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Zinc pulverization alleviates the adverse effect of water deficit on plant growth, yield and nutrient acquisition in grapevines (*Vitis vinifera* L.)

Ali Sabir[a,*], Gamze Sari[b]

[a] Selcuk University Agriculture Faculty Horticulture Department, Konya, Turkey
[b] Selcuk University Graduate School of Natural and Applied Science, Konya, Turkey

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ABSTRACT

Grapevine (*Vitis vinifera* L.) is an important dryland pulse crop in many parts of the world. However, productivity and quality are often limited by periods of water deficit. In a number of drought regions, drought is accompanied with zinc (Zn) deficiency, one of the most serious problems causing significant decreases in yield and quality in viticulture. In spite of this fact, possible effect of Zn treatment to alleviate the adverse effect of water stress on grapevines has not been studied. A pot culture research was designed under controlled glasshouse condition with the objective to investigate the effects of Zn pulverization on growth, physiology and nutrient acquisition of grapevine cultivars 'Italia' and 'Alphonse Lavallée' subjected to different irrigation levels. Six years old grapevines of the cultivars grafted on a drought tolerant rootstock Richter 99 (*Berlandieri* x *Rupestris*) were cultivated in pots (70 L) and subjected to two different irrigation regimes, FI-100% (replenishing the substrate water storage up to field capacity) and DI (40% of FI). Half of the vines for each irrigation group received leaf Zn pulverization (1%) twice (prior to flowering and berry set). DI caused overall decreases in shoot and leaf developments of cultivars, while Zn pulverization had alleviating effects on such vegetative growth in general. Generally, leaf chlorophyll content of the vines was also improved by Zn under both FI and DI conditions. Spraying of the leaves and green bunches with chelated Zn supported the grapevines of both cultivars 'Italia' and 'Alphonse Lavallée' in varying degrees by improving acquisition of many plant nutrients, promoting the vegetative and generative developments. Considering the overall response of the vines to Zn pulverization with a particular concern to DI condition, improved shoot and leaf growth, greener leaves, enhanced berry development and vine yield allow us to recommend Zn spraying as an environmentally friendly and sustainable cultural practice under drought stress which has been increasing with global climate change.

1. Introduction

Most of the vineyards around the world experience seasonal or long-term drought in conjunction with high temperature and radiation. It is estimated that nearly 1.8 billion people will be faced with absolute water shortage in the first quarter of the twenty-first century and 65% of the human population will live under conditions of partial shortage of water (Nezhadahmadi et al., 2013). Global climate change, causing temperature extremes and more frequent water deficit in agricultural areas, is also adversely influencing the grapevine phenology, physiology and development throughout the world (Webb et al., 2007). Jones et al. (2005) have already reported that certain European grape-growing regions are approaching to exceed the thresholds of temperature and rainfall for optimum grapevine growth. More frequent extreme weather is predicted by most models, along with a significant increase of the summer air temperature and water stress, particularly for regions with a Mediterranean-type environment (Tubiello et al., 2000), where a great majority of world grape production is found. If the climate change course proceeds, grape yield and quality will be seriously affected in the near future. Thus, viticulturists have to perform better adaptive strategies to ensure production of economically high quality grapes at acceptable yields under dryer climate conditions in order to match the food demands of ever-increasing world population. The use of genetically drought tolerant rootstock and scion materials is the primary strategy among various options one of which is the use of environment friendly and cost effective plant protection way. Grapevine is one of a well-known drought avoidance species (Schultz, 2003), although its degree of water loss control under stressful conditions depends on physiological and functional properties that have rarely quantified in experimental studies. In Mediterranean type agro-ecosystems,

* Corresponding author.
E-mail address: asabir@selcuk.edu.tr (A. Sabir).

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grapevine genotypes belonging to *Vitis vinifera* L. species have traditionally been grown in marginal ecologies without irrigation in spite of the fact that rainfall generally does not meet the evapotranspirative demand of vines. The efficient management of limited water resources in Mediterranean agriculture requires irrigation scheduling techniques based on deficit supply. However, irrigation waters in grape growing areas are usually alkaline with a pH higher than 7.0 level. Watering plants with alkaline water over the vegetation period inevitably raises the pH of growth medium. Too high a pH, greater than 6.5, increases the incidence of micronutrient deficiencies. Furthermore, many of the soils in regions, where viticulture is main crop, have low available zinc (Zn) and frequently requires Zn fertilization. Consequently, grapevines may be challenged by water deficit and Zn deficiency simultaneously. By reducing root growth, Zn deficiency may limit the ability of the crop to use the moisture reserves in the soil (Nable and Webb, 1993). Sharma et al. (1994) indicated that Zn deficiency causes a reduction in the instantaneous transpiration efficiency of leaves. Zn is one of the essential micronutrients and an integral component or activator of a number of enzymes that represent almost all plant enzymatic groups. But, interestingly, the effect of Zn nutrition on the response to water stress has received little attention in experimental studies. In fact, Zn deficiency is a widespread micronutrient disorder in different agroclimatic regions of the world, particularly within arid and semi-arid areas (White and Zasoski, 1999) where viticulture is widespread. Under drought condition, Zn mobility in the soil is extremely low (Cakmak et al., 1996) and thus Zn acquisition is commonly reduced by low water availability. Grewal and Williams (2001) indicated that the ability of plants to cope with water stress during vegetation period could be enhanced with adequate Zn supply. Vitosh et al. (1994) demonstrated that several crops, including grapes have most sensitivity to Zn deficiency. In grapes, poor fruit set and “hen and chicken” bunches of variable sized berries may occur due to Zn deficiency even when leaf symptoms are not observed. It was documented that Zn foliar application is a simple way for making quick correction of plant nutritional status, as reported by Erenoglu et al. (2002). Accumulating evidence proven that mineral-nutrient status of plants plays a fundamental role in increasing plant ability to resist to adverse stress conditions (Khan et al., 2004). Zn nutritional status of plants may affect their drought sensitivity (Cakmak, 2000). Zn-deficient plants use water less efficiently and are less able to respond to increasing soil water deficits by osmotic adjustment than plants that are supplied with adequate levels of Zn. Previous studies also revealed that Zn protects plants against oxidative damage resulting from abiotic and biotic stresses (Cakmak, 2000), and, by this way, supports the plants cope with harsh conditions (Alloway, 2008). In spite of this common knowledge, surprisingly, insufficient experimental literature has been available about the use of Zn supplementation in table grapes to mitigate adverse effect of drought in especially the Mediterranean Zone where water stress is frequent and pervasive in viticulture areas. The current experiment was therefore undertaken, (1) to examine the effects of water stress and Zn nutrition on grapevines, and (2) to reveal whether Zn foliar application alleviates the adverse effect of water deficit under full and deficit irrigation regimes, and (3) to compare the responses of two grapevine cultivars to contrasting irrigation levels and Zn pulverization.

2. Materials and methods

2.1. Growth conditions

The experiment was conducted at the research and implementation glasshouse (38°01.814 N, 032°30.546E, 1158 m above sea level) of Selcuk University, Turkey, in 2017. Table grape cultivars ‘Italia’ and ‘Alphonse Lavallée’ were selected for the study due to their extensive cultivation in Europe and Turkey. Six years old vines, grafted on drought tolerant rootstock Richter 99 (*V. berlandieri* x *V. rupestris*) (Carbonneau, 1985), were individually cultivated in 70 L (solid volume) pots (35 cm diameter, 35 cm height) containing the substrate prepared with sterile peat (1.034% N, 0.94% P_2O_5, 0.64% K_2O, Klassman®) and perlite (0–3 mm in diameter) mixture in equal volume. The vines were drip irrigated using one irrigation line for per row equipped with single emitter of 4 L h^{-1} each per vine. The pots were isolated from the ground with plastic sheets. In the winter season, the vines were spur pruned leaving four spurs having two buds each, considering the genetically sufficient fruitfulness of basal nodes of the cultivars. After bud break (in March), six or seven shoots per vine were allowed to grow to ensure homogenous plant growth for a logical comparison of treatment effects. At the beginning of the study, nine vines per treatment were selected on the basis of homogeneity in growth. A tap water with a pH ≈ 7.5 was used for irrigation because water sources in Central Anatolia (Turkey) are alkaline. The initial pH of growth medium, pH: 6.50, was thus gradually raised to exceed 7.0 by watering the experimental grapevines with alkaline water as commonly practiced by grape growers. Over a five month period, rootzone pH values for media subjected to DI and FI were 7.18 ± 0.03 and 7.23 ± 0.02, respectively where microelement imbalance begins in many perennials. Salinity levels (1.103 and 1.407 dS/m for DI and FI, respectively) were not at critical level according to the suggestions of Walker (2010).

2.2. Experimental layout

The study layout was a randomized complete block design with two irrigation regimes [full irrigation (FI) and deficit irrigation (DI)] and two treatments (Zn pulverization and non-treated control) for each cultivar. Irrigations were scheduled according to soil water matrix potential (Ψm) levels using several tensiometers (The Irrometer Company, Riverside, CA). In order to optimize the accurate tensiometer values for continuously monitoring of substrate matrix potential at two different levels, initially, the peat-perlite substrate (pot) water storage at field capacity was calculated following the methodology described by Satisha et al. (2006). For this, briefly, two randomly taken pots filled with known volume of oven-dried growth media for each group of FI and DI were irrigated with known quantity (5 L) of water up to saturation of substrate. Then the pots were placed in the buckets and maintained for 6 h to attain the field capacity after draining of the gravity water from larger pores. After six hours, the amount of the drained water in the bucket was counted as 4.23 L and was subtracted from total amount of water applied initially. The calculated value (770 mL) was considered as FI. Forty percent of FI (308 mL) was considered as DI (Sabir, 2016a; b). These water amounts were used for start levels. Two tensiometers for each treatment were employed for a long-term control and expression of substrate water depletion (Young and Sisson, 2002), in terms of Ψm following the slightly modified procedure described by Myburgh and van der Walt (2005). Tensiometers were placed at a depth of 20 cm and approximately 12 cm away from the trunk. Changes in Ψm were continuously recorded with five consecutive daily readings at around 13:00 pm as well as before and after irrigations (Okamoto et al., 2004). Repeated readings showed that the midday matrix potential values were persistently around 10 ± 3 cb and 38 ± 4 cb for FI and DI conditions, respectively. The start value of watering for FI group vines was adjusted to 12 cb, which is about the lower limit of the easily available water in substrate. In order to practice DI, drip irrigation system was started when Ψm reached 40 cb (the level at which slight wilting occurred) and was terminated at matrix potential of 34 cb. Tensiometer readings during the study were presented in Fig. 1. Relatively higher air temperature in the glasshouse was kept to simulate the typical semi-arid Mediterranean climate. During vegetation period, daily air temperature and relative humidity, recorded using data logger (Ebro EBI 20 TH1) inside the glasshouse, were 26.4–40.8 °C and 23.2–43.7%, respectively (Fig. 2). In the hot and dry days, excessive heat accumulation in glasshouse was avoided by opening the roof and sidewall windows as well as slight whitewash