Hydroponic Fertilizer Supply for Basil Using Controlled-release Fertilizer

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***Abstract*. Small-scale hydroponics is a growing urban horticulture trend, but nutrient solution management remains a challenge for small growers. The objective was to investigate the potential to use controlled-release fertilizer (CRF) to simplify nutrient management in small-scale hydroponic systems. Three experiments were conducted with the goal of a single fertilizer application during the crop cycle of basil (*Ocimum basilicum*). Nutrient release curves were quantified by adding prills to water and measuring nutrient content weekly in the solution for CRF products without plants. In all seven products tested (Osmocote Bloom 2–3M, Osmocote Plus 3–4M, E-Max Calcium Nitrate 2–3M, Agrocote MAP 3–4M, E-Max Keiserite 3–4M, E-Max K-Mag 2–3M, and Agrocote SOP 3–4M) an initial rapid release was followed by a plateau, but release rates differed between products varying from 100% ($MgSO_4$) to 60% release [$(NH_4).(H_2PO_4)$] over an 11-week evaluation period. Total nutrient content in two commercial N–P–K CRF products (3–4 months 15N–3P–10K and 2–3 months 12N–3.1P–14.9K) provided lower Ca and Mg compared with a typical hydroponic solution based on water-soluble fertilizer (WSF). A subsequent experiment evaluated plant growth response using the same two commercial CRF products (single application) or a WSF (replaced weekly) in growth chamber environment. Plants grown for 4 weeks under CRF treatments yielded less than half the shoot fresh weight of plants grown with WSF and exhibited symptoms of Ca deficiency and micronutrient toxicity (confirmed with tissue analysis). Electrical conductivity (EC) of CRF solutions increased over time indicating excess dose compared with plant uptake, reaching a maximum of 5.4 $dS \cdot m^{-1}$. Nutrient release curves from the first experiment were then used to estimate product release and create a single-application nutritional program based on a customized "Blend" developed from CRF macronutrients plus WSF micronutrients. Plants were grown hydroponically with two dosages of Blend (1X and 2X) and compared with a commercial WSF with weekly replacement of solution. Blend 2X and WSF treatments had similar shoot fresh weight (241 and 244 g/four plants, respectively) with healthy plant appearance and tissue nutrient levels generally within published survey ranges for basil. Commercial CRF products designed for soil or container production were unsuitable for hydroponics, but acceptable plant performance with the customized CRF Blend demonstrated proof-of-concept for a single CRF application.**

Almost 42 million U.S. households are engaged in food gardening (National Gardening Association, 2014). Indoor residential food gardening is an increasing trend, with 37% of millennials growing plants or herbs indoors compared with 28% of baby boomers (Garden Media Group, 2016). In this context, small-scale hydroponics is becoming more popular among homeowners and provides a market opportunity for transplants and growing systems. Closed hydroponics systems are suitable for indoor gardening (Resh, 2013); however, significant technical knowledge is required to successfully manage hydroponic recirculating solutions (Resh, 2015; Savvas et al., 2013).

In commercial production and research, complex methods are used to prepare, deliver, and maintain hydroponic nutrient solutions (Hoagland and Arnon, 1950; Sonneveld and Voogt, 2009; Steiner, 1961). Commercial operations typically use multiple tank systems to avoid undesired nutrient interactions. Optimum nutrient solutions should account for crop growth stage, plant uptake of minerals, substrate characteristics, water quality, and climate conditions (Bugbee, 2004; Hochmuth and Hochmuth, 2018; Trejo-Téllez and Gómez-Merino, 2012). To avoid precipitation and substitution reactions, at least two separate stock solutions are typically prepared, one containing calcium and iron, and the other containing sulfates and phosphates. In recirculating hydroponic systems, such as nutrient film technique (NFT) or deep-water culture, changes in ion concentration and pH over time require constant monitoring and adjustment (Sonneveld and Voogt, 2009). Sophisticated real-time monitoring and control are unlikely to be feasible for small-scale home gardeners.

Controlled-release fertilizers (CRFs) formulated from resin or polymer-coated water-soluble fertilizers are used primarily in substrate and field soil production. Release rates for polymer-coated CRFs are predictable and primarily driven by temperature and coating-membrane thickness. These coated fertilizers have the potential to be formulated such that nutrient release can be synchronized to plant physiological needs (Du et al., 2006; Ozores-Hampton, 2017; Trenkel, 2010). The relationship between these two factors allows for a single application of fertilizer rather than multiple low applications of granular or water-soluble fertilizer for substrate and soil production (Liu et al., 2017; Morgan et al., 2009; Oertli, 1980). The typical CRF release patterns are parabolic release (with or without "burst"), linear release, and sigmoidal release (Trenkel, 2010). Nutrient release curves for CRF can be generated by incorporating the CRF in a substrate such as sand, or by monitoring nutrient levels when CRF is placed in an aqueous solution (Adams et al., 2013; Du et al., 2006). Release rates in an aqueous solution vs. substrate can sometimes differ (Du et al., 2006). Solution temperature and pH are important parameters that affect nutrient release rate (Zografou and Lykas, 2017), with release rate through water diffusion being positively correlated with increasing temperatures (Merhaut et al., 2006).

However, the predictable release pattern of CRF in aqueous solution indicates the potential to match nutrient availability to plant requirements over time if CRF is used as the nutrient delivery method in hydroponics. The U.S. National Aeronautics and Space Administration has explored the use of slow-release fertilizers and CRFs in a series of controlled environment agriculture (CEA) simulated space farming trials. Nutrient delivery systems in those trials often included a mix of solid porous ceramic arcillite substrate and CRF, designed to fit the VEGGIE (ORBITEC, Madison, WI) production unit (Massa et al., 2017; Monje et al., 2003). Stutte et al. (2011) successfully used the same production unit to grow three lettuce varieties in a wicking system (where the wick was placed in clear water) fertilized with a 15N–3.9P–10K CRF (Osmocote Plus 15–9–12; ICL Fertilizers, St. Louis, MO) that was incorporated into the arcillite substrate at 7.5 or 15 g of fertilizer per L of substrate.

Other researchers (Albaho et al., 2010; Kinoshita and Masuda, 2011; Schnitzler et al., 2004) have tested CRF in closed irrigation systems that combine aspects of substrate and hydroponic systems. Albaho

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et al. (2010) grew plants in a wicking system in which nutrients were supplied by either a CRF or a granular fertilizer incorporated in the substrate, and water was supplied in a closed reservoir. This system resulted in similar or increased yields of cherry tomato (*Lycopersicon esculentum*) and peppers (*Capsicum frutescens*) with CRF compared with granular fertilizer. Kinoshita and Masuda (2011, 2012) and Kinoshita et al. (2014) grew high-wire tomatoes in a range of growing systems in which CRF was either incorporated into the substrate or placed into the reservoir tank, and plant growth and nutrient uptake were compared with water-soluble fertilizer (WSF) in the reservoir. Equivalent yields of tomatoes were possible with CRF use, along with increased nutrient use efficiency, but issues were identified, including the need for nitrification to convert NH_4^+ to NO_3^-, management of Ca uptake, and appearance of blossom end rot symptoms. Schnitzler et al. (2004) demonstrated that tomato plants could be grown with a combination of slow-release fertilizer incorporated in the substrate plus WSF supplementation in the nutrient solution as a simplified low-technology approach compared with WSF alone. Therefore, past research indicates that CRF can deliver nutrients in both CEA and greenhouse production and have the potential to simplify nutrient delivery for urban growers.

The hypothesis was that it would be possible to grow hydroponic basil using a single application of CRF with growth performance comparable to a retail hydroponic water-soluble fertilizer that had weekly correction of pH and replacement of the nutrient solution. The objective was to use CRF to simplify nutrient management in small-scale hydroponic systems by providing adequate nutrition for basil. The approach taken was a) to quantify nutrient release of from a selection of coated (CRF) salts and commercial blends, b) to evaluate plant growth responses to commercial CRF blends developed for soilless substrates, and c) to evaluate plant growth responses to a customized blend of CRF and water-soluble fertilizers.

Materials and Methods

Expt. A: Nutrient release curves. Release curves for seven CRF products were quantified based on the weekly release of nutrients from each individual product in aqueous solution. The experimental design was a randomized complete block design with three blocks and each CRF as a treatment. Each of the 21 experimental units consisted of a 1.9-L bucket containing a silk bag with one of the seven CRF treatments, described in Table 1, and 1 L of deionized (DI) water [7.2 mg·L^{-1} $CaCO_3$, 8.8 mg·L^{-1} HCO_3^-, 0.06 µS·cm^{-1} EC, 1.4 mg·L^{-1} Na^+, 5.9 mg·L^{-1} Cl^-]. The weight of each CRF product added per liter of water is shown in Table 1. The nutrient release rate was not known before the experiment, but label descriptions were between 2 and 4 months of total release. We therefore assumed that up to half of the fertilizer would release after 4 weeks in the laboratory procedure, and products were standardized by either N, K, or Mg content targeting nutrient concentrations that would allow direct analytical measurement without dilution (roughly up to 200 mg·L^{-1} N and K and 60 mg·L^{-1} of Mg per week).

Solutions were measured weekly for pH and EC (dS·m^{-1}). Average solution temperature during the experiment was 22.4 ± 1.6 °C (Hobo UX100; Onset Computer Corporation, Bourne, MA). Each time measurements were taken, solution contents were discarded and buckets replenished with fresh DI water. Samples for days 1, 5, 8, 14, 43, and 77 were analyzed by Quality Analytical Laboratories (Panama City, FL) for complete macro- and micronutrients.

The same products were tested for total nutrient content. Three solid samples for each CRF were ground with 1 mL of hydrochloric acid 0.1 N using a mortar and pestle (Table 1). Milled fertilizer was added to 2 L of DI water to form nutrient solution samples and analyzed for macro- and micronutrient contents.

The percentage of cumulative release (P_{ijd}) was calculated for each nutrient element (i) in each fertilizer (j) in each sampled day (d) according to the equation:

$$P_{ijd} = \frac{\sum_1^d \left(Creleased_{ijd}\right)}{Csolid_{ij}} \times 100 \qquad [1]$$

where [$Creleased_{ijd}$] is the mg·g^{-1} of nutrient i from fertilizer j at day d, calculated from the total mg·L^{-1} of nutrient released by 1 g of fertilizer j in 1 L of solution. The parameter $Csolid_{ij}$ in mg·g^{-1} represents the nutrient analysis of nutrient i from 1 g of solid fertilizer j based on the laboratory analysis (Table 2). In cases in which final $Creleased_{ijd}$ exceeded $Csolid_{ij}$, $Creleased_{ij77}$ was used to determine P_{ijd}. Linear regression was used to relate solution-EC to concentration of each nutrient for each product based on complete data for days 1, 5, 8, 14, 43, and 77. On sample days when only EC was measured (because of analytical cost), $Creleased_{ijd}$ was calculated using linear regression. Equations adopted a linear approach to model the relation between EC measured and nutrient concentration using the datapoints where nutrient concentration information was available. From these modeled curves, nutrient content was estimated for days 21, 28, 35, 49, 56, 63, and 70 based on EC measurements. Analysis of variance (ANOVA) was run within individual measurement days on three replicated experimental units per fertilizer treatment, and 95% confidence intervals for least-square means were estimated using R 3.6.3 (R Core Team, 2020) and emmeans (Lenth, 2020).

Expt. B: Basil plant growth with two commercial CRF products. Growth of hydroponic basil (*Ocimum basilicum* cv. Genovese) in a growth chamber was compared for five fertilizer treatments, which included "CRF Bloom" (Osmocote Bloom, ICL Fertilizers, St. Louis, MO) and "CRF Plus" (Osmocote Plus, ICL Fertilizers, St. Louis, MO) at two concentrations, and WSF (10N–$5P_2O_5$–$14K_2O$ MaxiGRO; General Hydroponics, Sebastopol, CA). From Oct. 22 to Nov. 19, 2018, basil was cultivated hydroponically at Gainesville, FL (lat. 29°38′22″N, long. 82°21′33″W). Plants were germinated in Rockwool media and were transplanted after 31 d to hydroponic systems. The experimental design was a randomized complete block design with four blocks and five treatments. Each hydroponic system consisted of

Table 1. Controlled-release fertilizers tested for nutrient release curves in Expt. A.

Product name and label duration in months	Nutrient release curve samples (g·L^{-1})	Solid samples (g·L^{-1})	Treatment
Osmocote Bloom 2–3M	12.7	1.65	CRF Bloom
Osmocote Plus 3–4M	10.1	1.35	CRF Plus
E-Max Calcium Nitrate 2–3M	9.6	1	$Ca(NO_3)_2$
Agrocote MAP 3–4M	3.87	1	MAP
E-Max Keiserite 3–4M	3.4	1	$MgSO_4$
E-Max K-Mag 2–3M	8.5	1.55	K-Mag
Agrocote SOP 3–4M	4.2	1	K_2SO_4

Table 2. Total nutrient content obtained from solid samples ($Csolid_{ij}$) in Expt. A. Values express mg of nutrient obtained from 1 g of milled fertilizer measured by laboratory analysis. Values represent an average of three samples.

	NH_4^+-N	NO_3^- -N	total N	P	K	Ca	Mg	SO_4-S	Fe	Mn	B	Cu	Zn	Mo
CRF Bloom	74	53	127	25	178	9	8	89	0.62	0.33	0.15	0.27	0.22	0.18
CRF Plus	100	70	170	37	108	12	15	70	0.55	0.39	0.22	0.46	0.14	0.29
$Ca(NO_3)_2$	10	130	140	0	0	174	5	7	0.00	0.00	0.02	0.00	0.02	0.00
MAP	98	0	98	187	2	3	6	12	0.75	0.21	0.02	0.00	0.03	0.01
$MgSO_4$	1	0	1	0	3	8	126	168	0.00	0.00	0.00	0.00	0.00	0.00
K-Mag	1	0	1	0	135	10	82	165	0.00	0.01	0.03	0.00	0.02	0.00
K_2SO_4	7	7	14	2	377	7	6	159	0.03	0.02	0.00	0.00	0.01	0.00

one 4.9-L bucket containing 4 L of DI water plus one silk bag filled with one fertilizer treatment. Solution aeration was constantly provided on each experimental unit by one 1-inch air stone attached to an air pump (Whisper 60; Tetra, Blacksburg, VA). The WSF solutions were discarded and replenished every week with fresh nutrient solution on the same concentration as initial (measured level 204 $mg \cdot L^{-1}$ N). For WSF solutions, pH was adjusted to 6.0 using a commercial potassium hydroxide plus potassium carbonate base solution ("pH UP"; General Hydroponics, Sebastopol, CA). The CRF Bloom and CRF Plus treatments were each applied at two concentrations. Based on release curves from Expt. A, the 1X fertilizer amount for CRF Bloom and CRF Plus was calculated to release ≈200 mg N per 4-L container per week. For example, CRF Bloom (12N–3.1P–14.9K) released 28% of its N content on the initial 28 d in Expt. A. Therefore, we used 24 g of CRF Bloom product to assure a total of 806 mg released after 28 d, equivalent to ≈200 mg N per 4 L container per week and 50 $mg \cdot L^{-1}$ N per week. In contrast, CRF Plus (15N–3.9P–10K CRF) released 45% of N after 28 d and 12 g of CRF Plus was added per container to provide similar nutrient levels to CRF Bloom after 4 weeks. Iron ethylenediamine-*N*,*N′*-bis(2-hydroxyphenylacetic acid) (FeEDDHA) was added to provide the equivalent of 5 $mg \cdot L^{-1}$ Fe at the 1X rate of CRF Bloom and CRF Plus, because measured iron levels from Expt. A were close to zero for these products. The chosen Fe concentration was higher than in the WSF (2.8 $mg \cdot L^{-1}$ Fe) because FeEDDHA was only applied once and Fe concentration was therefore expected to decrease over time. Both CRF and FeEDDHA were doubled in the 2X rates of CRF Bloom and CRF Plus. Growth chamber average air temperature was 22.9 °C ± 0.6 [average of 10-min intervals obtained from Hobo UX100 (Onset Computer Corporation, Bourne, MA)] and average photosynthetic photon flux was 207.2 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (GreenPower; Philips Lighting, Somerset, NJ; 150-cm long) with a photoperiod of 16 h resulting in a daily light integral of 11.93 $mol \cdot m^{-2} \cdot d^{-1}$.

At the end of the experiment, root and shoot fresh weight were measured. Plants were then oven-dried at 60 °C for 72 h and dry weights measured. Final solution-pH and EC were measured using an Orion Versa Star Pro meter (Thermo Fisher Scientific, Beverly, MA). The Soil Plant Analysis Development (SPAD) leaf greenness index was measured in three leaves for each experimental unit using a chlorophyll index meter (SPAD-502; Konica Minolta Sensing Inc., Osaka, Japan). Macro- and micronutrient concentration in solution and plant tissue were determined by Quality Analytical Laboratories (Panama City, FL). Treatment effects were analyzed by ANOVA using R 3.6.3 (R Core Team, 2020) and agricolae package (de Mendiburu, 2020). Pairwise comparisons were made using least-square means and Tukey's honestly significant difference test.

Expt. C: Basil growth in a customized blend of CRF vs. water-soluble fertilizer. A fertilizer blend was developed based on the nutrient release curves from Expt. A. The blend of CRF products at 2X dosage was developed following these criteria:

1. Release ≈1.5 g N in total over a 6-week period, based on Solis-Toapanta et al. (2020) who found that four hydroponically grown Genovese basil plants in an indoor environment required 2 g N over an 8-week period.
2. Provide a ratio between macronutrients similar to those reported for a "reference" WSF solution [University of Arizona Controlled Environment Agriculture Center solution, described by Mattson and Peters (2014)], of (in $mg \cdot L^{-1}$) 11 NH_4-N, 178 NO_3-N, 189 N, 39 P, 341 K, 170 Ca, 48 Mg, and 134 S. As a ratio between nutrients based on N level, this was equivalent to 1.00 N:0.21 P:1.8 K:0.90 Ca:0.25 Mg:0.71 S.

Based on the nutrient release curves from Expt. A, we computed the total expected mg of macronutrient i in blend solution at day d. Four CRF products {E-Max Calcium Nitrate [$Ca(NO_3)_2$], Agrocote MAP (MAP), E-Max KMag (K-Mag), and Everris 0–0–46 (K_2SO_4)} (Table 3) contributed to the nutrients in solution. Expected nutrient content from each fertilizer on a specific day was calculated by multiplying the mass (g) of the fertilizer j used in the blend formulation by the $Creleased_{ijd}$ from the same product, obtained in Expt. A. Nutrient content values were summed to compute total nutrient content in CRF Blend solution.

In contrast with a WSF that is replaced every week, the nutrient solution using a single application of CRF would result from the cumulative release of CRF minus uptake by the growing plant over time. Therefore, when a plant is small and early in the crop cycle, the net release of nutrients would be positive, whereas later in the crop cycle plant uptake rate may exceed the nutrient release rate from the CRF.

Micronutrients in water-soluble form were added at the start of the experiment, because limited options of coated micronutrients were commercially available in terms of ratio and form of CRF products. Initial CRF Blend 1X solution included 2 $mg \cdot L^{-1}$ Fe from FeEDDHA, with other micronutrients from a micronutrient blend (Micro Blend; Greencare Fertilizers, Kankakee, IL) at 1 $mg \cdot L^{-1}$ Mn, 0.5 $mg \cdot L^{-1}$ B, 0.5 $mg \cdot L^{-1}$ Cu, 1.0 $mg \cdot L^{-1}$ Zn, 0.2 $mg \cdot L^{-1}$ Mo. From Expt. B, we observed that a Fe concentration of 5 $mg \cdot L^{-1}$ was above demand and had not decreased over time as expected. Therefore, Fe was reduced to 2 $mg \cdot L^{-1}$ for the CRF Blend 1X treatment. All micronutrients concentrations were doubled from CRF Blend 1X to CRF Blend 2X treatment.

The experimental design was a randomized complete block design containing four blocks and three treatments (WSF, CRF Blend 1X, and CRF Blend 2X), with two replicates of each treatment per block, totaling 24 deep-water systems. Hydroponic systems used were the same as described in Expt. B. The WSF treatment consisted of 7.6 g of MaxiGro (10N–2.18P–11.6K_2O) hydroponic fertilizer in 4 L DI water solution, providing an average 204 $mg \cdot L^{-1}$ N. Plants were grown in a growth chamber with 207.2 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (GreenPower 150-cm long fixtures; Philips Lighting) in a 16-h photoperiod during 6 weeks resulting in 11.93 $mol \cdot m^{-2} \cdot d^{-1}$. Average room temperature was 22.7 °C ± 0.32, and solution temperature was 22.4 °C ± 0.31. Blend experimental units were refilled with DI water as needed (water addition was recorded for each replicate). The WSF solutions were discarded and buckets were replenished with fresh nutrient solution once a week. At the end of the experiment, final amount of solution was recorded, and buckets volume was replenished to 4 L with DI water before pH and EC measurements were taken. Other measurements included water consumption over the 6 weeks, root and shoot fresh and dry weights as well as SPAD index. Statistical analysis were conducted similarly to Expt. B.

Results and Discussion

Expt. A: Nutrient release curves. Patterns of nutrient release over time varied between CRF products in aqueous solution (Fig. 1). Cumulative release curves for CRF Bloom, CRF Plus, $Ca(NO_3)_2$, MAP, and K_2SO_4 showed an initial rapid discharge followed by a linear nutrient release over time. The initial rapid release can be explained by the presence of incompletely coated prills that provide an initial charge of readily soluble nutrients to the solution as described by Shaviv (2005). After this initial phase, ions were released at a fairly constant diffusion rate for these five products until the end of experiment, resulting in between 45% and 73% of the macronutrient content after 11 weeks. Magnesium-containing fertilizers ($MgSO_4$ and K-Mag) showed a similar initial

Table 3. CRF Blend composition applied at the 1X concentrations on Expt. C.

Fertilizer	Formulation	CRF Blend at 1X concn (g per 4-L container)
Greencare Micro Blend	water-soluble	0.0475
FeEDDHA	water-soluble	0.133
E-Max Calcium Nitrate [$Ca(NO_3)_2$]	coated	9.25
Agrocote MAP [$(NH_4).(H_2PO_4)$]	coated	2.50
E-Max K-Mag [$K_2Mg_2(SO_4)_3$]	coated	1.50
Everris 0–0–46 [K_2SO_4]	coated	8.00

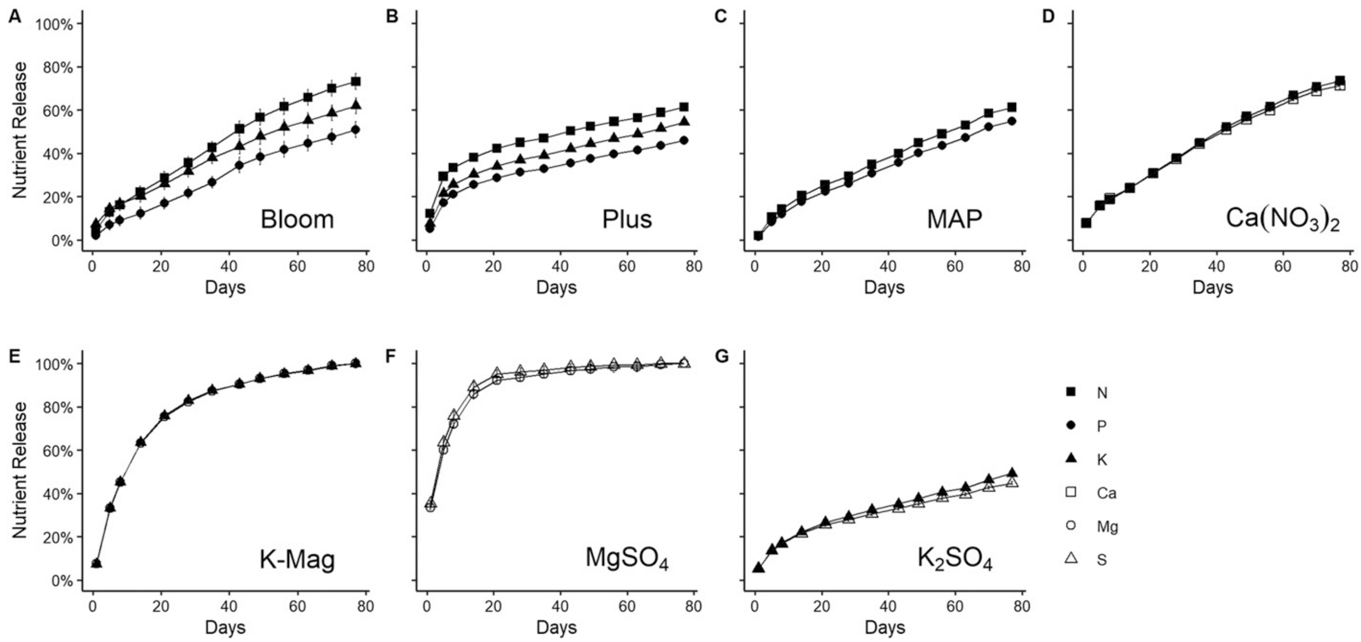

Fig. 1. Cumulative nutrient release curve on a percentage release basis (P_{ijd}) for seven different controlled-release fertilizers in aqueous solution without plants. Data points represent the cumulative average release of three samples, expressed as a percentage of the nutrient analysis per gram of solid fertilizer from Table 2. Fertilizers were placed in deionized water and solution was changed weekly and nutritional content analyzed for days 1, 5, 8, 14, 43, and 77. For additional data points, nutrient content was estimated based on linear regression of nutrient content and electrical conductivity. Analysis of variance was run within individual measurement days on three replicated experimental units per fertilizer treatment. On figures PLUS, MAP, $Ca(NO_3)_2$, K-Mag, $MgSO_4$, and K_2SO_4, 95% confidence intervals around least-square mean estimates equaled ±2.6% and therefore are not visible on graphs.

rapid nutrient phase followed by a diminishing return pattern over time. The $MgSO_4$ product achieved 95% release after 21 d, although label information indicated full release over 3 to 4 months (Table 1). Different patterns of CRF release result from diverse polymer coating types and thickness, as well as different ion diffusion rates for individual salts as discussed by Oertli (1980) and Trenkel (2010). Correlations between macronutrient concentration in solution and the solution-EC had an average coefficient of determination (R^2) of 0.70 across all 42 interactions analyzed (6 macronutrients × 7 fertilizers).

The release rate of individual macronutrients differed within blended products (Fig. 1). On coated individual salts [MAP, $Ca(NO_3)_2$, K_2SO_4, $MgSO_4$ and K-Mag], both the cations and the anions in each product were released at similar rate, as expected. In CRF Bloom, the initial faster release rate was faster for K than N and P, whereas in CRF Plus a very similar release pattern among these three macronutrients was observed. Differences observed can be explained by prill distribution and coating of CRF products, whereby all nutrients in CRF Plus are contained in every prill whereas CRF Bloom contained two different types of mini-prills, one composed of resin-coated NPK + micronutrients and the other being resin-coated K (ICL Fertilizers, St. Louis, MO). After the initial release phase, macronutrients on both the NPK products (CRF Bloom and CRF Plus) had a different release rate between ions, with P released at a slower rate than N and K. Other researchers (Broschat and Moore, 2007; Huett and Gogel, 2000) also found slower release of P relative to N and K in mixed CRF products modeled using sand columns. This release behavior was attributed to phosphates having a lower solubility in comparison with the other fertilizer ions, especially NO_3^- and NH_4^+ (Du et al., 2006).

The cumulative release of CRF tested after 43 d (Table 4) demonstrated a very different ratio between macronutrients compared with the reference hydroponic solution. Although the reference recipe presents a 6% NH_4^+ / total-N ratio, CRF Bloom and CRF Plus had 55% and 56% NH_4^+ / total N ratio, respectively. This high NH_4^+ ratio could lead to solution acidification and interfere with availability of other cations. The CRF Bloom had an N:P:K ratio (1.0 N:0.1 P:1.18 K) closer to reference (1.0 N:0.2 P:1.8 K), whereas CRF Plus had a much lower K proportion, with 1.0 N:0.15 P:0.54 K ratio. Total nutrient content in commercial mixed CRF (CRF Bloom and CRF Plus) exhibited very low amounts of Ca and Mg (Table 2). The reference solution contains almost equal parts of Ca and N, whereas CRF Bloom and CRF Plus had 1/16 to 1/22 less Ca compared with N. Given the fact that nutrient solutions are often based on N targets, this would cause CRF-based nutrient solutions to be very low in Ca. The relationship between Ca and Mg was also much higher in the reference than in NPK products, with equal parts of both nutrients in CRF Bloom, and 0.6 Ca: 1.0 Mg in CRF Plus compared with 3.5 Ca: 1.0 Mg in the reference.

The micronutrient content on CRF prills varied between products. From label information, CRF Bloom and CRF Plus were the only tested CRF products containing micronutrients. Iron form was iron-EDTA in CRF Bloom and a blend of iron phosphate and iron-EDTA in CRF Plus, with other micronutrients in a mineral form. The MAP contained a similar Fe content to the blended products, which would presumably be in an inorganic mineral form, and showed Mn content in the acid digestion of solid samples (Table 2). Despite the label information for CRF Bloom not listing copper or zinc content, solid samples contained 0.03% Cu and 0.02% Zn. Both CRF Bloom and CRF Plus had a lower content of Mn and Fe in the solid samples than expected from fertilizer label data, and therefore a lower ratio of Fe compared with other micronutrients. During the nutrient release experiment, solution-pH varied between 5.3 and 7.0, which would be expected to reduce solubility of inorganic Fe, although no sediment formation was observed on containers. Broschat and Moore (2007) described a low release of Fe and Mn when analyzing CRF products and reported that only 10% of the Mn and 13% of Fe stated in Osmocote product label information were released after 40 weeks.

The ratio between micronutrients in the solid CRF samples (Table 2) did not match the micronutrient ratio in the reference hydroponic solution. The reference hydroponic solution had a micronutrient ratio based on Fe level equivalent to 1.00 Fe:0.28 Mn:0.14 B:0.03 Cu:0.17 Zn:0.03 Mo. From solid samples of CRF (Table 2), micronutrient ratios were 1.0 Fe:0.53 Mn:0.24 B:0.44 Cu:0.35 Zn:Mo 0.29 for CRF Bloom and 1.0 Fe:0.71 Mn:0.40 B:0.84 Cu:0.25 Zn:Mo

0.53 for CRF Plus. Because micronutrients calculations are often based on Fe content, CRF Bloom and CRF Plus are likely to release high levels of Cu and Mo, given the high percentage of these nutrients encountered in prills. We found low correlations between micronutrient concentration in solution and the solution-EC in Expt. A (data not shown), with an average coefficient of determination (R^2) of 0.27 across all 42 interactions analyzed. The measured concentration of micronutrients in solutions is further complicated by the combination of low total ion release from prills and the solubility in solution. Overall, micronutrient release in CRF may be hard to predict in solution, and CRF products designed for container or soil production are unlikely to release micronutrient ratios similar to those typically used in hydroponics and therefore are not a reliable source of micronutrients for hydroponic solutions.

Expt. B: Basil plant growth with two commercial CRF products. Solution-pH dropped during the first 14 d for all CRF treatments and was fairly stable in the last 2 weeks (Fig. 2B). The pH initially measured (24 h) on CRF Blend treatments was between 6.3 and 6.6. After 2 weeks, pH values ranged from 3.6 to 4.0, and final pH values for those treatments was close to 3.6, indicating an unfavorable pH range for plant growth. This acidification in CRF treatments most likely resulted from the high percentage of ammoniacal nitrogen in fertilizers (53% in CRF Plus and 56% in CRF Bloom according to label information). Low alkalinity of DI water (7.2 mg·L^{-1} $CaCO_3$) resulted in very low buffer capacity of solution. When fresh WSF solution was prepared, the mix of WSF and DI water instantly generated a pH 4.2 solution (DI water pH was 4.8). Therefore, addition of a base ("pH UP," General Hydroponics, Sebastopol, CA) was needed to return solution-pH to 6.0 each week when fresh WSF solution was prepared. After pH was adjusted to 6.0, WSF solutions dropped in pH over the following 7 d before solution replacement occurred. For example, between days 7 and 14 the pH dropped from 6.0 to 4.3, before solution replenishment (not represented in Fig. 2B) and subsequent pH base adjustment.

Table 4. Cumulative release values ($Creleased_{ij\ 43}$) for the seven fertilizers in Expt. A at day 43 (week 6). Values express mg of nutrient released into solution per gram of fertilizer (average of three samples).

Fertilizer	NH_4-N	NO_3-N	Total N	P	K	Ca	Mg	SO_4-S
CRF Bloom	36	30	65	9	77	4	4	37
CRF Plus	124	98	222	34	120	10	16	78
$Ca(NO_3)_2$	5	68	73	0	0	92	3	5
MAP	36	0	37	61	2	18	14	25
$MgSO_4$	0	0	0	2	1	13	139	180
K-Mag	0	0	0	0	150	6	94	184
K_2SO_4	0	0	0	0	133	8	7	63

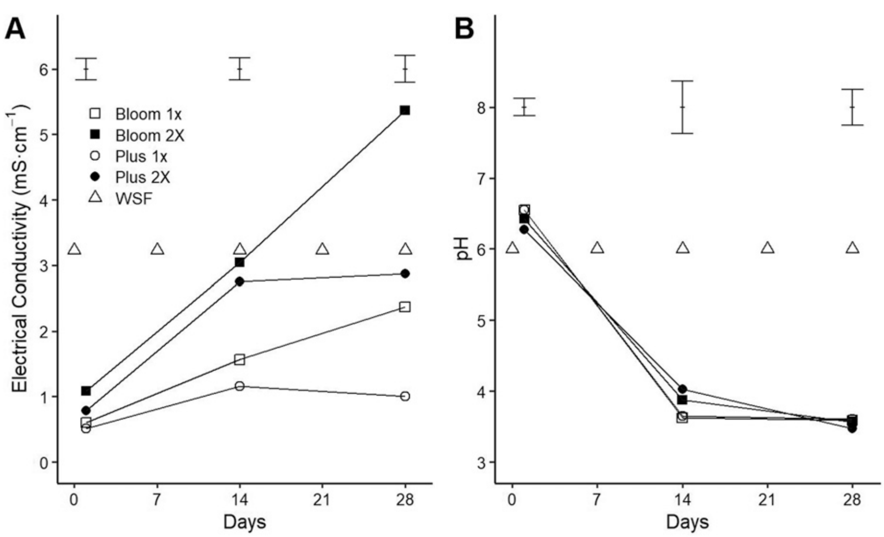

Fig. 2. Nutrient solution electrical conductivity (**A**) and pH (**B**) for nutrient solutions in Expt. B measured after 1, 14, and 28 d. Water-soluble fertilizer (WSF) solution was replaced every week with fresh solution containing 190 mg·L^{-1} N in deionized water. The pH level for WSF shown in this figure represents the initial pH 6.0 for fresh solution after adjusting pH each week with a blended potassium hydroxide plus potassium carbonate base. The pH was not corrected in the controlled-release fertilizer treatments. Analysis of variance was run within individual measurement days on four replicated experimental units per fertilizer treatment. Error bars represent the 95% confidence intervals around estimated least-square means.

The EC increased in all CRF treatments over time (Fig. 2A), indicating that fertilizers released nutrients faster than the ions were taken up by plants. In nutrient solutions containing CRF Bloom, EC levels increased over time. In CRF Plus solutions, nutrient release from prills appeared similar to plant uptake after day 14, based on a fairly constant EC between weeks 2 and 4. All CRF treatments except CRF Bloom 2X had EC values lower than the EC of the WSF treatment (3.2 dS·m^{-1} when solution was replaced each week).

All plants grown with CRF treatments showed reduced leaf expansion and darker green coloration when compared with those grown in the WSF, which appeared healthy (Fig. 3). Multiple disorders were observed in the plants grown with CRF treatments, with visual symptoms including tip burn and leaf distortion. These nutritional disorders led to lower basil fresh and dry weights for plants under CRF treatments compared with those grown with WSF (Table 5). The CRF-grown plants showed higher SPAD index than plants grown with WSF (Table 5) and exhibited dark green leaf coloration (Fig. 3). Greater water consumption was observed for plants grown with WSF compared with CRF treatments (Table 5), which was probably a result of the greater leaf area observed for basil grown under WSF treatment.

Symptoms observed in CRF-grown plants were consistent with copper toxicity and calcium deficiency described by Sonneveld and Voogt (2009). Despite the low Mg

Table 5. Growth parameters of basil cultivated in growth chamber for 4 weeks with nutrient solution from water-soluble fertilizer (WSF) or commercial controlled-release fertilizer (CRF) blends in Expt. B.

	Fresh wt (g/four plants)			Dry wt (g/four plants)				
Treatment	Shoot	Root	Total	Shoot	Root	Total	SPAD index	Water consumption (mL·g^{-1} fresh wt)
WSF	250 a	129 a	379 a	18 a	7.7 a	26 a	36 b	10 a
CRF Bloom 1X	89 b	48 b	137 b	8.5 b	4.7 b	13 b	48 a	23 b
CRF Bloom 2X	113 b	62 b	175 b	10 b	5.5 b	16 b	44 a	18 b
CRF Plus 1X	96 b	48 b	144 b	9.2 b	4.5 b	14 b	45 a	23 b
CRF Plus 2X	93 b	54 b	146 b	8.1 b	4.6 b	13 b	48 a	10 b
ANOVA	***	***	***	***	***	***	***	**

**$P < 0.01$, ***$P < 0.001$. Pairwise comparison between the treatments used Tukey's honestly significant difference test at the 5% level.

concentration encountered in tissue samples (Table 6) and in the residual nutrient solution (Table 7), no visual symptom of Mg deficiency was observed. The apparent Ca deficiency was confirmed by the low Ca content in both the tissue (Table 6) and the residual nutrient solution analyses (Table 7). Multiple factors contributed to this result, including the low Ca content in CRF products tested and unbalanced ratios between nutrients observed in Expt. A. Kinoshita and Masuda (2012) grew tomatoes in a wicking system with CRF placed in the irrigation reservoir, and also observed Ca deficiency symptoms. In both our study and the Kinoshita and Masuda (2012) experiment, CRF products had a high ammonium content, which is likely to suppress Ca absorption and favor NH_4^+ uptake due to differential cation uptake by plant. Similar causes led to a small Mg percentage observed in plant tissue analysis (Table 6). Levels of N, P, and K were adequate to high for plants grown in all treatments (Table 6).

The combination of high levels of Fe, Cu, and Zn in solution (Table 7) and the low solution-pH (Fig. 2A) increased the risk of micronutrient toxicities from CRF treatments, especially in 2X dosages. The high Fe verified in tissue sample analysis (Table 6) indicate that the amount of FeEDDHA we added to the CRF treatments was overestimated and could be reduced in future experiments. High levels of Fe, Cu, Zn, and Mo were observed in plant tissue (Table 6). Leaves showed multiple nutritional disorder symptoms, including chlorosis on new leaves and long narrow-shaped leaves, which were likely related to micronutrients toxicities. Abnormal lateral root formation was observed and was interpreted as a symptom of copper toxicity, particularly evident in plants grown under CRF Bloom 1X and 2X treatments.

Expt. C: Basil growth in a customized blend of CRF vs. water-soluble salts. Based on the nutrient release curves in Expt. A, it was possible to formulate a customized blend of CRF products that would be expected to result in similar ratios to the "reference" solution (Table 8). Given the Ca deficiency symptoms observed in Expt. B, we aimed to assure adequate supply of Ca in the CRF Blend using $Ca(NO_3)_2$, which also provided NO_3-N to avoid excess acidification. Similarly, Kinoshita et al. (2016) also based their CRF formulation with $Ca(NO_3)_2$ products while developing a CRF-based nutrient management strategy for tomato production in closed hydroponic systems. A practical concern with scaling up this approach is the limited commercial availability of coated $Ca(NO_3)_2$. Other than the high Ca [from $Ca(NO_3)_2$] and S (from K_2SO_4), macronutrient ratios in CRF Blend were similar to those observed in WSF fertilizer and reference solutions (Table 8). Expts. A and B results indicated that a very low content of micronutrients should be expected from individual minerals used to formulate CRF Blend and FeEDDHA and water-soluble micronutrients were therefore included in the formulation at a single initial dose (Table 3) with the expectation that these ions would be taken up over the 6-week experiment duration.

All three treatments resulted in healthy plants, with standard leaf expansion and coloration, and CRF-grown plants had similar growth to those under the WSF treatment (Fig. 4). All three fertilizer treatments resulted in plants with equivalent fresh weight (Table 9). However, the CRF Blend 2X and WSF resulted in plants with similar dry weights, whereas CRF Blend 1X had slightly less shoot and total dry mass. The SPAD values did not differ among the three treatments and water consumption was 18% higher for plants grown with WSF than with CRF Blend 2X. Kinoshita et al. (2014, 2016) grew tomato in a closed CRF-fertilized hydroponic system and a WSF-fertilized EC-based open drip system. The similar yield observed by Kinoshita et al. (2014, 2016) in the two systems provides more evidence that

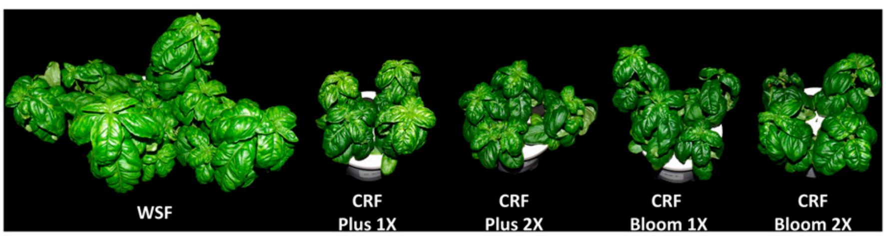

Fig. 3. Visual comparison between plants grown in the growth chamber under water-soluble fertilizer (WSF) and commercial controlled-release fertilizers (CRF) CRF Bloom and CRF Plus solutions on day 28 of Expt. B.

Table 6. Nutritional tissue analysis from basil cultivated in growth chamber for 4 weeks with nutrient solution made from water-soluble fertilizer (WSF) or commercial controlled-release fertilizer (CRF) blends in Expt. B. Pairwise comparison between the treatments used Tukey's honestly significant difference test at the 5% level.

	N	P	K	Ca	Mg	S	Fe	Mn	B	Cu	Zn	Mo
Treatment	(%)						(mg·kg⁻¹)					
WSF	5.2 ab	1.3 a	6.4 a	1.3 a	0.5 a	0.5 b	325 c	331 a	31 b	15 c	68 c	8 d
CRF Bloom 1X	5.0 b	0.7 b	4.3 bc	0.3 b	0.2 c	0.6 ab	1581 ab	123 b	31 b	177 ab	145 bc	38 c
CRF Bloom 2X	5.8 a	1.2 a	6.0 a	0.3 b	0.2 bc	0.8 a	1467 b	165 b	44 a	247 a	278 b	64 ab
CRF Plus 1X	5.3 ab	0.8 b	3.3 c	0.4 b	0.3 bc	0.6 ab	1583 ab	110 b	34 b	167 b	214 b	45 bc
CRF Plus 2X	5.8 a	1.4 a	5.2 ab	0.3 b	0.3 b	0.8 a	2059 a	167 b	44 a	184 ab	453 a	76 a
Survey range[z]	4–6	0.62–1.0	1.55–2.05	1.25–2.00	0.6–1.0	0.2–0.6	75–200	30–150	25–60	5–10	30–70	0.1–0.5
ANOVA[y]	**	***	***	***	***	**	***	**	**	***	***	***

[z]Survey ranges from field and garden-grown basil plants in Bryson and Mills (2014).

[y]Analysis of variance statistical test do not include survey ranges.

$^{**}P < 0.01$, $^{***}P < 0.001$. Pairwise comparison between the treatments used Tukey's honestly significant difference test at the 5% level.

Table 7. Residual nutrient solution concentrations after basil was cultivated in growth chamber for 4 weeks with nutrient solution made from water-soluble fertilizer (WSF) or commercial controlled-release fertilizer (CRF) in Expt. B. Results for WSF represent depletion of solution over 7 d (week 3 to week 4).

	NH_4^+-N	NO_3^- -N	total N	P	K	Ca	Mg	SO_4-S	Fe	Mn	B	Cu	Zn	Mo
Treatment	(mg·L⁻¹)													
WSF	3 e	164 b	167 c	29 a	296 b	147 a	78 a	112 c	4.5 c	0.09 c	0.44 b	0. 3 d	1.0 b	0.14 a
CRF Bloom 1X	104 c	70 d	173 c	11 bc	220 c	27 b	18 c	164 b	6.6 c	0.79 b	0.32 c	2.8 c	1.2 b	0.05 b
CRF Bloom 2X	304 a	223 a	527 a	28 a	545 a	36 b	28 b	331 a	12.1 a	1.33 a	0.78 a	6.1 a	2.3 a	0.12 a
CRF Plus 1X	46 d	24 e	70 d	4.0 c	6.6 e	26 b	21 c	82 d	5.8 c	0.58 b	0.15 d	2.2 c	0.9 b	0.04 b
CRF Plus 2X	166 b	117 c	283 b	26 ab	129 d	30 b	33 b	163 b	9.5 b	0.83 b	0.40 bc	4.8 b	2.2 a	0.11 a
ANOVA	***	***	***	***	***	***	***	***	***	***	***	***	***	***

$^{***}P < 0.001$. Pairwise comparison between the treatments used Tukey's honestly significant difference test at the 5% level.

Table 8. Comparison of several nutrient solutions without plants, including a commercial water-soluble fertilizer [WSF (MaxiGro)], "reference" water-soluble solution from Mattson and Peters (2014), and custom controlled-release fertilizer (CRF) Blend tested in Expt. C after 6 weeks. Custom CRF Blend values are based on the individual release curves for the formulation in Table 3. Micronutrient concentrations for Custom CRF Blends 1X are the initial water-soluble concentration. The fertilizer concentration represents the grams of product added per liter of solution.

Treatment	Fertilizer ($g \cdot L^{-1}$)	NH_4^+-N	NO_3^--N	total-N	P	K	Ca	Mg	SO_4-S	Fe	Mn	B	Cu	Zn	Mo
		($mg \cdot L^{-1}$)													
WSF (MaxiGro)	7.6	22	181	204	48	303	115	54	74	2.78	0.70	0.32	0.20	0.36	0.04
Mattson and Peters (2014) "reference"	1.9	11	178	189	39	341	170	48	134	2.00	0.55	0.28	0.05	0.33	0.05
Custom CRF Blend 1X (day 43)	5.4	35	157	192	39	324	243	65	221	2.0	1.0	0.5	0.5	1.0	0.2

Table 9. Growth parameters for basil cultivated in a growth chamber for 6 weeks with nutrient solution made from water-soluble fertilizer (WSF) or customized controlled-release fertilizer (CRF) blend in Expt. C. Pairwise comparison between the treatments used Tukey's honestly significant difference test at the 5% level.

Treatment	Fresh wt (g/four plants)			Dry wt (g/four plants)			SPAD index	Water consumption ($mL \cdot g^{-1}$ fresh wt)
	Shoot	Root	Total	Shoot	Root	Total		
WSF	241	167	409	16.7 a	10.4	27.1 ab	35.9	13.8 a
CRF Blend 1X	199	199	398	13.1 b	11.1	24.2 b	38.1	10.8 b
CRF Blend 2X	244	185	429	18.5 a	11.3	29.8 a	35.8	11.1 b
ANOVA	NS	NS	NS	***	NS	**	NS	**

NS = nonsignificant, ** $P < 0.01$, *** $P < 0.001$. Pairwise comparison between the treatments used Tukey's honestly significant difference test at the 5% level.

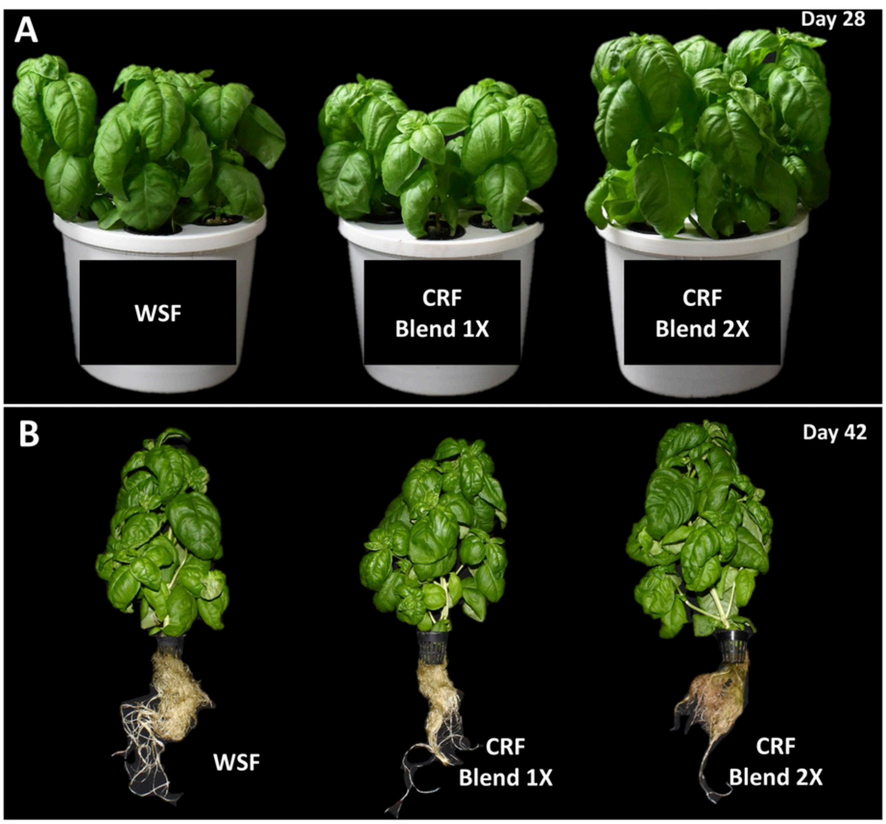

Fig. 4. Visual comparison of basil grown under water-soluble fertilizer (WSF) and controlled-release fertilizers (CRF) CRF Blend 1X and CRF Blend 2X fertilizer treatments on days 28 (**A**) or 42 (**B**) of Expt. C.

CRF use in hydroponics could be expanded to other horticultural crops.

Changes in solution-pH over time were observed for the CRF treatments in Expt. C (Fig. 5B). With the CRF 1X treatment, solution-pH dropped during the initial 3 weeks and then slowly rose to 5.9 at the harvest time (Fig. 5B). In the CRF 2X treatment, solution-pH decreased to pH 4 over the initial 4 weeks and then stabilized. In the WSF treatment, pH was adjusted to 6.0 at the start of each week in WSF solutions, similar to Expt. B. The use of DI water in this trial reduced pH buffering capacity due to the absence of alkalinity in water source. Accordingly, pH trends over time would be expected to differ with a higher-alkalinity water quality source, and less pH drop would be expected. The observed range in pH for CRF treatments from 3.8 to 6.4 values are close to the 4 to 7 pH range proposed by Bugbee (2004). Our observation of normal plant growth even when solution-pH was low is in accordance with Gillespie et al. (2020), who found that hydroponic basil exhibited similar growth at pH between 4.0 and 5.5.

The EC values measured resulted from the balance between CRF nutrient release and plant nutrient uptake. On CRF Blend 2X solutions, EC increased over the initial 4 weeks and peaked at week 5, after which started to decrease (Fig. 5A). For CRF Blend 1X solutions, EC increased on the initial 3 weeks, reaching a maximum of 1.4 $dS \cdot m^{-1}$, after that it started decreasing again until harvest, where it achieved 0.9 $dS \cdot m^{-1}$. This behavior indicates that plant nutrient uptake exceeded nutrient release after day 21 for CRF Blend 1X and after day 35 for CRF Blend 2X. The EC range over the entire production cycle was between 0.9 and 3.4 $dS \cdot m^{-1}$ for CRF treatments and 1.6 to 3.2 $dS \cdot m^{-1}$ for WSF. No salinity damage was observed in roots, and Walters and Currey (2018) found similar growth rates and healthy growth with nutrient solution-EC levels between 0.5 and 4 $dS \cdot m^{-1}$ for hydroponically grown basil.

Overall, the CRF Blend 2X dosage provided a closer match to plant nutritional demand over 6 weeks than CRF Blend 1X. Residual solution analysis (Table 10) indicates almost complete depletion of N, P, and K in the CRF Blend 1X treatment. That result indicates that CRF Blend 1X dosage would release sufficient nutrients in solution to grow basil only on the initial 5 to 6 weeks, when plants are smaller and nutrient demand is lower, demanding a new fertilizer addition if the crop cycle was continued.

With CRF Blend 2X, the residual nutrient concentration in solution at the end of week 6 was lower than the residual concentration from the WSF remaining at week 6 (after 1 week since nutrient replacement). However, based on the nutrient release curves from Expt. A, the CRF Blend main components

[Ca(NO$_3$)$_2$, K$_2$SO$_4$ and MAP] would continue to release nutrients after week 6. The analysis of the nutrient solution, with lower concentrations of nutrients from CRF Blend 2X than in WSF should be interpreted with the appreciation that roughly half of CRF nutrient would still be inside the fertilizer prill at week 6 (based on Fig. 1), and therefore were not detected in solution analysis. In addition, Bugbee (2004) pointed out that low ion concentration in solution does not necessarily imply a deficiency in the plant, rather it can indicate a healthy plant with rapid nutrient uptake. The only macronutrient that would be depleted after 6 weeks in CRF Blend 2X would be expected to be Mg, because the CRF source (KMag) used released 90% of its Mg content by day 42 (Expt. A, Fig. 1).

Tissue analysis revealed low macronutrient content in plants grown under CRF Blend 1X and high micronutrient content in those under CRF Blend 2X. Basil grown on CRF Blend 2X solutions showed adequate levels of macronutrients when compared with survey range (Bryson and Mills, 2014) (Table 11). On plants grown under CRF Blend 1X, the aforementioned depletion of N, P, and K caused lower levels of these nutrients in tissue when compared with other treatments, and N levels lower than the ones observed in survey range (Table 11). The lower N concentration probably limited growth in CRF Blend 1X plants as evidenced by the smaller dry shoot weight found in plants under this treatment (Table 9). High micronutrient levels were found in tissue analysis of plants grown under CRF Blend 2X, which indicates an excess of nutrient supply, although no toxicity symptoms were observed. For future experiments, macronutrient doses should be kept close to those used in CRF Blend 2X, but micronutrient dosage could be significantly reduced to avoid luxury consumption and possible toxicity.

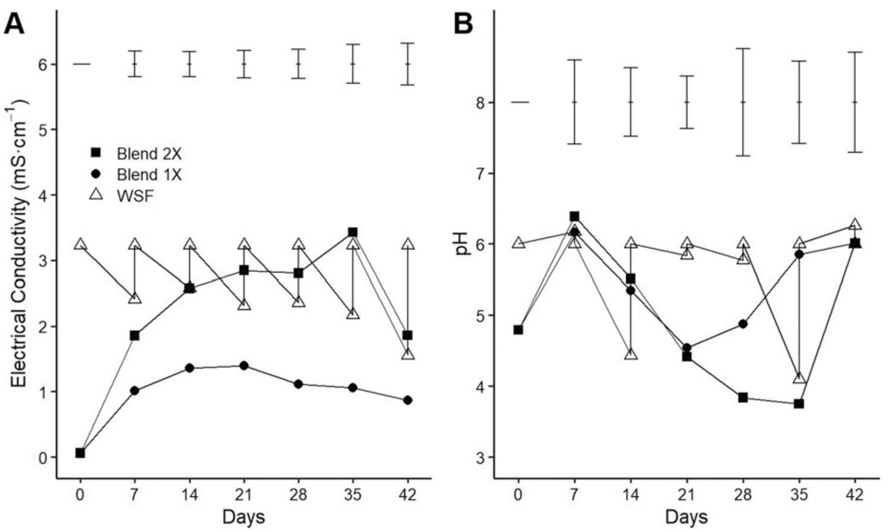

Fig. 5. Nutrient solution electrical conductivity (**A**) and pH (**B**) for nutrient solutions measured after 7, 14, 21, 28, 35, and 42 d of Expt. C. The water-soluble fertilizer (WSF) solution was replaced every week with fresh solution containing 190 mg·L^{-1} N in deionized water. A blended potassium hydroxide plus potassium carbonate base was used to adjust pH up to 6.0 every time the WSF solution was replenished, but pH was not corrected in the controlled-release fertilizer treatments. Analysis of variance was run within individual measurement days on eight replicated experimental units per fertilizer treatment. Error bars represent the 95% confidence intervals around estimated least-square means.

Conclusions

This study showed proof-of-concept for using CRF blends for small-scale hydroponic production of basil. Off-the-shelf CRF products (CRF Bloom and CRF Plus) were not suitable for a hydroponic system because their nutrient release rate was faster than plant uptake, and nutrient ratios were inadequate for plant growth in solution culture. In both products, micronutrients were unbalanced leading to nutritional disorders, and low calcium levels resulted in tip burn and leaf distortion. It was possible to blend CRF salts to provide macronutrients for hydroponics but limited commercial availability of CRF micronutrients required the use of water-soluble micronutrients at an initial high concentration. All CRF treatments lowered pH of solutions in plant growth Expts. B and C, presumably as a result of ammonium

Table 10. Residual nutrient solution after basil was cultivated in growth chamber for 6 weeks with nutrient solution made from water-soluble fertilizer (WSF) or customized controlled-release fertilizer (CRF) blend in two different doses in Expt. C. Results for WSF represent depletion of solution over 7 d (week 5 to week 6).

	NH_4^+-N	NO_3^- -N	total-N	P	K	Ca	Mg	S	Fe	Mn	B	Cu	Zn	Mo
Treatment							(mg·L^{-1})							
WSF	2.1 a	106 a	108 a	19 a	141 a	88 b	41 a	59 c	2.03 a	0.22 b	0.23 b	0.15 b	0.26 a	0.06 a
CRF Blend 1X	1.3 a	3.1 c	4.4 c	1.5 b	8.2 c	99 b	24 b	111 b	0.40 c	0.08 b	0.24 b	0.13 b	0.07 b	0.03 b
CRF Blend 2X	3.5 a	48 b	52 b	16 a	57 b	206 a	50 a	202 a	0.71 b	0.70 a	0.51 a	0.41 a	0.39 a	0.08 a
ANOVA	NS	***	***	***	***	***	***	***	***	***	***	***	***	***

NS = nonsignificant, ***$P < 0.001$. Pairwise comparison between the treatments used Tukey's honestly significant difference test at the 5% level.

Table 11. Tissue analysis from basil cultivated in growth chamber for 6 weeks with nutrient solution made from water-soluble fertilizer (WSF) or customized controlled-release fertilizer (CRF) blend in two different doses. Pairwise comparison between the treatments used Tukey's honestly significant difference test at the 5% level.

	N	P	K	Ca	Mg	S	Fe	Mn	B	Cu	Zn	Mo
Treatment	(%)						(mg·kg^{-1})					
WSF	5.1 a	1.2 a	6.0 a	1.0 ab	0.5	0.5 b	305 b	320 a	28 b	16 b	52 b	12 c
CRF Blend 1X	3.4 b	0.6 c	3.7 b	0.9 b	0.5	1.0 a	394 b	132 b	29 b	69 a	146 a	40 b
CRF Blend 2X	4.7 a	0.9 b	5.1 a	1.2 a	0.5	1.0 a	725 a	247 a	42 a	78 a	147 a	75 a
Survey range[z]	4–6	0.62–1.0	1.55–2.05	1.25–2.00	0.6–1.0	0.2–0.6	75–200	30–150	25–60	5–10	30–70	0.1–0.5
ANOVA[y]	***	***	***	*	NS	**	**	***	***	***	***	***

[z]Survey ranges from field and garden-grown basil plants in Bryson and Mills (2014).

[y]Analysis of variance statistical test do not include survey ranges.

NS = nonsignificant, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

in fertilizers. Future research should address micronutrient management, plant species type, crop duration, and water-quality impact on CRF-based hydroponic solutions to validate CRF use as a reliable and simple fertilization strategy in small-scale hydroponics.

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