Regulation of Growth and Nutrient Uptake under Different Transpiration Regimes

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Abstract
To determine the extent to which air humidity affects the regulation of nutrient demand, an experiment with tomato plants was carried out under fully controlled climate conditions. Treatments consisted of three levels of relative air humidity (RH): 50%, 70% (control) and 95%, corresponding to 1.32, 0.79 and 0.13 kPa vapour pressure deficit (VPD), respectively. High humidity reduced the total plant dry matter, leaf dry weight, and total leaf area but no effect was found in leaf dry matter percentage. High humidity also increased the dry matter partitioning into the stems but reduced the dry matter partitioning into the leaves. Relative growth rate (RGR) was reduced by both high and low air humidity compared with the control with the stronger effect at 95%RH. Net assimilation rate (NAR) was more reduced than leaf area ratio (LAR) at low humidity, but at high humidity both parameters were affected to a similar extent. Water use efficiency (WUE) increased from 3.4 mgDM/ml H_2O at 70%RH to 7.4 mgDM/ml H_2O at 95%RH. The concentrations of N, K and Mg were not affected by humidity but concentrations of P, Ca and S in the plant were reduced at high humidity.

INTRODUCTION

Many physiological and morphological processes of horticultural crops are affected by relative humidity. However, the effect on plant growth as a process related to water and nutrient uptake has been discussed. Grange and Hand (1987) reported that humidities between vapor pressure deficits (VPD) of 1.0 and 0.2 KPa had little effect on the physiology. However, VPD higher and lower than these values could be frequently reached in greenhouses. In Northern Europe greenhouses, the reduced air exchange often results to an increase of the inner humidity that leads to a reduction of transpiration (Stanghellini, 1987). By contrast, in greenhouses located in the Southern regions, usually not fully sealed, the higher temperatures in spring and summer are frequently associated with high mid-day air VPD (Romero-Aranda and Longuenese, 1995). High humidity can promote physiological disorders due to a reduced transpiration and thereby reduce the uptake of nutrients in general (Adams, 1980). However, the importance of transpiration as required for the long-distance transport of inorganic nutrients has been questioned recently (Tanner and Beevers, 2001). On the other hand, high VPD may also induce high stomatal resistance and plant water stress (Korner and Challa, 2003). Therefore, relative humidity could be a useful tool in modulating growth as it is intertwined in nutrient uptake and could affect some morphological aspects of the plant, since some biotic (ie. fungal disease) and abiotic stresses (salinity) could be diminished by modulating air humidity (Li and Stanghellini, 2001). The primary objective of this research was to evaluate the effect of different transpiration regimes on plant growth through the regulation of nutrient demand in tomato plants, under fully controlled climate conditions.

MATERIALS AND METHODS

Seeds of tomato (*Lycopersicon esculentum* Mill.). cv. Capita. (De Ruiter Seeds, The Netherlands) were sown in a growth chamber in moist vermiculite. Ten days after sowing (DAS), seedlings were transferred to modified Hoagland solution contained NO_3^-: 12.0; $H_2PO_4^-$: 1.0; SO_4^{2-}: 7.0; K+: 7.0; Ca^{2+}: 9.0; Mg^{2+}: 4.0. The temperature was 22°C, RH was 70 % and a photosynthetic photon flux of 250 µmol m-2 s-1 (fluorescent tubes: Philips TL-D-

HF) was supplied for 12 hours a day, followed by 30 minutes of incandescent light. At 24 DAS, each plant was transferred to a 12-L container. Containers contained 10 ± 0.01 L nutrient solution and were oxygenated continuously with compressed air. The day length was increased to 16 hours. All lateral shoots were removed during the experiment.

Treatments consisted of three levels of relative air humidity: 50%, 70% and 95%, corresponding to 1.32, 0.79 and 0.13 kPa vapor pressure deficits (VPD), respectively, held constant day and night. At 31 DAS, six plants were harvested for initial reference and six plants were placed in each climate chamber with the new air humidity conditions. At 35 DAS, nutrient solution in each container was replaced in order to avoid excessive salt concentration. Plants were harvested at 38 DAS. The experiment was performed twice.

At harvest time, the area and fresh weight of the leaves and roots and stem (including petioles) were measured. Roots were rinsed three times in tap water and dried with absorbent paper. Dry weight was determined after at least 72 h at 80°C. Water uptake was measured by weighing containers containing nutrient solution.

Transpiration was calculated from the water uptake minus the increase in plant fresh weight. The transpiration per unit leaf area of each plant was calculated by dividing the transpiration of the whole plant by the average leaf area at start and end of each period. Relative growth rate (RGR, g g^{-1} d^{-1}) was calculated as $(\ln(W_{t2}) - \ln(W_{t1}))/(t2-t1)$, where Wt is the dry matter in g per plant at time t. The leaf area ratio (LAR, m^2 Kg^{-1}) was calculated as At/Wp,t where At is leaf area per plant at time t and Wp,t is plant dry weight at time t. Net assimilation rate (NAR, g m^{-2} d^{-1}) $= (W_{t2}-W_{t1})/(t2-t1)*(\ln A_{t2}- \ln A_{t1})/(A_{t2}-A_{t1})$.

RESULT AND DISCUSSION

Transpiration is usually accepted as the driving force for the long distance transport of nutrients through the xylem vessels of higher plants. However, it is often argued to what extent the evaporative loss of water from the leaves is essential for this transport of nutrients. Transpirational water flow may affect ion transport and ion accumulation in the shoot, which may also affect growth (Salim, 1989). Our results show that, when the relative humidity was increased from 70% (control) to 95% after the seven days of new climate conditions, total leaf area was significantly reduced, from 0.276 m^2 to 0.232 m^2. Leaf dry weight was also reduced by 13.2%, but the leaf dry matter percentage of these leaves was not affected by high or low humidity compared with the control (Fig. 1). Total plant dry matter was reduced by 11.4% when plants were grown at high air humidity. However, when plants were grown at 50% RH, growth was not significantly reduced compared with the control plants. Tanner and Beevers (1990) found, in maize plants, that at higher RH (>95%) both fresh and dry weights were higher than at low RH (50%) and that these plants used a 2.7-fold greater amount of water. Gautier et al. (1999) found that misting in July reduced VPD and caused increases in leaf area and in yield. Contradictory findings about the response of tomato to different VPD conditions can be explained by the range of VPD reduction and the time of exposure (Gautier et al., 1999). Hoffman (1979) reported that an increase in VPD from 1 to 1.8 kPa led to the greatest reduction in plant growth. High VPD could produce leaf water stress, with leaves responding by reducing stomatal conductance (Grange and Hand, 1987), which may play a role in reducing growth via a decrease in photosynthesis.

Dry matter partitioning (DMP) was clearly affected when RH was modified (Fig. 2); DMP into the leaves was reduced as RH was increased whilst DMP into the stem increased from 0.28 gg^{-1} to 0.32 gg^{-1} when RH was increased from 70 to 95%. The effect on roots was similar to that on stems. When plants were grown at 95% RH, RGR was reduced more than at 50% RH (by 5.2% compared with 10.3%) (Fig. 3). At high RH, the net assimilation rate (NAR) and the leaf area ratio (LAR) were reduced to a similar extent. Water uptake was strongly diminished (66%) when plants were grown at high humidity (Fig. 4). The water use efficiency (WUE) increased from 2.79 gDM/mlH_2O to 6.8 gDM/mlH_2O when air humidity was increased from 50% to 95%.

The concentrations of N, K and Mg in the plant were not affected by high or low humidity (Fig. 5). However, concentrations of P, Ca and S were reduced by 9.6%, 8.7% and 27%, respectively, when plants were grown at 95%RH. Cockshull (1990) reported that high humidity at low light levels leads to yield losses for greenhouse tomato crops. These reductions in both growth and production have been related to deficiencies, especially with calcium in the young tissues. Gisleröd et al. (1987) found that at 55-60 or 70-75% RH, K, Ca

and Mg contents in tomato plants were significantly reduced compared to 90-95% RH, but for P and N the reductions were not significant. This study concluded that the content of macroelements of the plants decreased, together with transpiration from the plants, when the RH was increased (VPD lower than in our experiment). Armstrong and Kirkby (1979) found a 25% reduction in the Ca content in the young leaves grown at 95% RH. Adams and Ho (1985) found that constant high RH decreased Ca content in the young leaves of tomato although Brafield and Guttridge (1984) found that the Ca content in tomato fruits was also reduced when the RH was low during the night. Adams (1991) showed that high humidity during the night reduced the Ca, Mg, P and K contents of the leaf laminae whilst high humidity during the day reduced only the Ca and K contents.

ACKNOWLEDGEMENTS

Literature Cited

Adams, P. 1980. Nutrient uptake by cucumbers from recirculating solutions. Acta Hort. 98:119-126.

Adams, P. 1991. Effect of diurnal fluctuations in humidity on the accumulation of nutrients in the leaves of tomato (*Lycopersicon esculentum*). J Hortic Sci. 66:545-550.

Adams, P. and Ho, L. 1985. Two disorders but one cause. Grower 21:17,21,23,25.

Armstrong, M.J. and E.A. Kirkby. 1979. The influence of humidity on the mineral composition of tomato plants with special reference to calcium distribution. Plant and Soil 52:427-435.

Brafield, E.D. and Guttridge, C.G. 1984. Effects of night-time humidity and nutrient solution concentration on the calcium content of tomato fruit. Scientia Hort. 22:207-217.

Cockshull, K. 1990. Humidity and transpiration. The Grower 113:3-7.

Gautier, H., Tchamitchian, M. and Guichard, S. 1999. Effects of decreasing vpd by misting on leaf area and leaf inclination in tomato and estimation of consequences on light absorption. Acta Hort. 507:77-85.

Gisleröd, H.R., Selmer-Olsen, A.R. and Mortensen, L.M. 1987. The effect of air humidity on nutrient uptake of some greenhouse plants. Plant and Soil 102:193-196.

Grange, R.I. and Hand, D.W. 1987. A review of the effects of atmospheric humidity on the growth of horticultural crops. J. Hort. Sci. 62:125-134.

Hoffman, G.J. 1979. Humidity, In T.T. Kozlowski, ed. Controlled environment guidelines for plant research. Academic Press, London.

Korner, O. and Challa, H. 2003. Process-based humidity control regime for greenhouse crops. Computers and electronics in agri. 39:173-192.

Li, Y.L., and Stanghellini, C. 2001. Analysis of the effect of EC and potential transpiration on vegetative growth of tomato. Scientia Hort. 89:9-21.

Romero-Aranda, R. and Longuenese, J.J. 1995. Modelling the effect of air vapour pressure deficit on leaf photosynthesis of greenhouse tomatoes: The importance of leaf conductance to CO2. J. of Hort. Sci. 3:423-432.

Salim, M. 1989. Effects of salinity and relative humidity on growth and ionic relations of plants. New Phytol. 113:13-20.

Stanghellini, C. 1987. Transpiration of greenhouse crops, an aid to climate management, Agricultural University, Wageningen, The Netherlands.

Tanner, W. and Beevers, H. 1990. Does the transpiration have an essential function in long-distance ion transport in plants? Plant Cell Environ. 13:745-750.

Tanner, W. and Beevers, H. 2001. Transpiration, a prerequisite for long-distance transport of minerals in plants? Proc. Natl. Acad. Sci. USA 98:9443-9447.
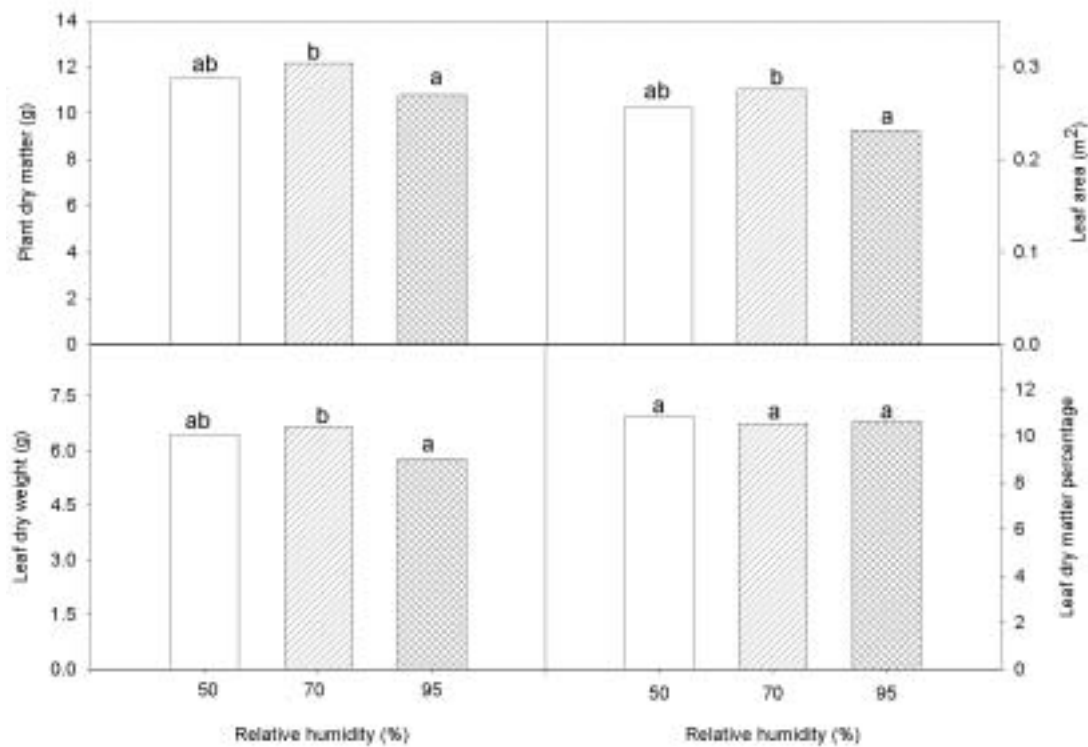
Figures

Fig. 1. Total plant dry matter, total leaf area, leaf dry weight and leaf dry matter percentage of control (70%RH) and treated plants (50 or 95%RH). Means with the same letter were not significantly different at the 0.05 threshold (Duncan test).
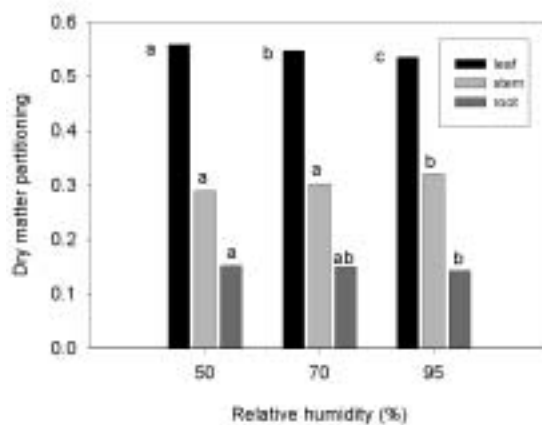

Fig. 2. Dry matter partitioning into the leaves, stems and roots of control (70%RH) and treated plants (50 or 95%RH). Means with the same letter were not significantly different at the 0.05 threshold (Duncan test).
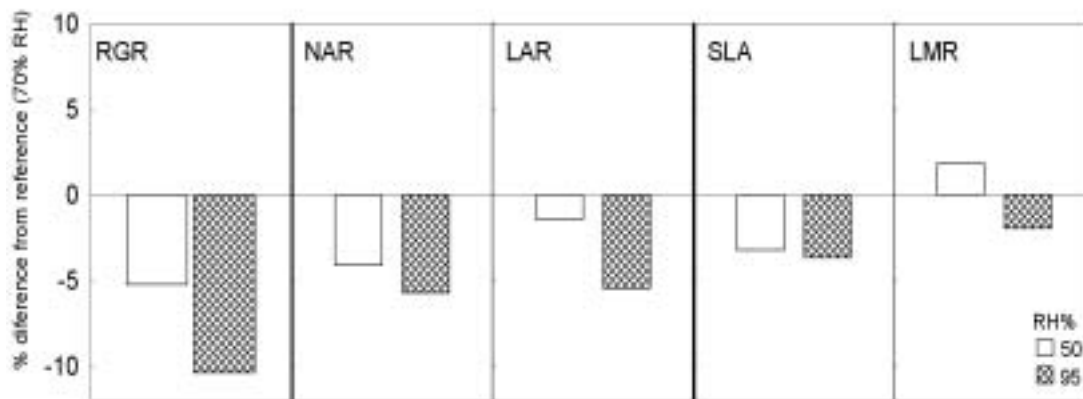
Fig. 3. Effect of different air humidities on the relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), specific leaf area (SLA) and biomass partitioning to the leaves (LMR).
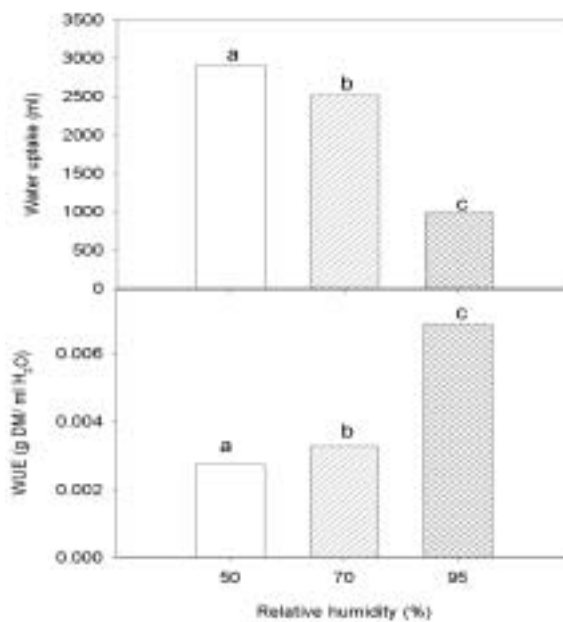

Fig. 4. Water uptake and water use efficiency (WUE) of control (70%RH) and treated plants (50 or 95%RH). Means with the same letter were not significantly different at the 0.05 threshold (Duncan test).
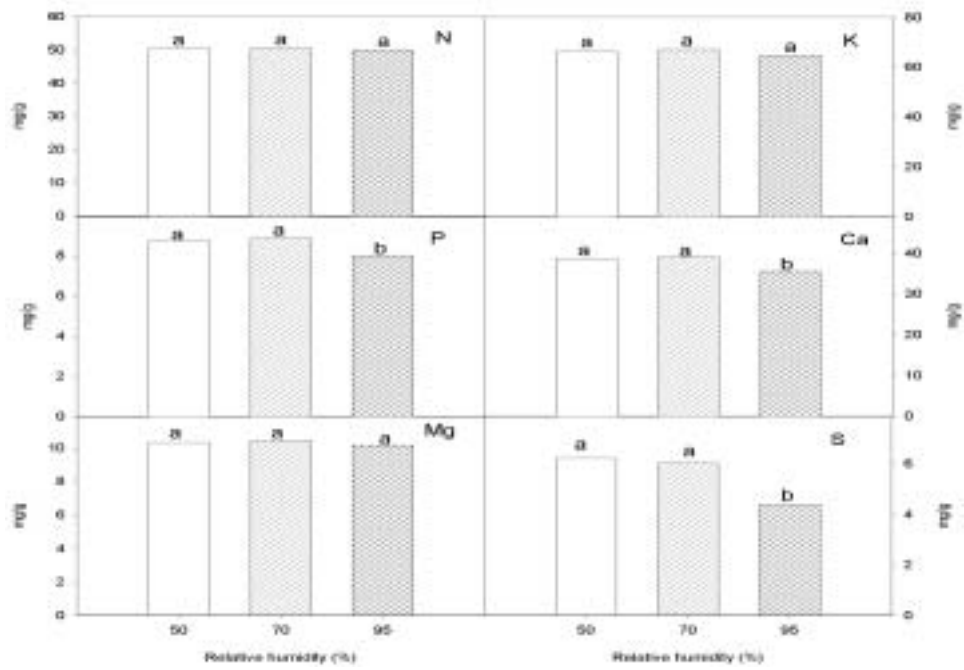
Fig. 5. Effect of air humidity treatments on the N, K, P, Ca, Mg and S concentrations (mg g^{-1} DW). Means with the same letter were not significantly different at the 0.05 threshold (Duncan test).