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ORIGINAL PAPER

Impact of different irrigation & trace metals treatments on onion (*Allium cepa L.*) plant growth cultivated in rural and urban soils

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Abstract

The present research attempts to evaluate the response of *Allium cepa L.* to different irrigation treatments and to indicate the optimum scheme along with plant growth, throughout a pot experiment during Spring 2021. The experimental procedure consisted of two different soil types, three treatments of irrigation and two levels of Cu and Zn (low and high), in four replications each. Irrigation events started when the lower allowable limit (LAL) reached a defined percentage of filed capacity (FC): 40% FC, 60% FC, and 75% FC and an irrigation event occurred with irrigation doses (D_n) equal to 60% FC, 40% FC, and 25% FC, respectively, to reach the value of FC. According to the results, the minimum yield was achieved by both soil types when Cu and Zn solution concentration and water stress were at their highest levels, although light texture soil (loamy sand—LS) allowed for superior growth. The optimum scheme was: the lower concentration of Cu and Zn solution along with LAL equal to 60% FC at the loamy sand soil. The outcomes suggest that frequent short irrigation doses at light-texture soils can result in yield response indicators when planted in pots. Furthermore, the influence of Cu and Zn cations at low concentrations can be advantageous for onions because Cu cations provide protection against fungal diseases, while Zn cations serve as nutrient support reducing the risk of metals deficiency.

Keywords Lower available limit of water · Field capacity · Permanent wilting point · Soil moisture · Copper · Zinc

Introduction

Water shortage is one of the global issues nowadays and the balance between water demands and water availability is nowadays in critical levels mostly in areas where the access to humanity's most valuable natural resource is limited (Al Khoury et al. 2023; Martínez-Valderrama et al. 2023). Thus, a sustainable approach to water resources management in irrigated areas is critical, by reaching the optimum efficiency of water and maximizing yield (Mancosu et al. 2015; Mubarak 2020; Tamburini et al. 2020; Emmanouil et al. 2023).

Onions are considered a shallow-rooted crop. From long ago, it has been discovered that even if the maximum root penetration reaches 0.76 m, most of the root volume appear in the top 0.18 m from soil surface, while the remaining few roots appear over 0.31 m (Ghodke et al. 2018, 2020). This trait leads to limitations of water availability and if irrigation water gets below 0.76 m, it is unavailable to the onion crop, which makes onion crop a more sensitive crop to water stress, than other deep-rooted crops. In regions where water is restricted, like in the Mediterranean area, sustainable water management along with crop production is a crucial challenge and a key solution for the future (Mubarak 2020; Panagopoulos et al. 2023). Water productivity is important and can be achieved at onion cultivation via sustainable irrigation without any negative effects on onion production (Belay et al. 2019, Yemane Mebrahtu 2019; Tolossa 2021).

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Some of the main limitations to sufficient food production in rural or urban areas are the lack of arable land and the lack of open space for gardening, especially in urban environment and on bad soils in rural areas (Wang 2022). Pot gardening (also may be known as container gardening) is the practice of growing plants including edible as well as non-edible plants in pots at the areas where limited space or at areas where the soil is not suitable for a particular crop (Bak et al. 2022). Even if it is believed to have come from the Near East, onion (*Allium cepa L.*) can be grown under various climates, either temperate or tropical. The optimum mean daily temperature for onion varies between 15 and 20 °C, and the length of the growing period varies with climate. Onion can be grown on many soils with pH range of 6–7, while the optimal soil pH is 6.2–6.8 at loamy sand soils (Karim et al. 2013) and the optimum water management consists of frequent and light irrigation doses (Gangwar et al. 2019; Asres et al. 2022).

As the demand for horticultural products is increasing, many small-scale farmers venture such cultivations in urban areas (Bak and Barjenbruch 2022). The accumulation of heavy metals both in agricultural and rural soils is an issue of major environmental concern worldwide (Golia 2023; Khan et al. 2023; Papadimou et al. 2023). Some heavy metals (HMs), such as Cu and Zn, are required in trace amounts for organisms to function properly (trace elements) (Zor and Kocaoba 2023). They become harmful and toxic, however, when their concentration exceeds a certain threshold (Kabata-Pendias 2010). The study of Habte et al. (2023) shows the levels of heavy metal concentrations in soil and onion samples collected from two sub-cities of Addis Ababa, Ethiopia. There was a distinct variation in the irrigated and non-irrigated soils in the study areas as indicated by the results of some metals in the irrigated soils. Metals essential for onion growth, such as Cu and Zn, were transferred to the plants from irrigation water, contributing significantly to the normal growth and successful harvesting of the plant mass. Furthermore, Dondini et al. (2024) found that soil texture, soil quality along with irrigation water quality and quantity are the key parameters regrading urban cultivation in Spain. Alternative elements, such as Cd, Pb, and Hg, on the other hand, are harmful and do not encourage the normal processes of plants and animals (Alloway 2013). HM contamination of agricultural environments has received substantial attention globally due to the potentially harmful impact that heavy metals may have on human health. They are primarily transported to plants through their growth media, which include soil, air, and water (Kanwar et al. 2020). Due to the ongoing use of pesticides, fertilizers, and municipal effluent, it has been discovered that the concentrations of heavy metals in agricultural soils are elevated (Singh et al. 2004; Golia et al. 2021). According to Zamora-Ledezma et al. (2021), the buildup of HMs in vegetables' edible sections has a negative impact on both plants and people. Furthermore, HM pollution of water is frequently reported (Zamora-Ledezma et al. 2021). Industrial effluents and the careless discharge of residential or sewer drainage into rivers that is untreated or just partially treated are the main sources of heavy metals. Several strategies for remediating polluted soils are being proposed and implemented. Phytoremediation, or the cultivation of plants that accumulate considerable amounts of metals in their tissues and help to reduce soil load, is a low-cost and environmentally benign approach with numerous uses (Kanwar et al. 2020; Golia et al. 2021; Zamora-Ledezma et al. 2021) used in the framework of the circular economy (Golia 2023; Golia et al. 2023).

Crop productivity is related to aggregation of the soil (Baghernejad et al. 2015), while hydraulic properties of the soil play crucial role to irrigation scheduling and irrigation practices (Asres et al. 2022; Angelaki et al. 2004, 2021; Batsilas et al. 2023; Kargas et al. 2023). The presence of Cu and Zn ions into the soil increases the hydraulic conductivity the more cohesive the soil is, due to adsorption capacity and interaction with clay particles, affecting aggregation, soil structure and hydraulic properties (Nartowska et al. 2019; Angelaki et al. 2022).

In 2015, the United Nations proposed the 2030 sustainable development agenda where sustainable agriculture plays fundamental role. When talking for sustainable agriculture, water management is on the top of the priorities. The present study focuses on irrigation water management in combination with the physical properties of the soil and the presence of nutrients. Knowing the water availability, the critical question is what is the best management for the available water quantity? What is the optimum scheme of irrigation dose, frequency, along with the soil type and the presence of nutrients (trace elements)?

Our study focuses on the above questions and the results give the directions for sustainable water management at onion cultivation, considering the soil texture along with the presence of Cu and Zn trace elements. Urban cultivation, i.e., cultivation not in traditional agricultural environments, requires intelligent management to prevent trace element deficiencies in plants, alongside the direct risk of pollution of urban, densely populated areas (Economou et al. 2023). Managing such soils involves innovative approaches to adapt to the urban environments, support urban populations and enhance urban sustainability. In this direction, sustainable water management could be an additional assistant towards rational agricultural treatments. Similar experiments are addressed to conduct on a larger scale, both in rural and urban areas. It is a challenge for future study, as additional parameters should be taken into account, such as climatic conditions in an ever-changing context, mainly due to the climate crisis.

Materials and methods

Soil sampling—experimental establishment

The soil samples were collected from a rural area of Almyros Magnesia (Golia 2023) and from the urban area of the Municipality of Volos (Papadimou et al. 2023). The soil samples were composite, consisting of six subsamples collected from a 1.5 m radius area. The experiments were carried out at the Laboratory of Agricultural Hydraulics, Department of Agriculture, Crop Production and Rural Environment, School of Agricultural Sciences at University of Thessaly, Volos, Greece, for one growing season, in Spring 2021. Each pot had a diameter equal to 18 cm, height equal to 20 cm, and half pots were filled with clay loam soil (soil A) and the remaining half were filled with loamy sand soil (soil B). Six premature small bulbs of *Allium cepa L.* were planted into each pot in April 2021. The experimental design consisted of two soil types × 2 levels of HM × (3 irrigation treatments + 1 control) × 4 replications = 64 pots. No extra fertilizers were used during the experiment. After harvest, crop features such as length, biomass, and number of leaves were measured (Fig. 1).

Soil analysis

Soil samples were carried to the laboratory, air-dried, and passed through a 2 mm diameter sieve. They were then processed for soil analyses as described by Page et al. (1982), Dimirkou et al. (2009), and Golia (2023). The particle size distribution was determined by the Bouyoucos method, using sodium metaphosphate dispersed solution. The pH value was determined in soil water soil suspension at a ratio of 1:2.5, using a Crison's pH meter suitably calibrated with pH 4 & 7 buffer solutions. The electrical conductivity (EC) values were determined in soil paste with a soil–water ratio of 1:1, and the results were expressed as μS/cm. The Walkley–Black method was used to measure the soil organic matter content, after oxidation with K_2CrO_4 accompanied with concentrated H_2SO_4. The quantitative determination of the total Cu and Zn concentrations was conducted by digesting 1 g of soil sample with Aqua Regia mixture (HCl: HNO_3, 3:1) in a closed system, after 4.5 h of a heating schedule. It was subsequently filtrated, and using a flame and graphite furnace setup, atomic absorption spectroscopy was used to determine the quantity of Cu and Zn in the filtrate (Golia 2023).

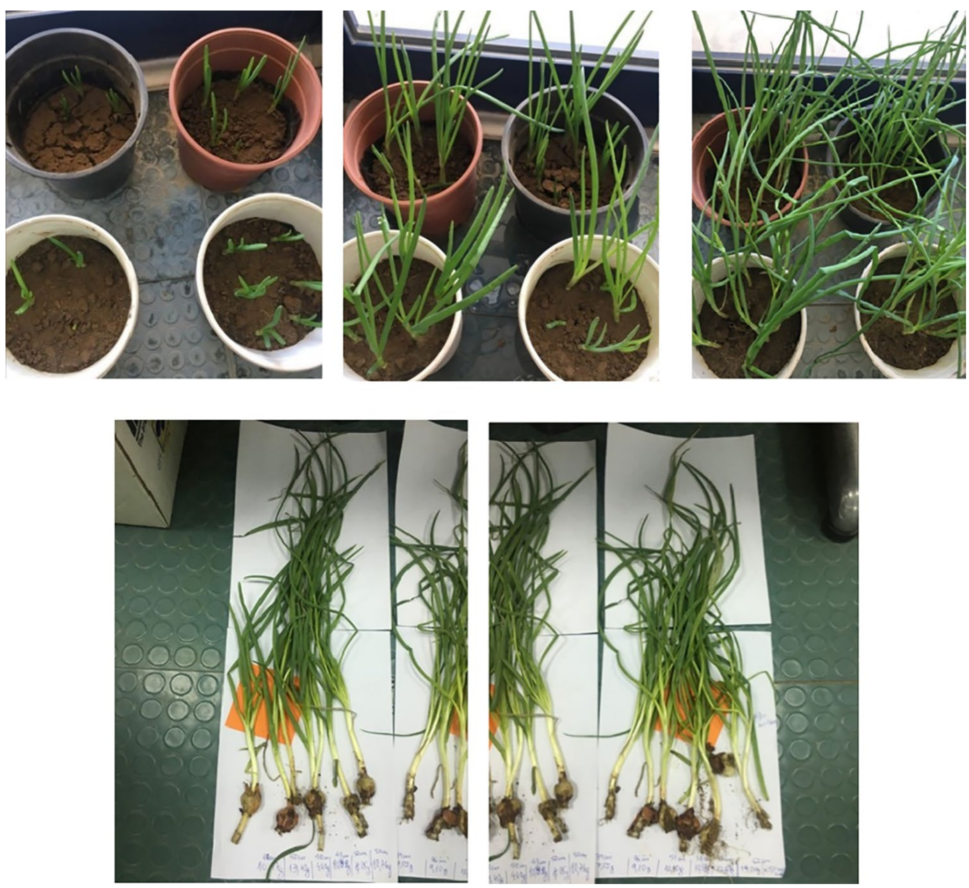

Fig. 1 Indicative photos of the experiment during various stages

Hydraulic parameters–irrigation

The soils were sieved, dried for 24 h in the oven at 105 °C and left for 24 h to reach saturation. Soil moisture at saturation was measured in the laboratory and then, the saturated soil samples were inserted to the pressure plate apparatus (Soil Moisture Equipment Corp., California). The pressure plate apparatus method was used to estimate the volumetric soil water content at field capacity (FC) and at the permanent wilting point (PWP) (Angelaki et al. 2023). The soil moisture was measured daily using Delta-T SM 150, a device which uses electromagnetic pulses to estimate the dielectric constant of the soil and calculates the soil moisture automatically. The experiment was started on the planting day with the soil moisture of all pots at FC. Three lower allowable limits (LAL) were set at various percentages of FC of each soil type. The three treatments of the different LAL were: 40% FC [soil A first irrigation treatment (A-I1) for CL, soil B first irrigation treatment (B-I1) for LS], 60% FC (A-I2 for CL, B-I2 for LS), and 75% FC (A-I3 for CL, B-I3 for LS). When the soil moisture reached the LAL, an irrigation event occurred to reach the FC. Thus, different irrigation doses (D_n) were applied, equal to 60% FC, 40% FC, and 25% FC, respectively, and the method led to different irrigation frequencies. Regarding irrigation treatments, the experimental procedure was designed so that the soil moisture never reaches the PWP (Angelaki et al. 2023). Table 1 shows the characteristics of the irrigation water (tap water), as they were published at Volos municipality public water company site. Table 1 also presents the physical and chemical soil properties of the two soil types under research, along with the characteristics of irrigation water. The soil pH values of the two soil samples are comparable as they are slightly alkaline. Both have the same electrical conductivity (EC) values; however, agricultural soil (soil A) contains almost twice as much organic content as inorganic urban soil (soil B).

Irrigation water analysis (from Volos municipality public water company).

Table 1 Physicochemical parameters of the soil samples

Parameter	Soil A	Soil B
Soil analysis		
pH	7.30 ± 0.45*	7.2 ± 0.24
EC (μS cm^{-1})	1982 ± 7.6	1995 ± 6.5
Organic C (%)	3.8 ± 0.8	1.4 ± 0.1
Total Cu (mg kg^{-1} dry soil)	68.1 ± 4.9	36.2 ± 4.1
Total Zn (mg kg^{-1} dry soil)	88 ± 5.5	37.8 ± 7.4
Bulk density (g cm^{-3})	1.40 ± 0.05	1.55 ± 0.05
Soil moisture at saturation (θ_s) (%v/v)	41.0 ± 0.01	36.0 ± 0.01
FC (% v/v)	28.00 ± 0.05	23.25 ± 0.05
PWP (% v/v)	10.00 ± 0.05	7.80 ± 0.05
Clay (%)	37 ± 0.1	11.0 ± 0.3
Sand (%)	34 ± 0.3	76.0 ± 0.4
Silt (%)	29 ± 0.2	13.0 ± 0.9
Soil texture characterization	CL	LS
Soil order	Vertisol	Endisol
Parameter		Value
Cl^- (mg l^{-1})		98
Cl_2 (mg l^{-1})		0.31
pH (at 25 °C)		7.9
EC (μS cm^{-1} at 20 °C)		595
NH_4^+ (mg l^{-1})		0.03
NO_3^- (mg l^{-1})		9.47
NO_2^- (mg l^{-1})		0.017
Fe (mg l^{-1})		0.03
Cu (mg l^{-1})		0.01
SO_4^- (mg l^{-1})		39

*RSD relative standard deviation, **ND not detectable

Agricultural soil (soil A) has a higher clay content than inorganic urban soil (soil B). According to the percentage values of clay, silt, and sand, the soils were characterized as follows: soil A—clay loam (CL) and soil B—loamy sand (LS). Soil samples have been contaminated using nitrate salts of metals. Specifically, solutions of the salts were prepared and the soil samples were incubated for 20 days before the experiment began. The nitrates were chosen to enhance the crop with nitrogen to enable the plant to cope with potential toxicity from the metals. The concentrations were chosen based on the limits set by the European Union (Council of European Communities 1986). In particular, the maximum allowable concentrations of Cu and Zn are 140 and 300 mg kg^{-1} soil, respectively. Therefore, we decided to have the maximum allowable concentration as the maximum level and half of the maximum allowable concentration as the first level.

To measure the biomass a weighing scales was used and measuring tape was used to measure the length of the plants.

Statistical analysis

Data were analyzed using R v4.2.2 and RStudio (RStudio Team 2020; R Core Team 2022). Analysis of variance (ANOVA) was conducted using general linear models. Factors that were not significant were excluded from the model. Afterwards, the models were fitted to the data using only the significant factors. Last, pairwise comparisons were performed using Tukey post hoc tests.

Results and discussion

The three treatments of irrigation along with Cu and Zn concentrations at both soil types are presented in Table 2. Two different concentrations of Cu and Zn were used as follows: 70 ppm Cu and 150 ppm Zn were considered as "low," while 140 ppm Cu and 300 ppm Zn were considered as "high" concentrations. The LAL was the minimum value of soil moisture that we let the soil reach after irrigation and drainage. The three irrigation treatments comprised three soil moisture thresholds (LAL) equal to three quota of the FC. For soil A, the three LAL were 11.2% v/v, 16.8% v/v, and 21.0% v/v, while for soil B, the three LAL were 9.3% v/v, 13.95% v/v, and 17.4% v/v, corresponding to 40% FC, 60% FC, and 75% FC.

Figures 2 and 3 represent the irrigation treatments, the FC, PWP, and LAL values, the duration and the irrigation frequency for the CL and LS soil respectively, for both concentrations of Cu and Zn (low and high). Figure 2 shows the irrigation treatments at CL soil [θ refers to the average values of soil moisture ($n=4$)] for both Cu and Zn concentrations (high and low). Each time soil moisture reached the values of LAL of the CL soil: 11.2% v/v, 16.8% v/v, and 21.0% v/v (referring to A-I1: 40% FC, A-I2: 60% FC, and A-I3: 75% FC treatments, respectively) an irrigation event occurred with irrigation doses (D_n) equal to 60% FC, 40% FC, and 25% FC, respectively, to reach the value of FC again. At the first treatment (A-I1) the irrigation doses were applied every 15 days, while at the second (A-I2) and the third (A-I3), the timing of the irrigation event was every 12 and 9 days, respectively, for both concentrations of Cu and Zn. All irrigation events were applied within a total of about 50 days for all treatments. Pots where the first irrigation treatment (A-I1) was applied, received three irrigation events, pots where the second irrigation treatment (A-I2) was applied, received four irrigation events and at the pots where the third irrigation treatment (A-I3) was applied, five irrigation events occurred, for both concentrations of Cu and Zn.

Figure 3 shows the irrigation treatments at LS soil [θ refers to average values of soil moisture ($n=4$)] for both Cu and Zn concentrations (high and low). The values of LAL of the LS soil were: 9.3% v/v, 13.95% v/v, and 17.4% v/v (referring to B-I1: 40% FC, B-I2: 60% FC, and B-I3: 75% FC treatments, respectively). The same procedure as at CL soil was followed, resulting in the following frequency of

Table 2 Irrigation treatments and concentrations of Cu and Zn solution

Soil type	LAL (% v/v)	Cu (ppm)	Zn (ppm)	
	11.2 (A-I1-L: 40% FC)	70	150	(Low)
	11.2 (A-I1-H: 40% FC)	140	300	(High)
Clay loam treatments	16.8 (A-I2-L: 60% FC)	70	150	(Low)
	16.8 (A-I2-H: 60% FC)	140	300	(High)
	21.0 (A-I3-L: 75% FC)	70	150	(Low)
	21.0 (A-I3-H: 75% FC)	140	300	(High)
	9.3 (B-I1-L: 40% FC)	70	150	(Low)
	9.3 (B-I1-H: 40% FC)	140	300	(High)
Loamy sand treatments	13.95 (B-I2-L: 60% FC)	70	150	(Low)
	13.95 (B-I2-H: 60% FC)	140	300	(High)
	17.4 (B-I3-L: 75% FC)	70	150	(Low)
	17.4 (B-I3-L: 75% FC)	140	300	(High)

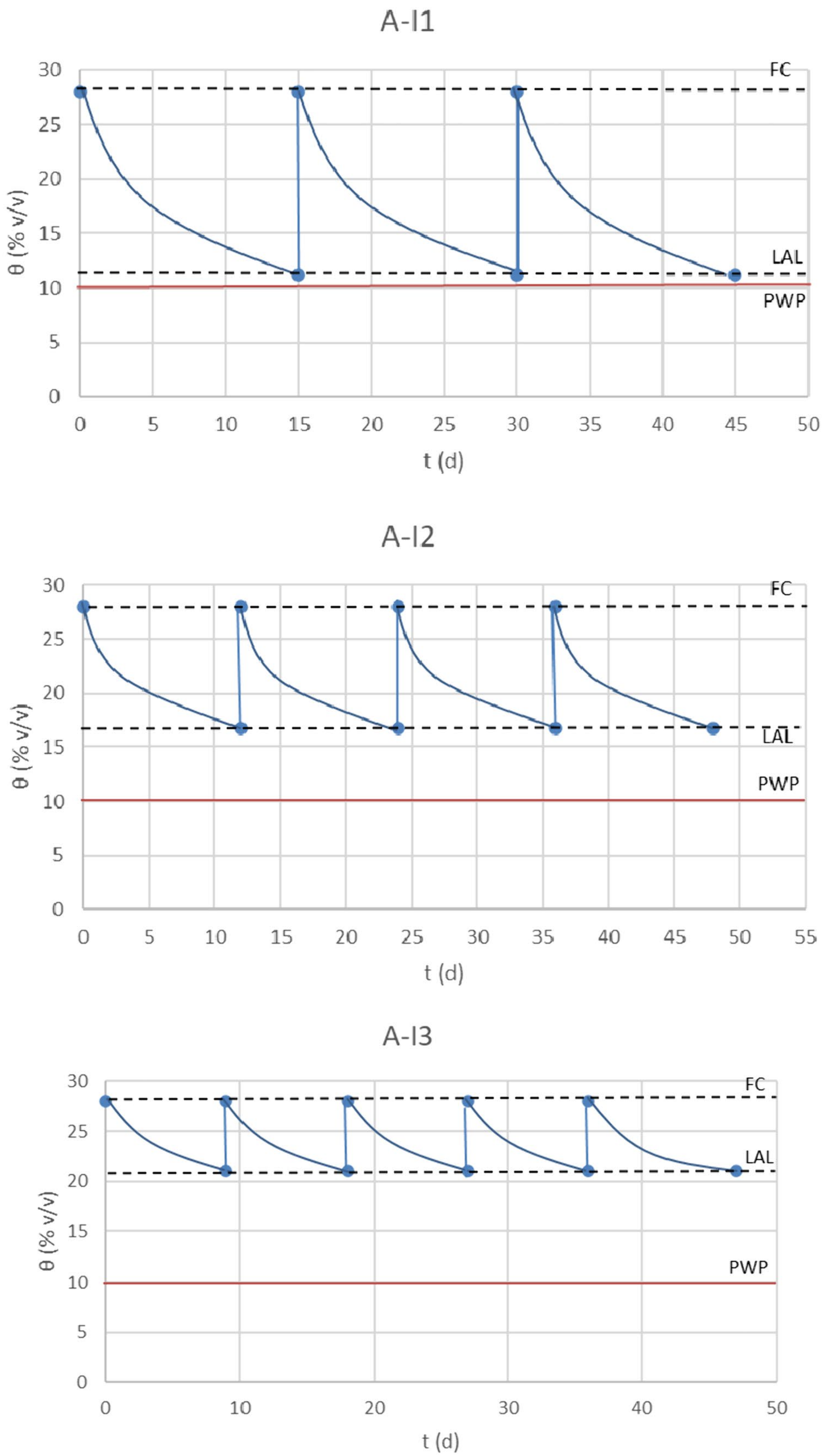

Fig. 2 Irrigation treatments at soil A (θ refers to average values of soil moisture, $n=4$) for both Cu and Zn concentrations (high and low). FC and PWP refer to field capacity and permanent wilting point respectively and I1, I2, and I3 refer to irrigation treatments corresponding to LAL of 40% FC, 60% FC, and 75% FC, respectively

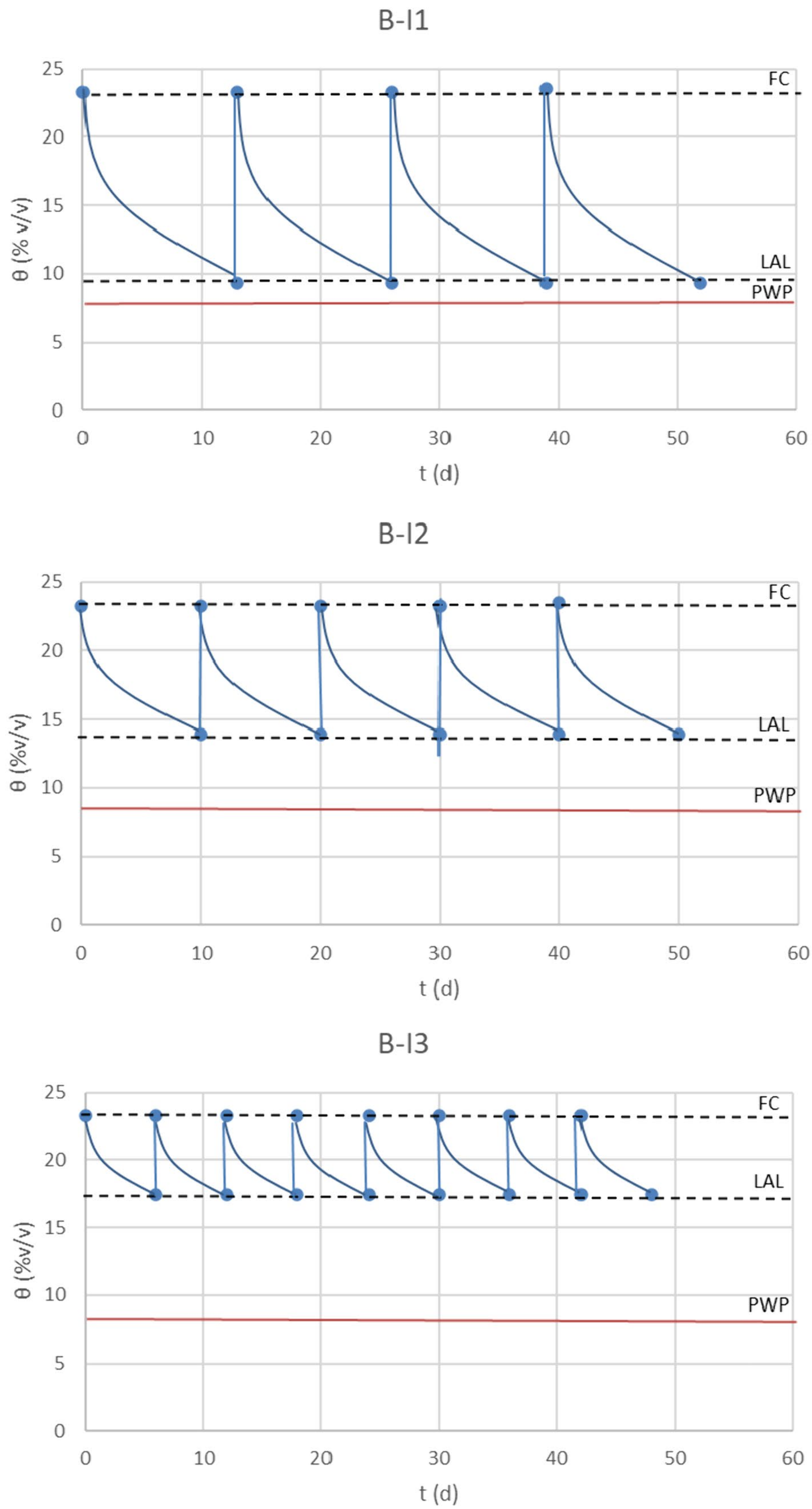

Fig. 3 Irrigation treatments at soil B (θ refers to average values of soil moisture, $n=4$) for both Cu and Zn concentrations (high and low). FC and PWP refer to field capacity and permanent wilting point, respectively, and I1, I2, and I3 refer to irrigation treatments corresponding to LAL of 40% FC, 60% FC, and 75% FC, respectively

irrigation events: B-I1: every 13 days, B-I2 every 10 days, and B-I3 every 6 days for both concentrations of Cu and Zn. The duration of all irrigation events was a bit less or equal to 50 days. The number of irrigation events was: four for the B-I1, five for the B-I2 and eight for the B-I3 treatment, for both concentrations of Cu and Zn.

Estimated marginal means are presented for the after harvest crop features, such as length, biomass, and number of leaves over the grid, comprising all (significant) factor combinations, in Figs. 4, 5, and 6. Figure 4 depicts the estimated marginal means for plant length over the grid comprising all (significant) factor combinations. The average plant length for the treatments A-Ij-L ($j=1, 2, 3$) was 42.0 cm, 45.8 cm, and 43.8 cm, respectively, while the average plant length for the treatments B-Ij-L ($j=1, 2, 3$) was 42.3 cm, 53.8 cm, and 44.5 cm, respectively. The average length for the treatments A-Ij-H ($j=1, 2, 3$) was 39.75 cm, 44.0 cm, and 42.75 cm, respectively, while the average

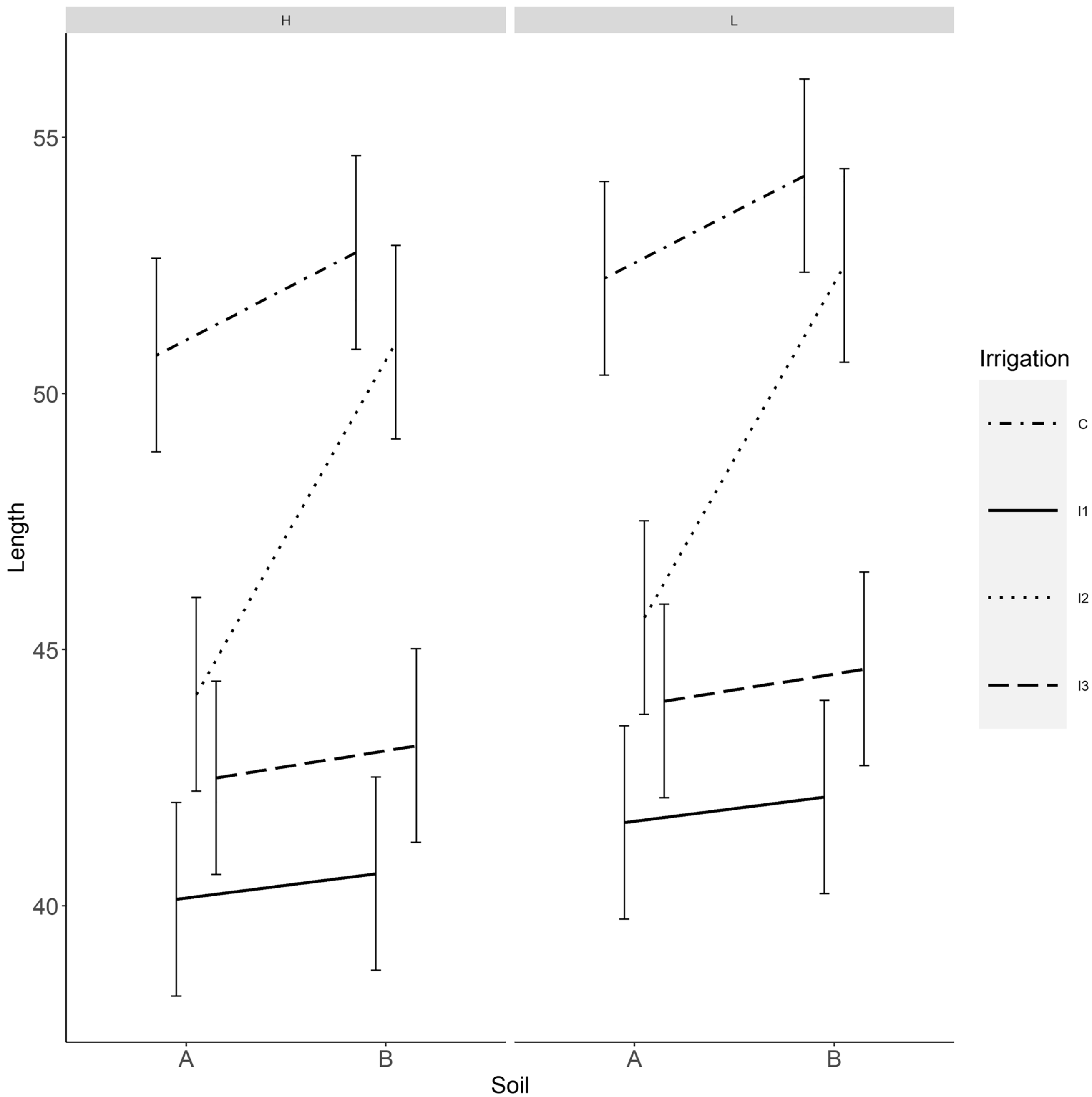

Fig. 4 Estimated marginal means for plant length over the grid comprising factor combinations for irrigation, soil, and Cu and Zn concentration. A and B corresponds to soil A and soil B, respectively; H and L corresponds to high and low concentrations of Cu and Zn, respectively

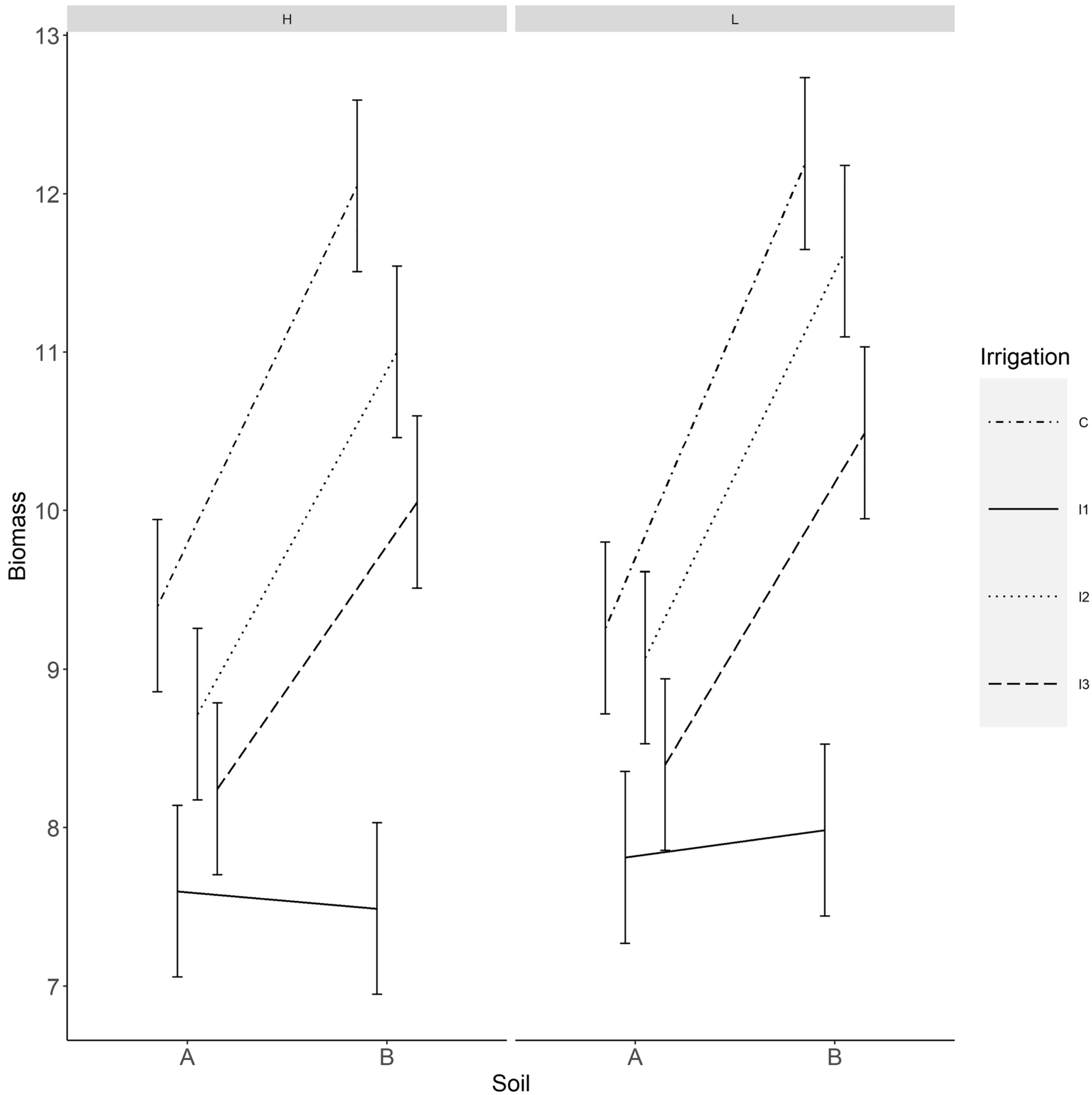

Fig. 5 Estimated marginal means for biomass, over the grid comprising factor combinations for irrigation, soil, and Cu and Zn concentration. A and B corresponds to soil A and soil B, respectively; H and L corresponds to high and low concentrations of Cu and Zn, respectively

length for the treatments B-Ij-H ($j=1, 2, 3$) was 40.5 cm, 49.75 cm, and 43.25 cm, respectively.

The estimated marginal means for biomass over the grid comprising all (significant) factor combinations is presented in Fig. 5. The average biomass values for the treatments A-Ij-L ($j=1, 2, 3$) were 7.88 g, 8.95 g, and 8.39 g [for each plant ($n=6$)] and 31.5 g, 35.8 g, and 33.54 g as the summary of the four replications, respectively. The average biomass for the treatments B-Ij-L ($j=1, 2, 3$) were 7.92 g, 11.76 g, and 10.50 g [for each plant ($n=6$)] and 31.68 g, 47.03 g, and 42.01 g as the summary of the four replications, respectively. The average values of biomass for the treatments A-Ij-H ($j=1, 2, 3$) were 7.54 g, 8.84 g, and 8.26 g [for each plant ($n=6$)] and 30.14 g, 35.15 g, and 33.03 g as the summary of the four replications, respectively, while the average values of biomass for the treatments B-Ij-H ($j=1, 2, 3$) were 7.55 g, 9.80 g, and 10.04 g [for each plant ($n=6$)] and

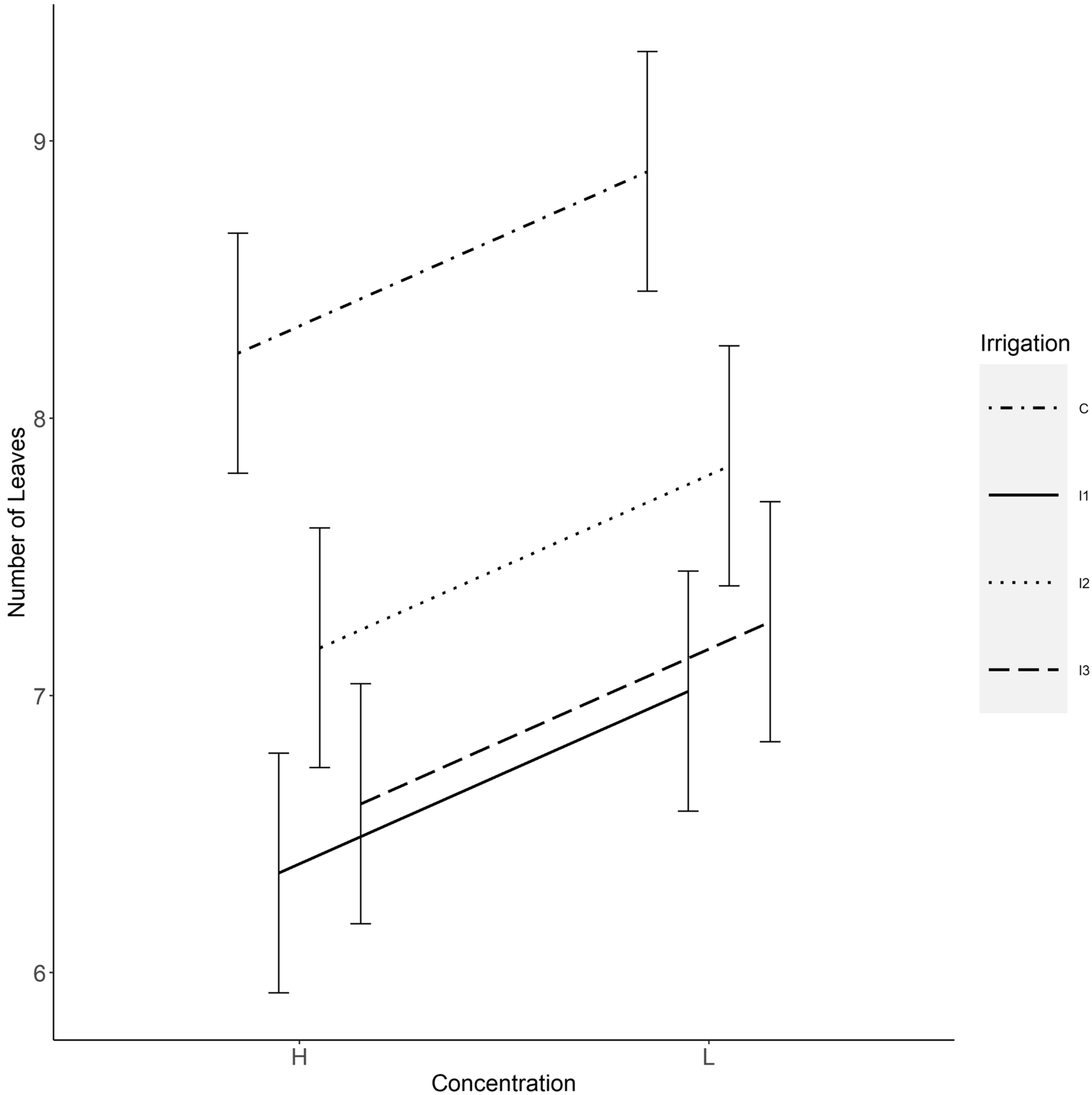

Fig. 6 Estimated marginal means for number of leaves, over the grid comprising factor combinations for irrigation, and Cu and Zn concentration. H and L corresponds to high and low concentrations of Cu and Zn, respectively

30.21 g, 43.52 g, and 40.17 g as the summary of the four replications, respectively.

The estimated marginal means for the number of leaves over the grid comprising all (significant) factor combinations are shown in Fig. 6 for all replications. In this case, the significant factors of irrigation, concentration, and soil type do not seem to affect the number of the leaves. For the treatments A-Ij-L ($j = 1, 2, 3$) the average number of leaves was 7.0, 7.8, and 7.3, respectively, while for the treatments B-Ij-L ($j = 1, 2, 3$) the average number of leaves was 6.8, 8.5, and 7.3, respectively. Also, for the treatments A-Ij-H ($j = 1, 2, 3$), the average number of leaves was the same (6.5), and for the treatments B-Ij-H ($j = 1, 2, 3$) it was 6.5, 7.3, and 6.8, respectively. Tables 3, 4, and 5 show the analysis of variance for the dependent variables (length, biomass, and number of leaves respectively) and combination of factors that were significant.

Table 3 Analysis of variance (length)

ANOVA—length	Sum of squares	df	Mean square	F	p
Soil	100.0	1	100.00	31.7	< 0.001
Irrigation	1227.9	3	409.29	129.7	< 0.001
Concentration	36.0	1	36.00	11.4	0.001
Soil × irrigation	107.6	3	35.87	11.4	< 0.001
Residuals	173.5	55	3.15		

Table 4 Analysis of variance (biomass)

ANOVA—biomass	Sum of squares	df	Mean square	F	p
Soil	51.81	1	51.809	286.01	< 0.001
Irrigation	81.12	3	27.041	149.28	< 0.001
Concentration	1.31	1	1.306	7.21	0.010
Soil × irrigation	18.09	3	6.030	33.29	< 0.001
Residuals	9.96	55	0.181		

Table 5 Analysis of variance (number of leaves)

ANOVA—no leaves	Sum of squares	df	Mean square	F	p
Irrigation	33.30	3	11.099	30.6	< 0.001
Concentration	6.89	1	6.891	19.0	< 0.001
Residuals	21.42	59	0.363		

Soils in urban environments have unique properties, functions, and values and require specific management practices. Anthropogenic activities often override the soil factors that determine their physicochemical properties (Mónok et al. 2021). Due to the direct risk of pollution in urban, highly inhabited regions, urban farming or cultivation outside of typical agricultural contexts requires careful oversight to minimize trace element deficits in plants (Wang 2022). Managing such soils requires innovative approaches including rational water management, to adapt to urban contexts, support urban people, and improve urban sustainability (Martínez-Valderrama et al. 2023).

At the present research, a pot experiment was carried out to evaluate the different irrigation treatments along with different soil types and different Cu and Zn concentrations at onion (*Allium cepa L.*) cultivation. As shown in Figs. 2 and 3, different irrigation frequencies were applied due to different soil moistures after irrigation and drainage (LAL) related to FC quota. Each soil was let to reach soil moisture equal to 40% FC, 60% FC, and 75% FC and then fulfilled with water until soil moisture became equal to FC. This means that to reach the value of FC, the irrigation doses (D_n) were set equal to 60% FC, 40% FC, and 25% FC, respectively. Figures 2 and 3 show the three irrigation treatments, for the two soil types and the two Cu and Zn concentrations, respectively. Soil A was irrigated every 15, 12, and 9 days, while loamy sand was irrigated every 13, 10, and 6 days according to the irrigation plan. The total duration of the irrigation events was about 50 days at all treatments.

The loamy sand soil (soil B) showed lower values of FC, PWP, and LAL, which is related to the texture of the soil. This soil type is coarse due to high percentage of sand and has lower soil moisture at saturation due to lower holding capacity, along with greater hydraulic conductivity (Angelaki et al. 2021; Sakellariou-Makrantonaki et al. 2016; Wang et al. 2021). The second soil sample (soil B), with higher sand content, is frequently observed in cities (Mónok et al. 2021). In the present study, the onion cultivation was based on sampling from the city center of Volos (Papadimou et al. 2023). This soil sample has a decreased ability for retaining soil water, resulting in frequent nutrient loss. Regarding heavy metals that may be present in the soil as a result of various human activities, the toxic components will be eliminated in the deeper levels of the soil compartment, limiting the danger of consuming contaminated crops produced in this soil (Kabata-Pendias 2010). Of course, less poisonous and maybe important substances (nutrients) may be leached off. Cu and Zn belong in this group, consequently, proper management is required to keep plants from becoming nutrition deficient. The more cohesive soil (soil A) showed greater values of FC, PWP and θ_s due to greater water holding capacity (Angelaki et al. 2023; Lemos-Paião et al. 2022; Ghanbarian and Skaggs 2022). This led to more frequent and light irrigation events at pots filled with loamy sand soil (soil B), which indicates that the soil texture is a key parameter in irrigation management. However, nutrient retention is governed by a variety of factors, including two opposing forces: the soil and the plant (Alloway 2013). Exogenous variables, such as human activities, additionally have an impact on the soil–plant system, altering the nutrient balance either directly or indirectly. The presence of trace elements in soils is critical for healthy plant development and disease prevention (Kabata-Pendias 2010). The quantity of irrigation water accessible determines its availability, and the quality and quantity of irrigation water should be carefully evaluated each time. Among the same irrigation treatment applied at different soil types, loamy sand soil (soil B), received slightly more irrigation events with higher frequency.

Regarding to the after-harvest crop features such as plant length, among all treatments the B-I2 treatment led to the greater length according to Fig. 4 and Table 3, regardless of the concentration. The L (low) concentration shows significantly higher length compared with H (high), adjusting for the other two factors. Referring to Fig. 5 along with Table 4, the B-I2 treatment also gave greater values of biomass, while L concentration gave significantly higher biomass in comparison with H, adjusting for the other two factors. When moderately contaminated urban soils are utilized to produce vegetables in pots, we find that the production and growth of plant mass is sufficient. Between the same irrigation regimes at the same soil type, the average number of leaves was slightly greater at low concentrations of Cu and Zn. Regarding the number of leaves, adjusting for irrigation, L concentration gave higher values, while adjusting for concentration, I2 treatment showed significant difference with I1 and marginally significant difference with I3 treatment.

The results are in agreement with several articles, which emphasize in soil texture, soil pH, and irrigation management, according to which onions can be grown at many soils with pH range from 6 to 7, while the optimal pH of the soil is between 6.2 and 6.8 at loamy sand soils (Karim et al. 2013), and the optimum water management consists of frequent and light irrigation doses (Gangwar et al. 2019; Asres et al. 2022). The soil response in urban soils is often alkaline, due to the effect of construction procedures, waste distribution, and a rise in the number of plastics that end up in the natural pollutant reservoir, the soil. When a plant is cultivated in slightly alkaline soil, the soil pH in the rhizosphere area is decreased owing to hydrogen cation secretion (Alloway 2013; Scharenbroch et al. 2022). This increases the availability of trace elements in the soil solution, which enhances the absorption process (Kabata-Pendias 2010; Golia 2023). Soil moisture close to FC is beneficial for plants, although it is suggested to not exceed this value during irrigation. Available soil moisture to plants is defined by the extraction of FC minus PWP, while root length is considered when calculating available water depth (Terán-Chaves et al. 2023). The findings of the present research indicate that knowing the value of the available water for irrigation is not the only factor that plays fundamental role on crop features and yield. The key factor is the irrigation water management, which means that the available water should be applied the best way. To manage the available water amount in an optimal way, it is crucial to consider several factors such as the timing and the frequency of watering. It is important to answer the questions “when?,” “how often?,” and “how much?” to manage the available water in the most efficient way. This means that the optimal scheme of water management is essential for the yield and the sustainable resources decisions (Kadayifci et al. 2005; Pejić et al. 2011; Piri et al. 2020; Barrales-Heredia et al. 2023; Terán-Chaves et al. 2023).

Rational water management often deals with the crucial moisture we let the soil drain to, hence it is important to determine the lower available limit (LAL), a moisture often related to FC quota. In the present study, as shown in Figs. 2 and 3 and Table 2, the LAL was 40% FC, 60% FC, and 75% FC. According to the results, when we let the soil drain to 60% FC and filling out the soil moisture with 40% FC, it gives us the optimal scheme for lighter soil texture, for both concentrations. However, the low concentration treatment gave better results for adjusting the factors soil and irrigation. This indicates that onions cultivated in light texture, well-drained soils with low concentrations of Cu and Zn can show better crop features and yield if we let the soil drain to 60% FC and fulfill the soil moisture to FC, indicating frequent and small irrigation events.

These results are in accordance with several researchers (Biswas et al. 2010; Piri et al. 2020; Barrales-Heredia et al. 2023; Terán-Chaves et al. 2023). Furthermore, it appears that an innovative perspective is being suggested for crops that meet food demands and the exploitation of non-fertilized soils using nontraditional agricultural methods (Wang 2022; Al Khoury et al. 2023). Growing in pots, on balconies, and on rooftops is becoming more popular due to intense urbanization and a decline in cultivated area (Paraskevopoulou et al. 2020; Bak and Barjenbruch 2022). While selecting the optimal irrigation system, urban soils with low organic matter content, barrenness, and mild pollution can be utilized to their most significant advantage (Tamburini et al 2020). Furthermore, if the best-proposed scheme is adopted, Cu and Zn cations can be avoided from leaching, preventing pollution of the aquifer in the studied area.

Conclusions

In the current research, a comparative evaluation of the response of *Allium cepa L.* to different irrigation treatments and plant nutrition at two soil types is presented. The main objective of the research was to indicate the optimal scheme of irrigation regimes and nutrition when applied at cohesive and light texture soils. According to the results, the treatment of LAL equal to 60% FC at the light texture soil with low Cu and Zn concentration is the optimal scheme for cultivating *Allium cepa L.* in pots. Hence, well drained loamy sand soils, treated with small irrigation doses, frequent irrigation events, and low trace elements addition are ideal for onions pot cultivation in urban environments. The current life pace, with intense urbanization, requires human adaptation to the new reality. The adoption of smart methods for the exploitation of limited arable land and water sources is required to avoid inhibiting neither the quantity nor the quality of the produced goods.

Author contributions A.A. was involved in method design, study design, data processing, resources, writing, editing and reviewing,

and supervision. E.E.G. was involved in method design, study design, chemical analysis, analytical protocol design, data processing, resources, writing, editing and reviewing, and supervision.

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Data availability Data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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