Scientia Horticulturae 240 (2018) 179–185

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Potassium humate improves physio-biochemical attributes, defense systems activities and water-use efficiencies of eggplant under partial root-zone drying

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ARTICLE INFO

Keywords:
Biostimulants
Growth and yield
Antioxidants
Solanum melongena

ABSTRACT

Partial root-zone drying (PRD) applied in an alternate strategy (PRDalt) can regulate plant physiological and antioxidative defense system responses, and it is considered as an irrigation water-saving method. The current study was carried out using pot experiments to elucidate the potential role of potassium humate (KH) in integration with PRDalt in regulating eggplant physiological and defense systems responses, and irrigation water-saving. PRDalt significantly reduced the plant growth and yield, leaf photosynthetic gas exchange, leaf relative water content (RWC) and membrane stability index (MSI), while significantly increased leaf and root contents of malondialdehyde (MDA), hydrogen peroxide (H_2O_2), and leaf and root activities of enzymatic and non-enzymatic antioxidants compared to Full irrigation (control; FI). Integrative application of PRDalt + KH increased water-use efficiencies; WUE_{fw} (calculated as g fruits L^{-1} applied water) by 97.9% and WUE_{pt} (calculated by dividing the net photosynthetic rate by transpiration rate) by 20.3% compared to the controls. It also further increased leaf and root activities of enzymatic and non-enzymatic antioxidants, while controlled the contents of MDA and H_2O_2, and maintained plant growth and yield, leaf photosynthetic gas exchange, RWC and MSI at the same levels in plants of FI. Results of this study recommend using the integrative strategy of PRDalt + KH to confer the same eggplant growth and yield of the FI control and save about 50% of irrigation water.

1. Introduction

Eggplant (*Solanum melongena* L.); a warm season plant is an important traditional vegetable crop in many tropical, subtropical and Mediterranean countries. Water requirement of eggplant is affected by Soil moisture, physiological and environmental factors. Crop evapotranspiration (ET), activity of antioxidative defense system, and plant growth and productivity are also affected by water deficit induced stress in vegetable crops including eggplant (Kirnak et al., 2002; Hu et al., 2010; Çolak et al., 2015). Nowadays, limited available fresh water resources are caused by many factors such as rapid increase of world population and their food and water demand, natural resources contamination, climate change and global warming. Therefore, water deficit in agricultural sector is expected and the effective use of limited water in agriculture needs modern irrigation methods to save water and increase water-use efficiency (WUE) with maintaining satisfactory crop yield.

One of alternative irrigation methods that can save water and increase the efficiency of WUE, partial root-zone drying in alternate method (PRDalt) is applied to some crops if the water amount is limited (Sun et al., 2013; Barrios-Masias and Jackson, 2016; Du et al., 2017; Adu et al., 2018). Partial root-zone drying (PRD) is based on the knowledge of crop's reactions to drought (FAO, 2002). PRD is irrigation technique when a one side of plant's roots is exposed to drought and in the same time the other side is irrigated. To avoid root drying the wet/dry sides are rotated. Theoretical background of PRD is that irrigation of the part of root system keeps the upper part of crops in favorable water conditions, while the drought in other part of the roots induces formation of root chemical signals (mainly hormones) (Jovanovic and Stikic, 2018). Root born chemical signals are transported to the upper part of the plants to induce reduction of stomatal conductance and shoot growth (Dodd et al., 2006). Partial reduction of stomatal conductance prevents serious water loss by transpiration and reduction of CO_2 assimilation, which could happen in drought conditions (Chaves et al., 2007).

Using some crops, many reports (Hu et al., 2010; Sun et al., 2013; Barrios-Masias and Jackson, 2016; Du et al., 2017; Adu et al., 2018) have concluded that PRDalt saves water by 30–50% without significant loss in yield and increases canopy WUE. And under appropriate conditions of fertilization and well-watering, PRDalt treatment saves

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https://doi.org/10.1016/j.scienta.2018.06.020
Received 13 October 2017; Received in revised form 27 May 2018; Accepted 8 June 2018
0304-4238/

irrigation water by approximately 38% and improves canopy WUE by approximately 25%. PRDalt improves photosynthetic and transpiration processes of crop plants (Du et al., 2006, 2017), plant water deficit stress responses such as membrane lipid peroxidation, soluble sugar content and the activity of antioxidative defense system (enzymatic and non-enzymatic antioxidants) (Zhou et al., 2007).

However, no reports were conducted to assess the effect of PRDalt in integration with potassium humate (KH) on plant growth, water deficit stress-induced physiological responses and the activity of antioxidative defense systems in plants. KH; a commercial product contains nutrients for soil fertility, increases the availability of nutrients in soil solution for plant root system and, consequently, influences plant growth and productivity. It can provide growing plants with nutrient elements, particularly potassium (K^+; considers an osmolyte element in its cationic form), making the soil more fertile and productive, and increase soil water-holding capacity (WHC) (Rady, 2011a). KH acts also as hormone-like, activating photosynthesis, accelerating cell division, increasing permeability of plant cell membranes and nutrients uptake and improving plant response to environmental stresses (Verlinden et al., 2009). Therefore, application of KH along with PRDalt helps plants to tolerate water deficit, helps soil to establish a desirable environment for sustaining water through increasing soil WHC and, consequently, stimulating plant growth and productivity. Soil supplying with KH enhances plant growth and physio-biochemical attributes that are positively reflected in crop yield and quality (Rady, 2011a; Hemida et al., 2017; Mohsen et al., 2017).

Therefore, the main aim of the current piece of work was to assess if PRDalt singly or together with KH can improve plant water-use efficiencies, in addition to, enhance eggplant tolerance to water deficit stress through evaluating plant growth, physio-biochemical attributes and activity of antioxidative defense system.

2. Methodology

2.1. Experimental site, soil and potassium humate characteristics

A pot experiment was carried out using a wire-house (an open greenhouse with a wire net to protect plants from insects attack) at Albaha University (latitude 20° 17' 41"N, longitude 41° 38' 35"E), Elevation 1651.88 m above sea level, Albaha, Saudi Arabia. The climate of the study area is semiarid (Zabin and Howladar, 2015) and is characterized as follows: the mean annual temperature varies from a minimum of 17.8 °C and a maximum of 29.9 °C. The average annual rainfall is about 62.45 mm. The relative humidity minimum 15% and maximum 87%, the mean wind speed around 175 m/sec (P.M.E.P., 2016). The experimental soil type is a sandy loam having low organic matter content that is shown in Table 1 with other physico-chemical characteristics prior and next to applying tested potassium humate (KH). The main characteristics of the tested KH on a dry weight (DW) basis were as follows: humic acid content 65.0% (w/w), total N 6.0% (w/w), total P 1.0% (w/w), total K 16.0% (w/w), Fe 0.06% (w/w), Mn 0.04% (w/w), and Zn 0.03% (w/w).

2.2. Plant material, experimental design and experiment management

Transplants of eggplant (30 days old) were transplanted on 15 April 2016 in pots (38 cm in top diameter, 32 cm in bottom diameter, and 38 cm in depth) at a rate of 1 transplant per pot. Plants were well-watered for ten days after transplanting. Thereafter, the plants were subjected to two irrigation treatments: (1) The control treatment with or without KH was received full irrigation (FI) that was conducted at 16:00 h and kept close to water-holding capacity (90%). (2) Partial root-zone drying (PRD) treatments with or without KH, scheduled to receive 50% of the irrigation water volume of FI and divided into two systems; fixed partial root-zone drying (PRDfix) irrigation, in which half of the root system was watered daily at 16:00 h to a water content of 50% of FI while the other half was allowed to dry until harvest stage, and alternate partial root-zone drying (PRDalt) irrigation, where half of the root system was watered daily at 16:00 h to a water content of 50% of FI while the other half was allowed to dry for seven days, then the irrigation was switched between the two soil compartments (Yan et al., 2012). The average soil water content in the pot was monitored by using digital WET sensors (Moisture Meter type HH2, Cambridge, CB5 0 EJ, UK). The water used for irrigation was tap water with negligible concentrations of nutrients. The irrigation treatments lasted 96 days, during which period each soil compartment of the (PRDalt) plants had experienced seven dry/wet cycles. Irrigation water applied (IWA) in FI treatment was 106 litter per pot, and 58 litter per pot for PRD treatments. All pots of the 6 treatments were arranged in a completely randomized design (CRD) with 10 pots for each treatment, and each pot was represented a replicate. The experiment was repeated 3 times. Potassium humate (KH) was added at a rate of 0.5 g kg^{-1} soil. PRDalt and PRDfix at 50% of soil WHC, in addition to KH level of 0.5 g kg^{-1} soil used for this experiment were chosen based on preliminary experiments (data not shown).

Using plastic sheets, the inside of all pots was equally separated tightly into two halves from the middle to prevent water exchange between the two halves. Each uniform transplant was put at the center of the pots through sliding in the middle of the plastic sheet to fairly distribute the roots into the two separated halves. In addition, to prevent the exchange of water from the above, the edge of the plastic sheet was kept 2–3 cm above the soil inside each pot. At both side of each pot near the bottom, 3 small holes were respectively left to maintain the aeration of the soil. Each half of each pot was filled with 5 kg air-dried soil. In all pots, soil water regime was kept 90% of WHC before transplanting.

The fertilization program for this experiment was applied as follows: A dose of 50 mg calcium superphosphate (15.5% P_2O_5) per kg soil was added before transplanting, a dose of 90 mg ammonium nitrate (33.3% N) per kg soil was added in three splits; the first split was added at 20 days after transplanting (DAT), the second and third splits were added 20 and 40 days later, respectively, and 50 mg potassium sulphate (48% K_2O) per kg soil was added at two equal additions; during soil preparation and 40 DAT. All agricultural practices were done as commonly followed in the commercial production of eggplant.

Table 1
Physico-chemical characteristics of a sandy loam soil prior and next to applying the potassium humate (KH).

Soil WHC* (%)	CEC** ($cmol^+/kg$)	pH	EC ($dS\ m^{-1}$)	OM***	N	P	K	Ca	Fe	Mn	Zn
				($g\ kg^{-1}$)		($mg\ kg^{-1}$)					
Prior to conducting the experiment											
22.3	8.0	7.8	2.3	8.6	0.74	15.3	71.1	80.4	5.8	3.2	1.8
Next to applying the KH											
25.1	8.7	7.1	2.0	9.5	0.80	15.6	77.0	80.2	6.3	3.5	2.0

*WHC means water holding capacity, **CEC means cation exchangeable capacity, and ***OM means organic matter content.