Scientia Horticulturae 168 (2014) 218–228

Contents lists available at ScienceDirect

Scientia Horticulturae

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

Growth, developmental, and physiological responses of two sweetpotato (*Ipomoea batatas* L. [Lam]) cultivars to early season soil moisture deficit

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ARTICLE INFO

Article history:
Received 15 November 2013
Received in revised form 12 January 2014
Accepted 15 January 2014

Keywords:
Cell membrane thermostability
Drought
Photosynthesis
Pigments
Soil moisture
Transpiration

ABSTRACT

Soil moisture deficit at early season is detrimental for sweetpotato growth and development affecting final yield. This study investigated the effects of different soil moisture regimes on early season growth, developmental, and physiological responses of two sweetpotato cultivars, 'Beauregard' and 'Evangeline', grown in a greenhouse environment. Five levels of soil moisture treatments, 0.256, 0.216, 0.164, 0.107, and 0.058 $m^3\ m^{-3}$ of VWC, were maintained through sensor-based soil moisture monitoring, and semi-automated programmed irrigation. Midday leaf water potential (LWP), gas exchange, and fluorescence were measured weekly from 30 to 50 days after transplanting (DAT). Growth and development of plants were evaluated through harvesting four plants at 5-day intervals from 14 to 50 DAT. Leaf pigments and cell and chlorophyll stability indices were also determined. Midday LWP of sweetpotato declined linearly with decreasing soil moisture levels. The photosynthetic rate also declined linearly in Beauregard and quadratically in Evangeline with decreasing soil moisture. Both cultivars had a close association between photosynthetic rate and stomatal conductance over the soil moisture treatments, suggesting that stomatal closure is a key limitation for the drop in photosynthesis. Chlorophyll concentration was significantly lower at extreme soil moisture deficit conditions. Significant difference was found in water use efficiency between cultivars and among soil moisture treatments. Rates of vine elongation and leaf formation of Evangeline decreased more rapidly than Beauregard with declining soil moisture levels. Also with decreasing soil moisture, the shoot biomass declined more rapidly than root biomass. The results showed that maintaining soil moisture closer to field capacity (0.256 $m^3\ m^{-3}$ of VWC) during early season is beneficial for early development of both root and shoot system and thus better crop performance. The data and the inferences derived from the functional algorithms developed in this study will be useful for crop modelling, field-level irrigation scheduling, and planting decisions.

1. Introduction

Drought is one of the crucial abiotic stresses affecting plant growth and development, especially at the initial phase of plant establishment, ultimately limiting crop productivity (Chaves et al., 2002; Jaleel et al., 2009). Plants experience drought stress either when the water supply to roots becomes difficult or when the transpiration rate becomes very high (Reddy et al., 2004). Due to fluctuating rainfall patterns and lack of irrigation, crops are subjected to different intensities of soil moisture deficits resulting in variable growth and productivity (Doupis et al., 2013) through altering metabolic functions (Jaleel et al., 2009). The worldwide yield losses due to water deficit exceeded the losses from all other stresses combined (Jaleel et al., 2008) and the consequences of predicted climate change further intensify such losses due to precipitation extremes and drought intensities (Singh and Reddy, 2011). Under irrigated conditions, plant water is one of the most crucial and manageable factors for successful crop production (Taylor et al., 1983). Understanding the array of responses of crop plant processes and mechanisms to a wide range of available soil moisture is crucial and a fundamental part of crop stress tolerance (Reddy et al., 2004; Zhao et al., 2008), and important to improve their agronomic performances. Sweetpotato [*Ipomoea batatas* (L.) Lam.] is one of the world's most important root crops and ranks as the seventh major food crop in the world (FAO, 2009). It is mostly cultivated in tropical and subtropical regions (Bovell-Benjamin, 2007; Ku et al., 2008; Mukhopadhyay et al., 2011) under

Abbreviations: DAT, days after transplanting; FC, field capacity; LWP, leaf water potential; SMC, soil moisture content; VWC, volumetric water content; WUE, water use efficiency.

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0304-4238/$ – see front matter
http://dx.doi.org/10.1016/j.scienta.2014.01.018

a broad range of environments and cultural practices. Sweetpotato production in the United States is primarily concentrated in the southern states and California as an important agri-business (U.S. Department of Agriculture, 2002) and cultivated in both rain-fed and irrigated environments (Stoddard et al., 2013). The crop contributed more than $500 million to the country's economy in 2012 (U.S. Department of Agriculture, 2013). Even though sweetpotato is a moderately drought tolerant crop (Ghuman and Lal, 1983; Valenzuela et al., 2000), the plant is sensitive to water deficit, particularly during the establishment phase, including early vine development and storage root initiation (Pardales and Esquibel, 1997; Indira and Kabeerathumma, 1988; Gajanayake et al., 2013). Also, a significant yield reduction has been reported under compacted and very high soil moisture (Watanabe, 1979) as well as poorly drained and water logged conditions (Ghuman and Lal, 1983). Under rain-fed conditions, drought is a major environmental factor delimiting sweetpotato production (Anselmo et al., 1998). Also, cultivars respond differently to limited quantities of soil moisture levels (Saraswati et al., 2004) and understanding cultivar responses to a wide range of soil moisture levels is important both for crop improvement, modelling, and managing inputs for higher productivity.

Water deficit is a condition that affects several physiological and biochemical processes in the plants such as photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism, and growth promoters (Farooq et al., 2008; Jaleel et al., 2008). According to Laurie et al. (2009) shoot growth and photosynthetic rates are the two major factors responsible for withstanding water deficits in sweetpotato. Plants subjected to water stress are characterised by reduced water content, diminished leaf water potential and turgor loss, closure of stomata, and decreased cell enlargement. Severe soil moisture stress could result in the arrest of photosynthesis, disturbance of metabolic activities, and even plant death (Jaleel et al., 2008). Maximum yield potential depends on an early development of source organs (leaf area) for optimum light interception and photosynthesis and sink organs (both initiation and enlargement of storage roots or tubers) in root crops. Apart from the sink organs, enhancement of source organ functions and capacity are crucial for increasing the sweetpotato yield. In order to produce high dry matter through photosynthesis process, it is important to develop an optimum leaf area. Water deficit stress predominantly reduces leaf growth resulting in less leaf area in many crop species (Farooq et al., 2009). Sweetpotato leaf area index increases with increasing soil moisture content during vegetative development (Indira and Ramanujam, 1985) by adding more source capacity. Stomatal conductance has a strong impact on leaf photosynthesis rate, in particular under drought stress condition (Cornic and Fresneau, 2002). Furthermore, differences in photosynthesis rate among sweetpotato cultivars act as a key determinant of storage root yield (Haimeirong and Kubota, 2003).

Drought during summer in the Southern USA delimits sweetpotato yields and the quality of storage roots causing enormous economic losses to producers (Smith et al., 2009). Water deficit as well as flood conditions during establishment period negatively affects final yield. Considerable yield increments have been gained by irrigating sweetpotato while maintaining soil moisture at 40% of field capacity (Lambeth, 1956). According to Thomson et al. (1992), total marketable grade yield can be significantly improved through 76% of pan evaporation-based irrigation practices. They also found that any irrigation beyond that level resulted in rapid decrease in marketable grade yields. Also, sweetpotato production regions in the United States are subjected to variation in soil moisture due to inadequate precipitation and irrigation. Fluctuations in soil moisture during the cropping season, particularly in the summer months, could affect crop survival, performance, and final yield. Information regarding the responses of sweetpotato to

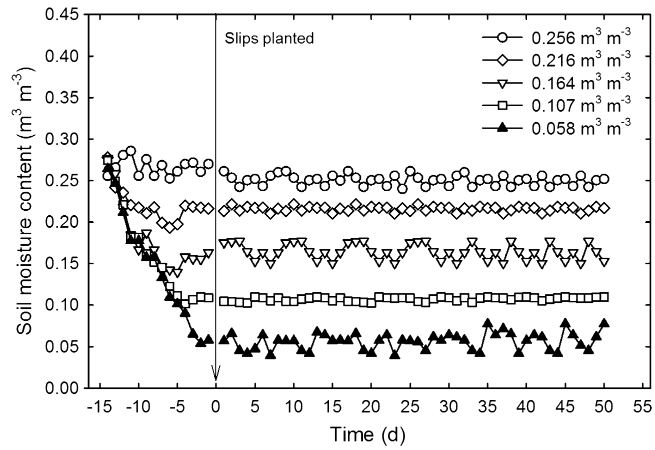

Fig. 1. Volumetric soil moisture content across treatments before and during the experimental period were maintained using sensor-based monitoring and irrigation system. The arrow indicates the day sweetpotato slips were planted and the time when all the soil moisture levels reached the desired treatment levels.

a wide range of soil moisture regimes is limited and such information on optimum soil moisture during different stages of growth and physiological processes found in the literature are limited and conflicting. Therefore, this study aimed to quantify the effects of wide range of soil moisture levels on growth, developmental, and physiological performances of two commercial sweetpotato cultivars.

2. Materials and methods

2.1. Experimental facility, plant material, and soil moisture treatments

The experiment was conducted from May to June, 2012, using two commercial sweetpotato cultivars, Beauregard (Rolston et al., 1987) and Evangeline (La Bonte et al., 2008) in the USA. They were evaluated at five levels of soil moisture contents (SMC) under greenhouse conditions at the Rodney Foil Plant Science Research Center, Mississippi State University, Mississippi State (33°28′N, 88°47′W), Mississippi, USA. The temperature in the greenhouse was maintained between 24 and 33 °C during the experimental period. The average photosynthetically active radiation measured using a line quantum sensor (LI-191 Line Quantum Sensor; LI-COR, Inc., Lincoln, NE, USA) at noon on several clear days was over 1200 $\mu mol\, m^{-2}\, s^{-1}$. Thirty two 2-L plastic pots (17 cm diameter and 16 cm height) filled with sandy clay loam soil as a growth substrate were used for each moisture treatment to accommodate eight harvest dates. Accordingly, 320 pots were arranged in rows oriented east to west direction on benches in the greenhouse as a completely randomised design with four replications per harvest per treatment for each cultivar. Before planting, pots were fully saturated using full-strength Hoagland nutrient solution (Hewitt, 1952) and allowed to free-drain. Then, five soil moisture treatments, expressed as volumetric water content (VWC) of 0.256, 0.216, 0.164, 0.107, and 0.058 $m^3\, m^{-3}$, representing 100%, 84%, 64%, 42%, and 23% of field capacity (FC) were imposed two weeks prior to transplanting of sweetpotato slips (Fig. 1). Once the desired soil moisture levels were achieved, sweetpotato slips were transplanted with two nodes in the soil and two nodes above the soil surface. Soil moisture contents in each treatment were monitored and maintained based on the VWC determined by moisture sensors (Model EC-5; Decagon devices, Inc., Pullman, WA, USA) inserted at a depth of 10 cm on five random pots in each treatment and semi-automated irrigation system. All the sensors were connected