



Hydrogel substrate amendment alleviates drought effects on young citrus plants

Vicent Arbona¹, Domingo J. Iglesias², Josep Jacas¹, Eduardo Primo-Millo², Manuel Talon² & Aurelio Gómez-Cadenas^{1,3}

¹*Departamento de Ciencias Experimentales. Universitat Jaume I. Campus Riu Sec. E-12071 Castelló, Spain.*

²*Departamento de Citricultura y Otros Frutales, Instituto Valenciano de Investigaciones Agrarias, E-46113 Moncada, Valencia, Spain.* ³*Corresponding author**

Received 1 April 2004. Accepted in revised form 6 July 2004

Key words: ethylene, hydrogel, leaf abscission, photosynthesis rate, soilless media, stomatal conductance

Abstract

Water deficits affect citrus physiology, yield, fruit size and quality. Citrus can respond to drought stress conditions through endogenous hormonal regulation of water status and leaf abscission. In this work, we assayed the efficiency of an amendment to soilless media in delaying the drought stress effect in young citrus seedlings and trees. Substrate amendment promoted plant survival of citrus seedlings subjected to several cycles of drought stress and rehydration. In budded trees, the amendment increased substrate water content, leaf water potential, leaf number, root biomass, CO₂ assimilation and stomatal conductance over that of control plants growing in non-amended substrates. We conclude that the substrate amendment reduced the damaging effects of drought stress in citrus plants. The longer survival of seedlings in the amended treatment together with the reduction in leaf abscission and the improvement of physiological parameters, can account for a higher vigour of citrus grown under water stress conditions.

Introduction

Water stress from drought affects multiple physiological parameters in citrus including a reduction in water potential and stomatal conductance (Gómez-Cadenas et al., 1996). Under severe water deprivation, stomata close very rapidly, arresting water flux almost completely in only two hours (Tudela and Primo-Millo, 1992). Continuous water stress conditions inhibit plant growth and reduce CO₂ assimilation (Brakke and Allen, 1995). In citrus, as in other plants, a period of drought followed by a restoration of hydration conditions favorable to growth promotes flowering (Lovatt et al., 1988; Southwick and Davenport, 1986). In this case, a direct relation between the general effect of water stress on growth inhibition and the promotion of flowering has been proposed (Monselise, 1985).

Citrus plants subjected to severe drought can show leaf injuries and even wilting without leaf abscission (Tudela and Primo-Millo, 1992). However, when water stress is relieved by rain or irrigation, leaves recover turgor and shortly thereafter, some of them may abscise (Gómez-Cadenas et al., 1996; Tudela and Primo-Millo, 1992). The hormonal regulation of this response may be related to severe water stress conditions promoting synthesis and accumulation of 1-aminocyclopropane-1-carboxylic acid (ACC, the ethylene metabolic precursor) in roots (Tudela and Primo-Millo, 1992). Rehydration of plants results in ACC transport to the shoots, where it is oxidized to ethylene and subsequently promotes leaf abscission (Tudela and Primo-Millo, 1992). Moreover, abscisic acid (ABA) seems to be the mediator between water stress conditions and ethylene production. Therefore, these plant growth regulators link water status to a plant survival response such as leaf abscission (Gómez-Cadenas et al., 1996).

* FAX No: 34-964728066.

E-mail: cadenas@exp.uji.es

Not only is total production decreased by drought stress (Reuther, 1973) but also fruit size, acid and total soluble solid contents in juice (Sánchez et al., 1978). Moreover, drought deprivation reduces peel thickness, making citrus fruits more vulnerable to damage during manipulation and shipping (Agustí, 1999).

In many countries where citrus are economically important, commercial propagation is done in private nurseries where rootstocks grown from seeds are grafted with different cultivars. The whole period of propagation lasts from one to three years. The final transplant of the grafted tree to the orchard involves its acclimation to new soil and environmental conditions and, almost certainly, a stress situation. This stress will be more intense if transplanting is preceded by root pruning as is usual in many areas (Aubert and Vullin, 1997).

To mitigate the damage caused by water deprivation, different soil conditioners have been assayed in crops and landscape plants. The success of this technique has been erratic. In some cases, negative (Austin and Bondari, 1992) or non-measurable (Keever et al., 1989; Swietlik, 1989; Tripepi et al., 1991; Wang, 1989) effects were observed while in others, positive effects were recorded (Hüttermann et al., 1999). Beneficial results were obtained with a new group of soil conditioners, known as hydrogels which are highly cross-linked polyacrylamides with 40% of the amides hydrolyzed to carboxylic groups (Hüttermann et al., 1999). Citrus seedlings grown in well-watered sand soil amended with these hydrogels showed increases in growth, water use and nitrogen uptake while losses of nitrogen by leaching were reduced (Syvertsen and Dunlop, 2004).

The objective of this study was to evaluate the efficiency of a hydrogel in delaying the effect of water deprivation in young citrus plants. We hypothesized that hydrogel amendment would increase substrate water content and therefore reduce or, at least, delay the effects of drought stress on plant growth and physiology.

Materials and methods

Plant material

All plants were obtained from a commercial nursery and transplanted to plastic containers, at least one month prior to the beginning of the experiments. Plants were cultivated in a greenhouse under the following conditions: day temperature, 26–32 °C; night

temperature, 18–20 °C; photoperiod, 16:8 (L:D) and 50–95% relative humidity. Maximum photosynthetically active radiation (PAR): 1200 $\mu\text{mol m}^{-2} \text{s}^{-1}$. Each plant was watered three times a week with 500 mL of a half-strength modified Hoagland solution (Gómez-Cadenas et al., 2003).

Substrate amendments and drought treatments

As a substrate conditioner treatment, the hydrogel Stockosorb Agro (Degussa-Hüls Ibérica, S.A., Barcelona, Spain) was used. This product was added (0.2% or 0.4%) to the substrates before transplanting citrus plants. Two different kind of substrates were used: perlite and a mix of sphagnum peat and perlite (80:20). Drought stress was imposed by eliminating watering for different periods of time until leaf wilting was apparent (14 days in the experiments conducted on perlite and 21 days in those on peat/perlite). Complete rehydration was achieved by watering to saturation (when perlite was used as a substrate) or by maintaining the pots in a bath with water for 6 h (when the mix of peat and perlite was used as a substrate).

Description of the different experiments

Three different experiments were performed.

Experiment 1. The effect of substrate amendment on plant survival was studied on A) four-month-old Carrizo citrange seedlings (*Poncirus trifoliata* [L.] Raf. \times *Citrus sinensis* [L.] Osb.), grown in 2-L pots filled with perlite as a substrate. B) one-year-old Cleopatra mandarin seedlings (*Citrus reshni* Hort. ex Tan.) grown in 4-L containers filled with a mix of sphagnum peat and perlite (80:20) as a substrate. Two different concentrations of hydrogel (0.2 and 0.4%) were assayed. Six blocks of 16 plants were established following a randomized design: Control, well-watered plants without substrate amendment; well-watered plants with the substrate amended with 0.2% or 0.4% hydrogel; plants subjected to repeated drying/recovery cycles without substrate amendment and, plants subjected to repeated drying / recovery cycles with the substrate amended with 0.2% or 0.4% hydrogel.

Experiment 2. The effect of substrate amendment on water content was studied by using 4-L containers without plants. These containers were filled with a mix of sphagnum peat and perlite (80:20) as a substrate and the hydrogel was added to achieve a final concentration of 0.4%. Pots were watered to saturation

and substrate water content measured by weight loss. Two blocks (with or without hydrogel-amendment) of 6 containers were established following a randomized design.

Experiment 3. The effect of substrate amendment on plant performance was studied on two-year-old plants of 'Clementina de Nules' cultivar (*Citrus reticulata* Blanco) grafted on Carrizo citrange rootstock grown in 10-L containers filled with a mix of sphagnum peat and perlite (80:20) as a substrate. Four blocks of 40 plants were established following a randomized design: Control, well-watered plants without substrate amendment; well-watered plants with the substrate amended with 0.4% hydrogel; plants subjected to four repeated drying/recovery cycles without substrate amendment and, plants subjected to four repeated drying/recovery cycles with the substrate amended with 0.4% hydrogel.

Leaf number and root biomass

The number of leaves was recorded regularly and expressed as a percentage of that present in each plant the first day of experiment (which was considered as a 100%). When plants grew, new leaves were counted only when they achieved half of the fully expanded size. Five plants per block were used for these measurements. Root biomass was measured at the end of the experiment after four repeated drying/recovery cycles. The whole root system of seven plants per block was carefully separated from the substrate, rinsed with water, dried in a filter paper and immediately weighted.

Leaf water potential

Leaf water potential was determined by using a pressure chamber (model 3000, Soilmoisture Equipment, Santa Barbara, CA) as described in Gómez-Cadenas et al. (1996). Leaves in the middle of the shoot were separated from the plant using a scalpel at the base of the petiole. Leaves were immediately placed in the pressure chamber cylinder with the cut end out. The pressure was gradually increased until the first drop of xylem fluid was observed with a magnifying glass. Five fully expanded leaves randomly chosen from each experimental block of plants were used for these measurements.

Ethylene production

Ethylene was measured in mid-shoot leaves by gas chromatography following Gómez-Cadenas et al. (2003). Briefly, leaves were separated from plants and enclosed in sealed tubes with the petiole submerged in water. Following a rehydration period of 4 h, 1 mL of the enclosed atmosphere was injected into a gas chromatograph (Agilent 4890D, Agilent Technologies, Inc. Wilmington, DE, U.S.A) equipped with an activated alumina column and a flame ionization detector. Seven leaves randomly chosen from each experimental block of plants were used for these measurements.

Gas exchange parameters

Net photosynthetic rate and stomatal conductance were measured with a LI-6400 portable photosynthetic system (Li-Cor, Inc.) equipped with a 18 cm³ prismatic leaf chamber that carried a Gallium Arsenide Phosphide (GaAsP) PAR sensor. All measurements were performed under a constant air-flow rate of 500 $\mu\text{mol s}^{-1}$, and at ambient humidity and CO₂. Photon flux density (PFD) was adjusted to 750 $\mu\text{mol m}^{-2} \text{s}^{-1}$, the saturating value found after light calibration in preliminary experiments (Iglesias et al. 2002). Within the cuvette, average temperature was 23.0 ± 0.5 °C and leaf-to-air vapour pressure deficit was 1.6 ± 0.2 kPa.

Determinations were performed in the greenhouse (9:00–10:00 a.m.) when temperature was 24 ± 2 °C. Measurements were always carried out on mature leaves because of the higher stability and response of their photosynthetic rates (Iglesias et al. 2002). The instrument used for the measurement of photosynthesis was programmed to perform continuous determinations on a single leaf, usually about 30 repeated determinations until the data stored showed a coefficient of variation lower than 1%. Once this was reached, the average of the whole set of data was taken as the best estimation of the photosynthetic rate of each leaf.

Statistical analyses

In general, means were compared by using the least significant difference (LSD) test ($P \leq 0.05$). Statistical analyses were performed using StatGraphics Plus (V. 2.1.) for Windows.

Table 1. Plant survival (% respect to the initial number of plants) after several cycles of water stress followed by rehydration in seedlings of 4-month-old Carrizo citrange grown on perlite and 12-month-old Cleopatra mandarin grown on a mix of peat and perlite. Means ($n \geq 16$) within each column followed by the same letter do not differ significantly at $P \leq 0.05$

Treatment	Number of cycles of stress/rehydration		
	2	4	6
Carrizo citrange			
Control	100 ^a	100 ^a	100 ^a
Control +0.2% hydrogel	100 ^a	100 ^a	100 ^a
Control +0.4% hydrogel	100 ^a	100 ^a	100 ^a
Stress/rehydration	72 ^c	35 ^d	12 ^d
Stress/rehydration +0.2% hydrogel	81 ^b	42 ^c	20 ^c
Stress/rehydration +0.4% hydrogel	100 ^a	93 ^b	79 ^b
Cleopatra mandarin			
Control	100 ^a	100 ^a	–
Control + 0.2% hydrogel	100 ^a	100 ^a	–
Control +0.4% hydrogel	100 ^a	100 ^a	–
Stress/rehydration	88 ^b	63 ^b	–
Stress/rehydration +0.2% hydrogel	84 ^b	67 ^b	–
Stress/rehydration +0.4% hydrogel	100 ^a	96 ^a	–

Results

Plant performance and substrate water content

Experiment 1

In a first set of experiments, plant performance under repeated cycles of water deprivation followed by rehydration was studied. Twelve percent of the four-month-old seedlings of the citrus rootstock, Carrizo citrange, grown on perlite survived after 6 complete cycles (Table 1). Substrate amendment with 0.4% hydrogel was effective in increasing plant survival to 79% after 6 cycles. The behavior of one-year-old Cleopatra mandarin seedlings was comparable to Carrizo citrange despite differences in the duration of the drought period and in the substrate used. After 4 complete cycles of drying/recovery, 63% of plants survived. Addition of hydrogel (0.4%) to the substrate had a positive effect on Cleopatra mandarin survival although lower concentrations of hydrogel (0.2%) rendered erratic results (Table 1). The hydrogel did not affect normal growth in well-watered plants. In view of these results, the concentration of hydrogel used for following experiments was 0.4%.

Experiment 2

In a second group of experiments, hydrogel addition to the substrate resulted in an increase in water content

Table 2. Substrate water content (kg) at the beginning and at the end of a 21-day desiccation period. Containers were filled with substrate and kept in the greenhouse without plants. Means ($n \geq 6$) within each column followed by different letters differ significantly at $P \leq 0.05$

Substrate amendment	Water content (kg)	
	Day 0	Day 21
Control	2.45 ^b	1.37 ^b
0.4% hydrogel	3.13 ^a	2.05 ^a

both at the beginning (128%) and at the end of a 21-day desiccation period (150%, Table 2).

Experiment 3

For the third group of experiments, two-year-old budded trees were used (Clementina de Nules cultivar grafted onto Carrizo citrange rootstock). Preliminary studies indicated that more than 50% of the plants died when six drying / recovery cycles were assayed (data not shown). Therefore, in all subsequent studies, plants were subjected to only four cycles of drought/rehydration and no significant mortality was observed.

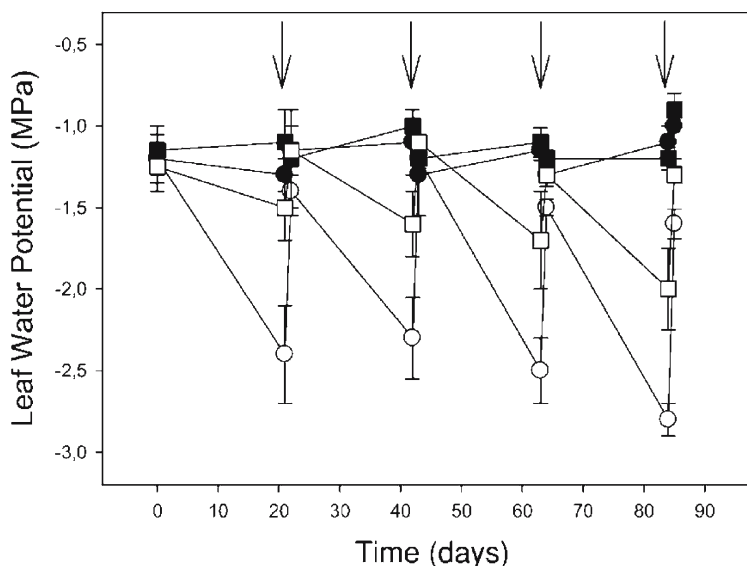


Figure 1. Effect of four cycles of water stress/rehydration on leaf water potential. Circles represent plants grown on non-treated substrates. Squares represent plants grown on amended substrates. White symbols represent water-stressed plants. Black symbols represent well-watered plants. Data are means \pm SE. Arrows indicate the onset of the rehydration periods.

Leaf water potential

Leaf water potential on control well-watered plants did not show significant variation during the experimental period (-1.0 to -1.3 MPa, Figure 1). In contrast, each period of stress reduced leaf water potential to reach a minimal value of -2.8 MPa, 84 days after the onset of the experiment. Rehydration of the substrate allowed leaf water status to recover almost to control levels during the first three drought cycles but leaf water potential did not recover fully after 4 cycles.

Although substrate amended with 0.4% hydrogel did not significantly modify water status in well-watered plants, it had an important effect on water-stressed plants. Hence, leaf water potential in the latter was always higher than in non-treated stressed-plants and it did not reach values lower than -2 MPa. Moreover, in hydrogel-treated plants, rehydration resulted in total recovery of leaf water content during the entire experimental period.

Leaf abscission and ethylene production

Plants under regular irrigation increased leaf number after 40 days of experiment (Figure 2). Plants on amended substrate sprouted earlier than those on non-treated peat (see Figure 2, days 63 and 64) although after 84 days, relative numbers of leaves converged for both kinds of plants. The first cycle of water deficit

did not promote leaf abscission on day 20 (Figure 2). However, alleviation of this stress by rehydration resulted in the drop of 8.5% of the leaves. Similarly, the successive drought periods did not cause important leaf drops but each subsequent re-watering induced abscission of more than 10% of the leaves. Therefore, after the 4 cycles of stress/rehydration, plants had lost more than 40% of the leaves. Substrate amendment with 0.4% hydrogel had a very pronounced inhibitory effect on leaf abscission under water deprivation as the final number of leaves was much higher in treated plants than in non-treated ones. This was a consequence of a combination of reduction in leaf abscission after each rehydration together with a moderate leaf growth throughout the experimental period.

Leaves on well-irrigated plants (either treated with the soil conditioner or not) always produced small amounts of ethylene, ranging between 0.22 and 0.41 $\text{nl g}^{-1} \text{h}^{-1}$ (Figure 3). In stressed-plants, leaf ethylene production remained very low throughout the subsequent water deficit periods but sharply increased each time that stress was alleviated by watering. The highest endogenous production of the plant hormone was detected on day 43 when leaves showed an ethylene production rate of 1.40 $\text{nl g}^{-1} \text{h}^{-1}$, which was about 5-fold higher than the value in well-watered plants. Substrate amendment reduced the range of ethylene variation, since the hormone production was not

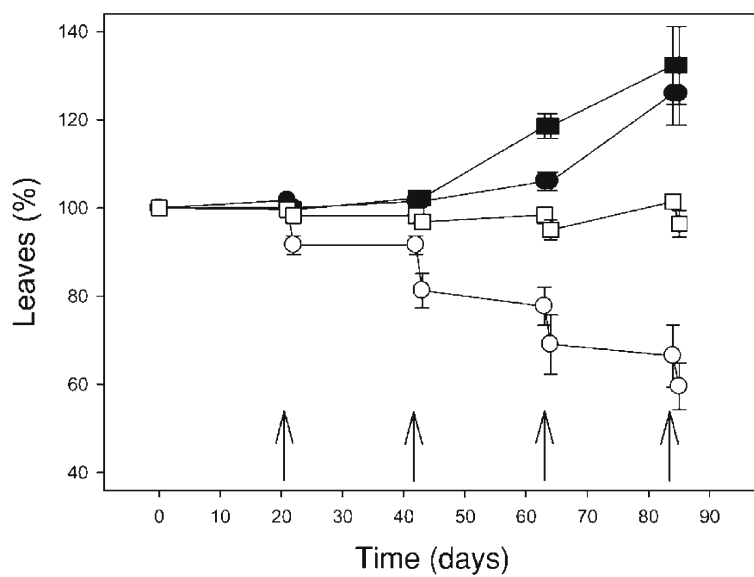


Figure 2. Effect of four cycles of water stress/rehydration on leaf percentage. Symbols as in Figure 1. Data are means \pm SE.

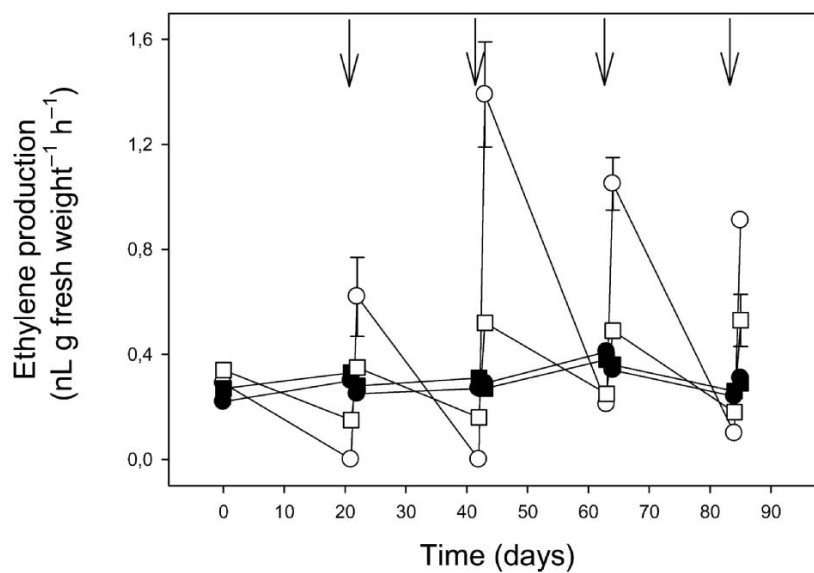


Figure 3. Effect of four cycles of water stress/rehydration on leaf ethylene production. Symbols as in Figure 1. Data are means \pm SE.

Table 3. Root fresh weight (g plant^{-1}) after four cycles of water stress followed by rehydration in plants of two-year-old 'Clementina de Nules' cultivar grafted on Carrizo citrange rootstock. Row means ($n \geq 6$) followed by the same letter do not differ significantly at $P \leq 0.05$

Treatments	Control	Control +0.4% hydrogel	Stress/rehydration	Stress/rehydration +0.4% hydrogel
Root weight	58.21 ^a	53.55 ^a	22.22 ^c	38.93 ^b

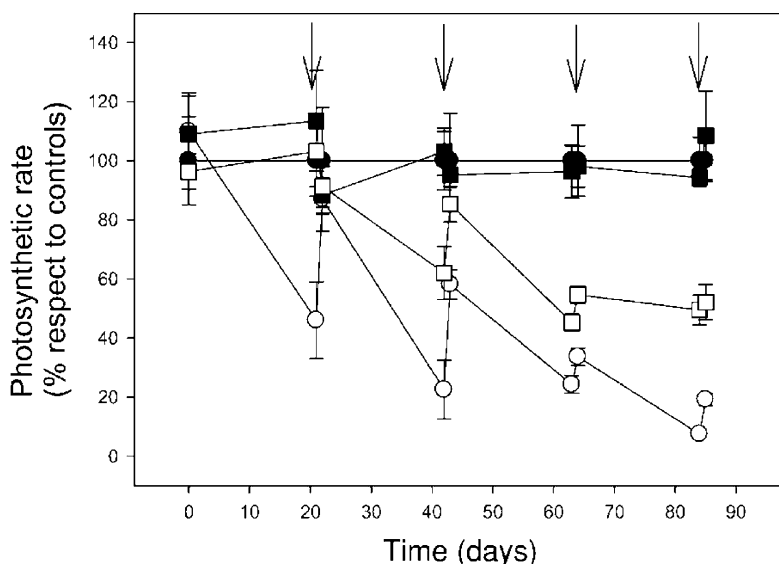


Figure 4. Effect of four cycles of water stress / rehydration on photosynthetic rate. Symbols as in Figure 1. Data are means \pm SE.

only less intense after rehydration but also slightly higher at the end of each drought period (Figure 3).

Photosynthetic rate and stomatal conductance

Well-watered plants had photosynthetic rates that varied between 5.2 and $8.3 \mu\text{mol m}^{-2} \text{s}^{-1}$ throughout the study period depending on leaf age and environmental conditions (data not shown). To facilitate the interpretation of data, gas exchange values of control plants were always taken as 100%, and photosynthetic rates were expressed as percentage of control (Figure 4). Addition of the hydrogel to the substrate did not modify the pattern of photosynthetic rate in well-watered plants. The drying/recovery cycles reduced CO_2 assimilation of leaves such that by the end of the experimental period, photosynthetic rates were more than 80% lower than the initial values. Substrate amendment partially prevented plants from the photosynthesis decline (Figure 4) although after four drying/recovery cycles, photosynthetic rates remained 50% lower than those in control plants even after recovery.

Well-irrigated citrus plants showed variations in stomatal conductance ranging between 90 and $230 \text{mmol m}^{-2} \text{s}^{-1}$ in these experiments depending on leaf age and environmental conditions (data not shown). After 20 days of drying, stomatal conductance had declined to levels 50% lower than those in control plants. Despite recoveries after rehydration treatments, the subsequent periods of water depriva-

tion led to more than 90% inhibition of gas exchange in leaves of citrus plants. Substrate amendment did not significantly modify stomatal conductance in well-watered plants but it increased stomatal conductance caused by drought (Figure 5).

Root biomass

Addition of hydrogel did not significantly modify root weight in well-watered plants (Table 3). Water stress reduced fibrous root biomass although root weight decreased less in the amended treatment than in the unamended one.

Discussion

Data presented in this work show that substrates amended with a hydrogel can prevent or, at least, delay the injury caused by drought in young citrus plants.

The 0.4% concentration of hydrogel increased plant survival in seedlings of two different citrus rootstocks subjected to several drying/recovery cycles. The important difference in plant survival between Carrizo citrange and Cleopatra mandarin seedlings subjected to water deficit may have been due in part to the different substrate used in the experiments; Carrizo was grown in perlite, a substrate with low water retention potential while Cleopatra was grown on peat which can retain higher amounts of water. Although different age and genotypes can also contribute to the

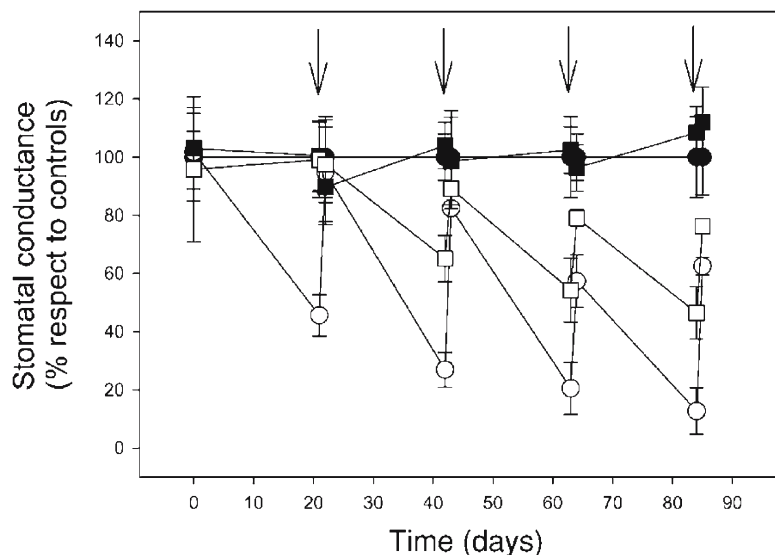


Figure 5. Effect of four cycles of water stress/rehydration on stomatal conductance. Symbols as in Figure 1. Data are means \pm SE.

observed differences (Moya et al., 2002), we conclude that the hydrogel treatment was beneficial in all cases.

The hydrogel also induced less drought stress of two-year-old citrus budded trees as reflected in several growth and physiological parameters. Leaf number was higher in water-stressed plants in an amended substrate than on water-stressed plants as a consequence of a reduction in leaf abscission together with an increase in newly formed leaves. Drought stress-induced root loss was ameliorated by the hydrogel treatment. CO_2 assimilation and stomatal conductance were less inhibited by water stress in plants growing in amended substrates than in plants in non-amended substrates.

Substrate water content increased in amended substrates both at the beginning and at the end of a drought period as previously reported (Al-Darby, 1996; Hüttermann et al., 1999). Leaf water potential was increased in water-stressed plants on amended substrates (Figure 1). Comparable results were observed in *Pinus halepensis* grown on sandy soils amended with a similar hydrogel (Hüttermann et al., 1999). Thus, due to the higher water content of substrates and the subsequent higher leaf water potential levels, drought stress was lower in those plants on amended substrate as supported by the lower production of ethylene and the higher gas exchange.

Although it is difficult to extrapolate data from soilless media to responses in field soil, our results suggest that hydrogels could have a role in preventing drought stress after transplanting citrus from the

nursery to the orchard. Transplant represents a stress situation for the plant particularly if root pruning is done to avoid future malformation (Aubert and Vullin, 1997). This work together with the recent report by Syvertsen and Dunlop (2004) can be a basis for future field studies to gain insights into reducing transplant stress.

It has been previously reported (Gómez-Cadenas et al., 1996; Tudela and Primo-Millo, 1992) that severe water stress conditions block xylem flux and 1-aminocyclopropane-1-carboxylic acid (ACC) transport from roots to shoots. When stress is alleviated by watering, the ACC previously accumulated in the roots is rapidly transported to the aerial part and oxidized to ethylene. Ethylene has been confirmed as the hormone that triggers leaf and fruit abscission in response not only to water deprivation (Gomez-Cadenas et al., 1996), but also to several adverse growth conditions, such as salinity or nutritional deficiencies (Gómez-Cadenas et al., 1998, 2000, 2003). In these experiments, water stress was imposed by simply ceasing watering and therefore, allowing a progressive desiccation of the substrate over 21 days compared to 24 h in previous studies (Gómez-Cadenas et al., 1996; Tudela and Primo-Millo, 1992). Despite this important difference, leaf abscission was observed (Figure 2) and interestingly, it was always preceded by increases in leaf ethylene production (Figure 3). Moreover, in both rapid (Gómez-Cadenas et al., 1996; Tudela and Primo-Millo, 1992) and gradual dehydration (Figures 2 and

3), amounts of ethylene produced were always proportional to the abscission observed. Thus, data presented here extend the findings to grafted citrus plants and water stress conditions more similar to gradual drying under field conditions. Similarly, data confirm an often observed behaviour of adult citrus trees where successive periods of drought alleviated by rehydration are followed by leaf drops. At the end of each drought period, leaf ethylene levels in stressed plants were lower than those in control plants. This decline could be related to a xylem flux interruption (or a reduction to very low levels) as supported by the decline in leaf water potential and stomatal conductance.

Leaf water potential (Figure 1), CO₂ assimilation (Figure 4) and stomatal conductance (Figure 5) recovered to different levels after each drying/recovery cycle. However, the process was not totally reversible since after four cycles, values were clearly lower in stressed plants even after the rehydration period (Figures 1, 4 and 5; day 85). This seems to indicate that in addition to leaf abscission, the successive cycles of stress injured or drought-hardened leaf tissues. One of the parameters initially affected by water stress was the photosynthetic rate, values after the first period of stress were very low and CO₂ assimilation did not fully recover after the successive cycles of rehydration in stressed plants. At the end of the experimental period, photosynthetic rates in stressed plants were 90% lower than in control plants. Furthermore, although the hydrogel amendment contributed to improve photosynthesis rates in stressed plants, after four cycles of drought the photosynthetic rate was also reduced 50% below control values. These data support the high sensitivity of the photosynthetic machinery to environmental stresses in citrus as in other plant species (Brakke and Allen, 1995; Gómez-Cadenas et al., 2003; Popova et al., 1995; Romero-Aranda et al., 1998).

In conclusion, hydrogel amendment to substrates reduced the damaging effects of drought in citrus plants. The longer survival of seedlings together with the reduction in leaf abscission and the improvement of photosynthesis rate, stomatal conductance, and root growth can considerably improve the vigour of citrus plants grown under drought stress conditions.

Acknowledgements

This paper is dedicated to Dr Darius Tudela who first showed the hormonal regulation of leaf abscission in

water-stressed citrus plants. The work was supported by the Ministerio de Ciencia y Tecnología (Spain) and the Fundació Bancaixa/Universitat Jaume I through grants No. AGL2003-08502-C04-03 and P1 1B2003-05 respectively to A. G-C. The hydrogel used in this research was a gift from Degussa-Hüls Ibérica, S.A.

References

- Agustí M 1999 Preharvest factors affecting postharvest quality of citrus fruits. *In* Advances in postharvest diseases and disorders control of citrus fruit, Ed. M Schirra. pp. 213–217. Research Signpost, Trivandrum, India.
- Al-Darby A M 1996 The hydraulic properties of a sandy soil treated with gel-forming soil conditioner. *Soil Technol.* 9, 15–28.
- Aubert B and Vullin G 1997 Citrus nurseries and planting techniques. Ed. Cirad, Montpellier, France, 184 pp.
- Austin M E and Bondari K 1992 Hydrogel as a field medium amendment for blueberry plants. *HortSci.* 27, 973–974.
- Brakke M and Allen L H 1995 Gas-exchange of citrus seedlings at different temperatures, vapor-pressure deficits, and soil-water contents. *J. Am. Soc. Hort. Sci.* 120, 497–504.
- Gómez-Cadenas A, Arbona V, Jacas J, Primo-Millo E and Talon M 2003 Abscisic acid reduces leaf abscission and increases salt tolerance in citrus plants. *J Plant Growth Regul* 21, 234–240.
- Gómez-Cadenas A, Mehouchi J, Tadeo F R, Primo-Millo E and Talon M 2000 Hormonal regulation of fruitlet abscission induced by carbohydrate shortage in citrus. *Planta* 210, 636–643.
- Gómez-Cadenas A, Tadeo F R, Primo-Millo E and Talón M 1998 Involvement of abscisic acid and ethylene in the response of citrus seedlings to salt shock. *Physiol. Plant.* 103, 475–484.
- Gómez-Cadenas A, Tadeo F R, Talon M and Primo-Millo E 1996 Leaf abscission induced by ethylene in water stressed intact seedlings of Cleopatra mandarin requires previous abscisic acid accumulation in roots. *Plant Physiol.* 112, 401–408.
- Hüttermann A, Zomporodi M and Reise K 1999 Addition of hydrogels to soil for prolonging the survival of *Pinus halepensis* seedlings subjected to drought. *Soil Tillage Res.* 50, 295–304.
- Iglesias D J, Lliso I, Tadeo F R and Talon M 2002 Regulation of photosynthesis through source:sink imbalance in Citrus is mediated by carbohydrate content in leaves. *Physiol. Plant.* 116, 563–572.
- Keever G J, Gobb G S, Stephenson J C and Foster W J 1989 Effect of hydrophilic polymer amendment on growth of container grown landscape plants. *J. Environ. Hort.* 7, 52–56.
- Lovatt C J, Zheng Y and Hake K D 1988 Demonstration of a change in nitrogen metabolism influencing flower initiation in Citrus. *Isr. J. Bot.* 37, 181–188.
- Monselise S P 1985 Citrus and related genera. *In* Handbook of Flowering Vol II. Ed. A H Halevy. CRC Press, Boca Raton, Florida, USA.
- Moya J L, Tadeo F R, Gómez-Cadenas A, Primo-Millo E and Talón M 2002 Transmissible salt tolerance traits identified through reciprocal grafts between sensitive Carrizo and tolerant Cleopatra citrus genotypes. *J. Plant Physiol.* 159, 991–998.
- Popova L P, Stoinova Z G and Maslenkova L T 1995 Involvement of abscisic acid in photosynthetic process in *Hordeum vulgare* L. during salinity stress. *J. Plant Growth Regul.* 14, 211–218.
- Reuther W 1973 Climate and citrus behavior *In* The Citrus Industry, Vol III. Ed. W Reuther. Univ. California, Div. Agric. Sci, California, USA.

- Romero-Aranda R, Moya J L, Tadeo F R, Legaz F, Primo-Millo E and Talon M 1998 Physiological and anatomical disturbances induced by chloride salts in sensitive and tolerant citrus: beneficial and detrimental effects of cations. *Plant Cell Environ.* 21, 1243–1253.
- Sánchez C D, Blondel L and Cassin J 1978 Influence du climat sur la qualité des clémentines de Corse. *Fruits* 33, 811–813.
- Southwick S M and Davenport T L 1986 Characterization of water stress and low temperature effects on flower induction in Citrus. *Plant Physiol.* 81, 26–29.
- Swietlik D 1989 Effect of soil amendment with Viterra hydrogel on establishment of newly-planted grapefruit trees cv Ruby Red. *Commun. Soil Sci. Plant Anal.* 20, 1697–1705.
- Syvertsen J P and Dunlop J M 2004 Hydrophilic gel amendments to sand soil can increase growth and nitrogen uptake efficiency of citrus seedlings. *HortSci.* 39, 267–271.
- Tripepi R R, George MW, Dumroese R K and Wenny D L 1991 Birch seedling response to irrigation frequency and a hydrophilic polymer amendment in a container medium. *J. Environ. Hortic.* 9, 119–123.
- Tudela D and Primo-Millo E 1992 1-aminocyclopropane-1-carboxylic acid transported from roots to shoots promotes leaf abscission in Cleopatra mandarin (*Citrus reshni* Hort. ex Tan.) seedlings rehydrated after water stress. *Plant Physiol.* 100, 131–137.
- Wang Y T 1989 Medium and hydrogel affect production and wilting of tropical ornamental plants. *HortSci.* 24, 941–944.

Section editor: T. Kalapos