exogenous potassium silicate under deficit irrigation and semiarid conditions. *Agronomy*, vol. 10, no. 8, pp. 1212. http://dx.doi.org/10.3390/agronomy10081212.

KUMAR, S., IMTIYAZ, M., KUMAR, A. and SINGH, R., 2007. Response of onion (*Allium cepa* L.) to different levels of irrigation water. *Agricultural Water Management*, vol. 89, no. 1-2, pp. 161-166. http://dx.doi.org/10.1016/j.agwat.2007.01.003.

NAGHDYZADEGAN JAHROMI, M., RAZZAGHI, F. and ZAND-PARSA, S., 2023. Strategies to increase barley production and water use efficiency by combining deficit irrigation and nitrogen fertilizer. *Irrigation Science*, vol. 41, no. 2, pp. 261-275. http://dx.doi.org/10.1007/s00271-022-00811-0.

SEMIDA, W.M., ABD EL-MAGEED, T.A., MOHAMED, S.E. and EL-SAWAH, N.A., 2017. Combined effect of deficit irrigation and foliar-applied salicylic acid on physiological responses, yield, and water-use efficiency of onion plants in saline calcareous soil. *Archives of Agronomy and Soil Science*, vol. 63, no. 9, pp. 1227-1239. http://dx.doi.org/10.1080/03650340.2016.1264579.

SEN NAG, O., 2017 [viewed 28 December 2023]. *The top onion producing countries in the world* [online]. Available from: https://www.worldatlas.com/articles/the-top-onion-producing-countries-in-the-world.html

SHRESTHA, N., 2021. Factor analysis as a tool for survey analysis. *American Journal of Applied Mathematics and Statistics*, vol. 9, no. 1, pp. 4-11. http://dx.doi.org/10.12691/ajams-9-1-2.

TOLOSSA, T.T., 2021. Onion yield response to irrigation level during low and high sensitive growth stages and bulb quality under semi-arid climate conditions of Western Ethiopia. *Cogent Food & Agriculture*, vol. 7, no. 1, pp. 1859665. http://dx.doi.org/10.1080/23311932.2020.1859665.

YADAV, B.D., KHANDELWAL, R.B. and SHARMA, Y.K., 2005. Use of bio-fertilizer (*Azospirillum*) in onion. *Indian Journal of Horticulture*, vol. 62, no. 2, pp. 168-170.

ZAKY, A., OBIADALLA-ALI, H.A., EL-SHAIKH, K.A.A. and MAREY, R.A., 2022. Effect of mineral (NPK) rates and injection with nano NPK on Growth, yield and quality of onion. *Journal of Sohag Agriscience*, vol. 7, no. 2, pp. 60-76. http://dx.doi.org/10.21608/jsasj.2022.284252.