

Hot Mess: Heatwave Effects on Controlled-release Fertilizer

Lloyd Nackley and Dalyn McCauley

Department of Horticulture, 4017 Agriculture and Life Sciences Building, Corvallis, OR 97331, USA

Carolyn Scagel

US Department of Agriculture–Agricultural Research Service, Horticultural Crops Production and Genetic Improvement Research Unit, 3420 NW Orchard Avenue, Corvallis, OR 97330, USA

Keywords. climate change, Pacific Northwest, root-zone

Abstract. Controlled-release fertilizers (CRFs) are water-soluble pellets of homo- or heterogenous mineral nutrients covered with polymer or resin that become increasingly porous as temperature increases, releasing water-soluble fertilizer through diffusion. An experiment was carried out at the North Willamette Research and Extension Center located in Aurora, OR, USA (lat. 45°16'51"N, long. 122°45'04"W) with six fertilizer concentrations of a CRF fertilizer that was designed to last 6 to 7 months at 70 °F. During the experiment, the Pacific Northwest experienced a series of early-summer (June) heatwaves that caused an unanticipated and excessive release of mineral salts. Extreme weather adaptation strategies are necessary to sustain horticultural production in a period with increased temperature volatility.

Controlled-release fertilizers (CRFs) are widely used in horticultural production systems because of their ability to match nutrient release with plant demand, and to reduce labor costs and volatilization (Halvorson et al. 2014). These temperature-based, pelleted delivery systems are created by encapsulating fertilizer granules with synthetic polymers, forming a diffusion barrier (Adams et al. 2013; Ransom et al. 2020; Vejan et al. 2021). However, the increasing occurrence of heatwaves (Marx et al. 2021) poses a challenge to the effectiveness of coating technology, which are sensitive to temperature fluctuations.

Manufacturers typically provide nutrient release-rate curves for CRFs based on incubation tests in controlled environments, specifying the expected “longevity in months” at certain average media temperatures (Adams et al. 2013). However, research has demonstrated a disconnect between nutrient release

patterns determined in the laboratory and those observed in actual production conditions resulting from daily and seasonal environmental fluctuations (Medina et al. 2008; Merhaut et al. 2006; Ransom et al. 2020). This study highlights the influence of heatwaves on CRF nutrient delivery and discusses strategies for adaptation in anticipation of the continued impact of extreme temperatures (Fischer et al. 2021).

Materials and Methods

Plant material and experimental setup. On 6 Apr 2021, 60 bare-root Red Sunset[®] maple rooted cuttings (*Acer rubrum*, ‘FranksRed’), Campfire[™] shrub rose rooted cuttings (*Rosa* ‘Campfire’), and ‘Compactus’ burning bush rooted cuttings (*Euonymus alatus*) were planted in 9-L black plastic nursery containers (#3 Squat Nursery Pot; Anderson Pots, Portland, OR, USA) at the North Willamette Research and Extension Center in Aurora, OR (lat. 45°16'51"N, long. 122°45'04"W). The containers were filled with a nursery potting mix (80% Douglas fir bark, 10% coir, and 10% Perlite, with dolomite lime added to stabilize the pH between 5.5 and 6.5). The pots were placed on a gravel pad, hand-watered to saturation, and allowed to acclimate for 1 month, with natural rainfall providing sufficient irrigation during this period.

Fertilizer treatments and irrigation. On 4 May 2021, pots were assigned to six fertilizer treatments. The fertilizer used was a 20% N (6.94% nitrate-N, 6.98% ammonia-N, and 6.07% urea-N), 1.3% P, and 7.47% K with minors (Polylon CRF Fertilizer; Harrell Ag Products, Bainbridge, GA, USA) designed to last 6 to 7 months at 70 °F. The highest application rate was 44 g of fertilizer per pot, which corresponded to the manufacturer’s recommended “high” rate for a 3-gallon

(11.3-L) container. The other five fertilizer application rates were 35.2 g (80%), 26.4 g (60%), 17.6 g (40%), 8.8 g (20%), and 0 g (0%), representing decreasing increments of 20% from the high rate. The CRF was top-dressed in each pot.

Leachate collection and analysis. Each treatment group (species × fertilizer concentration, n = 18) was placed on a row of specially designed gravel-covered gutter systems to capture leachate from the pots, with 10 pots per row, resulting in six rows per species. Irrigation was provided by a 3.2 gallons per hour (12.1 liters per hour) pressure-compensated spray-stake emitter (Netafim USA, Fresno, CA, USA) in each pot. The irrigation system was activated three times a day for 2 min each time (at 0600, 1200, and 1600 HR).

Leachate from the 0600 HR irrigation event was collected once a week by placing 5-gallon (18.9-L) plastic buckets under the pots overnight. Opaque lidded buckets with a hole cut in the lid were attached to a polyvinylchloride pipe that collected the leachate. Water samples (50 mL) were collected from the buckets before the 1200 HR irrigation cycle and stored in a refrigerator at 34 °F. After collecting the water samples, the buckets were rinsed with water, wiped with a cloth, and inverted to dry.

Water samples were analyzed for P, K, Ca, Mg, S, Fe, B, Cu, Mn, Zn, and Na using inductively coupled plasma - optical emission spectrometry (Optima 3000DV; Perkin Elmer, Wellesley, MA, USA). Nitrate and NH₄ were analyzed using a flow injection system (FIAlyzer 1000; FIA Laboratories, Seattle, WA, USA), whereas pH and electrical conductivity (EC) were measured using a pH electrode (InLab Expert Pro-ISM; Mettler-Toledo Inc., Columbus, OH, USA) and an EC electrode (InLab 742-ISM, Mettler-Toledo Inc.) attached to a portable meter (SevenGo Duo Pro SG78, Mettler-Toledo Inc.).

Results and Discussion

During the experiment, the Pacific Northwest encountered an unprecedented heatwave.

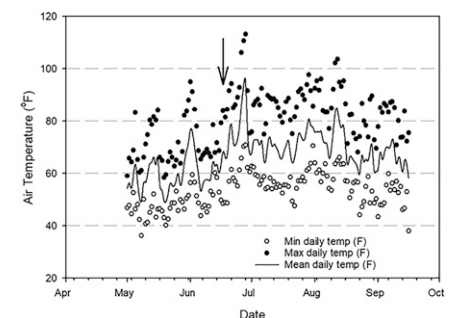


Fig. 1. Temporal variation of air temperature (measured in degrees Fahrenheit) throughout the experimental period from April to October recorded by the Aurora, OR, Agrimet Weather Station onsite. The plot includes open circles that indicate the minimum daily temperature, closed circles that represent the maximum daily temperature, and a smooth spline line depicting the mean daily temperature. A black arrow highlights 17 Jun, corresponding to the day with the highest recorded nitrate leaching. This figure provides insights into the seasonal air-temperature patterns and the association between extreme temperature events and nitrate leaching dynamics.

Received for publication 26 Jun 2023. Accepted for publication 11 Sep 2023.

Published online 24 Oct 2023.

We thank Marj Storm, Raven Hartley, Sadie Keller, Brian C. Hill, and Jesse Mitchell; Bailey Nurseries Inc.; and J. Frank Schmidt & Son Co.

This work was funded in part by the US Department of Agriculture (USDA)–Agricultural Research Service (Project No. 2072-21000-055-000-D) and the Floral and Nursery Crop Initiative (No. 0500-00059-001-000-D).

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.

L.N. is the corresponding author. E-mail: lloyd.nackley@oregonstate.edu.

This is an open access article distributed under the CC BY-NC-ND license (<https://creativecommons.org/licenses/by-nc-nd/4.0/>).

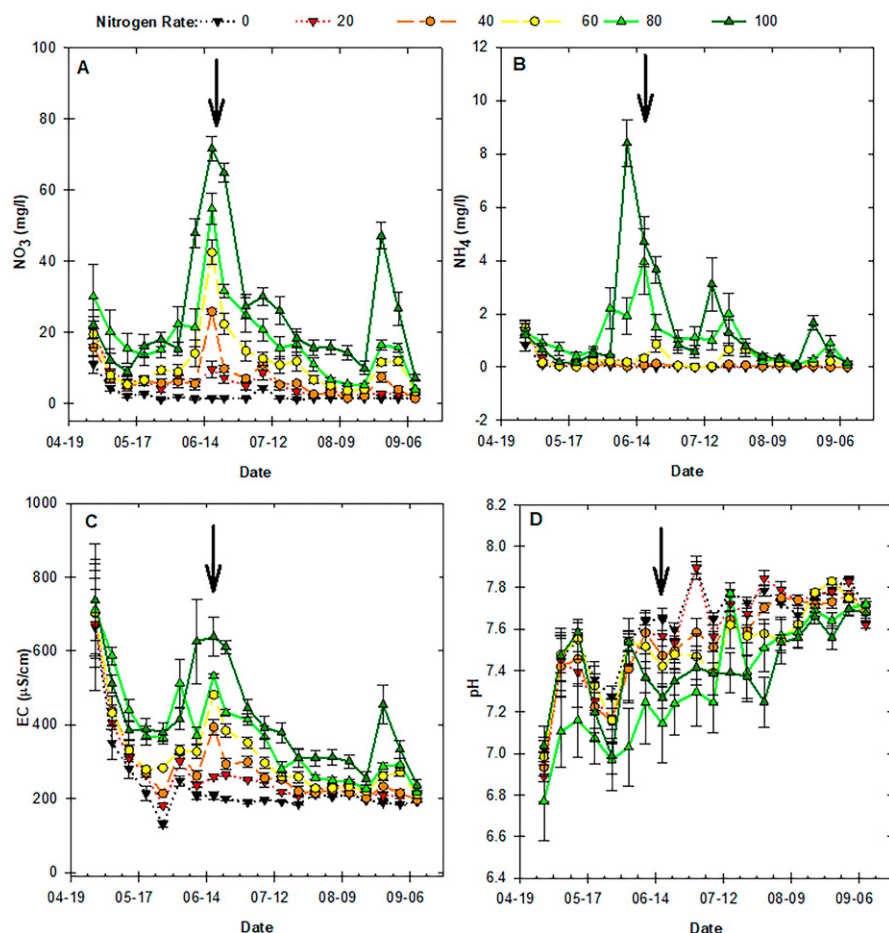


Fig. 2. Temporal dynamics of key water-quality parameters during an experimental period from 19 Apr to 6 Sep: (A) nitrate (NO_3^-) concentration, (B) ammonium (NH_4^+) concentration, (C) electrical conductivity (EC), and (D) pH. Black arrows indicate the occurrence of a heatwave on 19 Jun that resulted in a peak for all four variables, suggesting an increased release of fertilizer associated with elevated temperature. The synchronized peaks of NO_3^- , NH_4^+ , EC, and pH further demonstrate the heatwave's influence on water-quality dynamics.

From 23–29 Jun 2021, a high-pressure system known as a heat dome led to extraordinary air temperatures (Bartusek et al. 2022). The Aurora, OR, Agrimet Weather Station onsite recorded temperatures as high as 113 °F (45 °C) during this period. The heat dome was actually the second record-setting heatwave of the year, with temperatures between 29 May and 4 Jun 2021 reaching 94.9 °F (34.9 °C), surpassing the average temperatures for that time of year in the Willamette Valley by ~20 to 30 °F (Fig. 1).

The 29 May to 4 Jun heatwave triggered an excessive release of CRF, evident in the concentrations of NO_3^- and NH_4^+ ions in the 100% and 80% fertilizer concentration groups (Fig. 2). High levels of NO_3^- and NH_4^+ leaching persisted through June and subsided after the second heatwave that occurred a month later (29 Jun 2021). We posit that the increased leaching rates exhibited greater prominence in the 100% and 80% groups because of their provision of mineral salts surpassing plant requirements; lower rates were needed to support growth and development. Rapid temperature fluctuations create a mismatch between CRF release and plant demand. For instance, after the first heatwave on 29 May 2021, air temperatures dropped by 20 to 30 °F, a trend that continued for 2 weeks until temperatures started to rise again in late June. Although nutrients remained available throughout June,

plant demand decreased as growth slowed with cooler temperatures, leading to increased material loss. Rapid temperature swings have become common across the United States in recent years and are projected to intensify in all regions.

Container-grown crops are more vulnerable to air-temperature variations and, consequently, are more susceptible to temperature-related plant damage. Studies have demonstrated that container color and substrate texture can provide cooling effects on root-zone temperatures (Witcher et al. 2020). Pot-in-pot and fiber pot production are also regarded as methods for reducing temperature stress (Mathers 2003). Another approach involves using less temperature-sensitive CRF formulations when confronted with hot temperatures. Certain CRF formulations are highly responsive to temperature, whereas others exhibit less sensitivity (Adams et al. 2013; Cabrera 1997). Regular monitoring of nutrient leaching represents an existing yet underused strategy for CRF management during heatwaves. For example, the pour-through extraction method has been widely described by numerous extension groups and offers an accurate and user-friendly approach for monitoring container-grown plant nutrition.

Incorporating new strategies for applying CRF nutrition could involve adopting a less-for-more approach, using multiple applications of shorter duration (3–4 months) CRFs. In this

scenario, there would be reduced fertilizer loss during a heatwave because there would be less overall fertilizer in the pot. Growers would need to monitor nutrition (weekly or biweekly) to determine the timing of successive applications of shorter duration CRFs. Another option could involve an optional final-quarter-finish strategy, combining a medium-duration (7–9 months) CRF with a short-duration (3–4 months) CRF. In this case, an optional late-season (i.e., final-quarter) second application of CRF would be scheduled into the workflow and verified, if necessary, by monitoring container leachate. The development and application of new climate-ready best management practices is crucial as growers adapt to extreme weather conditions.

References Cited

- Adams C, Frantz J, Bugbee B. 2013. Macro- and micro-nutrient-release characteristics of three polymer-coated fertilizers: Theory and measurements. *J Plant Nutr Soil Sci.* 176:76–88. <https://doi.org/10.1002/jpln.201200156>.
- Bartusek S, Komhuber K, Ting M. 2022. 2021 North American heatwave amplified by climate change-driven nonlinear interactions. *Nat Clim Chang.* 12:1143–1150. <https://doi.org/10.1038/s41558-022-01520-4>.
- Cabrera RI. 1997. Comparative evaluation of nitrogen release patterns from controlled-release fertilizers by nitrogen leaching analysis. *HortScience.* 32:669–673. <https://doi.org/10.21273/HORTSCI.32.4.669>.
- Fischer EM, Sippel S, Knutti R. 2021. Increasing probability of record-shattering climate extremes. *Nat Clim Chang.* 11:689–695. <https://doi.org/10.1038/s41558-021-01092-9>.
- Halvorson AD, Snyder CS, Blaylock AD, Del Grosso SJ. 2014. Enhanced-efficiency nitrogen fertilizers: Potential role in nitrogen oxide emission mitigation. *Agron J.* 106:715–722. <https://doi.org/10.2134/agronj2013.0081>.
- Marx W, Haunschild R, Bornmann L. 2021. Heat waves: A hot topic in climate change research. *Theor Appl Climatol.* 146:781–800. <https://doi.org/10.1007/s00704-021-03758-y>.
- Mathers HM. 2003. Summary of temperature stress issues in nursery containers and current methods of protection. *HortTechnology.* 13:617–624. <https://doi.org/10.21273/HORTTECH.13.4.0617>.
- Medina LC, Obreza TA, Sartain JB, Rouse RE. 2008. Nitrogen release patterns of a mixed controlled-release fertilizer and its components. *HortTechnology.* 18:475–480. <https://doi.org/10.21273/HORTTECH.18.3.475>.
- Merhaut DJ, Blythe EK, Newman JP, Albano JP. 2006. Nutrient release from controlled-release fertilizers in acid substrate in a greenhouse environment: I. Leachate electrical conductivity, pH, and nitrogen, phosphorus, and potassium concentrations. *HortScience.* 41:780–787. <https://doi.org/10.21273/HORTSCI.41.3.780>.
- Ransom CJ, Jolley VD, Blair TA, Sutton LE, Hopkins BG. 2020. Nitrogen release rates from slow- and controlled-release fertilizers influenced by placement and temperature. *PLoS One.* 15:e0234544. <https://doi.org/10.1371/journal.pone.0234544>.
- Vejan P, Khadiran T, Abdullah R, Ahmad N. 2021. Controlled release fertilizer: A review on developments, applications and potential in agriculture. *J Control Release.* 339:321–334. <https://doi.org/10.1016/j.jconrel.2021.10.003>.
- Witcher AL, Pickens JM, Blythe EK. 2020. Container color and compost substrate affect root zone temperature and growth of “Green Giant” arborvitae. *Agronomy (Basel).* 10:1–11. <https://doi.org/10.3390/agronomy10040484>.