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Effect of Irrigation Regimes on Growth and Yield of Onion (*Allium cepa* L.)

Abdulaziz R. Al-Harbi
Plant Production Department, College of Agriculture
King Saud University, Riyadh, Saudi Arabia

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Abstract. Onion (*Allium cepa* L.) cultivars were grown in two successive field experiments under three levels of applied irrigation water over two seasons of 1999 and 2000. Six onion cultivars: El-Hassawy, Contessa, Dorado, UND Grande, Yellow Spanish and Texas Early Grano 502 were grown under three levels of applied irrigation water. In the second season of (2000), Yellow Spanish cultivar was excluded due to its poor seed germination. Plants were irrigated at 120%, 80% and 40% of the total evapotranspiration based on cumulative evaporation from a water pan (free surface water). Generally, an improvement was noticed on plant growth with increasing the amounts of irrigation water. Increasing total water application from 762 to 2381 and 857 to 2095 mm resulted in total yield increases of 70% and 37.6% in the first and second seasons respectively. Average bulb weight, length and diameter were significantly increased at higher levels of irrigation water in both seasons. Relative water content (RWC) and water use efficiency (WUE) were also increased with increasing the amounts of applied water. Higher total yields (Ton/ha) were recorded for UND grand in the first season and for El-Hassawy in the second season. El-Hassawy also had a higher bulb length, double bulb % and lower bulb diameter in both seasons. No differences were observed among cultivars on RWC, while, El-Hassawy had a significant higher WUE in both seasons. Insignificant interactions were recorded between the irrigation levels and cultivars on growth and total yield of onion.

Introduction

Shortage of water is a limiting factor for agricultural productivity in the arid and semi-arid regions. Most of the commercially grown crops in Saudi Arabia require successive irrigations for higher yield and best quality. On the other side, most of the agricultural soils are sandy to sandy-loam types and the major share of the limited water resources (about 91%) is directed towards agriculture. After decreasing the wheat production area, onion became an alternative crop for wheat. This trend results in a dramatic increase in onion production in the last few years. The production was increased from 42618 tons in 1994 to 210998 in 1997 [1] of which 81% was produced at Riyadh region.

Onion, with a shallow root system, makes it very vulnerable to loss of moisture from the upper layer of the soil. Irrigation or supplemental watering must be provided if the crop is to maintain efficient growth [2, pp 295-311]. Dorrenbos and Kassam [3, pp 1-193] reported that onion growth in sandy soil under arid and semi-arid conditions must be adequately irrigated to meet the high evaporative demand and to assure maximum or near maximum yield with acceptable quality.

Managing the irrigation system to achieve high crop productivity with a great saving of water needs a knowledge of the irrigation level required for an optimum yield [4] or a maximum water use efficiency [5]. Ellis *et al.* [6] compared water use efficiency of surface, sprinkler and trickle irrigation on dry onions. Under the condition of their experiments, the results did not justify the expenses of conversion from furrow to other methods of irrigation. Kruse *et al*. [7] compared two onion irrigation scheduling programs. The first one (McSay-Moore model) uses volume of distilled water evaporated from calibrated Bellani atmometers as a basis for predicting irrigation. This model predicts when to irrigate, but not how much to apply. The second model (ARS/USDA model) uses energy and aerodynamic equation to make estimates of evaporation rates from meteorogical data. This model not only predicts when to irrigate, but also the amount to apply. They found that onion yield and water use efficiency were higher with the second model than with the first one.

El-Haris and Abdel-Razek [8] found an increase in total yield and water use efficiency of three onion cultivars when the amounts of applied water were increased from 425 and 462 mm to 749 and 687 mm in two seasons field experiments at AlQassim area in the central region of Saudi Arabia. Recently, Shock *et al* [9] reported increases in total yield, marketable yield and profit of onion with increasing frequency of irrigation (soil water potential measured at 0.2 –m depth ranged from –12.5 to –100 Kpa). The objective of the undertaken study is to investigate the effects of different water regimes on growth, yield and water use efficiency of six onion cultivars grown in the central region of Saudi Arabia.

Materials and Methods

The field trials were conducted in two successive seasons at the Agriculture and Experimental Station, College of Agriculture, King Saud University, located at Dirab, 50 km south of Riyadh, Saudi Arabia. Seeds of six commercially grown onion cultivars, including; El-Hassawy, Contessa, Dorado, UND Grand, Yellow Spanish and Texas Early Grano 502 were locally purchased. Yellow Spanish cultivar was excluded in the second year due to its poor germination. Seeds were sown in flat beds and when the seedlings reached a suitable size, approximately after four weeks, they were transferred to the open field. Transplanting was carried out on second and sixteenth of January 1999 and 2000 seasons respectively, in three single rows, using a split-plot system in a randomized complete block design with four replicates.

The treatments consisted of three levels of irrigation water. The experimental unit received an equal amount of irrigation water based on the ratio of water applied to the cumulative pan evaporation (CPE), registered from a computerized weather station. The corresponding amounts of irrigation water applied were 762, 1619 and 2381 mm in the first season, and 857, 1619 and 2095 mm, in the second season. The irrigation rates were assigned as main plots and the onion cultivars were considered as the sub-plots. Each sub-plot consisted of three rows, 2 m long and 0.7 m wide. Spacing in the row was 20 cm, giving a total number of 30 plants per sub plot of 4.2 m^2. Plants were furrow irrigated and general agricultural procedures were followed, as used in the commercial onion production.

Five plants were randomly taken from each sub-plot, 90 days after starting the irrigation treatments. Plant height, number of leaves, leaf area, fresh and dry weight percentage of the shoot were recorded. After the final drying of leaves for each cultivar, the harvest was carried out and the bulb yield and quality were measured; as total bulb yield, and average bulb weight, diameter and length. Plant water relation measurements, including relative water content (RWC) and water use efficiency (WUE), were conducted. The RWC measurement was carried out, according to Weatherly [10], and WUE for bulb yield was calculated as Kg of total bulb yield produced per mm of water applied, according to Downy [11].

Analysis of variance procedures were performed to test various treatments and interactions using SAS system. The least significant difference (LSD) test was used at ($P< 0.05$) to compare the treatment means, according to Gomez and Gomez [12, pp 189-207].

Results and discussion

Several investigators reported the sensitivity of onion growth and yield to water stress [7, 9, 13]. Abu-Awwad [14] classified the winter onion in Jordan valley as moderately sensitive to water stress. Results presented in Tables (1 and 2) showed the plant length, leaves number, shoot fresh, dry weight percentage and leaf area of onion plant as affected by different levels of irrigation water and cultivars. In the first season (1999), the results did not revealed any significant differences on plant growth with increasing the amounts of irrigation water. Plant length, leaf number and shoot fresh weight tended to increase, and dry weight percentage to decrease with increasing irrigation water, but the differences did not reach the used significant level.

In the second season (2000), the results did not show significant differences in plant length, leaf number and area among the irrigation treatments. Shoot fresh weight appeared significantly higher for the second irrigation treatment, compared to the first one, and the shoot dry weight percentage was significantly lower for the second treatment, compared to other treatments. El-Haris and Abdel-Razek [8] reported an increase in the plant length, shoot fresh weight and leaf number of onion with increasing the amount of irrigation water from 462 mm to 749 mm.

Table 1. Effect of irrigation rates, cultivars and their interaction on the vegetative growth of onion during the first season (1999)

Treatment	Plant length (cm)	Number of leaves (l/P)	Shoot fresh weight (g/p)	Shoot dry weight (%)	Leaf area (cm2/p)
Water applied (mm)					
762	62.78 A[1]	10.4 A	135.36 A	16.14 A	514.25 A
1619	65.09 A	11.5 A	189.38 A	15.37 A	531.90 A
2381	70.33 A	11.8 A	228.48 A	12.52 A	527.17 A
LSD 0.05	15.73	3.98	153.83	5.84	210.85
Cultivar					
El-Hassawy	65.20 AB	11.92 A	164.39 B	15.62 A	625.20 A
Contessa	63.18 B	10.67 A	163.12 B	13.50 A	436.45 B
Dorado	63.53 B	11.17 A	177.37 B	14.39 A	477.32 AB
UND Grande	62.61 B	10.75 A	184.52 AB	13.50 A	482.82 AB
Yellow Spanish	70.84 A	11.17 A	225.96 A	15.35 A	572.49 AB
Texas Early Grano 502	71.05 A	11.50 A	190.49 AB	15.48 A	552.34 AB
LSD 0.05	6.35	2.07	47.85	3.66	150.39
Water × cultivar	NS[2]	NS	NS	NS	NS

[1] Values in a column separated by LSD test, P< 0.05.
[2] NS, *not significnat and significant at 0.05 level of probability.

Table 2. Effect of irrigation rates, cultivars and their interaction on the vegetative growth of onion during the second season (2000)

Treatment	Plant length (cm)	Number of Leaves (l/P)	Shoot fresh weight (g/p)	Shoot dry weight (%)	Leaf area (cm2/p)
Water applied (mm)					
857	46.35 A[1]	6.7 A	75.27 B	9.05 A	90.9 A
1619	51.30 A	7.4 A	108.10 A	7.12 B	116.1 A
2095	49.23 A	7.7 A	87.02 AB	8.47 A	98.9 A
LSD 0.05	6.75	1.90	25.54	1.13	44.3
Cultivar					
El-Hassawy	53.83 A	8.3 A	101.47 A	8.62 A	146.8 A
Contessa	46.25 B	7.3 A	80.98 A	7.88 A	92.7 B
Dorado	48.30 AB	6.8 A	101.73 A	7.90 A	100.0 B
UND Grande	49.29 B	7.2 A	81.56 A	8.33 A	96.0 B
Texas Early Grano 502	47.13 B	6.7 A	84.91 A	8.33 A	74.2 B
LSD 0.05	4.32	2.3	23.85	1.91	273.3
Water × cultivar	NS[2]	NS	NS	NS	NS

[1] Values in a column separated by LSD test, P< 0.05.
[2] NS, *not significnat and significant at 0.05 level of probability.

Plant length was higher for Yellow Spanish and Texas Early Grano 502, compared to other cultivars except El-Hassawy in the first season while in the second season El-Hassawy had significantly a higher plant length, compare to all other cultivars. Insignificant differences in the leaf number and dry weight percentage were observed among the tested cultivars in both seasons. Yellow Spanish had significantly a higher shoot fresh weight in the first season, but this cultivar was excluded in the second season due to its poor seed germination. In the second season insignificant differences were found among the tested cultivars, although Texas Early Grano 502 tended to have a higher fresh weight. El-Hassawy had a higher leaf area in both seasons compared to other cultivars and the difference was found significant in the second season. Significant interaction effects between irrigation water treatments and the tested cultivars were not observed on the general responses of the studied characters. Similar results were reported by El-Haris and Abdel-Razek [9].

Onion yields were increased significantly with increasing the amounts of irrigation water in the first season (Table 3). The same trend was observed in the second season, but the difference was not high enough to be significant (Table 4). Bulb characters including average weight, length and diameter increased significantly as a result of increasing the amounts of irrigation water in both seasons. The relationships between the amounts of applied water and averages total yield of the tested cultivars in both seasons are presented in Figs. 1 & 2. These results seemed to be in a close agreement with those reported by several investigators [15,16]. Shock *et al.* [17], also, reported increases in total and marketable yields with increasing irrigation threshold. The improvements of total yield response to high amounts of total water application could be attributed to the enhancing effects of water to crop's biological functions and growth in addition to the improving effects of water on nutrients availability [8].

Table 3. Effect of irrigation rates, cultivars and their interaction on the bulb yield, bulb quality, relative water content and water use efficiency of onion during the first season (1999)

Treatment	Total yield (Ton/ha)	Average bulb weight (gr)	Bulb length (cm)	Bulb diameter (cm)	Double bulbs (%)	Relative water content	Water use efficiency (kg/ha/mm)
Water applied (mm)							
762	4.5 B[1]	61.40 B	6.3 B	4.18 B	4.92 A	76.68 B	318.3 B
1619	12.5 A	120.35 A	7.6 A	5.86 A	2.54 A	84.56 A	567.3 A
2381	14.7 A	157.73 A	8.4 A	6.30 A	5.38 A	89.39 A	562.5 A
LSD 0.05	6.41	40.06	0.77	1.25	8.26	5.86	159.7
Cultivar							
El-Hassawy	10.19 AB	86.37 DE	12.92 A	3.27 C	17.75 A	84.04 A	588.2 A
Contessa	12.84 A	118.99 BC	6.14 C	6.18 A	0.00 B	82.09 A	556.7 AB
Dorado	8.33 AB	102.64 CD	5.46 C	5.29 B	000 B	85.41 A	427.9 BC
UND Grande	12.76 A	143.89 AB	6.96 B	6.41 A	0.000 B	82.59 A	490.2 AB
Yellow Spanish	6.94 B	71.23 E	6.72 B	4.74 B	0.00 B	82.62 A	334.4 C
Texas Early Grano 502	12.44 A	155.85 A	6.40 BC	6.78 A	7.92 B	84.49 A	498.8 AB
LSD 0.05	4.58	28.31	0.94	0.77	8.65	4.63	138.5
Water × cultivar	NS[2]	NS	NS	*	*	NS	NS

[1] Values in a column separated by LSD test, P< 0.05.
[2] NS, * not significnat and significant at 0.05 level of probability.

Table 4. Effect of irrigation rates, cultivars and their interaction on the bulb yield, bulb quality, relative water content and water use efficiency of onion during the second season (2000)

Treatment	Total yield (Ton/ha)	Average bulb weight (gr)	Bulb length (cm)	Bulb diameter (cm)	Double bulbs (%)	Relative water content	Water use efficiency (kg/ha/mm)
Water applied (mm)							
857	1.97 A[1]	22.52 B	5.20 B	3.43 B	3.30 A	76.03 B	171.4 A
1619	3.19 A	42.43 A	5.69 B	3.93 AB	3.40 A	86.46 A	227.8 A
2095	3.16 A	49.26 A	6.65 A	4.18 A	8.25 A	87.99 A	245.0 A
LSD 0.05	2.92	19.70	0.76	0.72	7.09	3.97	165.4
Cultivar							
El-Hassawy	4.01 A	45.768 A	8.9 A	3.5 B	19.33 A	83.71 A	318.6 A
Contessa	2.61 BC	39.713 AB	5.0 B	4.2 A	3.58 B	83.20 A	218.0 B
Dorado	1.98 C	30.383 B	4.9 B	3.5 B	0.00 B	86.00 A	154.3 B
UND Grande	3.42 AB	43.020 AB	5.3 B	4.3 A	0.00 B	81.41 A	204.1 B
Texas Early Grano 502	1.86 C	31.460 B	5.1 B	3.8 AB	2.00 B	83.14 A	178.6 B
LSD 0.05	1.29	13.29	0.87	0.62	9.71	5.93	83.5
Water × cultivar	NS[2]	NS	NS	NS	NS	*	NS

[1] Values in a column separated by LSD test, P< 0.05.
[2] NS, * not significnat and significant at 0.05 level of probability.

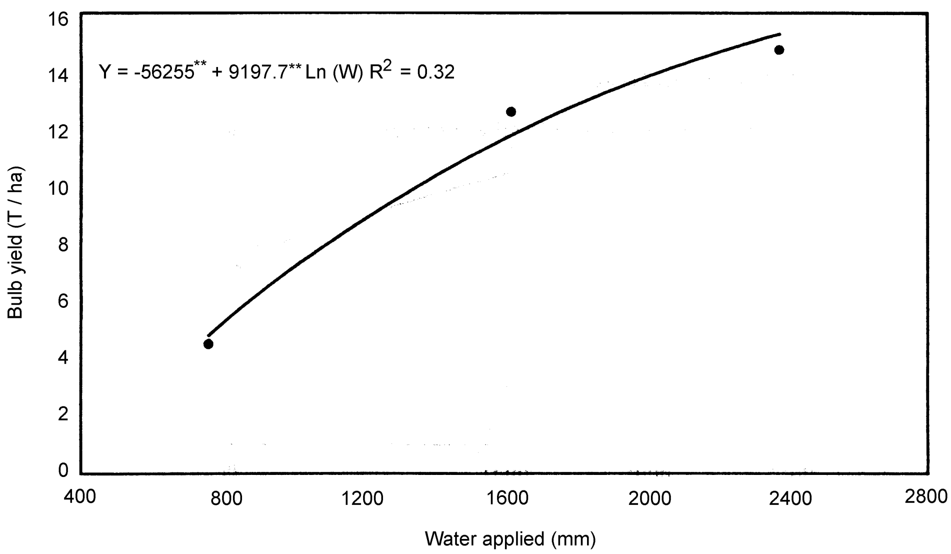

Fig. 1. Relationship between bulb yield (Y) of inion and total amount of irrigation water (W) during the first year of 1999.

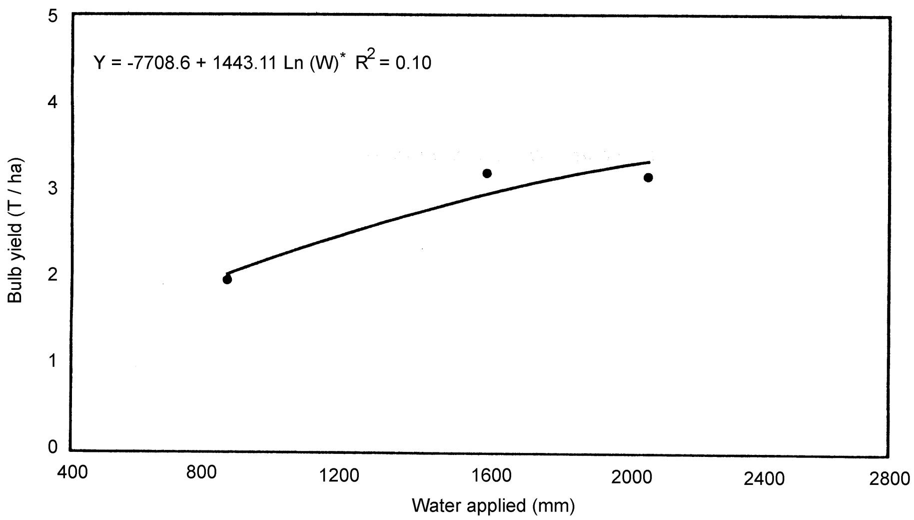

Fig. 2. Relationship between bulb yield (Y) of inion and total amount of irrigation water (W) during the second year of 2000.

Yellow Spanish had significantly lower total yield and average bulb weight, compared to other cultivars; while, insignificant differences were observed among other cultivars on total yield. In the second season El-Hassawy had a significantly higher total yield, compared to other cultivars with the exception of UND Grande. The results showed that the differences among the various cultivars on average bulb weight were inconsistence in the first and second seasons. El-Hassawy had a significant highest bulb length and lowest bulb diameter, compared to all other cultivars, in the first season. The same trend was observed in the second season, except that the differences in bulb diameter were not significant between El-Hassawy and Dorado. Double bulbs percentage tended to increase with increasing the amounts of irrigation water in both seasons; but the differences did not reach the used significant level. El-Hassawy had the significant highest double bulb percentage, compared to other cultivars, in both seasons.

Onion vegetative growth and yield characters decline in the second season (2000) compared to the first season (1999). This reduction might be attributed to the prevailing weather condition in each season. Accumulation of salts in the soil caused by irrigation water salinity could be another factor leading to this reduction.

Relative water content of the plants that received the lowest amount of irrigation water was significantly decreased, compared to the other levels of applied water, in both seasons. The plants which received the highest amount of water had a relatively higher water content, but the difference did not reach the significant level, compared to the second irrigation treatment. The same trend was also observed in the second season. The results did not show any significant differences among the tested cultivars in relative water content in both seasons. These results are in general agreement with those reported by Thakur [18], who found significant and continuous declines in relative water contents with increasing water stress duration. Water use efficiency (WUE) increased with increasing the amounts of irrigation water in both seasons; but the differences did not reach the used significant level, in the second season. In the first season, El-Hassawy and UND Grand had significantly higher WUE, compared to the other cultivars, except Contessa, while, in the second season, El-Hassawy had the significant highest WUE, compared to all other cultivars. Results presented in Figs. 3 & 4 illustrated the relationship between the amount of water applied WUE, in the first and second seasons. Similar results were reported by El-Haris and Abdel-Razek [8], who found increases of 16.6% and 20.4%, as the total applied water was increased from 425 and 462 mm to 749 and 687 mm. The presented results did not show any significant effect for interaction between irrigation water treatments and cultivars except on bulb diameter and double bulb percentage, in the first season, and on relative water content in the second season.

In general, total yield and water use efficiency were found greater when highest amounts of irrigation water were applied. This irrigation regime, also, resulted in more frequent applications. The highest irrigation frequency might be considered another additional factor that contributed positively to high yield by maintaining high water content in the effective onion rooting depth.

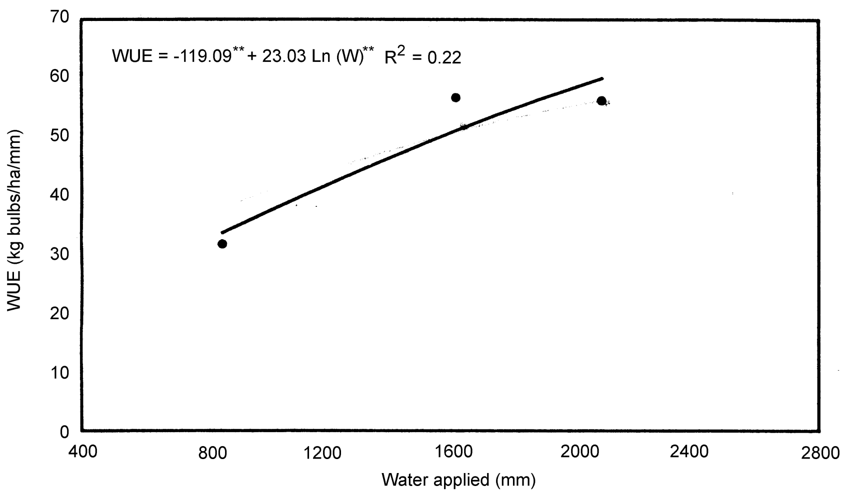

Fig. 3. Relationship between bulb water use efficiencies (WUE) of onion and total amount of irrigation water (W) during the first year of 1999.

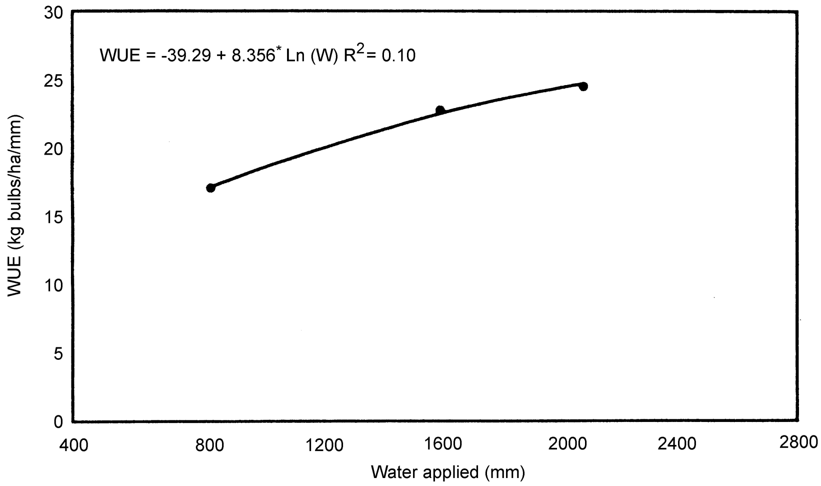

Fig. 4. Relationship between bulb water use efficiencies (WUE) of onion and total amount of irrigation water (W) during the first year of 2000.

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تأثير مستويات مياه الري على نمو وإنتاجية محصول البصل

عبدالعزيز بن رابح الحربي

قسم الإنتاج النباتي، كلية الزراعة ، جامعة الملك سعود

(قدم للنشر في ١١/٨/ ١٤٢١ وقبل للنشر في ٢٣/١/ ١٤٢٢ هـ)

ملخص البحث: زرعت ستة أصناف من البصل في تجارب حقلية لمدة عامين تحت مستويات مختلفة من مياه الري. حيث استخدمت ستة أصناف من البصل وهى: El-Hassawy و Contessa و Dorado و UND Grande و Yellow Spanish و Texas Early Grano 502 . في السنة الثانية استبعد الصنف Yellow Spanish وذلك لضعف إنبات بذوره. تم ري النباتات بثلاث مستويات من مياه الري (عند ١٢٠% و ٨٠% و ٤٠% من البخر الكلى) اعتماداً على كمية البخر من وعاء البخر. أظهرت نتائج الدراسة تحسناً واضحاً في نمو النباتات والمحصول مع زيادة كمية مياه الري المضافة، حيث زادت كمية المحصول الكلى بنسبة ٧٠% و ٣٧,٦% بزيادة كميات مياه الري من ٧٦٢ الى ٢٣٨١ مم ومن ٨٥٧ إلى ٢٠٩٥ مم، في السنةالاولى والثانية على التوالي. كما أدت زيادة مستويات مياه الري إلى زيادة متوسط وزن وقطر وطول البصلة. كما أدت زيادة مياه الري إلى زيادة محتوي الماء النسبي وكفاءة استخدام المياه للنباتات. و أظهرت نتائج الدراسة أن الصنف UND Grande قد أعطى أعلى محصول في السنة الأولى بينما أعطى الصنف الحساوي أعلى محصول فى السنة الثانية. كذلك فإن أبصال الحساوى كانت أطول وأقل في القطر، مقارنة بأبصال الأصناف الأخرى، ولكن الأبصال المزدوجة قد ظهرت بنسبة أعلى في هذا الصنف. لم تظهر نتائج الدراسة فروقاً معنوية في محتوى الماء النسبي بين الأصناف، ولكن كانت كفاءة استخدام المياه أعلى في الصنف الحساوي مقارنة ببقية الأصناف في السنتين الأولى والثانية. لم تظهر النتائج تداخلاً في التأثير بين مستويات الري والأصناف المستخدمة على النمو الخضري والمحصول الكلى خلال موسمي الزراعة.