Colegio de Postgraduados

Influence of Irrigation Interval and Soil Texture on Onion Bulb Development (*Allium cepa* L.)

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ABSTRACT

Objective: To determine the influence of soil texture and irrigation interval on onion bulb development.

Design/Methodology/Approach: The experimental design consisted of a 12×2 factorial arrangement, comprising 12 soil textural classes and two distinct irrigation frequencies. Thus, 24 treatments were evaluated, each with four replicates. The response variables included bulb weight, equatorial bulb diameter (ED), polar bulb diameter (PD), total soluble solids (TSS), bulb firmness, and bulb dry weight.

Results: The treatment combining sandy loam soil texture with daily irrigation exhibited the highest yields.

Study Limitations/Implications: The experiment was conducted under greenhouse conditions, whereas onion is typically grown under open-field conditions. Moreover, no prior physical analysis was performed for each soil texture. Therefore, the results should be interpreted in light of these considerations.

Findings/Conclusions: In most treatments, no significant differences were observed among the response variables analyzed.

Keywords: °Brix, firmness, irrigation frequency, soil moisture, production.

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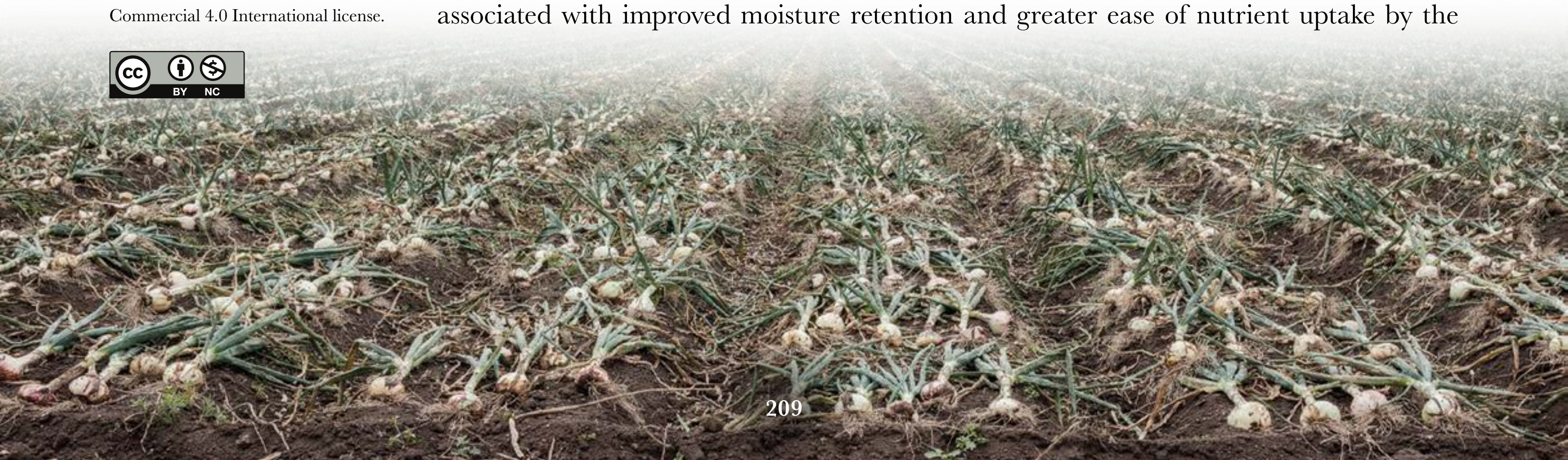
INTRODUCTION

Onion (*Allium cepa* L.) cultivation is of considerable importance worldwide due to its nutritional value. For this reason, the area devoted to this vegetable crop is extensive globally, with China as the leading producer, while Mexico ranks among the top 20 producing countries (FAOSTAT, 2023), with yields below 20 t ha^{-1} in the states of Hidalgo, State of Mexico, Guerrero, and Oaxaca (SIAP, 2024). This crop adapts well to deep, cool soils rich in organic matter; however, it does not tolerate stony, poorly drained, or shallow soils, since bulb development is adversely affected under such conditions (Zarza *et al.*, 2018). Therefore, an appropriate soil must be selected to ensure optimal growth, preferably one that remains cool while allowing rapid drainage, such as silt loam and clay loam soils (Tiscornia, 2018), given that loam-textured soils exhibit physical and chemical properties associated with improved moisture retention and greater ease of nutrient uptake by the



plant (Zhao *et al*., 2015). Nevertheless, other factors also influence the growth of this crop, including temperature (McClung and Davis, 2010) and irrigation supply (Álvarez *et al*., 2018). Estrada *et al*. (2015) reported, in a study conducted with different onion varieties under varying drought conditions, that water deficit constitutes the main factor affecting bulb filling and, consequently, bulb size.

Authors such as Tambo (2016) reported in their research that the application of biol prepared from bovine manure influenced the characteristics and yield of two onion varieties, with the treatment receiving the highest amount of biol showing the best results; notably, this treatment was irrigated daily in comparison with the remaining treatments evaluated. Therefore, drip irrigation, as a localized irrigation system, is considered the most suitable method for onion cultivation, since it maintains constant moisture in the root zone at the required depth. Furthermore, it is important to emphasize that constant moisture also contributes to a reduction in the occurrence of double bulbs, thereby increasing the commercial value of onion production (Angulo-Aguilar, 2023). Based on the foregoing, the aim of this study was to determine the influence of different soil textures and two irrigation intervals on the yield and quality of white onion grown under a drip irrigation system.

MATERIALS AND METHODS

The research was conducted during the 2021/2022 autumn-winter growing cycle at the experimental field of the Faculty of Agronomy of the Autonomous University of Sinaloa, located at kilometer 17.5 of the Culiacán-Eldorado highway, in the Culiacán Valley. The study area was geographically situated in the central region of the state of Sinaloa (24° 27’ 27.64” N, 107° 16’ 1.45” W), at an altitude of 40 m. According to the Köppen climate classification system, the climate is classified as BS1(h’)w(w)(e), described as semiarid, very warm, and extreme, with summer rainfall, a mean annual precipitation of 670 mm, and a mean annual temperature of 25.9 °C (García, 2004).

Twelve soil textural classes were used according to USDA (1987), which were collected from different sites within the state of Sinaloa. The soil was placed in slotted plastic boxes measuring 40 cm × 60 cm × 40 cm. To retain the soil inside the boxes, a mesh was installed, which also allowed water drainage. In addition, the soil was prepared through the necessary cultural practices to provide an appropriate structure for onion cultivation, including tillage, leveling, row formation, and removal of surface clods.

The experiment was carried out inside a zenith-type greenhouse covered with plastic providing 65% transparency on the upper section and black mesh on the sides. Irrigation was applied באמצעות a drip irrigation system, using drip tape with emitters spaced 20 cm apart, and each emitter had a flow rate of 1 L h^{-1}. Two different irrigation intervals were evaluated: daily irrigation supplying 1 L and irrigation every five days supplying 5 L.

For crop production, onion bulbs of the cv. Carta Blanca were used. These were planted in the boxes containing previously moistened soil, at a spacing of 12 cm between plants. Fertilizer supply, and particularly nitrogen in any of its forms, improves the photosynthetic process and, consequently, increases net assimilation rate, leaf area duration, yield, and biomass (Khanzada *et al*., 2016). For crop fertilization, the six macronutrients nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) were applied. The source of each nutrient and the dose of each are presented in Table 1.

A completely randomized experimental design with a 12×2 factorial arrangement was employed. Twelve soil textural classes and two irrigation intervals were evaluated: the first treatment received water at a daily irrigation interval, whereas the second was irrigated every five days, while maintaining the soil moisture throughout the experimental period. In total, 24 treatments were established, each with four replicates. Each treatment consisted of one soil textural class (Table 2) and one irrigation interval. The experimental units were 40 cm × 60 cm × 40 cm boxes, each filled with soil corresponding to a different textural class, resulting in a total of 96 experimental units (Table 3).

The response variables were evaluated using a sample of onion bulbs (16 bulbs per treatment selected at random) at harvest, 121 days after planting (DAP), when leaf doubles were observed, as reported by López *et al.* (2017). Equatorial bulb diameter (ED) and polar bulb diameter (PD) were measured using a digital vernier caliper. For ED, the caliper was positioned at the center of the bulb, whereas for PD, it was placed along the central axis from the stem to the bulb neck. Harvested bulb weight was determined using a precision balance (Sza110, SAFSTAR), from which onion yield (g $plant^{-1}$) was obtained.

Table 1. Steiner source and solution of nutrition applied for onion development.

Phenological stage	Electrical conductivity (dS/m)	Nutritional requirement (mg L^{-1})					
		N	P	K	Ca	Mg	S
Transplanting	0.5	42.04	7.75	68.25	45	12	27.97
Vegetative	1.0	84.07	15.50	136.50	90	24	55.94
	1.8	126.11	23.25	204.75	135	36	83.91
Bulb formation begins	2.0	168.15	31.00	273.00	180	48	111.88

Source: Proposed nutrient solutions for onion cultivation by phenological stages (Sánchez-García unpublished results).

Table 2. Sand-silt-clay percentage of each soil texture used in the experiment.

Textural class	Abbreviation	Sand (%)	Silt (%)
Sandy	are	96	1
Loamy sand	aref	82	15
Sandy loam	fare	64	30
Sandy clay loam	faare	62	10
Loam	f	47	32
Sandy clay	aare	51	12
Clay loam	fa	43	26
Clay	a	16	21
Silt loam	fl	20	62
Silty clay loam	fal	19	48
Silty clay	al	18	41
Silt	l	18	81

Table 3. Identification of treatments according to soil texture and irrigation interval.

Textural class	Abbreviation	Irrigation Interval Factor	
		Daily irrigation interval (A)	Irrigation every five days (B)
Sandy	are	Aare	Bare
Loamy sand	aref	Aaref	Baref
Sandy loam	fare	Afare	Bfare
Sandy clay loam	faare	Afaare	Bfaare
Loam	f	Af	Bf
Sandy clay	aare	Aaare	Baare
Clay loam	fa	Afa	Bfa
Clay	a	Aa	Ba
Silt loam	fl	Afl	Bfl
Silty clay loam	fal	Afal	Bfal
Silty clay	al	Aal	Bal
Silt	l	Al	Bl

Abbreviations: A=daily irrigation interval; B=irrigation interval every five days; are=sandy; aref=loamy sand; fare=sandy loam; faare=sandy clay loam; f=loam; aare=sandy clay; fa=clay loam; a=clay; fl=silt loam; fal=silty clay loam; al=silty clay; l=silt.

Postharvest quality, in terms of total soluble solids (TSS) of the onion bulb, was determined from five bulbs per treatment according to the methodology proposed by AOAC and Horwitz (1998). Total soluble solids were measured by placing three drops of onion bulb extract onto a digital refractometer (300010, Sper Scientific). Bulb firmness was measured using a GY-4 BASE GY-4S penetrometer equipped with an 8 mm diameter steel tip. A precision balance (Sza110, SAFSTAR) was used to determine bulb fresh biomass (g) and bulb dry biomass (g). Drying was carried out in a forced-air oven (Felisa 292) at 80 °C for 24 h, until constant weight was achieved, in order to determine bulb dry matter.

The data obtained were analyzed using the statistical package XLSTAT version 2022.3.1 (Addinsoft, 2023). The Shapiro-Wilk test indicated that the field data followed a normal distribution. Homogeneity of variance was also assessed using Levene's test. Mean comparisons were subjected to analysis of variance (ANOVA) and Tukey's test ($p \leq 0.05$) to determine the most effective treatment for the variables associated with onion bulb performance.

RESULTS AND DISCUSSION

Treatments under irrigation factor A (daily irrigation) showed better performance for the variables analyzed than those under irrigation factor B (irrigation every five days). Because onion has a shallow root system, it is highly susceptible to fluctuations in soil moisture; consequently, bulb yield and quality are directly affected by irrigation frequency. This finding is consistent with Torres (2012), who stated that irrigation is a key factor in crop production and that knowledge of soil type is essential for efficient water use. It also agrees with Ramos (1999), who observed that onion yield increased as a function of irrigation depth and frequency, with the best yields obtained under daily irrigation.

With respect to irrigation factor A, bulbs developed greater weight than those established under treatments with irrigation factor B. Regarding bulb ED, irrigation factor A exhibited, on average, higher values than irrigation factor B. As for PD, no statistically significant differences were observed among treatments, except for Afal, which showed a diameter 21.13% lower than that of the best-performing treatment, Afare, with 75.567 mm. These results may be attributed to the fact that irrigation factor A prevented the occurrence of water stress in the crop, unlike the treatments under irrigation factor B. This agrees with Petit (2004), who observed that onion quality and yield improve when irrigation is applied daily or every third day, compared with irrigation every fourth day. It is also consistent with Graham *et al.* (2016), who demonstrated that inadequate water supply, whether in quantity or timing, may induce water stress and, consequently, reduce crop yield. This is because maintaining the soil moist for the longest possible period enhances nutrient uptake by onion plants, which possess a shallow root system.

These findings also agree with Rodríguez *et al.* (2013), who indicated that intermittent furrow irrigation increases water application efficiency compared with the traditional furrow irrigation method, which consists of continuous irrigation without interruption. This improves the technical and productive indicators of agricultural activity, particularly in onion cultivation. In other words, intermittent irrigation maintains soil moisture for a longer period than traditional irrigation. Likewise, Assuero *et al.* (2007) indicated that limited water availability during the bulb-filling process results in reduced bulb size, which corroborates the observations made in this study, where irrigation factor A maintained water availability in the soil for a longer time than the treatments under irrigation factor B. According to De Santa Olalla *et al.* (2005), the growth process, as well as any process involving cell division, is adversely affected by low water availability, and once the primordia are initiated, the final size of the onion bulb is determined by the duration of cell division. Moreover, water availability markedly influences many vital processes in onion cultivation. This indicates that limited water availability in the soil directly affects bulb growth. Similarly, Estrada *et al.* (2015), in a study conducted on different onion varieties under drought conditions, reported that water deficit, both in magnitude and in the speed at which it occurs, is the main factor influencing onion bulb filling and, consequently, bulb size (Table 4).

With respect to bulb dry weight (BDW), the treatments with sandy clay texture under both irrigation factors, A and B, showed the best results and did not differ statistically significantly ($p \leq 0.05$). This is consistent with Kumar *et al.* (2007a), who, when using microsprinkler irrigation in sandy soil, found that irrigation at 100% and 120% of evaporation resulted in greater dry matter accumulation than irrigation at 60% and 80%. In other words, maintaining sandy soil under adequate moisture conditions promoted a better response in onion cultivation (Table 5).

Plant growth decreases when the applied water volume reaches 1.4 times evaporation, compared with the application of 1.2 times evaporation. This occurs because excessive moisture saturation in the soil results from applying a water volume greater than the soil can infiltrate, thereby reducing oxygen availability and causing anoxic conditions in the plant (Sauter, 2013). Under anoxic conditions, the plant produces higher amounts of

Table 4. Mean comparison among treatments for the variables equatorial diameter (ED), polar diameter (PD), and weight.

Treatment	ED (mm)	PD (mm)	Weight (g)
Aare	65.275±1.36 abcde	69.342±1.62 ab	156.19±6.30 abcd
Aaref	55.717±1.23 de	65.392±1.33 ab	108.21±4.51 cd
Afare	71.200±1.79 a	75.567±1.40 a	193.19±9.15 a
Afaare	68.442±2.24 abc	70.225±1.24 ab	171.94±13.26 abc
Af	65.200±2.65 abcde	68.433±1.24 ab	154.90±15.31 abcd
Aaare	69.208±2.16 ab	68.075±1.88 ab	177.46±13.00 ab
Afa	64.017±2.91 abcde	70.517±0.82 ab	161.06±13.89 abcd
Aa	68.042±1.52 abcd	66.225±1.66 ab	168.38±10.31 abcd
Afl	63.900±2.53 abcde	71.567±3.46 ab	161.92±17.88 abcd
Afal	62.258±3.02 abcde	62.383±1.66 b	137.94±13.98 abcd
Aal	60.917±5.15 bcde	62.792±1.94 ab	157.80±11.93 abcd
Al	68.617±1.12 abc	71.050±1.00 ab	172.13±5.83 abc
Bare	59.433±2.00 bcde	64.367±1.70 ab	123.02±9.53 bcd
Baref	57.183±1.50 bcde	67.350±2.21 ab	115.76±7.72 bcd
Bfare	61.317±2.51 abcde	70.283±2.67 ab	147.48±13.13 abcd
Bfaare	59.092±1.67 bcde	64.692±2.89 ab	123.28±11.42 bcd
Bf	54.242±2.53 e	64.325±1.10 ab	105.33±10.80 d
Baare	68.142±2.14 abcd	66.708±2.16 ab	166.04±12.61 abcd
Bfa	62.825±2.16 abcde	69.183±2.03 ab	144.35±10.83 abcd
Ba	62.900±1.43 abcde	67.058±1.64 ab	140.27±7.50 abcd
Bfl	70.417±2.81 a	66.725±5.89 ab	192.42±19.36 a
Bfal	56.275±3.02 cde	66.317±2.35 ab	117.93±14.13 bcd
Bal	64.483±3.26 abcde	67.733±2.52 ab	157.01±18.66 abcd
Bl	62.667±2.16 abcde	71.283±1.82 ab	149.08±11.10 abcd

Identical letters within each column indicate no statistically significant differences according to Tukey's test ($p \leq 0.05$). The standard error of the mean is shown. Abbreviations: A=daily irrigation interval; B=irrigation interval every five days; are=sandy; aref=loamy sand; fare=sandy loam; faare=sandy clay loam; f=loam; aare=sandy clay; fa=clay loam; a=clay; fl=silt loam; fal=silty clay loam; al=silty clay; l=silt.

1-aminocyclopropane-1-carboxylic acid (ACC), which is transported from the roots to the upper parts of the plant, where it is converted into ethylene (Irfan *et al.*, 2010).

This process slows growth and induces leaf abscission, which in turn leads to lower dry matter accumulation (Steffens, 2014), thus explaining the reduced growth observed under the 1.4 coefficient. Kumar *et al.* (2007b) likewise reported that, in sandy soil under microsprinkler irrigation, applying 100% of evaporation (Ev) produced the same effect as applying 120% in terms of total plant dry matter accumulation. Similarly, Metwally (2011), working with a clay soil in Australia, found that both leaf number and leaf dry mass were lower under irrigation of 1.75 $m^3\ m^{-2}$ than under 0.9 $m^3\ m^{-2}$. Onion bulb weight increases proportionally with the amount of water applied; that is, when irrigation increases from 0.8 times evaporation to 1.4 times evaporation, bulb weight also increases.

Table 5. Mean comparison among treatments for bulb firmness, total soluble solids (TSS), and bulb dry weight (BDW).

Treatment	Firmness (N)	TSS (°Brix)	BDW (g)
Aare	115.650±2.52 abcdefg	10.000±0.21 abc	8.498±0.84 def
Aaref	107.675±3.06 efgh	9.400±0.29 bc	8.151±0.45 def
Afare	124.583±6.34 abcd	9.167±0.37 bc	10.661±0.83 bcde
Afaare	118.058±1.96 abcdef	10.167±0.17 abc	10.723±0.95 bcde
Af	112.825±2.62 bcdefgh	9.583±0.31 bc	9.628±1.21 cdef
Aaare	119.742±2.54 abcdef	9.250±0.28 bc	14.166±1.23 ab
Afa	109.933±2.36 cdefgh	10.333±0.14 ab	10.752±1.66 bcde
Aa	129.975±2.20 a	9.583±0.29 bc	11.696±0.56 bcd
Afl	118.450±6.40 abcdef	10.083±0.26 abc	11.329±1.46 bcde
Afal	111.675±3.16 bcdefgh	8.500±0.26 bc	8.570±0.95 def
Aal	118.975±2.60 abcdef	9.208±0.31 bc	11.089±0.89 bcde
Al	123.483±4.86 abcde	9.667±0.19 abc	10.297±0.57 bcde
Bare	98.700±2.33 h	9.333±0.26 bc	9.438±0.97 cdef
Baref	105.967±2.40 fgh	9.583±0.23 bc	5.873±0.54 f
Bfare	112.558±3.36 bcdefgh	9.417±0.45 bc	9.395±0.86 cdef
Bfaare	101.525±5.08 gh	8.750±0.13 c	7.406±0.84 ef
Bf	108.667±4.29 defgh	11.042±0.39 a	5.920±0.65 f
Baare	120.867±3.92 abcdef	9.250±0.33 bc	16.000±1.08 a
Bfa	115.917±2.99 abcdefg	9.583±0.51 bc	7.819±0.62 def
Ba	127.250±6.19 ab	9.667±0.19 abc	8.865±0.82 def
Bfl	125.067±2.65 abc	9.167±0.37 bc	13.158±1.48 abc
Bfal	120.850±2.61 abcdef	9.917±0.34 abc	9.051±1.10 def
Bal	111.125±3.84 cdefgh	9.917±0.29 abc	9.638±1.40 cdef
Bl	120.325±4.34 abcdef	9.083±0.34 bc	9.821±1.25 cdef

Identical letters within each column indicate no statistically significant differences according to Tukey's test ($p \leq 0.05$). The standard error of the mean is shown. Abbreviations: A=daily irrigation interval; B=irrigation interval every five days; are=sandy; aref=loamy sand; fare=sandy loam; faare=sandy clay loam; f=loam; aare=sandy clay; fa=clay loam; a=clay; fl=silt loam; fal=silty clay loam; al=silty clay; l=silt.

However, the dry matter content of this organ remains constant after the application of 1.2 times evaporation (Ev) (Álvarez *et al.*, 2018).

Furthermore, these findings are consistent with Zhao *et al.* (2015), who analyzed the effect of different soil textures on peanut development and growth and observed that loam soil was favorable for the development of this crop. This is attributed to the physical and chemical properties of loam soil, such as improved moisture retention and greater ease of nutrient uptake by the plant.

For bulb firmness, it was observed that the clay soil texture combined with irrigation factor A yielded better results than the other treatments. This may be attributed to enhanced calcium and magnesium uptake by the onion crop. This finding agrees with Zhao, Li, and Sun (2007), who observed that clay soil favored alfalfa growth. It is also consistent with

Huang *et al.* (2006), who demonstrated that, to achieve better grain, protein, oil, and starch yields in high-oil maize, cultivation in clay soils was more advantageous, followed by loam soils and then sandy soils. In the treatment combining loam soil texture (47% sand, 32% silt, and 21% clay) with irrigation factor B, onions exhibited a significantly higher ($p \leq 0.05$) total soluble solids (TSS) concentration, with an average value of 11, compared with the treatment combining sandy clay loam soil texture (62% sand, 10% silt, and 29% clay) with irrigation factor B, which showed average TSS values of 8.8.

This is likely because the amount of water retained in clay-rich soils is greater due to the micropores characteristic of this soil texture, thereby allowing nutrients to remain available to the onion crop for a longer period. This agrees with Escobar (2016), who pointed out that the relative amount of available water in the soil is directly related to its solid mass (Table 5).

CONCLUSIONS

In general, onion cultivation exhibited higher yield and superior bulb quality under treatments with irrigation factor A compared with those under irrigation factor B. Regarding soil textural classes, among the 12 textures evaluated, silt loam (fl) and sandy clay (aare) showed the highest onion yield and the best bulb quality. Under the combination of loam soil texture and irrigation factor A, onion bulbs developed with greater quality and yield.

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