Growth, Gas Exchange, and Mineral Nutrients of Hydrangea Hybrids Irrigated with Saline Water

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Abstract. Hydrangeas are popular landscape plants that are widely grown in many parts of the world. The objective of this study was to evaluate the salinity tolerance of three novel *Dichroa* × *hydrangea* hybrids [*Dichroa febrifuga* ‘Yamaguchi Hardy’ × *Hydrangea macrophylla* ‘Hamburg’ (YH × Hamburg), *Dichroa febrifuga* ‘Yellow Wings’ × *Hydrangea macrophylla* ‘Nigra’ (YW × Nigra), and *Dichroa febrifuga* ‘Yellow Wings’ × *Hydrangea macrophylla* ‘Oakhill’ (YW × Oakhill)]. A 52-day greenhouse study was conducted by irrigating container-grown plants with nutrient solution at an electrical conductivity (EC) of 1.1 dS·m⁻¹ (control) or saline solution at an EC of 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10). At harvest, YH × Hamburg and YW × Nigra in EC 5 and EC 10 still exhibited good quality with average visual scores greater than 4.1 (0 = dead; 5 = excellent). For YW × Oakhill, moderate foliar salt damage was observed with an average visual score of 2.9 in EC 5 and 2.2 in EC 10. Compared with control, the shoot dry weight of YH × Hamburg, YW × Nigra, and YW × Oakhill in EC 5 reduced by 35%, 35%, and 55%, respectively, whereas that in EC 10 decreased by 58%, 58%, and 67%, respectively. Elevated salinity also decreased plant height, leaf area, and leaf greenness [Soil Plant Analysis Development (SPAD) readings]; chlorophyll fluorescence (F_v/F_m); performance index (PI); and net photosynthetic rate (P_n). All these responses might result from excess accumulation of sodium (Na⁺) and chloride (Cl⁻) ions in hydrangea leaves. In this study, compared with control, leaf Na⁺ concentration of YH × Hamburg, YW × Nigra, and YW × Oakhill increased 11, 36, and 14 times, respectively, in EC 5, and 31, 53, and 18 times, respectively, in EC 10. Compared with control, leaf Cl⁻ concentration increased 4, 9, and 7 times in EC 5, and 10, 11, and 8 times in EC 10 for YH × Hamburg, YW × Nigra, and YW × Oakhill, respectively. Leaf nitrogen (N), phosphorous (P), potassium (K⁺), and iron (Fe³⁺) concentrations decreased at elevated salinity levels but did not cause any nutrient deficiency. In summary, the three *Dichroa* × *hydrangea* hybrids exhibited different salinity tolerance: YH × Hamburg and YW × Nigra were more tolerant than YW × Oakhill. Salt-tolerant hydrangea hybrids should be chosen for landscape use if soil and/or irrigation water are salty.

Hydrangea (*Hydrangea* sp.), a large group of flowering plants, includes more than 70 species indigenous to Asia and the Americas (Dirr, 1998). Hydrangea plants are slow-growing shrubs that typically reach 2 to 5 m

in height. As one of its distinctive characteristics, hydrangea produces large clusters of star-shaped flowers with four to five sepals typically and a range of flower color (e.g., blue, purple, pink, white, and red). Hydrangeas are

widely grown landscape plants in many parts of the world. In the United States, more than 10 million plants are sold annually with an estimated sales value of \$91 million, accounting for 13.4% of the total value of deciduous shrubs sold in the U.S. market (U.S. Department of Agriculture, 2015). Hydrangea plants can be planted individually as specimens or collectively as hedges. They prefer nutrient-rich, moist but well-draining soil. Many hydrangea plants can be grown in plant hardiness zones 3 through 9 (Dirr, 1998).

Hydrangea macrophylla (bigleaf hydrangea, French hydrangea, lacecap hydrangea, mophead hydrangea) is a deciduous species native to Japan. It grows up to 2 m tall and 2.5 m wide with corymbs of blue, pink, purple, and red flowers in summer and autumn (Dirr, 1998). As one of the most popular landscape plants, *H. macrophylla* has received much attention in breeding efforts that have led to many popular cultivars to date. For example, *H. macrophylla* ‘Blaumeise’ and ‘Taube’, Swiss-bred “Teller” blue lacecaps, have received the Royal Horticultural Society’s Award of Garden Merit (Royal Horticultural Society, 2020).

Interspecific hybridization, or wide hybridization, is a common method used to increase genetic variability in traits such as flower color and shape, plant form and growth, and stress and disease resistance. *Dichroa febrifuga* Lour. is a small shrub, growing 1 to 2 m in height, that is evergreen or semievergreen in USDA Hardiness Zones 7 and warmer, and deciduous in colder areas (Hinkley, 2005). *D. febrifuga* has several unique ornamental traits, including flowers that are blue even in the absence of aluminum, and metallic blue berries that persist into the winter (Rinehart et al., 2010). Morphological, molecular genetics, and hybridization studies indicate a close genetic relationship between *H. macrophylla* and *D. febrifuga*, and fertile reciprocal hybrids between the two species have been produced (Hufford, 2001; Jones et al., 2006; Reed et al., 2008; Rinehart et al., 2006).

Landscape plants in the southwestern and western United States frequently encounter salinity stresses that adversely affect plant growth and development as well as its aesthetically pleasing appearance. Salinity stress triggers a wide range of plant responses such as stunted growth, small leaves, delayed flowering, and reduced photosynthesis (Munns and Tester, 2008). Salinity stress also causes visible salt damage on foliage, such as burn, necrosis, and/or discoloration (Niu and Cabrera, 2010). The duration, severity, and rate at which a stress is imposed influence how plants respond (Taiz et al., 2015). The resistance and sensitivity to salinity stress depend on plant species, genotype, and age development of the plant (Taiz et al., 2015).

Salinity tolerance of hydrangea species and/or cultivars has been investigated. For example, Conolly et al. (2010) reported that *H. paniculata*, *H. anomala*, and *H. arborescens* were less tolerant than *H. macrophylla* and *H. serrata* based on plant responses to foliar salt spray with full (with ion

concentration approximate to seawater) or half strength solution of sodium chloride (NaCl) during a 7-week study. *H. macrophylla* was moderately tolerant to soil salinity at an electrical conductivity (EC) of 2.0 to 4.0 dS·m⁻¹, and tolerant to salt spray with solution containing between 200 mg·L⁻¹ sodium and 400 mg·L⁻¹ chloride (Wu and Dodge, 2005). Miralles et al. (2013) found that *H. macrophylla* 'Leuchtheuer' (pink flower) had smaller size and expressed reduced dry weight of aerial organs including leaf, inflorescence, and flowers when they were irrigated with saline reclaimed water at EC of 5.65 dS·m⁻¹ compared with those with fresh water at EC of 0.87 dS·m⁻¹. Among 10 woody ornamental taxa evaluated in an 8-week study with saline water irrigation at EC levels of 5.0 or 10.0 dS·m⁻¹, *H. macrophylla* 'Smhmtau' and 'Smhmsigma' were the most salt-tolerant taxa with minor foliar damage and with the highest leaf sodium and chloride concentrations (Liu et al., 2017). Niu et al. (2020) evaluated 11 hydrangea cultivars with a nutrient solution at an EC of 1.0 dS·m⁻¹ and saline solution at an EC of 5.0 or 10.0 dS·m⁻¹. They found that *H. macrophylla* 'Ayesha' and *H. serrata* × *macrophylla* 'Sabrina' and 'Selina' were relatively salt-tolerant; *H. macrophylla* 'Merritt's Supreme' and 'Mathilda' were moderately tolerant, *Hydrangea quercifolia* 'Snowflake' and *H. macrophylla* 'Emotion' were moderately salt sensitive; and *H. paniculata* 'Bulk', *H. paniculata* 'Interhydia', *H. serrata* 'Preciosa', and *H. macrophylla* 'Passion' were salt sensitive.

With many newly developed hybrids or cultivars for *H. macrophylla*, further research is needed to evaluate their salinity tolerance. Such information would guide nursery growers and landscape professionals to select the most

tolerant varieties for nursery production and landscape use. The objectives of this study were to investigate the morphological and physiological responses and to evaluate nutrition status of three *H. macrophylla* hybrids to saline water irrigation.

Materials and Methods

Plant materials and greenhouse condition. *Dichroa febrifuga* 'Yellow Wings' × *H. macrophylla* 'Oakhill' (YW × Oakhill) and *D. febrifuga* 'Yellow Wings' × *H. macrophylla* 'Nigra' (YW × Nigra) are diploid hybrids developed in the hydrangea breeding program of the National Arboretum, U.S. Department of Agriculture. *Dichroa febrifuga* 'Yamaguchi Hardy' × *H. macrophylla* 'Hamburg' (YH × Hamburg) is a tetraploid hybrid created in the same program. Individual F₁ plants from these families were selected based on ornamental merit. On 5 Apr. 2017, *Dichroa* × *hydrangea* (YW × Oakhill, YH × Hamburg, and YW × Nigra) plants were received from United States National Arboretum (McMinnville, TN). Plants were potted immediately in 11.4-L (3-gal) injection-molded, polypropylene containers (Nursery Supplies, Orange, CA) filled with a commercial soilless substrate (Metro-Mix 360 RSI; SunGro Horticulture, Agawam, MA). The medium consists of Canadian sphagnum peatmoss (45% to 55%), vermiculite, composted bark, dolomitic limestone, and silicon dioxide (SiO₂; 0.0001%). All plants were grown in a greenhouse in El Paso, TX (lat. 31°41'45" N, long. 106°16'54" W, elev. 1139 m) and irrigated using a Dosatron injector (D14M22; Dosatron, Clearwater, FL) with a water-soluble 15N-2.2P-12.5K fertilizer solution (Peters 15-5-15 Cal-Mag Special; Scotts, Marysville, OH) at a nitrogen concentration of 150 mg·L⁻¹.

On 23 May 2017, softwood cuttings were taken and treated with 1000 mg·L⁻¹ indole-3-butyric acid (IBA)/500 mg·L⁻¹ 1-naphthalene-acetic acid (NAA) as Dip'N Grow (1% IBA, 0.5% NAA; Dip'N Grow, Clackamas, OR) in 25% ethanol following a quick-dip technique (5 s, 1 cm deep). Cuttings were then stuck in a rooting medium containing perlite (Hess perlite, Malad City, ID) and peatmoss (Canadian sphagnum peatmoss; SunGro Horticulture) at a volumetric ratio of 1:1. Cuttings were kept on a bench with an intermittent mist system with a misting frequency of 15 s every 30 min controlled using a Trident controller (T3A-1 Zone; Phytotronics, Earth City, MO).

The average air temperature was 29.5 ± 4.1 °C during the day and 22.1 ± 2.0 °C at night in the greenhouse. The average daily light integral and relative humidity inside the greenhouse with a piece of silver shade cloth (30% light exclusion) on the top of the roof was 13.31 ± 1.1 mol·m⁻²·d⁻¹ and 63.0% ± 14.2%. Abamectin (Avid 0.15EC; Syngenta Crop Protection, Greensboro, NC) at 0.03 mL·L⁻¹ was sprayed to control aphids (Aphidoidea) as needed, while Thiophanate-Methyl (Dimethyl [1,2 phenylene]bis-(iminocarbonothioyl)]bis-[Carbamate]) (OHP 6672; OHP,

Mainland, PA) was applied at 0.3 mL·L⁻¹ to control powdery mildew.

Treatments. On 19 June 2017, rooted cuttings were transplanted into 3.79-L injection-molded, polypropylene containers (PC1D-4; Nursery Supplies, Orange, CA). Eighteen days later (i.e., 7 July), treatment solutions were applied manually, once a week, a total of eight times. The water-soluble fertilizer 15N-2.2P-12.5K (Peters 15-5-15 Cal-Mag Special; Scotts) at 1.0 g·L⁻¹ was dissolved in reverse osmosis water to create a nutrient solution at an average EC of 1.12 ± 0.03 dS·m⁻¹ (mean ± sd), which represented the control treatment. Sodium chloride (NaCl; Fisher Scientific, Waltham, MA) at 1.29 g·L⁻¹ and dihydrate calcium chloride (CaCl₂·2H₂O; Fisher Scientific) at 1.24 g·L⁻¹ were added to the nutrient solution to create a saline solution at an EC of 5.09 ± 0.15 dS·m⁻¹ (EC 5) as one saline treatment. The nutrient solution was supplemented with 2.84 g·L⁻¹ NaCl and 2.70 g·L⁻¹ CaCl₂·2H₂O to create a saline solution at an EC of 9.73 ± 0.29 dS·m⁻¹ (EC 10) as the other saline treatment. The pH of all solutions was adjusted using 1 mol·L⁻¹ nitric acid to 5.70 ± 0.33. One liter of treatment solution was applied at each treatment-irrigation event, which resulted in ≈20% leaching fraction. Between weekly treatment events, the control nutrient solution (≈300 mL) was applied to maintain substrate moisture.

Visual score and plant growth. EC level of leachate solution was measured weekly following a pour-through technique (Cavins et al., 2008; Wright, 1986). One plant per hybrid per treatment was chosen randomly after treatment solutions were applied, and EC values were averaged across three hybrids (Fig. 1). Visual score was recorded for each plant using a five-point scale, where 0 = dead; 1 = severe foliar salt damage (>90% leaves with burn, necrosis, and/or discoloration); 2 = moderate foliar salt damage (50% to 90% leaves); 3 = slight foliar salt damage (< 50% leaves); 4 = good quality with minimal foliar salt damage; 5 = excellent without foliar salt damage (Sun et al., 2015). Visual scores were recorded after the second, fourth, sixth, and eighth irrigation events. Plant height (cm) was measured at the beginning and end of the experiment. Increase in plant

Fig. 1. Leachate electrical conductivity (EC) recorded when three hydrangea hybrids were irrigated with a nutrient solution at an EC of 1.1 dS·m⁻¹ (Control) or saline solution at an EC of 5.0 (EC 5) or 10.0 dS·m⁻¹ (EC 10). Vertical bars indicate standard errors of three samples, one per hybrid.

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height was calculated as the differences between the initial height and the final height. At harvest, total leaf area per plant was recorded using a leaf area meter (LI-3100C; LI-COR Biosciences, Lincoln, NE). Shoots were oven dried at 60 °C for 3 d, after which shoot dry weight (DW) was determined.

Relative chlorophyll content, chlorophyll fluorescence, and gas exchange. Relative chlorophyll content (leaf greenness) was recorded using a chlorophyll meter (SPAD-502; Minolta Camera Co., Osaka, Japan). Five mature leaves per plant were measured, and average values were recorded. Maximal photochemical efficiency of PSII (F_v/F_m , where $F_v = F_m - F_0$; F_0 : minimal fluorescence, and F_m : maximum fluorescence) and performance index (PI) were measured using a chlorophyll fluorimeter (Pocket PEA; Hansatech, Norfolk, UK). Healthy, fully expanded, mature leaves in the middle of shoots were chosen for measurements, and six plants per hybrid per treatment were measured. The leaves were dark adapted for at least 30 min before measurements.

Net photosynthetic rate (P_n), stomatal conductance (g_s), and transpiration rate (E) were measured using a portable photosynthesis system with an automatic universal PLC6 broad leaf cuvette (CIRAS-3; PP Systems, Amesbury, MA). Fully expanded, mature leaves at the top of six plants per treatment per hybrid were chosen for the measurements. Environmental conditions within the cuvette were maintained at averaged temperature of 32 °C, photosynthetic photon flux of 1000 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, and CO_2 concentration of 375 $\mu\text{mol}\cdot\text{mol}^{-1}$. Data were recorded when the environmental conditions and gas exchange rates in the cuvette became stable. These measurements were taken on sunny days between 1000 and 1400 hr. Plants were watered sufficiently the day before to avoid water stress.

Osmotic potential and mineral nutrients. Leaf osmotic potential (ψ_s) was determined as described in Niu and Rodriguez (2006) and Niu et al. (2010, 2012). Six plants per treatment were sampled for each hydrangea hybrid at the end of the experiment. Leaves were collected in the early morning from the middle part of hydrangea shoots, washed in deionized water, dried using paper towels, sealed in a Ziploc bag, and immediately stored in a freezer at -80 °C until analysis. Frozen leaves were kept in plastic bags and thawed at room temperature. Sap was pressed out with a Markhart leaf press

(LP-27; Wescor, Logan, UT) and analyzed using a vapor pressure osmometer (Vapro Model 5520, Wescor). Osmometer readings (in millimoles per kilogram) were converted to MPa (megapascal) using the Van't Hoff equation at 25 °C (Nobel, 1991).

Dried leaf samples were ground using a Wiley Mill grinder (Thomas Scientific, Swedesboro, NJ) with a 40-mesh screen. Dry powdered samples were extracted with 2% acetic acid (EM Science, Gibbstown, NJ) according to the protocol described by Gavlak et al. (1994). Chloride (Cl^-) concentration was measured for the extracted solution using a Chloride Analyzer (M926; Cole Parmer Instrument Company, Vernon Hills, IL). Powdered samples were also analyzed in the Soil, Water, and Forage Testing Laboratory at Texas A&M University (College Station, TX) for other mineral elements according to the methods described by Havlin and Soltau (1980) and Isaac and Johnson (1975).

Experimental design and statistical analyses. The experiment was organized using a randomized complete block design with 10 blocks. Analysis of variance (ANOVA) was used to test the effects of salinity on the growth, gas exchange, and mineral nutrition data. For visual score, an ANOVA with repeated measures was conducted. Means separation among treatments was adjusted using Tukey's honestly significant difference at $\alpha = 0.05$. Correlation analyses were also conducted between leaf Na^+ and Cl^- concentrations and visual score, growth, gas exchange, and mineral nutrient using pairwise method. All statistical analyses were carried out using JMP (Version 13.2; SAS Institute, Cary, NC).

Results and Discussion

Visual score. Saline solution irrigation affected visual score with various responses among hydrangea hybrids ($P = 0.0007$; Table 1). Hydrangea visual score was also impacted by the duration of the exposure to salinity stress ($P < 0.001$). After the fourth irrigation event (i.e., 24 d after the initiation of treatment), all hydrangea plants had no foliar salt damage, except YW $\times$ Oakhill, which experienced slight foliar salt damage with an average visual score of 3.7 and 3.3 when irrigated with saline solution at an EC of 5.0 or 10.0 $\text{dS}\cdot\text{m}^{-1}$, respectively (data not shown). After the sixth irrigation event (i.e., 38 d after the initiation of treatment), YW $\times$ Nigra were in good quality with average visual scores

greater than 4.7. YH $\times$ Hamburg exhibited minimal foliar damage with average visual scores greater than 4.2. YW $\times$ Oakhill irrigated with saline solution at an EC of 5.0 or 10.0 $\text{dS}\cdot\text{m}^{-1}$ showed slight foliar salt damage with an average visual score of 3.2 and 3.0, respectively (data not shown). At harvest (i.e., 52 d after the initiation of treatment), YW $\times$ Nigra and YH $\times$ Hamburg were still in good quality with minimal foliar damage and average visual scores greater than 4.1 (Table 2), although YW $\times$ Nigra had lower visual score when irrigated with saline solution at an EC of 10.0 $\text{dS}\cdot\text{m}^{-1}$ (4.1), compared with control (4.8). For YW $\times$ Oakhill, moderate foliar salt damage was observed with an average visual score of 2.9 and 2.2, respectively, when irrigated with saline solution at an EC of 5.0 or 10.0 $\text{dS}\cdot\text{m}^{-1}$.

These results suggest that hydrangea hybrids tested in this study experienced salinity stress, and the extent and severity of foliar damage varied with the duration of exposure to salinity stress and the salinity level of irrigation solution. Foliar salt damage was observed in our previous studies on hydrangea species and cultivars. Liu et al. (2017) reported that *H. macrophylla* 'Smhmtau' and 'Smnhmsigma' irrigated with saline solution at an EC of 10.0 $\text{dS}\cdot\text{m}^{-1}$ experienced foliar salt damage with visual scores of 3 on the same scale described in this paper, but when they were irrigated with saline solution at an EC of 5.0 $\text{dS}\cdot\text{m}^{-1}$, the visual scores were ≈ 4 . Niu et al. (2020) reported that *H. macrophylla* 'Ayesha', 'Mathilda Gutges', and 'Merritt's Supreme', *H. serrata* $\times$ *macrophylla* 'Sabrina' and 'Selina' exhibited much better visual scores than *H. paniculata* 'Interhydia' and 'Bulk', *H. quercifolia* 'Snow Flake', and *H. serrata* 'Preciosa', especially when they were irrigated with saline solution at an EC of 10.0 $\text{dS}\cdot\text{m}^{-1}$. With respect to the visual score only, YW $\times$ Nigra and YH $\times$ Hamburg exhibited more tolerance to salinity stress than those cultivars of *H. macrophylla*, *H. paniculata*, *H. quercifolia*, *H. serrata*, and *H. serrata* $\times$ *macrophylla* that were evaluated in different experiments with the same saline solutions and experimental duration, but different growing seasons (Niu et al., 2020), but the salinity tolerance of YW $\times$ Oakhill was similar to those cultivars.

Increased salinity levels in the growing substrate might cause hydrangea leaf burn, necrosis, and/or discoloration. In this study, when nutrient solution at an average EC of

Table 1. Analysis of variance (ANOVA) for the effects of hybrid, electrical conductivity (EC) of saline solutions and their interaction on visual score, height, leaf area, shoot dry weight (DW), relative chlorophyll content [Soil Plant Analysis Development (SPAD) reading], chlorophyll fluorescence (F_v/F_m), performance index (PI), net photosynthetic rate (P_n), stomatal conductance (g_s), and transpiration rate (E) of three hydrangea hybrids irrigated with a nutrient solution at an EC of 1.1 $\text{dS}\cdot\text{m}^{-1}$ or a saline solution at an EC of 5.0 $\text{dS}\cdot\text{m}^{-1}$ or 10.0 $\text{dS}\cdot\text{m}^{-1}$ in a greenhouse.²

ANOVA										
Source	Visual score	Ht	Leaf area	Shoot DW	SPAD	F_v/F_m	PI	P_n	g_s	E
Hybrid	***	***	NS	*	***	*	***	***	***	***
Treatment	***	***	***	***	***	***	***	***	***	***
Hybrid $\times$ Treatment	***	***	***	*	NS	*	**	NS	NS	NS

²Saline solution was created by adding sodium chloride (NaCl) and dihydrate calcium chloride ($\text{CaCl}_2\cdot 2\text{H}_2\text{O}$) to the nutrient solution.

NS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

Table 2. Visual score, plant height increase, leaf area, shoot dry weight (DW), and relative chlorophyll content [Soil Plant Analysis Development (SPAD) reading] of *Dichroa febrifuga* ‘Yellow Wings’ × *Hydrangea macrophylla* ‘Nigra’ (YW × Nigra), *Dichroa febrifuga* ‘Yellow Wings’ × *Hydrangea macrophylla* ‘Oakhill’ (YW × Oakhill), and *Dichroa febrifuga* ‘Yamaguchi Hardy’ × *Hydrangea macrophylla* ‘Hamburg’ (YH × Hamburg) irrigated with a nutrient solution [electrical conductivity (EC) = 1.1 dS·m⁻¹; control] or a saline solution [EC = 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10)] in a greenhouse.^z

Hybrid	Treatment	Visual score ^y	Ht (cm)	Leaf area (cm ²)	Shoot DW (g)	SPAD
YW × Nigra	Control	4.8 a ^x	18.3 a	1252 a	9.7 a	50.8 a ^y
	EC 5	4.4 ab	9.3 b	801 b	6.3 b	47.9 a
	EC 10	4.1 b	1.1 c	403 c	4.1 c	47.1 a
YW × Oakhill	Control	4.0 a	10.2 a	1715 a	12.7 a	50.6 a
	EC 5	2.9 b	6.2 b	390 b	5.7 b	43.4 b
	EC 10	2.2 c	2.2 c	155 c	4.2 b	41.4 b
YH × Hamburg	Control	4.5 a	31.1 a	1052 a	8.5 a	58.2 a
	EC 5	4.6 a	16.5 b	644 b	5.5 b	60.1 a
	EC 10	4.1 a	4.8 c	295 c	3.6 b	52.8 b

^zSaline solution was created by adding sodium chloride (NaCl) and dihydrate calcium chloride (CaCl₂·2H₂O) to the nutrient solution. Plants were harvested after the eighth irrigation (52 d after the initiation of treatment).

^yVisual score (0–5), 0 = dead, 1 = over 90% foliar damage (salt damage: burn, necrosis, and/or discoloration); 2 = moderate (50% to 90%) foliar damage; 3 = slight (<50%) foliar damage; 4 = good quality with minimal foliar damage; and 5 = excellent with no damage.

^xWithin each hybrid, means with same lowercase letters within dependent variable and column are not significantly different among treatments by Tukey’s honestly significant difference at $\alpha = 0.05$.

1.1 dS·m⁻¹ (control) was applied, EC levels of leachate solution stayed ≈ 2.8 dS·m⁻¹ (Fig. 1). The EC of leachate of container-grown plants, which is often higher than that of irrigation water, depends on type of growing substrate, irrigation water EC, and duration of cultivation in the container. When the irrigation water EC is within recommended range (Whipker, 1999) and there is sufficient leaching, the leachate EC should be stable like the control in our study. However, EC levels of leachate solution ranged from 4.0 to 9.7 dS·m⁻¹ when saline solution at an EC of 5.0 dS·m⁻¹ was applied, but were 4.4 to 14.0 dS·m⁻¹ when saline solution at an EC of 10.0 dS·m⁻¹ was used. Although flowers are the most important characteristics of hydrangea, foliar salt damage may lead to poor visual quality and impact marketability and therefore serves as one of the most important parameters in assessing its salt tolerance. Best management practices including monitoring water quality, and increasing leachate fraction should be adopted to limit salt damage and produce high-quality hydrangea plants during nursery production, especially when peat-based growing substrate and poor-quality water are used. It is more sustainable to monitor water quality than to use a high leaching fraction from the perspective of water conservation.

Plant growth. There were significant interactive effects between saline solution treatment and hydrangea hybrid for plant height ($P < 0.001$), leaf area ($P < 0.001$), and shoot DW ($P = 0.03$) (Table 1). Saline solution irrigation significantly slowed plant growth (Table 2). YW × Nigra, YW × Oakhill, and YH × Hamburg plants irrigated with saline solution at an EC of 5.0 dS·m⁻¹ were 49%, 39%, and 47% shorter, respectively, than those in the control, whereas plants at an EC of 10.0 dS·m⁻¹ were 94%, 79%, and 85% shorter than those in the control, respectively. This is similar to our previous study (Liu et al., 2017) in which, compared with control, *H. macrophylla* ‘Smhmtau’ and ‘Smnhmsigma’ were 58% and 75% shorter, respectively, when irrigated with saline solution

at an EC of 5.0 dS·m⁻¹, and 87% and 94% shorter, respectively, when irrigated with saline solution at an EC of 10.0 dS·m⁻¹.

Saline solution irrigation significantly decreased leaf area (Table 2). There was 36% and 68% reduction in leaf area for YW × Nigra, 77% and 91% for YW × Oakhill, and 39% and 72% for YH × Hamburg, compared with control, when irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹, respectively. Similarly, Niu et al. (2020) reported that elevated salinity stress reduced leaf area of *H. macrophylla*, *H. paniculata*, *H. quercifolia*, *H. serrata*, and *H. serrata* × *macrophylla* cultivars by 20% to 58% and 42% to 89%, respectively, when irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹. *H. macrophylla* ‘Smhmtau’ and ‘Smnhmsigma’ also had reduced leaf area when irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹ (Liu et al., 2017).

Saline solution irrigation also significantly inhibited hydrangea biomass accumulation (Table 2). Compared with control, shoot DW was reduced by 35% and 58% for YW × Nigra, 55% and 67% for YW × Oakhill, and 35% and 58% for YH × Hamburg, when they were irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹, respectively. Niu et al. (2020) also reported that elevated salinity stress reduced shoot DW in most cultivars of *H. macrophylla*, *H. paniculata*, *H. quercifolia*, *H. serrata*, and *H. serrata* × *macrophylla*. In the study by Liu et al. (2017), *H. macrophylla* ‘Smhmtau’ and ‘Smnhmsigma’ had 55% and 63% reductions in shoot DW, respectively, when they were irrigated with saline solution at an EC of 5.0 dS·m⁻¹, and 73% and 76% reductions in shoot DW, respectively, when they were irrigated with saline solution at an EC of 10.0 dS·m⁻¹.

Based on visual score and growth data, YW × Oakhill was less tolerant to the salinity levels tested in this study compared with YW × Nigra and YH × Hamburg.

Relative chlorophyll content, chlorophyll fluorescence, and gas exchange. Saline solution irrigation affected the relative chlorophyll content of hydrangea hybrids as indicated by

SPAD readings ($P < 0.001$) with similar response among hybrids (Table 1). Saline solution at an EC of 5.0 dS·m⁻¹ did not impact SPAD readings of all hydrangea hybrids, except YW × Oakhill (Table 2). Saline solution at an EC of 10.0 dS·m⁻¹ reduced SPAD readings of YW × Oakhill and YH × Hamburg, but not YW × Nigra. Similarly, saline solution at an EC of 5.0 dS·m⁻¹ did not affect SPAD readings of *H. macrophylla* ‘Smhmtau’ and ‘Smnhmsigma’ (Liu et al., 2017). SPAD readings of *H. macrophylla* ‘Smhmtau’ were decreased by saline solution at an EC of 10.0 dS·m⁻¹, but this was not the case for *H. macrophylla* ‘Smnhmsigma’ (Liu et al., 2017).

There were interactive effects between saline solution treatment and hydrangea hybrid on chlorophyll fluorescence ($P = 0.01$) and PI ($P = 0.002$) (Table 1). Saline solution at an EC of 5.0 dS·m⁻¹ had no effect on the F_v/F_m and PI values of all three hydrangea hybrids (Table 3). However, saline solution at an EC of 10.0 dS·m⁻¹ reduced F_v/F_m and PI values of YW × Oakhill and YH × Hamburg, but not for YW × Nigra. This is similar to the report by Liu et al. (2017) in which saline solution at an EC of 10.0 dS·m⁻¹ decreased F_v/F_m of *H. macrophylla* ‘Smhmtau’ and ‘Smnhmsigma’. F_v/F_m and PI values are important indicators for determining the effect of elevated salinity on leaf photosynthetic apparatus. The preceding results indicate that leaf photosynthetic apparatus was still intact, especially at low salinity levels (EC = 5.0 dS·m⁻¹).

No interactive effects were observed between saline solution treatment and hydrangea hybrid in monitoring gas exchange (Table 1). Saline solution at an EC of 5.0 dS·m⁻¹ did not affect P_n , g_s , and E of all three hydrangea hybrids, except YW × Oakhill, of which P_n , g_s , and E reduced by 26%, 32%, and 26%, respectively, compared with control (Table 3). Saline solution at an EC of 10.0 dS·m⁻¹ reduced the P_n of YW × Nigra by 36%, compared with control, but not g_s and E . Compared with control, saline solution at an EC of 10.0 dS·m⁻¹ also reduced the P_n , g_s , and E by 63%, 60%, and 50% for YW × Oakhill and by 37%, 39%, and 37% for YH × Hamburg.

Table 3. Chlorophyll fluorescence (F_v/F_m), performance index (PI), net photosynthesis rate (P_n), stomatal conductance (g_s), and transpiration rate (E) of *Dichroa febrifuga* ‘Yellow Wings’ $\times$ *Hydrangea macrophylla* ‘Nigra’ (YW $\times$ Nigra), *Dichroa febrifuga* ‘Yellow Wings’ $\times$ *Hydrangea macrophylla* ‘Oakhill’ (YW $\times$ Oakhill), and *Dichroa febrifuga* ‘Yamaguchi Hardy’ $\times$ *Hydrangea macrophylla* ‘Hamburg’ (YH $\times$ Hamburg) irrigated with a nutrient solution [electrical conductivity (EC) = 1.1 dS·m⁻¹; control] or a saline solution [EC = 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10)] in a greenhouse.²

Hybrid	Treatment	F_v/F_m	PI	P_n ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)	g_s ($\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)	E ($\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)
YW $\times$ Nigra	Control	0.71 a ^y	1.39 a	9.8 a	98 a	3.6 a
	EC 5	0.70 a	1.16 a	8.6 a	69 a	3.2 a
	EC 10	0.70 a	1.10 a	6.2 b	58 a	2.3 a
YW $\times$ Oakhill	Control	0.75 a	1.97 a	11.1 a	122 a	4.3 a
	EC 5	0.75 a	2.09 a	8.2 b	83 b	3.2 b
	EC 10	0.65 b	0.88 b	4.1 c	49 c	2.1 c
YH $\times$ Hamburg	Control	0.76 a	3.31 a	6.4 a	58 a	2.4 a
	EC 5	0.76 a	3.20 a	5.7 ab	48 ab	2.0 ab
	EC 10	0.68 b	1.26 b	4.1 b	35 b	1.5 b

²Saline solution was created by adding sodium chloride (NaCl) and dihydrate calcium chloride (CaCl₂·2H₂O) to the nutrient solution. Plants were harvested after the eighth irrigation (52 d after the initiation of treatment).

^yWithin each hybrid, means with same lowercase letters within dependent variable and column are not significantly different among treatments by Tukey’s honestly significant difference at $\alpha = 0.05$.

Saline solution at an EC of 5.0 or 10.0 dS·m⁻¹ decreased g_s and E of *H. macrophylla* ‘Smhmtau’, but not for *H. macrophylla* ‘Smnhmsigma’ (Liu et al., 2017). However, saline solution at an EC of 5.0 or 10.0 dS·m⁻¹ decreased P_n for both *H. macrophylla* ‘Smhmtau’ and ‘Smnhmsigma’ (Liu et al., 2017).

Osmotic potential and mineral nutrients. Saline water irrigation impacted the ψ_s of three tested hydrangea hybrids with different responses among hybrids (Table 4). The ψ_s decreased by 34% and 15% for YW $\times$ Nigra and YW $\times$ Oakhill, respectively, when they were irrigated with saline solution at an EC of 5.0 dS·m⁻¹ but was not statistically different from control. YH $\times$ Hamburg irrigated with saline solution at an EC of 5.0 dS·m⁻¹ had 34% lower ψ_s than the control. When hydrangea plants were irrigated with saline solution at an EC of 10.0 dS·m⁻¹, compared with control, the ψ_s decreased by 139%, 104%, and 76%, respectively, for YW $\times$ Nigra, YW $\times$ Oakhill, and YH $\times$ Hamburg.

These results indicate that hydrangea plants have osmotic adjustment capability (Zhang et al., 2010).

Saline solution irrigation affected leaf Na⁺, Cl⁻, and Ca²⁺ concentrations with varying responses among hydrangea hybrids (Table 4). Leaf Na⁺ concentrations of three hydrangea hybrids in the control were 0.4 to 0.5 mg·g⁻¹, which is within typical Na⁺ concentration for glycophytes (0.1 to 2.0 mg·g⁻¹) (Green et al., 2017). However, actual amount of Na⁺ ions in the leaves of hydrangea hybrids irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹ was beyond the typical range for glycophytes mentioned previously. Compared with control, leaf Na⁺ concentration increased 36, 14, and 11 times for YW $\times$ Nigra, YW $\times$ Oakhill, and YH $\times$ Hamburg, respectively, when irrigated with saline solution at an EC of 5.0 dS·m⁻¹, and 53, 18, and 31 times at an EC of 10.0 dS·m⁻¹ (Table 4). Niu et al. (2020) also reported that elevated salinity increased leaf Na⁺ concentration by 2 to 18 times and 6 to

100 times greater than the control, respectively, when different hydrangea species were irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹. Leaf Na⁺ concentration of *H. macrophylla* ‘Smhmtau’ and ‘Smnhmsigma’ increased 22 and 14 times, respectively, at an EC of 5.0 dS·m⁻¹ and 64 and 45 times, respectively, at an EC of 10.0 dS·m⁻¹ (Liu et al., 2017).

Compared with control, leaf Cl⁻ concentration of YW $\times$ Nigra, YW $\times$ Oakhill, and YH $\times$ Hamburg increased 9, 7, and 4 times, respectively, when irrigated with saline solution at an EC of 5.0 dS·m⁻¹, and 11, 8, and 10 times at an EC of 10.0 dS·m⁻¹ (Table 4). Niu et al. (2020) also reported that elevated salinity increased leaf Cl⁻ concentrations with 2 to 63 times and 5 to 107 times greater than the control, respectively, when different hydrangea species were irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹. Leaf Cl⁻ concentration of *H. macrophylla* ‘Smhmtau’ and ‘Smnhmsigma’ increased 11 and 11 times, respectively, at an EC of 5.0

Table 4. Osmotic potential (ψ_s), sodium (Na⁺), chloride (Cl⁻), calcium (Ca²⁺), potassium (K⁺), nitrogen (N), phosphorous (P), and iron (Fe³⁺) concentrations of *Dichroa febrifuga* ‘Yellow Wings’ $\times$ *Hydrangea macrophylla* ‘Nigra’ (YW $\times$ Nigra), *Dichroa febrifuga* ‘Yellow Wings’ $\times$ *Hydrangea macrophylla* ‘Oakhill’ (YW $\times$ Oakhill), and *Dichroa febrifuga* ‘Yamaguchi Hardy’ $\times$ *Hydrangea macrophylla* ‘Hamburg’ (YH $\times$ Hamburg) irrigated with a nutrient solution [electrical conductivity (EC) = 1.1 dS·m⁻¹; control] or a saline solution [EC = 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10)] in a greenhouse.²

Hybrid	Treatment	ψ_s (MPa)	(mg·g ⁻¹)						
			Na ⁺	Cl ⁻	Ca ²⁺	K ⁺	N	P	Fe ³⁺
YW $\times$ Nigra	Control	-0.95 b ^y	0.4 c	6.0 c	21.8 b	44.4 a	39.1 a ^y	5.6 a	0.3 a
	EC 5	-1.27 b	13.0 b	58.4 b	29.1 a	39.3 b	31.2 b	4.0 b	0.2 ab
	EC 10	-2.27 a	18.8 a	69.2 a	27.7 a	38.1 b	28.8 c	3.3 b	0.1 b
YW $\times$ Oakhill	Control	-1.03 b	0.5 b	6.3 c	19.3 b	43.7 a	40.0 a	6.1 ab	0.2 a
	EC 5	-1.19 b	7.3 a	48.8 b	27.9 a	45.3 a	34.3 b	6.5 a	0.1 ab
	EC 10	-2.11 a	9.3 a	59.5 a	30.1 a	46.1 a	32.2 c	5.4 b	0.1 b
YH $\times$ Hamburg	Control	-0.96 c	0.5 c	5.8 c	14.6 c	48.9 a	46.0 a	8.3 a	0.2 a
	EC 5	-1.30 b	6.4 b	30.2 b	20.4 b	39.8 b	41.5 b	7.5 a	0.2 a
	EC 10	-1.70 a	17.1 a	62.7 a	27.7 a	39.4 b	33.0 c	5.9 b	0.1 b
Hybrid		NS	***	***	***	**	***	***	*
Treatment		***	***	***	***	***	***	***	***
Hybrid $\times$ Treatment		*	***	***	**	***	***	**	NS

²Saline solution was created by adding sodium chloride (NaCl) and dihydrate calcium chloride (CaCl₂·2H₂O) to the nutrient solution. Plants were harvested after the eighth irrigation (52 d after the initiation of treatment).

^yWithin each hybrid, means with same lowercase letters within dependent variable and column are not significantly different among treatments by Tukey’s honestly significant difference at $\alpha = 0.05$.

NS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

dS·m⁻¹ and 19 and 20 times, respectively, at an EC of 10.0 dS·m⁻¹ (Liu et al., 2017).

There were negative correlations between leaf Na⁺ concentration and plant height, leaf area, shoot DW, F_v/F_m, PI, P_n, g_s, or E, but no significant correlations were observed between leaf Na⁺ concentration and visual score or SPAD (Table 5). Leaf Cl⁻ concentration also correlated negatively with visual score, plant height, leaf area, shoot DW, SPAD, F_v/F_m, PI, P_n, g_s, or E (Table 5). These correlations indicated that both Na⁺ and Cl⁻ ions accumulated in hydrangea leaves imposed deleterious influences on plant growth and development as well as photosynthesis system functions. Chloride ions accumulated in hydrangea leaves imposed more detrimental effects on visual score and relative chlorophyll content compared with Na⁺ ions. High Na⁺ and/or Cl⁻ accumulation in plants has been reported to cause damage to plant foliage, chloroplasts, and photosynthesis systems as well as inhibit photosynthesis (Taiz et al., 2015). Cayan et al. (2008) reported that *Hydrangea paniculata* 'Grandiflora' was sensitive to free chlorine in overhead irrigation water and exhibited premature abscission of foliage and decreased leaf area and g_s when irrigated with 5 mg·L⁻¹ or more of free chlorine for 6 weeks. In another study, in *H. paniculata* overhead-irrigated with water containing 2.4 mg·L⁻¹ of free chlorine for 11 weeks, chlorine injury on mature leaves and flowers, leaf drop, and reduced leaf area were observed (Cayan et al., 2009). The leaf Na⁺ and Cl⁻ contents in this study are high enough to inhibit hydrangea plant growth and photosynthesis, but leaf Na⁺ contents might not be enough to cause salt damage to hydrangea foliage and chlorophyll content. In addition, both leaf Na⁺ and Cl⁻ concentration positively correlated with ψ_s (Table 5), which suggests that osmotic adjustment occurred when saline solution irrigation was applied.

In addition, leaf Ca²⁺ concentration of YW × Nigra, YW × Oakhill, and YH × Hamburg increased by 33%, 45%, and 40%, respectively, when irrigated with saline solution at an EC of 5.0 dS·m⁻¹, and 27%, 56%,

and 90% when irrigated with saline solution at an EC of 10.0 dS·m⁻¹ (Table 4). There was 15% to 81% and 12% to 121% greater leaf Ca²⁺ concentration than the control, respectively, when hydrangea cultivars were irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹ (Niu et al., 2020). Leaf Ca²⁺ concentration of *H. macrophylla* 'Smhmtau' and 'Smnhmsigma' increased by 37% and 35%, respectively, at an EC of 5.0 dS·m⁻¹ and by 58% and 63%, respectively, at an EC of 10.0 dS·m⁻¹ (Liu et al., 2017).

Saline solution irrigation also affected leaf K⁺ concentration with varying responses among hydrangea hybrids (Table 4). Leaf K⁺ concentration of YW × Nigra irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹ decreased by 12% and 14%, respectively, whereas that of YH × Hamburg decreased both by 19% for plants irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹. A similar trend was observed in *H. macrophylla* 'Passion' and *H. serrata* × *macrophylla* 'Selina' (Niu et al., 2020). In contrast, leaf K⁺ concentration of YW × Oakhill did not change (Table 4), which is similar to a previous report by Liu et al. (2017) that *H. macrophylla* 'Smhmtau' and 'Smnhmsigma' had the same leaf K⁺ concentration among saline solution treatments. Niu et al. (2020) also reported the same leaf K⁺ concentration in *H. macrophylla* 'Ayesha' and 'Mathilda Gutges', *H. paniculata* 'Bulk', *H. serrata* 'Preciosa', and *H. serrata* × *macrophylla* 'Sabrina' among saline solution treatments. Negative correlations were observed between leaf K⁺ and Na⁺ or Cl⁻ concentrations (Table 6). These results suggested that hydrangea plants can either maintain or decrease K⁺ contents in plant tissue to survive in a saline environment (Grattan and Grieve, 1998).

Saline solution irrigation affected leaf N and P concentrations with varying responses among hydrangea hybrids (Table 4). YW × Nigra, YW × Oakhill, and YH × Hamburg had reduced leaf N concentrations by 20%, 14%, and 10%, respectively, when they were irrigated with saline solution at an EC of 5.0 dS·m⁻¹, and by 26%, 20%, and 28%,

respectively, when they were irrigated with saline solution at an EC of 10.0 dS·m⁻¹. Leaf P concentration was reduced by 30% and 11%, respectively, for YW × Nigra and YH × Hamburg irrigated with saline solution at an EC of 5.0 dS·m⁻¹, but not for YW × Oakhill. Leaf P concentration was reduced by 42%, 12%, and 29%, respectively, for YW × Nigra, YW × Oakhill, and YH × Hamburg irrigated with saline solution at an EC of 10.0 dS·m⁻¹. Saline solution irrigation also affected leaf Fe³⁺ concentrations with similar responses among hydrangea hybrids (Table 4). Saline solution at an EC of 5.0 dS·m⁻¹ did not affect leaf Fe³⁺ concentration, but saline solution at an EC of 10.0 dS·m⁻¹ reduced leaf Fe³⁺ concentration by 60%, 40%, and 40%, respectively, for YW × Nigra, YW × Oakhill, and YH × Hamburg. Saline solution irrigation did not affect the concentration of boron, copper, magnesium, manganese, sulfur, and zinc in leaves (data not shown). Correlation analyses showed that both Na⁺ and Cl⁻ ions accumulated in hydrangea leaves negatively impacted leaf N, P, and Fe³⁺ concentrations (Table 6). These results suggest that NaCl-dominated salinity stress disrupts plant nutrient balance that might cause plant nutrient deficiency or toxicity (Munns and Tester, 2008); however, we did not observe any nutrient deficiency or toxicity induced by salinity stress in this study.

In conclusion, saline solution irrigation had adverse impacts on plant growth and visual score of these *D. febrifuga* × *H. macrophylla* hybrids with varying morphological responses among hybrids. Salinity stress led to low visual quality of hydrangea plants with reduced visual scores and SPAD readings and resulted in stunted growth as indicated by plant height, leaf area, and shoot DW. Salinity stress also reduced the efficacy of the photosynthesis system of hydrangea plants and inhibited their photosynthesis, especially at higher salinity levels. All these morphological and physiological responses might be caused by excess Na⁺ and Cl⁻ uptake and accumulation in hydrangea plants. Salinity-induced nutrient imbalance was also observed, especially N, P, K⁺, and Fe³⁺

Table 5. Correlation probability (upper triangular) and coefficients (lower triangular) for sodium (Na⁺), chloride (Cl⁻), visual score (VS), plant height, leaf area (LA), dry weight (DW), relative chlorophyll content [Soil Plant Analysis Development (SPAD) reading], chlorophyll fluorescence (F_v/F_m), performance index (PI), net photosynthesis rate (P_n), stomatal conductance (g_s), transpiration rate (E), and osmotic potential (ψ_s) of three hydrangea hybrids irrigated with a nutrient solution at an electrical conductivity (EC) of 1.1 dS·m⁻¹ or saline solution at an EC of 5.0 or 10.0 dS·m⁻¹ in a greenhouse.

	Na ⁺	Cl ⁻	VS	Ht	LA	DW	SPAD	F _v /F _m	PI	P _n	g _s	E	ψ _s
Na ⁺		<0.0001	NS	<0.0001	<0.0001	<0.0001	NS	0.0139	0.0138	0.0164	0.0257	0.0237	<0.0001
Cl ⁻	0.9135		0.0011	<0.0001	<0.0001	<0.0001	0.0181	0.0026	0.0048	0.0014	0.0070	0.0061	<0.0001
VS	-0.2051	-0.4496		0.0001	0.0011	0.0736	<0.0001	0.0271	NS	0.0324	NS	NS	0.0023
Height	-0.6601	-0.7529	0.5115		0.0008	0.0123	0.0003	0.0054	0.0002	NS	NS	NS	<0.0001
LA	-0.6823	-0.7501	0.4481	0.4576		<0.0001	NS	NS	NS	<0.0001	0.0004	0.0005	<0.0001
DW	-0.6841	-0.6759	0.2552	0.3514	0.9493		NS	NS	NS	0.0003	0.0008	0.0017	<0.0001
SPAD	-0.1993	-0.3331	0.6076	0.4953	0.1224	0.0651		0.0003	<0.0001	NS	NS	NS	0.0457
F _v /F _m	-0.3459	-0.4176	0.3125	0.3878	0.2165	0.2231	0.4922		<0.0001	NS	NS	NS	0.0107
PI	-0.3463	-0.3923	0.2329	0.4965	0.0819	0.0845	0.5390	0.7978		NS	NS	NS	0.0424
P _n	-0.3380	-0.4387	0.3031	0.1572	0.5497	0.4953	-0.0562	0.2315	-0.0374		<0.0001	<0.0001	0.0065
g _s	-0.3154	-0.3770	0.1578	0.0357	0.4800	0.4609	-0.1586	0.1906	-0.0661	0.9424		<0.0001	0.0314
E	-0.3196	-0.3824	0.1469	0.0478	0.4719	0.4327	-0.1944	0.1773	-0.0685	0.9340	0.9817		0.0521
ψ _s	0.7225	0.7229	-0.4207	-0.6372	-0.5909	-0.5897	-0.2839	-0.3581	-0.2881	-0.3802	-0.3048	-0.2764	

NS = nonsignificant.

Table 6. Correlation probability (upper triangular) and coefficients (lower triangular) for sodium (Na^+), chloride (Cl^-), calcium (Ca^{2+}), potassium (K^+), nitrogen (N), phosphorous (P), and iron (Fe^{3+}) concentrations of three hydrangea hybrids irrigated with a nutrient solution at an electrical conductivity (EC) of 1.1 $\text{dS}\cdot\text{m}^{-1}$ or saline solution at an EC of 5.0 or 10.0 $\text{dS}\cdot\text{m}^{-1}$ in a greenhouse.

	Na^+	Cl^-	Ca^{2+}	K^+	N	P	Fe^{3+}
Na^+		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
Cl^-	0.9133		<0.0001	0.003	<0.0001	<0.0001	<0.0001
Ca^{2+}	0.7021	0.8362		0.0125	<0.0001	<0.0001	0.0143
K^+	-0.5248	-0.4006	-0.3377		0.0003	0.0001	NS
N	-0.7930	-0.8701	-0.8607	0.4723		<0.0001	0.0080
P	-0.5594	-0.5661	-0.5892	0.5020	0.8152		NS
Fe^{3+}	-0.4889	-0.5538	-0.3316	0.1189	0.3572	0.1860	

NS = nonsignificant.

concentrations, but did not cause nutrient deficiency or toxicity in this study. YW $\times$ Nigra and YH $\times$ Hamburg were more tolerant to the salinity stress than YW $\times$ Oakhill.

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