Scientia Horticulturae 126 (2010) 172–179

Contents lists available at ScienceDirect

Scientia Horticulturae

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

Growth, yield and water use efficiency response of greenhouse-grown hot pepper under Time-Space deficit irrigation

Shao Guang-Cheng [a,b,*], Liu Na [c], Zhang Zhan-Yu [a,b], Yu Shuang-En [a,b], Chen Chang-ren [d]

[a] Key Laboratory of Efficient Irrigation-Drainage and Agricultural Soil-Water Environment in Southern China, Ministry of Education, Nanjing 210098, PR China
[b] College of Water Conservancy and Hydropower Hohai University, Nanjing 210098, PR China
[c] School of Economics and Management, Nanjing University of Information Science & Technology, Nanjing 210044, PR China
[d] Water Resources Department of Jiangsu Province, Nanjing 210029, PR China

ARTICLE INFO

Article history:
Received 8 February 2010
Received in revised form 28 June 2010
Accepted 1 July 2010

Keywords:
Regulated deficit irrigation
Partial rootzone drying
Dry matter biomass
Total fresh mass of fruit
Irrigation water use efficiency

ABSTRACT

Greenhouse-grown hot pepper was used to investigate the effect of Time-Space deficit irrigation (TSDI), a newly developing irrigation technique based on regulated deficit irrigation (RDI) and partial rootzone drying (PRD), by measuring plant growth, yield and irrigation water use efficiency. The treatments consisted of factorial combinations of three factors, organized following an orthogonal $L_9(3)^4$ test design with four growing stages. Three irrigation strategies (conventional furrow irrigation with full-water when soil water content was lower by 80% of field capacity (F), conventional furrow irrigation with 50% of full-water (D) and alternate furrow irrigation with 50% of full-water (P)) as the main plot factor were applied to select the optimum irrigation parameter at different stages of crop development, the treatment in which irrigation water was applied to both sides of root system when soil water content was lower by 80% of field capacity during all stages was considered as control (FFFF). Water consumption showed some significant effect of irrigation treatment during the growing period of different drought stress patterns application, and therefore decreased in these treatments to a level around 54.68–70.33% of FFFF. Total dry mass was reduced by 1.17–38.66% in TSDI treatments compared to FFFF. However, the root–shoot ratio of FFFF was lower than other treatments and the differences from FFFF and other TSDI treatments were statistically significant. The highest total fresh fruit yield (19.57 T ha^{-1}) was obtained in the FFFF treatment. All deficit irrigations increased the water use efficiency of hot pepper from a minimum of 1.33% to a maximum of 54.49%. At harvest, although there was difference recorded as single fruit weight and single fruit volume were reduced under the TSDI treatments, total soluble solids concentration of fruit harvested under the water-deficit treatments were higher compared to FFFF.

1. Introduction

The greenhouse industry has expanded in many parts of the world and particularly throughout mild winter areas in the south of China. Hot pepper (*Capsicum annuum* L.) is one of the vegetable crops commonly grown in greenhouse and consumed in a variety of ways in China, Korea, East Indies, USA, and many other countries, not only because of its economic importance, but also for the nutritional value of its fruits, which is an excellent source of natural colors and antioxidant compounds, like vitamin C and carotenoids (Howard et al., 2000; Russo and Howard, 2002; Navarro et al., 2006). In the greenhouse, irrigation is necessary to ensure stable yield of high quality, because it is considered one of the most susceptible crops to water stress in horticulture. However, inappropriate irrigation method may result in waste of water resources and poor fruit quality.

The world's apparent warming climate has caused fresh water reserves to fall across the globe consequently waking people up to the importance of water saving. The decline in water availability for irrigation and the positive results obtained in some fruit tree crops have renewed the interest in developing information on deficit irrigation for a variety of crops (FAO Report, 2002; Dorji et al., 2005; Fereres and Soriano, 2007; Wakrim et al., 2005; Paul and Goodwin, 2003; Zegbe-Dominguez et al., 2003). Deficit irrigation should be applied at those phonological stages that are least sensitive to water deficits, in the case of vegetable crops such as pepper, water stress should be avoided during flowering and fruit set, a difficult task given the long duration of these processes in most pepper cultivars. Regulated deficit irrigation (RDI) is one way of maximizing water use efficiency (WUE) for higher yields per unit

* Corresponding author at: Key Laboratory of Efficient Irrigation-Drainage and Agricultural Soil-Water Environment in Southern China, Ministry of Education, Nanjing 210098, PR China. Tel.: +86 25 8378 6964; fax: +86 25 8378 6992.
E-mail address: sgcln@126.com (S. Guang-Cheng).

0304-4238/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.scienta.2010.07.003

of irrigation water applied. In this method, the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season (English and Raja, 1996). RDI scheduling is applied by reducing irrigation rates only in those periods when fruit growth is less sensitive to water and irrigation reductions are often defined as a percentage of an optimal irrigation rate (Chalmers et al., 1981; Girona et al., 1993; Marsal and Girona, 1997). Over the past 20 years, evidence has accumulated to suggest that the leaf growth response to soil drying cannot always be explained by the plant's water relations alone (Bacon et al., 1998; Davies and Zhang, 1991). Under water-deficit conditions, partial stomatal closure occurs (Croker et al., 1998; Sauter et al., 2001), signaled by ABA produced by temporarily dried roots together with an increase in xylem pH (Davies et al., 2000; Sobeih et al., 2004). The results of such plant response have led to the development of a new irrigation technique called partial rootzone drying where two halves of plant-rooting zones are exposed alternately to dry and wet cycles (Kang et al., 1997). Irrigation water use efficiency of plants in the greenhouse has been shown to benefit from this type of irrigation and thereby reduction in irrigation water supply. For example, Grimes et al. (1968) and Shao et al. (2008) used partial rootzone drying method. They concluded that the use of partial rootzone drying method allows for a reduction in volume of irrigation water and completion of irrigation in shorter time, thus reducing labor use when compared to conventional furrow (every furrow) irrigation method. The partial rootzone drying method (PRD) provides the means to control plant–water stress to slow down vegetative growth and promote a favorable balance in crop production (Grimes et al., 1968). Yield response of tomato to partial rootzone drying method, however, remained contentious. Recent PRD studies conducted on pot-grown pepper (Kang et al., 2001) and pear orchard (Kang et al., 2002) also showed that PRD can increase IWUE with no significant reduction in crop yield.

Regulated deficit irrigation and partial rootzone drying were proposed long ago as a technique to reduce irrigation water use while maintaining farmers' net profits, and they are common practices worldwide. However, for many crop systems the best deficit irrigation strategy for improving water productivity has not yet been established (Fereres and Soriano, 2007). RDI applied at those phonological phases less sensitive to water stress (Chalmers et al., 1981; Mitchell et al., 1984) has been successfully studied for fruit trees and vines (Fereres and Soriano, 2007), but less attention has been paid for other crop systems, especially greenhouse crops (Katerji et al., 1993), for which water and nutrients are usually applied at non-limiting rates. The initial goal of RDI was to improve yield and increase irrigation water use efficiency in arid and semi-arid zones, the focus is primarily related to the efficient management of limited water resources at both sides of root system during the growth stages of the crops, otherwise, the irrigation method ignores the response of plant growth under partial rootzone drying. On the other hand, PRD focus on the effect of partial rootzone drying on plant growth without thinking about the sensitivity to irrigation water of plant growth at different growth stage. Based on PRD and RDI, Time-Space deficit irrigation (TSDI) was put forth with full coverage with optimal distribution of irrigation water and the influence of partial rootzone drying on plant growth. In current, the research on the effects of Time-Space deficit irrigation on hot pepper growth in the greenhouse is scanty.

The main aim of this work was to assess the effects of Time-Space deficit irrigation on yield, WUE and growth of greenhouse-grown hot pepper. The experiment was carried out in a glasshouse to avoid interference by rain and to minimize the adverse effects that frequently changing weather might have on plant response.

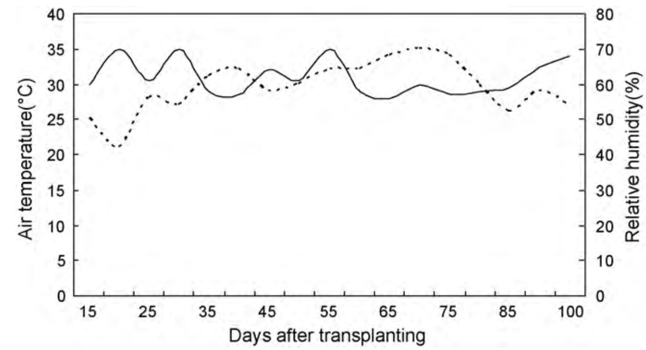

Fig. 1. Mean temperature (°C; dashed line) and relative humidity (%; solid line) during the experiment.

2. Materials and methods

2.1. Experimental conditions and plant material

The experiment was conducted during warm-wet season, May 2006 through October 2006 in the glass greenhouse of Key Laboratory of Efficient Irrigation-Drainage and Agricultural Soil-Water Environment in Southern China, Ministry of Education (latitude 31°57′N, longitude 118°50′E 144 m above sea level). Greenhouse air temperature and relative humidity at 1.5 m above the soil were measured daily. Mean daily temperature during the experiment ranged from 21 to 38 °C (Fig. 1). The soil type was clay loam with a pH of 6.4% and 0.86% of organic matter content, soil bulk density for 0–50 cm depth was 1.35 g cm^{-3}, field capacity was 25.6%, as weight of water on dried soil. Hot pepper (Zao feng) seedlings were raised in a nursery and transplanted at the six-leaf stage (5 weeks after sowing). A week before transplanting, the experimental site was ploughed and harrowed to depths of 25 cm. In all treatments, fertilizers (15:10:15) at the rate of 300 kg ha^{-1} were applied and incorporated into soil. All the furrows were irrigated and allowed to drain to field capacity. After 24 h, the seedlings were transplanted into 27 plots. Each plot consisted of three rows of 2 m in length, among which plants were grown 50 cm apart with 40 cm spacing in each row. The one central row was the only harvested for production measurements. It was followed by a light irrigation to ensure seedling establishment. The treatments were imposed 2 weeks after transplanting. Calcium Ammonium Nitrate (26% N) fertilizer was applied as side dressing at the rate of 250 kg ha^{-1} in two equal split doses at 5th and 7th week after transplanting when the plants were at flowering and first fruit set stages, respectively. The plots were manually weeded three times in the season. The plants were sprayed against white flies, fruit worms and other pests with insect powder at the rate of 0.8 l ha^{-1} at the 6th week.

2.2. Treatments and experimental design

An orthogonal experimental design L_9 (3^4) in triplicate was used to evaluate effects of furrow irrigation strategy and irrigation level on yield, WUE and growth of greenhouse-grown hot pepper, as shown in Table 1. Experiments were done with the full amount of irrigation water applied to the roots on all sides of the plant when the soil water content was lower by 80% field capacity and half of the full amount of irrigation water applied at the irrigation time of FFFF treatment, two furrow irrigation strategies (conventional furrow irrigation, in which every furrow is irrigated; and the alternate furrow). These treatments were arranged in a randomized complete block design with three replications and means were compared with a Least Squares Means procedure.