THE EFFECTS OF SUBSTRATE MOISTURE CONTENT ON WATER POTENTIAL, GAS EXCHANGE RATES, GROWTH, AND YIELD IN STRAWBERRY PLANTS GROWN UNDER GREENHOUSE CONDITIONS

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(Received August 7, 2006/Accepted October 20, 2006)

A B S T R A C T

The aim of this study was to determine the effects of different levels of moisture content in the growth substrate on water potential, gas exchange rates, growth, and yield in strawberry plants grown under greenhouse conditions. Strawberry plants of the cultivar 'Elkat' were grown in containers stacked in columns. The containers were filled with a substrate consisting of sandy loam and perlite. Each column consisted of three sections. The bottom section was partially submerged in a container filled with water. Water flowed to the upper sections of the column by capillary action. The moisture content of the substrate was not uniformly distributed in the column. The moisture content of the substrate was about 34% v/v in the bottom section, about 25% v/v in the middle section, and about 14% v/v in the top section of the column. Leaf fresh weight, leaf surface area, and yield were highest in the plants growing in the bottom and middle sections of the column, and lowest in the plants growing in the top section of the column. However, there were no significant differences in root fresh weight and total root length between plants from different sections of the column. Water potential and gas exchange rates were measured in order to assess the physiological state of the plants. Water potential in the leaves decreased when the availability of water was limited. This was especially true for the plants growing in the top section of the column. Photosynthetic rates and transpiration rates were also lowest in the plants growing in the top section of the column.

Key words: *Fragaria ananassa*, photosynthesis, transpiration, Elkat, vertical system

INTRODUCTION

Strawberries have a high water requirement because they have shallow root systems, a large leaf area, and fruits with a high water content (Matuškovič, 1999; Treder, 2003). Generally, plants grown in soilless culture under greenhouse conditions are exposed to sudden and severe stress when irrigation fails. This is because the volume of the substrate in which the plants are growing is limited. Water reserves are therefore quickly exhausted, and the plants suffer from water stress.

Reduced water availability induces numerous physiological and bio-chemical changes in all plant organs. Gas exchange in the leaves is limited, which in turn reduces carbon assimilation. Changes in the distri-bution of photoassimilates can reduce vegetative growth and even severely retard the development of plant reproductive organs (Boyer, 1970; Gehrmann, 1985; Singer et al., 2003).

Better understanding of plant responses to water stress may help improve irrigation management practices. The aim of this study was to examine the effect of different levels of moisture content in the substrate medium on growth, water potential, and gas exchange in strawberries grown under greenhouse conditions.

MATERIAL AND METHODS

The experiment was carried out in 2005 in the greenhouse of the Research Institute of Pomology and Floriculture in Skierniewice, Poland. ‘Frigo’ plants of the cultivar ‘Elkat’ were planted in containers stacked in columns filled with a substrate consisting of three parts of sandy loam and one of part perlite (Fig. 1). Each column was divided into three sections connected by water absorbing material. The bottom section was partially submerged in a container filled with 2 to 5 cm of water. The containers were arranged so that the moisture content of the substrate was different in each section of the column. The moisture content of the substrate was monitored with ECH_2O capacitance probes connected to a data logger (Decagon Devices, USA). The experiment was carried out in three replicates of one column each. Each section of each column contained six plants.

The physiological state of the strawberry plants was assessed by measuring water potential and gas exchange rate in the leaves. Measu-rements were performed thirty and sixty days after the start of the experiment. The gas exchange rate was measured in two leaves from each plant using an LI-6400 portable photosynthesis system (LI-COR, USA). Temperature, CO_2 concentration, and irradiance in the leaf chamber during analysis were set to approximate ambient condi-tions. Midday leaf water potential was measured using an SKMP-1400/40 pressure chamber (Skye Instruments, UK).

The leaf fresh weight, leaf surface area, root fresh weight and total root length were measured at

Figure 1. Column of stacked containers

the end of the experiment. The leaf surface area was measured using a WinDIAS image analysis system (Delta-T Devices, UK). Root samples from each plant were collected and cleaned. Total root length was then measured using a SCAN image analysis system (Delta-T Devices, UK).

All data were statistically elaborated using analysis of variance (ANOVA), followed by means separation using Duncan's multiple-range t-test at $P<0.05$. All calculations were performed with the help of the Statistica 6.0 software package (StatSoft, USA).

RESULTS AND DISCUSSION

The moisture content of the substrate was not uniformly distributed in the column (Fig. 2). The moisture content of the substrate in the bottom section of the column was about 34% v/v, or 100% of the water holding capacity. The moisture content in the middle section of the column was about 25% v/v, or 74% of the water holding capacity. The moisture content in the top section of the column was about 14% v/v, or 41% of the water holding capacity. During the course of the experiment, the moisture content in the top

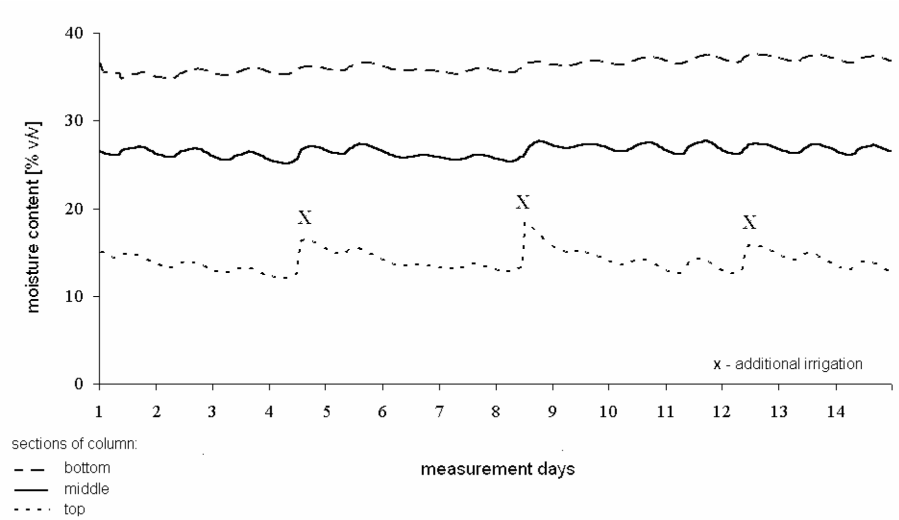

Figure 2. Moisture content of the substrate in different sections of the column (representative data for a two-week period)

section of the column gradually decreased so that additional irrigation was necessary.

Water availability is a limiting factor for a wide range of physiological processes in plants. One of the first responses of plants to drought is stomatal closure. The stomata regulate gas exchange between the inside of the leaf and the atmosphere. Therefore, they are the main means of regulating water relations and carbon assimilation in plants (Hetherington and Woodward, 2003). Stomatal closing protects plants against excessive water loss, but also restricts the diffusion of CO_2 into the leaves (Chaves et al., 2003). In the present study, the physiological state of the strawberry plants was estimated by measuring water potential and a rate of leaf gas exchange.

Gas exchange rates varied depending on which section of the column the plants were growing in (Tab. 1). The highest photosynthetic rates and transpiration rates were found in the plants growing in the bottom section of the column, where the moisture content of the substrate was highest. Water potential in the leaves decreased when the availability of water was limited (Tab. 1). This was especially true for the plants growing in the top section of the column. Gas exchange rates were also lowest in the plants growing in the top section of the column. The photosynthetic rate was not significantly reduced in the plants growing in the middle section of the column. On the other hand, sixty days after the start of the experiment, the transpiration rate was reduced in this group of plants because the water reserves in the substrate were exhausted.

Table 1. Water potential, photosynthetic rate, transpiration rate and water-use efficiency (WUE) in strawberry plants of the cultivar ‘Elkat’ growing in different sections of the column

Parameter	Sampling date and the section of the column					
	30 days after the start of the experiment			60 days after the start of the experiment		
	top	middle	bottom	top	middle	bottom
Water potential (MPa)	-1.51 a	-1.09 b*	-0.56 c	-1.55 a	-1.18 b	-0.77 c
Photosynthetic rate [μmol CO_2 m^{-2} s^{-1}]	10.62 a	13.11 b	13.57 b	4.11 a	5.26 ab	7.39 b
Transpiration rate [mmol H_2O m^{-2} s^{-1}]	2.50 a	3.88 b	4.04 b	0.59 a	0.99 a	1.83 b
WUE [μmol CO_2 m^{-2} s^{-1} /mmol H_2O m^{-2} s^{-1}]	4.95 b	3.47 a	3.38 a	7.10 b	6.47 b	4.69 a

*Means in the same line followed by the same letter are not significantly different according to Duncan’s multiple-range t-test at P<0.05. Analysis performed separately for each sampling date

A reduction in gas exchange rates has been observed in many fruit crops grown under drought conditions (Jorba et al., 1985; Chandler and Ferree, 1990; Klamkowski and Treder, 2002). The response of strawberry plants to different levels of water availability was studied in detail by Sruamsiri and Lenz (1986). These authors suggested -1 MPa as a first threshold for drought effects, -1.7 MPa as an onset of wilting and -2.5 MPa as an onset of irreversible drought effects in strawberry plants. This agrees well with the results of the present study, in which the plants in the top section of the column began to wilt when the water potential fell below -1.5 MPa, making additional irrigation necessary.

The water-use efficiency (WUE) was calculated in order to integrate the results on changes in gas exchange rates. WUE can be described in different ways. At the leaf level, WUE can be defined as the ratio of the photosynthetic rate to the transpiration rate (Sinclair et al., 1984; Pietkiewicz et al., 2005). WUE has been used in many experiments on water relations and drought resistance in various crop species (Flore et al., 1985; Escalona et al., 1999).

In the present study, WUE varied depending on which section of the column the plants were growing in (Tab. 1). WUE was highest in the plants growing in the top section of the column, where water stress was most severe. According to Chaves et al. (2003) most plants tend to show an increase in water-use efficiency when water deficit is mild. This increase results from a non-linear relationship between stomatal conductance and carbon assimilation. Water loss is reduced before and more intensely than photosynthesis is inhibited (Chaves et al., 2003; Pietkiewicz et al., 2005). These changes lead to optimization of carbon assimilation in relation to water supply. This agrees well with the results of the present study. The differences in WUE in plants growing in different sections of the column were mainly due to differences in the transpiration rate. For example, sixty days after the start of the experiment, the difference in the photosynthetic rate between the plants growing in the bottom section of the column and the plants growing in the top section of the column was about 44%. The difference in the transpiration rate was even greater, 68%. The reduction in the transpiration rate was the main reason why values for WUE were higher sixty days after the start of the experiment than they were thirty days after the start of the experiment.

Another one of the earliest responses of plants to water deficit is growth inhibition (Boyer, 1970; Hsiao, 1973). In the present study, growth rate in the strawberry plants was affected by differences in water availability (Tab. 2). The leaf fresh weight and the leaf surface area were highest in the plants growing in the bottom and the middle sections of the column. However, there were no significant differences in the root fresh weight and total root length between plants from different sections of the column. This indicates that growth inhibition in response to reduced water availability was higher in the above-ground portions of the plants than in the root systems. An increase of investment in roots results in enhancement of root depth. This enables the plants to increase water uptake and survive during drought. This agrees well with other studies (Chandler and Ferree, 1990; Gehrmann and Lenz, 1991).

Photosynthesis is an important factor that determines plant productivity. Inhibition of photosynthesis in response to reduced water availability reduces yield. In the present study, yield was highest in the plants growing in the bottom and middle sections of the column, and lowest in the plants growing in the top section of the column, where the moisture content of the substrate was lowest (Tab. 3). Reduced yields during drought were also observed in other studies (Gehrmann, 1985; Chandler and Ferree, 1990).

There were no significant differences in vegetative growth and yield between the plants growing in the bottom and middle sections of the column (Tab. 2 and 3). This indicates that the optimal moisture content for the substrate used in this experiment is between 25 and 34% v/v. If the water content was below 25% v/v, growth and yield would be strongly reduced.

CONCLUSIONS

Maintaining the proper level of moisture in the growth substrate is one of the most important requirements

Table 2. Leaf and root parameters in strawberry plants of the cultivar 'Elkat' growing in different sections of the column

Section of the column	Leaf fresh weight per plant [g]	Total leaf area per plant [cm^2]	Root fresh weight per plant [g]	Root length per plant [cm]
Top	6.8 a*	175 a	2.79 a	1213 a
Middle	13.3 b	427 b	3.04 a	1598 a
Bottom	17.5 b	530 b	3.12 a	953 a

*Means in the same column followed by the same letter are not significantly different according to Duncan's multiple-range t-test at P< 0.05

Table 3. Moisture content of the substrate and yield in strawberry plants of the cultivar 'Elkat'

Section of column	Moisture content [% v/v]	Moisture content [% of water holding capacity]	Yield [%]
Top	14	41	61 a*
Middle	25	74	95 b
Bottom	34	100	100 b

*Explanation, see Table 2

for successful strawberry production in soilless culture under greenhouse conditions. The optimal moisture content for the substrate used in this study was between 25 and 34% v/v, or between 74 and 100% of the water holding capacity. In a previous study in which strawberries were cultivated in a peat substrate, yield was reduced in the plants growing in the bottom section of the column because of the high moisture content (unpublished data). In the present study, yield was not reduced in the plants growing in the bottom section of the column. In fact, the best conditions for plant growth were in the bottom section of the column.

The column method used in this study is very useful in determining plant responses to different levels of water availability. The columns do not take up a lot of space. It is also easy to regulate the moisture content of the substrate using this method.

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FIZJOLOGICZNA I MORFOLOGICZNA REAKCJA ROŚLIN TRUSKAWKI NA ZRÓŻNICOWANE ZAOPATRZENIE W WODĘ

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STRESZCZENIE

Celem doświadczenia było określenie wpływu różnej wilgotności podłoża na wybrane parametry fizjologiczne, wzrost i plonowanie truskawki. Truskawki odmiany ‘Elkat’ posadzono do specjalnie skonstruowanych kolumn wypełnionych glebą zmieszaną z perlitem. Kolumny były podzielone na 3 strefy odizolowane od siebie i połączone matą o właściwościach podsiąkowych. Po rozpoczęciu wzrostu roślin, dolną część kolumn umieszczono w wodzie tak, aby mogła ona dzięki siłom kapilarnym podsiąkać w górę kolumny. Pomiary zawartości wody w poszczególnych częściach kolumny wykazały, że w dolnej strefie wilgotność podłoża utrzymywała się na stałym poziomie (ok. 34% v/v). W strefie górnej obserwowano stałe obniżanie się wilgotności podłoża, co pociągało za sobą konieczność dodatkowego nawadniania roślin tam rosnących. W celu oceny stanu fizjologicznego roślin, w trakcie wzrostu wykonano pomiary natężenia wymiany gazowej oraz potencjału wody w liściach. Rośliny rosnące w dolnej części kolumny, gdzie wilgotność podłoża była największa, transpirowały z najwyższą intensywnością. U roślin tych stwierdzono również najwyższe wartości natężenia fotosyntezy i potencjału wody. Ograniczona wilgotność podłoża była przyczyną obniżenia potencjału wody w tkankach roślinnych, co zaobserwowano u roślin rosnących w górnej oraz środkowej części kolumny. Niedobór wody spowodował wyraźne zahamowanie natężenia wymiany gazowej, szczególnie u roślin rosnących w górnej strefie kolumny, gdzie stres wodny był najsilniejszy. Zróżnicowane zaopatrzenie w wodę wpłynęło na wzrost i plonowanie roślin. Świeża masa części nadziemnej roślin oraz powierzchnia liści były najwyższe w przypadku roślin rosnących w strefie dolnej i środkowej. Nie zaobserwowano natomiast istotnych różnic w wielkości systemu korzeniowego pomiędzy roślinami rosnącymi w różnych strefach kolumny. Stres wodny w istotnym stopniu ograniczył plonowanie roślin. Najwyższy plon uzyskano z roślin rosnących w strefie dolnej i środkowej, najniższy w strefie górnej kolumny, gdzie wilgotność podłoża była najniższa.

Słowa kluczowe: *Fragaria ananassa*, wymiana gazowa, potencjał wody, ‘Elkat’, system pionowy