# Water pH and Soluble Salts Levels Affects Vase Life of Cut Callas, Hydrangeas and Snapdragons

Iftikhar Ahmad, John Dole and Alicain Carlson
North Carolina State University

Report Date:  June 30, 2011 (2011-12 First and Final Report
Funded by the Joseph H. Hill Memorial Foundation, Inc.
ICFG-HILL, P.O. Box 99, Haslett, MI  48840
ICFG.HILL@yahoo.com

## Summary

Water quality can have a significant impact on vase life and two of the most important characteristics of water are pH and electrical conductivity (EC), a measure of water's salinity.  Cut flowers are usually placed in tap water, which can vary greatly in pH and EC.  Callas were quite tolerant of high water EC and water pH.  Vase life varied only from a low of 9.2 days for acidic solutions to a high of 10.1 days for neutral solutions.  Increasing EC, low water pH and the use of floral preservatives increased hydrangea vase life.  Increasing EC increased vase life from a low of 3.5 days to a high of 5.7 days at 4.0 dS/m in water and from a low of 7.3 days to a high of 15.4 days at 2.5 dS/m, when floral preservatives were used.  For snapdragon, increasing EC and the use of floral preservatives increased vase life to a maximum of 9.7 days with 3.0 dS/m with floral preservatives and to 14.8 days with 2.0 dS/m with only water.  Water pH had no statistical effect on snapdragon vase life.  In summary, water EC for these three species should be approximately 2.0 dS/m, which is higher than most recommendations.  Water pH should be low, as high pH solutions either had no effect or reduced vase life, such as with hydrangea.

## Background and Literature Review

Many factors affect vase life in cut flower stems, including temperature, transpiration rates, microbial populations, sucrose levels, and so forth.  Durkin (1979) states that solution uptake is a "central consideration in the longevity of cut flowers" and Conrado et al. (1980) describes it as the "limiting factor" for cut flower vase life.  Durkin (1979) and Conrado et al. (1980) state that water pH and mineral content, among other variables, are key factors in solution uptake.  Cut flowers are usually placed in tap water. Depending on its source, however, tap water can vary greatly in pH and EC (Gast, 2000).

Water with a low pH is taken up more easily by cut flowers than water with a higher pH.  A pH of approximately 3.5 is considered most beneficial because it deters the growth of harmful microbes (Gast, 2000; Reid and Kofranek, 1980).  Reduced microbe contamination leads to reduced stem plugging and increased vase life (Gast, 2000). Conrado et al. (1980) found that solution uptake increased with roses at a low pH (below 3) whereas, high pH (above 6) decreased uptake.  Maximum vase life in their study was achieved with a pH of 5, which is well below that of most untreated water sources. Durkin (1979) also found that acidifying solutions enhance hydration rates of rose peduncle tissue. Regan (2008, 2010) found that optimal vase life, averaging 13.2 days, for cut 'Freedom,' 'Charlotte,' and 'Classy' roses resulted from a low pH of 3.1 to 4.0. Solutions with an initial pH of 6.1 to 6.3 produced a vase life averaging 11.6 days and those with a pH of 7.3 to 8.2 produced a vase life averaging 9.8 days. A two-hour treatment in high pH solutions had no effect on vase life. Increasing pH was correlated with reduced water uptake.

Electrical conductivity (EC) estimates the amount of total dissolved salts/solids (TDS), or the total amount of dissolved ions in the water (salinity). The EPA's guideline for tap water stands at 500 $mg \cdot L^{-1}$ total dissolved solids, which translates to 0.71 $dS \cdot m^{-1}$. However, many water sources have higher levels: College Station, Texas at 0.75 $dS \cdot m^{-1}$; San Diego, California at 0.82 $dS \cdot m^{-1}$; and Madison, Wisconsin up to 0.93 $dS \cdot m^{-1}$ (www.epa.gov). On the other hand, the tap water in Birmingham, Alabama has an EC of only 0.14 $dS \cdot m^{-1}$ (www.epa.gov). Hard water containing calcium and magnesium is less harmful to vase life than softer water that contains a higher concentration of sodium ions; a low soluble salt content reduces interference with water uptake and can cause marginal necrosis of leaves and petals (Gast, 2000). The mineral salts reduce the effectiveness that preservatives have in lowering the pH of the vase solution (Gast, 2000). Salinity affects the vase life of flowers depending on the concentration and flower species. For example, gladiolus vase life starts to decrease at 1.0 $dS \cdot m^{-1}$ (700 ppm), whereas carnations are harmed at 0.3 $dS \cdot m^{-1}$ (200 ppm). Saline water may also harm leaves and stems.

Regan (2008, 2010) found that optimal vase life for cut 'Freedom,' 'Charlotte,' and 'Classy' roses resulted from EC of 1.0 to 1.3 $dS \cdot m^{-1}$. Two others salts, $Na_2SO_4$ and $CaCl_2$, produced a similar effect as NaCl. The addition of floral preservatives to the vase solution not only extended the vase life, but also partially overcame negative effects of high EC. In solutions where both initial pH and EC varied, initial pH accounted for 30 to 54% of variation in vase life (average 44%) and initial EC accounted for 18 to 48% of variation (average 36%). In all cases, final pH and EC were not as strongly correlated with vase life as initial pH and EC.

## Objectives

The objectives of this project are to determine the optimal pH and EC for maximum calla, hydrangea and snapdragon vase life.

## Methods

*pH*. Cut calla, hydrangea and snapdragon stems were received from commercial producers. Stems were held in water amended with one of the following buffer solutions: 1) bis-tris propane, 2) citrate only and 3) phosphate only. Each of the three buffers had an acidic, neutral and basic pH treatment, which was accomplished by amending the already basic buffer solutions with either HCl or $H_2SO_4$. The acidic treatments were modified to a target pH of 3.0 to 3.4, the basic treatments to 7.7 to 8.3, and the neutral treatments to 6.1 to 6.4. Distilled water controls were included that were not amended with any chemical. Each treatment had five replications of three stems per vase, except for snapdragon, which had five replications of 3 stems per vase and one replication of 2 stems per vase. Data collected included vase life, initial wet weight, termination fresh weight, water uptake, final solution pH and EC, and reasons for termination. Initial and final solution EC was also recorded.

*EC*. NaCl was be added to either DI water or DI water plus a holding preservative to create an EC of 0.25, 0.5, 0.75, 1.0, 2.0, 2.5, 3.0, or 4.0 $dS\cdot m^{-1}$. DI water and DI water plus holding preservative controls were also used. Each treatment had five replications of three stems per vase. Data collected included vase life, initial wet weight, termination fresh weight, water uptake, and reasons for termination of each flower. Initial and final solution pH was also recorded.

**Results and Discussion**

Calla. Calla was quite tolerant of high water EC (Table 1). While EC had a statistically significant effect on calla vase life, it varied only by 1.5 days from a low of 8.9 to a high of 10.4 days. Interestingly, floral preservative had no effect on vase life; however, the use of preservatives increased water uptake, reduced water pH and EC change and reduced fresh weight change. Increasing EC increased water uptake and increased stem rolling after splitting from base.

Calla was also quite tolerant of water pH (Table 2). Vase life was statistically higher for neutral solutions, but varied only from a low of 9.2 days for acidic solutions to a high of 10.1 days for neutral solutions. The use of buffers increased stem rolling after splitting from base.

Hydrangea. Increasing EC increased vase life (Table 3). As with many cut flowers the use of floral preservatives greatly increased vase life from a low of 4.5 days for water to 10.6 days with preservative. Increasing EC increased vase life from a low of 3.5 days to a high of 5.7 days at 4.0 dS/m in water and from a low of 7.3 days to a high of 15.4 days at 2.5 dS/m, when floral preservatives were used. Increasing EC reduced water uptake and increased brown spots on petals and petal drying. The use of floral preservatives reduced bending of stems from just below inflorescence but increased petal drying and leaf wilting, the latter probably due to the longer vase life of the flowers in preservatives.

Hydrangea vase life was longest when acidic water was used and buffer had no effect (Table 4). Flowers in acidic solutions also had the highest incidence of brown spots on petals and leaf wilting, possibly due to longer vase life.

Snapdragon. Increasing EC increased vase life to a maximum of 9.7 days with 3.0 dS/m with floral preservatives and to 14.8 days with 2.0 dS/m with only water (Table 5). Regardless of the use of floral preservatives, once the maximum vase life was reached, increasing EC reduced vase life. The use of floral preservatives greatly increased vase life from a low of 7.7 days for water to 13.7 days with preservative. Increasing EC increased the incidence of floret drying, shedding and fading of florets. The use of floral preservatives increased the incidence of floret drying and fading, but reduced stem bending.

Water pH had no statistical effect on vase life or water uptake (Table 6). The use of buffers increased incidence of floret fading.

In summary, postharvest water EC for the three cut flower species tested should be approximately 2.0 dS/m, which is higher than most recommendations that call for "low" water EC. Water pH should be low, as high pH solutions either had no effect or reduced vase life, such as with hydrangea. Low water pH is the general recommendation for cut flowers, which is consistent with these studies. This work will decrease postharvest problems associated with cut flowers by providing growers, wholesalers and retailers with specific pH and EC recommendations for their water, which will alert them to when they need to modify the pH and/or EC of their water.

## Literature Cited


Conrado, L.L., R. Shanahan, and W. Eisinger. 1980. Effects of pH, osmolarity and oxygen on solution by cut rose flowers. *J. Am. Soc. Hort. Sci*. 105:680-683.

Durkin, D. 1979. Effect of Millipore filtration, citric acid, and sucrose on peduncle water potential of cut rose flower. *J. Am. Soc. Hort. Sci*. 104:860-863.

Gast, K.L.B. 2000. Water quality for florists-why is it so important. Kans. State Univ. Agr. Expt. Sta. Coop. Ext. Serv.

Regan, E.M. 2008. Developing water quality and storage standards for cut Rosa stems and postharvest handling protocols for specialty cut flowers. NC State Univ., Raleigh, MS thesis.

Regan, E.M. and J.M. Dole. 2010. Determining optimum pH and EC levels for extended vase life of cut *Rosa* 'Freedom', 'Charlotte', and 'Classy'. *Acta Hort*. 870:263-271.

Reid, M.S. and A.M. Kofranek. 1980. Postharvest physiology of cut flowers. *Chronica Hort.* 20 (2): 25-27.

Table 1. The effect of vase solution EC and commercial holding solution (Floralife Professional) on vase life, water uptake, fresh weight, and stem rolling, and change in water pH, EC and fresh weight of calla 'Nicole Yellow'. Treatments with holding solution had an initial pH of 3.6. Treatments without holding solution had an initial pH of 5.3. Means are an average of 15 stems, except for main effect means, which were an average of 30 or 135 stems.

| Holding solution | EC (dS/m) | Vase life (d) | Change in fresh weight | Water uptake (mL) | Change in pH | Change in EC (dS/m) | Stem rolling (%)[z] |
|---|---|---|---|---|---|---|---|
| Yes | 0.40 | 8.9 ab | -1.6 a | 39 ab | -0.07 cde | 0.04 gf | 33 abc |
| | 0.50 | 9 ab | - 2.9 a | 36 abc | 0.13 bc | 0.08 gh | 40 abc |
| | 0.75 | 10.7 a | -2.1 a | 36 ab | 0.17 bc | 0.1 gh | 47 abc |
| | 1.00 | 9.2 ab | -2.4 a | 31 bcd | 0.03 c | 0.13 efg | 20 abc |
| | 2.00 | 8.7 b | -2.3 a | 43 ab | 0.02 c | 0.26 cd | 20 abc |
| | 2.50 | 8.9 ab | -1.6 a | 33 abcd | -0.03 cd | 0.29 bc | 27 abc |
| | 3.00 | 9.6 ab | -1.7 a | 50 a | -0.01 cd | 0.41 ab | 47 abc |
| | 4.00 | 10 ab | -2.2 a | 42 ab | -0.03 cd | 0.5 a | 67 a |
| No | 0.00 | 9.6 ab | -2.02 a | 30 bcd | -0.45 fg | 0.02 gh | 33 abc |
| | 0.25 | 10 ab | -2.1 a | 30 bcd | 0.61 a | 0.003 h | 0 c |
| | 0.50 | 9 ab | -2.5 a | 36 ab | 0.41 ab | 0.01 gh | 1 bc |
| | 0.75 | 10.1 ab | -3.04 a | 30 bcd | -0.3 def | 0.05 gh | 60 ab |
| | 1.00 | 10.3 ab | -2.9 a | 19 cd | -0.46 fg | 0.14 defg | 33 abc |
| | 2.00 | 9.4 ab | -2.4 a | 18 d | -0.09 cde | 0.11 fgh | 40 abc |
| | 2.50 | 9.2 ab | -3.1 a | 28 bcd | -0.62 g | 0.23 cdef | 33 abc |
| | 3.00 | 10.4 ab | -2.2 a | 26 bcd | -0.13 cde | 0.24 cde | 67 a |
| | 4.00 | 10.1 ab | -3.3 a | 30 bcd | -0.37 efg | 0.31 bc | 53 abc |
| *Main effects* | | | | | | | |
| Yes | | 9.4 b | -2.1 a | 39 a | 0.02 a | 0.23 a | 38 a |
| No | | 9.8 a | -2.6 b | 27 b | -0.16 b | 0.12 b | 36 a |
| | 0.00 | 9.6 ab | -2.02 a | 30 ab | -0.45 e | 0.02 f | 33 ab |
| | 0.25 | 10 ab | -2.1 a | 30 ab | 0.61 a | 0.00 f | 0 b |
| | 0.41 | 8.9 b | -1.6 a | 29 ab | -0.07 c | 0.04 f | 33 ab |
| | 0.50 | 9 b | -2.7 a | 36 ab | 0.3 b | 0.05 ef | 23 ab |
| | 0.75 | 10.4 a | -2.6 a | 33 ab | -0.07 c | 0.07 ef | 53 a |
| | 1.00 | 9.8 ab | -2.6 a | 25 b | -0.22 cd | 0.13 de | 27 ab |
| | 2.00 | 9.03 b | -2.3 a | 30 ab | -0.03 c | 0.19 de | 30 ab |
| | 2.50 | 9.1 b | -2.4 a | 31 ab | -0.33 de | 0.26 bc | 30 ab |
| | 3.00 | 10 ab | -2.0 a | 38 a | -0.07 c | 0.33 ab | 57 a |
| | 4.00 | 10.03 ab | -2.8 a | 36 ab | -0.2 cd | 0.4 a | 60 a |
| *Significance* | | | | | | | |
| Holding | | NS | 0.0217 | <0.0001 | <0.0001 | <0.0001 | NS |
| EC | | 0.0002 | NS | 0.0093 | <0.0001 | <0.0001 | 0.0004 |
| Linear | | NS | NS | NS | 0.0002 | <0.0001 | - |
| Quadratic | | NS | NS | NS | NS | NS | - |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Cubic | | NS | 0.0386 | NS | NS | NS | - |
| Residual | | 0.0012 | NS | 0.0045 | <0.0001 | NS | - |
| H*E | | NS | NS | 0.0011 | <0.0001 | 0.0011 | NS |
| H*EL | | NS | NS | 0.0219 | NS | 0.0185 | - |
| H*EQ | | NS | NS | 0.0124 | NS | NS | - |
| H*EC | | NS | NS | NS | 0.00049 | NS | - |
| H*ER | | NS | NS | 0.0096 | 0.0010 | NS | - |

NS=not significant.

[z]Percentage of stems showing characteristic.

Table 2. The effect of vase solution pH and buffer on vase life, water uptake, and stem rolling, and change in water pH, EC and fresh weight of calla 'Nicole Yellow'. Treatments had an initial pH and EC of 3.3 and 0.44 dS/m (acidic), 6.4 and 0.25 dS/m (neutral) or 8.3 and 0.22 dS/m (basic). A control treatment of unaltered water was included, which had an initial pH and EC of 5.8 and 0.00 dS/m. Means are an average of 15 stems, except for main effect means, which were an average of 15, 45 or 60 stems.

| Buffer | pH | Vase life (d) | Change in fresh weight | Water uptake (mL) | Change in pH | Change in EC (dS/m) | Stem rolling (%)[z] |
|---|---|---|---|---|---|---|---|
| No buffer | Unaltered | 9.5 a | -1.92 ab | 39 a | -0.37 cde | 0.01 ab | 7 a |
| | Acidic | 8.5 a | -1.18 a | 27 a | -0.08 bcd | -0.04 bcd | 7 a |
| | Neutral | 9.9 a | -1.70 a | 23 a | -0.95 ef | 0.01 ab | 33 a |
| | Basic | 9.0 a | -2.30 ab | 29 a | 0.06 bc | 0.01 ab | 20 a |
| Bis-tris | Acidic | 9.8 a | -2.02 ab | 29 a | 1.10 a | -0.10 e | 53 a |
| | Neutral | 10.1 a | -1.96 ab | 37 a | -0.08 bcd | 0.03 a | 7 a |
| | Basic | 10.0 a | -2.44 ab | 22 a | -0.74 de | -0.01 abc | 20 a |
| Citrate | Acidic | 9.1 a | -1.92 ab | 23 a | 1.26 a | -0.07 de | 7 a |
| | Neutral | 10.5 a | -2.10 ab | 24 a | 0.63 ab | 0.03 a | 27 a |
| | Basic | 10.3 a | -2.74 ab | 32 a | -0.31 cde | -0.01 abc | 47 a |
| Phosphate | Acidic | 9.5 a | -2.32 ab | 26 a | 0.54 ab | -0.05 cde | 40 a |
| | Neutral | 10.1 a | -2.54 ab | 25 a | 0.05 bc | 0.02 a | 47 a |
| | Basic | 9.4 a | -3.72 b | 27 a | -1.53 f | -0.05 cde | 13 a |
| *Main effects* | | | | | | | |
| No buffer | | 9.2 a | -1.78 a | 30 a | -0.33 c | 0.00 a | 17 a |
| Bis-tris | | 10.0 a | -2.14 ab | 29 a | 0.09 b | -0.03 b | 27 a |
| Citrate | | 10.0 a | -2.25 ab | 27 a | 0.53 a | -0.02 ab | 27 a |
| Phosphate | | 9.7 a | -2.86 b | 26 a | -0.31 c | -0.02 ab | 33 a |
| | Unaltered | 9.5 a | -1.92 a | 39 a | -0.37 bc | 0.01 ab | 7 a |
| | Acidic | 9.2 a | -1.86 a | 26 b | 0.71 a | -0.06 c | 27 a |
| | Neutral | 10.1 a | -2.08 a | 28 b | -0.09 b | 0.02 a | 28 a |
| | Basic | 9.7 a | -2.80 a | 28 a | -0.63 c | -0.01 b | 25 a |
| *Significance* | | | | | | | |
| Buffer | | NS | 0.0079 | NS | <0.0001 | NS | NS |
| pH | | 0.0271 | 0.0080 | 0.0389 | <0.0001 | <0.0001 | NS |
| B*P | | NS | NS | NS | <0.0001 | 0.0004 | 0.0005 |

NS=not significant.

[z]Percentage of stems showing characteristic.

Table 3. The effect of vase solution EC and commercial holding solution (Floralife Professional) on vase life, water uptake, fresh weight, petal browning, bent stem at base of inflorescence, petal drying, petal fading, and leaf wilting, and change in water pH, EC and fresh weight of *Hydrangea macrophylla*. Treatments with holding solution had an initial pH of 3.5. Treatments without holding solution had an initial pH of 5.1. Means are an average of 15 stems, except for main effect means, which were an average of 30 or 135 stems.

| Holding solution | EC (dS/m) | Vase life (d) | Change in fresh weight | Water uptake (mL) | Change in pH | Change in EC (dS/m) | Petal browning (%)[z] | Bent stem (%)[z] | Petal drying (%)[z] | Petal fading (%)[z] | Leaf wilting (%)[z] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Yes | 0.40 | 7.3 defg | -21.9 ab | 300 a | 0.00 f | 0.02 e | 100 a | 13 ab | 7 b | 7 a | 60 a |
| | 0.50 | 8.9 cde | -24.3 ab | 289 abc | 0.13 ef | 0.14 de | 60 ab | 13 ab | 13 b | 27 a | 53 a |
| | 0.75 | 11.3 bc | -15.5 a | 279 abcd | 0.12 ef | 0.29 cd | 100 a | 7 ab | 7 b | 7 a | 60 a |
| | 1.00 | 10.5 bcd | -19.3 ab | 302 a | 0.19 cde | 0.24 cde | 87 ab | 13 ab | 20 ab | 33 a | 67 a |
| | 2.00 | 9.6 cd | -20.4 ab | 228 cd | 0.06 ef | 0.45 bc | 93 a | 13 ab | 20 ab | 13 a | 67 a |
| | 2.50 | 15.4 a | -18.1 ab | 263 abcd | 0.15 de | 0.59 b | 100 a | 7 ab | 60 a | 33 a | 80 a |
| | 3.00 | 8.1 cdef | -24.7 ab | 256 abcd | 0.06 ef | 0.20 cde | 93 a | 0 b | 40 ab | 7 a | 67 a |
| | 4.00 | 13.4 ab | -19.8 ab | 253 abcd | 0.05 ef | 1.36 a | 100 a | 33 ab | 20 ab | 27 a | 67 a |
| No | 0.00 | 3.5 h | -19.2 ab | 297 ab | 0.37 abcd | 0.01 e | 47 b | 27 ab | 7 b | 0 a | 47 a |
| | 0.25 | 3.7 gh | -22.6 ab | 270 abcd | 0.38 abc | 0.03 de | 67 ab | 7 ab | 7 b | 13 a | 60 a |
| | 0.50 | 4.5 fgh | -27.2 b | 276 abcd | 0.46 a | 0.07 de | 87 ab | 33 ab | 20 ab | 7 a | 47 a |
| | 0.75 | 4.6 fgh | -27.2 b | 271 abcd | 0.53 a | 0.07 de | 80 ab | 47 ab | 7 b | 7 a | 47 a |
| | 1.00 | 4.8 fgh | -19.2 ab | 242 abcd | 0.43 ab | 0.09 de | 80 ab | 20 ab | 7 b | 13 a | 20 a |
| | 2.00 | 4.3 gh | -21.8 ab | 234 bcd | 0.49 a | 0.17 cde | 80 ab | 40 ab | 0 b | 13 a | 27 a |
| | 2.50 | 4.5 fgh | -21.0 ab | 229 cd | 0.52 a | 0.20 cde | 87 ab | 53 a | 13 b | 0 a | 27 a |
| | 3.00 | 5.3 efgh | -20.6 ab | 215 d | 0.23 bcde | 0.27 cde | 100 a | 40 ab | 7 b | 7 a | 53 a |
| | 4.00 | 5.7 efgh | -25.8 ab | 245 abcd | 0.47 a | 0.24 cde | 80 ab | 20 ab | 7 b | 0 a | 33 a |
| Yes | | 10.6 a | -20.5 a | 271 a | 0.08 b | 0.41 a | 92 a | 13 b | 23 a | 19 a | 65 a |
| No | | 4.5 b | -22.7 b | 253 b | 0.43 a | 0.13 b | 79 b | 32 a | 8 b | 7 b | 40 b |
| | 0.00 | 3.5 d | -19.2 a | 297 a | 0.37 a | 0.01 e | 47 c | 27 a | 7 a | 0 a | 47 a |
| | 0.25 | 3.7 d | -22.6 a | 270 abc | 0.38 a | 0.03 de | 67 bc | 7 a | 7 a | 13 a | 60 a |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.41 | 7.3 abc | -21.9 a | 300 a | 0.00 c | 0.02 e | 100 a | 13 a | 7 a | 7 a | 60 a |
| | 0.50 | 6.7 c | -25.8 a | 282 ab | 0.30 ab | 0.17 cde | 73 abc | 23 a | 17 a | 17 a | 50 a |
| | 0.75 | 7.9 abc | -21.3 a | 275 abc | 0.33 a | 0.18 cde | 90 ab | 27 a | 7 a | 7 a | 53 a |
| | 1.00 | 7.6 abc | -19.3 a | 272 abc | 0.31 ab | 0.17 cde | 83 ab | 17 a | 13 a | 23 a | 43 a |
| | 2.00 | 6.9 bc | -21.1 a | 231 c | 0.28 ab | 0.31 bc | 87 ab | 27 a | 10 a | 13 a | 47 a |
| | 2.50 | 10.0 a | -19.6 a | 246 bc | 0.33 a | 0.39 b | 93 ab | 30 a | 37 a | 17 a | 53 a |
| | 3.00 | 6.7 c | -22.6 a | 236 bc | 0.14 b | 0.23 bcd | 97 ab | 20 ab | 23 a | 7 a | 60 a |
| | 4.00 | 9.5 ab | -22.6 a | 249 bc | 0.26 ab | 0.80 a | 90 ab | 27 a | 13 a | 13 a | 50 a |
| *Significance* | | | | | | | | | | | |
| Holding | | <0.0001 | 0.0161 | 0.0017 | <0.0001 | <0.0001 | NS | <0.0001 | 0.0003 | 0.0017 | <0.0001 |
| EC | | <0.0001 | NS | <0.0001 | <0.0001 | <0.0001 | 0.0014 | NS | 0.0224 | NS | NS |
| Linear | | 0.0003 | NS | <0.0001 | NS | <0.0001 | | | | | |
| Quadratic | | NS | NS | 0.0015 | NS | 0.008 | | | | | |
| Cubic | | 0.0068 | NS | NS | NS | 0.0005 | | | | | |
| Residual | | NS | NS | NS | <0.0001 | 0.0357 | | | | | |
| H*E | | <0.0001 | 0.0312 | NS | 0.0259 | <0.0001 | NS | NS | 0.0457 | NS | NS |
| H*EL | | NS | NS | NS | NS | <0.0001 | | | | | |
| H*EQ | | NS | NS | NS | NS | <0.0001 | | | | | |
| H*EC | | NS | NS | NS | NS | 0.0001 | | | | | |
| H*ER | | 0.0152 | 0.0312 | 0.0312 | NS | 0.0052 | | | | | |

NS=not significant.

[z]Percentage of stems showing characteristic.

Table 4. The effect of vase solution pH and buffer on vase life, water uptake, petal browning, and leaf wilting, and change in water pH, EC and fresh weight of *Hydrangea macrophylla*. Treatments had an initial pH and EC of 3.0 and 0.44 dS/m (acidic), 6.1 and 0.25 dS/m (neutral) or 7.7 and 0.22 dS/m (basic). A control treatment of unaltered water was included, which had an initial pH and EC of 4.7 and 0.00 dS/m. Means are an average of 15 stems, except for main effect means, which were an average of 15, 45 or 60 stems.

| Buffer | pH | Vase life (d) | Change in fresh weight | Water uptake (mL) | Change in pH | Change in EC (dS/m) | Petal browning (%)[z] | Leaf wilting (%)[z] |
|---|---|---|---|---|---|---|---|---|
| No buffer | Unaltered | 3.3 d | -20.9 a | 220 a | 0.23 bc | 0.01 bc | 27 bc | 27 a |
| | Acidic | 7.4 a | -17.9 a | 235 a | 0.09 cd | -0.07 f | 87 a | 53 a |
| | Neutral | 3.7 cd | -17.9 a | 214 a | 0.13 d | 0.01 bc | 33 abc | 27 a |
| | Basic | 3.7 cd | -24.5 a | 212 a | -2.59 g | 0.00 cd | 27 bc | 33 a |
| Bis-tris | Acidic | 5.2 b | -28.1 a | 212 a | 1.15 a | -0.04 e | 80 ab | 53 a |
| | Neutral | 3.6 cd | -18.9 a | 236 a | -0.05 d | 0.04 b | 27 bc | 40 a |
| | Basic | 3.7 cd | -18.9 a | 261 a | -1.31 f | 0.08 a | 27 bc | 20 a |
| Citrate | Acidic | 4.7 bc | -26.5 a | 231 a | 0.35 b | -0.07 f | 67 abc | 60 a |
| | Neutral | 3.7 cd | -18.2 a | 225 a | -0.03 d | -0.02 cde | 20 c | 27 a |
| | Basic | 3.8 cd | -21.6 a | 190 a | -0.78 e | -0.03 de | 20 c | 40 a |
| Phosphate | Acidic | 5.7 b | -22.9 a | 236 a | 0.41 b | -0.12 g | 80 ab | 27 a |
| | Neutral | 3.1 d | -17.7 a | 226 a | -0.10 d | 0.01 bc | 33 abc | 7 a |
| | Basic | 4.6 bc | -23.6 a | 219 a | -0.99 e | -0.02 cde | 47 abc | 40 a |
| *Main effects* | | | | | | | | |
| No buffer | | 4.5 a | -20.3 a | 221 a | -0.60 c | -0.01 b | 43 a | 35 a |
| Bis-tris | | 4.2 a | -21.9 a | 236 a | -0.07 a | 0.03 a | 44 a | 38 a |
| Citrate | | 4.0 a | -22.1 a | 215 a | -0.15 ab | -0.04 c | 36 a | 42 a |
| Phosphate | | 4.5 a | -21.4 a | 227 a | -0.23 b | -0.05 c | 53 a | 24 a |
| | Unaltered | 3.3 c | -20.9 a | 220 a | 0.23 b | 0.01 a | 27 bc | 27 a |
| | Acidic | 5.7 a | -23.9 a | 229 a | 0.50 a | -0.08 b | 78 a | 48 a |
| | Neutral | 3.5 bc | -18.2 a | 225 a | -0.08 c | 0.01 a | 28 b | 25 a |
| | Basic | 4.0 b | -22.2 a | 221 a | -1.42 d | 0.01 a | 30 b | 33 a |
| *Significance* | | | | | | | | |
| Buffer | | <0.0001 | NS | NS | <0.0001 | <0.0001 | NS | NS |
| pH | | <0.0001 | NS | NS | <0.0001 | <0.0001 | <0.0001 | 0.0452 |
| B*P | | <0.0001 | NS | NS | <0.0001 | <0.0001 | NS | NS |

NS=not significant.

[z]Percentage of stems showing characteristic.

Table 5. The effect of vase solution EC and commercial holding solution (Floralife Professional) on vase life, water uptake, fresh weight, petal drying, stem bending, floret shedding, and petal fading, and change in water pH, EC and fresh weight of snapdragon 'Pink'. Treatments with holding solution had an initial pH of 3.6. Treatments without holding solution had an initial pH of 5.4. Means are an average of 15 stems, except for main effect means, which were an average of 30 or 135 stems.

| Holding solution | EC (dS/m) | Vase life (d) | Change in fresh weight | Water uptake (mL) | Change in pH | Change in EC (dS/m) | Petal drying (%)$^z$ | Stem bending (%)$^z$ | Floret shedding (%)$^z$ | Petal fading (%)$^z$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Yes | 0.39 | 12.9 a | -1.14 bcde | 90 a | -0.19 f | 0.00 i | 100 a | 27 bcd | 7 a | 100 a |
| | 0.50 | 13.1 a | 1.10 abc | 85 a | 0.07 de | 0.06 hi | 100 a | 7 d | 33 a | 100 a |
| | 0.75 | 13.7 a | 1.63 ab | 76 abc | 0.08 de | 0.13 fghi | 93 ab | 0 d | 7 a | 100 a |
| | 1.00 | 13.9 a | -0.14 abcd | 81 ab | 0.01 def | 0.19 efgh | 100 a | 7 d | 20 a | 100 a |
| | 2.00 | 14.8 a | 2.08 ab | 90 a | 0.01 def | 0.29 cdef | 100 a | 0 d | 13 a | 100 a |
| | 2.50 | 14.5 a | 2.46 a | 81 ab | -0.06 ef | 0.45 abc | 100 a | 0 d | 7 a | 100 a |
| | 3.00 | 13.7 a | 0.76 abc | 81 ab | -0.18 f | 0.54 ab | 93 ab | 13 cd | 40 a | 100 a |
| | 4.00 | 13.0 a | 3.20 a | 83 ab | -0.07 ef | 0.59 a | 100 a | 7 d | 7 a | 100 a |
| No | 0.00 | 5.7 c | -3.72 def | 46 cd | -0.46 g | 0.00 i | 20 e | 93 a | 7 a | 13 d |
| | 0.25 | 7.3 bc | -4.58 ef | 52 bcd | 0.59 a | 0.03 hi | 27 de | 73 ab | 13 a | 27 cd |
| | 0.50 | 5.5 c | -2.46 cdef | 35 d | 0.44 ab | 0.04 hi | 13 e | 87 a | 7 a | 7 d |
| | 0.75 | 7.9 bc | -3.42 def | 36 d | 0.21 bcd | 0.08 ghi | 47 cde | 73 ab | 20 a | 47 bcd |
| | 1.00 | 8.0 bc | -3.62 def | 63 abcd | 0.35 bc | 0.10 ghi | 53 bcde | 67 ab | 20 a | 47 bcd |
| | 2.00 | 8.5 b | -4.66 ef | 60 abcd | 0.34 bc | 0.23 defg | 40 cde | 73 ab | 33 a | 40 bcd |
| | 2.50 | 9.4 b | -6.02 f | 35 d | 0.22 bcd | 0.31 cde | 67 abcd | 60 abc | 27 a | 67 abc |
| | 3.00 | 9.7 b | -5.52 f | 58 abcd | 0.03 def | 0.37 bcd | 73 abc | 33 bcd | 47 a | 73 ab |
| | 4.00 | 7.4 bc | -4.98 f | 42 d | 0.13 cde | 0.36 cde | 40 cde | 60 abc | 7 a | 40 bcd |
| Yes | | 13.7 a | 1.25 a | 83 ab | -0.04 b | 0.28 a | 98 a | 8 b | 17 a | 100 a |
| No | | 7.7 b | -4.33 b | 47 b | 0.21 a | 0.17 b | 42 b | 69 a | 20 a | 40 b |
| | 0.00 | 5.7 d | -3.72 bc | 46 cd | -0.46 f | 0.00 e | 20 d | 93 a | 7 b | 13 d |
| | 0.25 | 7.3 d | -4.50 c | 52 bcd | 0.59 a | 0.03 de | 27 cd | 73 ab | 13 ab | 27 cd |
| | 0.39 | 12.9 a | -1.14 ab | 90 a | -0.19 e | 0.00 e | 100 a | 27 c | 7 b | 100 a |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.50 | 9.3 c | -0.68 a | 60 bc | 0.25 b | 0.05 de | 57 bc | 47 bc | 20 ab | 53 bc |
| | 0.75 | 10.8 bc | -0.89 a | 56 bc | 0.15 bc | 0.11 de | 70 ab | 37 c | 13 ab | 73 ab |
| | 1.00 | 10.9 bc | -1.88 ab | 72 ab | 0.18 bc | 0.15 cd | 77 ab | 37 c | 20 ab | 73 ab |
| | 2.00 | 11.7 ab | -1.29 ab | 75 ab | 0.18 bc | 0.26 bc | 70 ab | 37 c | 23 ab | 70 ab |
| | 2.50 | 11.9 ab | -1.78 ab | 58 bc | 0.08 cd | 0.38 ab | 83 ab | 30 c | 17 ab | 83 ab |
| | 3.00 | 11.7 ab | -2.38 abc | 70 abc | -0.08 de | 0.46 a | 83 ab | 23 c | 43 a | 87 a |
| | 4.00 | 10.2 bc | -0.89 a | 62 bc | 0.03 cd | 0.48 a | 70 ab | 33 c | 7 b | 70 ab |
| *Significance* | | | | | | | | | | |
| Holding | | <0.0001 | <0.0001 | <0.0001 | <0.001 | <0.0001 | <0.0001 | <0.0001 | NS | <0.0001 |
| EC | | <0.0001 | 0.0117 | NS | <0.001 | <0.0001 | 0.0063 | 0.0268 | 0.0187 | 0.0002 |
| Linear | | <0.0001 | NS | NS | 0.035 | <0.0001 | | | | |
| Quadratic | | <0.0001 | NS | 0.0215 | 0.0023 | 0.0459 | | | | |
| Cubic | | 0.0017 | 0.0001 | NS | <0.0001 | NS | | | | |
| Residual | | <0.0001 | 0.0095 | 0.0001 | <0.0001 | NS | | | | |
| H*E | | NS | 0.0013 | NS | NS | 0.0302 | 0.0138 | 0.0460 | NS | 0.0057 |
| H*EL | | 0.0509 | <0.0001 | NS | NS | 0.0123 | | | | |
| H*EQ | | NS | NS | NS | NS | NS | | | | |
| H*EC | | NS | NS | NS | NS | NS | | | | |
| H*ER | | NS | NS | NS | NS | NS | | | | |

NS=not significant.

[z]Percentage of stems showing characteristic.

Table 6. The effect of vase solution pH and buffer on vase life, water uptake, and petal fading, and change in water pH, EC and fresh weight of snapdragon 'Pink'. Treatments had an initial pH and EC of 3.4 and 0.44 dS/m (acidic), 6.3 and 0.25 dS/m (neutral) or 8.1 and 0.22 dS/m (basic). A control treatment of unaltered water was included, which had an initial pH and EC of 5.8 and 0.00 dS/m. Means are an average of 14 stems, except for main effect means, which were an average of 14, 42 or 56 stems.

| Buffer | pH | Vase life (d) | Change in fresh weight | Water uptake (mL) | Change in pH | Change in EC (dS/m) | Petal fading (%)[z] |
|---|---|---|---|---|---|---|---|
| No buffer | Unaltered | 6.3 a | -3.54 a | 69 a | -0.51 ef | 0.02 bc | 14 a |
| | Acidic | 7.1 a | -2.00 a | 72 a | 0.06 bcd | -0.09 f | 36 a |
| | Neutral | 8.0 a | -4.24 a | 69 a | 0.34 ab | 0.02 bc | 43 a |
| | Basic | 7.2 a | -4.46 a | 64 a | -0.23 cde | 0.01 bcd | 21 a |
| Bis-tris | Acidic | 6.3 a | -3.94 a | 55 a | 0.37 ab | -0.06 ef | 21 a |
| | Neutral | 6.0 a | -3.82 a | 51 a | 0.21 bc | 0.04 b | 7 a |
| | Basic | 5.7 a | -4.08 a | 65 a | -0.68 ef | 0.07 a | 7 a |
| Citrate | Acidic | 8.0 a | -4.86 a | 71 a | 0.76 a | -0.06 e | 29 a |
| | Neutral | 7.2 a | -4.46 a | 67 a | 0.31 ab | 0.01 cd | 43 a |
| | Basic | 5.9 a | -3.26 a | 60 a | -0.32 de | -0.01 d | 14 a |
| Phosphate | Acidic | 6.8 a | -3.72 a | 64 a | 0.35 ab | -0.04 e | 36 a |
| | Neutral | 7.7 a | -5.42 a | 59 a | -0.01 bcd | 0.02 bc | 43 a |
| | Basic | 7.1 a | -4.46 a | 59 a | -0.98 f | 0.00 dc | 36 a |
| | | | | *Main effects* | | | |
| No buffer | | 7.2 a | -3.56 a | 68 a | -0.09 b | -0.01 b | 29 ab |
| Bis-tris | | 6.0 a | -3.95 a | 57 b | -0.03 b | 0.01 a | 12 b |
| Citrate | | 7.0 a | -4.19 a | 66 ab | 0.25 a | -0.02 b | 29 ab |
| Phosphate | | 7.2 a | -4.53 a | 61 ab | -0.21 b | -0.01 b | 38 a |
| | Unaltered | 6.3 a | -3.54 a | 69 a | -0.51 b | 0.02 a | 14 a |
| | Acidic | 7.1 a | -3.63 a | 65 a | 0.39 a | -0.06 b | 30 a |
| | Neutral | 7.2 a | -4.49 a | 62 a | 0.21 a | 0.02 a | 34 a |
| | Basic | 6.5 a | -4.07 a | 62 a | -0.55 b | 0.02 a | 20 a |
| | | | | *Significance* | | | |
| Buffer | | NS | NS | 0.0498 | <0.0001 | <0.0001 | 0.0381 |
| pH | | NS | NS | NS | <0.0001 | <0.0001 | NS |
| B*P | | NS | NS | NS | <0.0001 | <0.0001 | NS |

NS=not significant.

[z]Percentage of stems showing characteristic.