Initial Substrate Moisture Content Affects Chemical Properties of Bagged Substrates Containing Controlled Release Fertilizer at Two Different Temperatures

Ka Yeon Jeong¹

Department of Horticulture and Crop Science, The Ohio State University, 2021 Coffey Road, Columbus, OH 43210

James E. Altland^{2,3}

USDA-ARS, Application Technology Research Unit, Ohio Agricultural Research and Development Center, 1680 Madison Avenue, Wooster, OH 44691

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Abstract. Bagged potting mixes can be stored for weeks or months before being used by consumers. Some bagged potting mixes are amended with controlled release fertilizers (CRFs). The objective of this research was to determine how initial substrate moisture content and storage temperature affect the chemical properties of bagged potting mix with CRF incorporated and stored for up to 180 days. The base substrate composed of 60 sphagnum peat: 30 bark : 10 perlite (by vol.) amended with 5.5 g·L⁻¹ dolomitic limestone and 0.5 g·L⁻¹ granular wetting agent. This base substrate was either not amended with additional fertilizer (control) or amended with 0.59 kg·m⁻³ N of a CRF (Osmocote 18N–1.3P–5K) that was either ground (CRF-G) or whole prills (CRF-P). Substrates had initial moisture contents (IMCs) of 25%, 45%, or 65% and were stored at temperatures of either 20 or 40 °C. IMC and fertilizer type affected pH, electrical conductivity (EC), and nutrient release. Substrate pH increased with increasing IMC due to greater lime reactivity. About 25% of N from CRF-G treatments was immobilized between 2 and 14 days of storage. Low moisture content of bags, due to low IMC or storage at 40 °C, reduced the rate of N release from CRF-P treatments. Substrate P was rapidly immobilized by microbial communities.

Consumer potting mixes are designed for container gardening, hanging baskets, indoor plants, and raised beds. They are often purchased at mass merchants or garden centers in plastic bags to facilitate transportation and storage by consumers. The primary component of these potting mixes is sphagnum peatmoss. The United States used over 14 million cubic meters of peat for horticultural applications in 2014, while worldwide usage was 100 million cubic meters (Apodaca, 2016). Specific uses of imported peat within the horticulture industry are not known. However, Slivka et al. (1992) estimate 4.5–6.0 million cubic meters of bagged potting soil are purchased by homeowners and landscapers annually.

Some bagged potting mixes include one or more types of fertilizer to provide plant nutrients. There can be a significant delay,

weeks or months, from the time the potting mixes are bagged and stored until they are purchased and used by consumers. As such, nutrient release from the fertilizers and changes in the chemical properties of bagged potting mixes in storage have been studied. Carlile (2004) warned that in potting mixes containing CRFs, the slow release of the nutrients over time can lead to serious problems stemming from high nutrient levels and soluble salts at the time of use. It has been suggested by both manufacturers (Hulme, 2011) and researchers (Carlile, 2004; Zaccheo et al., 2013) that media with CRF be used immediately after mixing (within 30 d) to avoid problems with soluble salts.

Temperature and moisture content are the primary factors affecting CRF release and microbial activities, such as nitrification and nitrogen (N)-immobilization, in bagged potting mixes during storage (Cabrera, 1997; Husby et al., 2003). Zaccheo et al. (2013) measured the chemical properties of two peat-based substrates amended with CRF (product not specified) and stored over a 12-month period at either 21 °C (which the authors considered proper) or stored for 15 d

at 40 °C and the remainder of the time at 21 °C (considered improper). Elevated temperatures for just 15 d resulted in greater dissolution of lime in the substrate and greater release of ammonium (NH₄⁺) through the first 120 d compared with the substrates stored at constant 21 °C. Selmer-Olsen and Gislerod (1986) evaluated the change in N form in a peat substrate stored at 4 to 35 °C. They observed greater reductions in the amount of recoverable N, as well as greater changes of N form, in substrates stored at 12 to 35 °C compared with substrates stored at 4 °C. Dickinson and Carlile (1995) showed that a peat substrate amended with inorganic nutrients (unspecified) at 2 kg·m⁻³ stored at 20 °C resulted in a greater increase in nitrate (NO₃⁻) and decrease in NH₄⁺ over a 12-month period compared with storage at 10 °C. This was attributed to an increased microbial activity at the higher temperature.

Moisture content during storage can also affect substrate quality and nutrient release. Selmer-Olsen and Gislerod (1986) also evaluated substrate quality when stored at 30% to 75% moisture content. They observed greater nitrification rates in peat stored at higher moisture contents and speculated that N loss in drier substrates (30% moisture content) was due to N-immobilization and not nitrification. Likewise, Saadi et al. (2010) reported that microbial activity of composts using organic nutrient sources stored at 55% to 65% moisture content was greater than those stored at 15% to 35% moisture content, which resulted in higher NO₃⁻ concentration due to increased nitrification under wet conditions.

One of the most important implications of nutrient release from CRFs in bagged substrates is how it affects shelf life. While research has shown general trends in how moisture content and temperature affect pH, EC, and nutrient dynamics in stored substrates, they do not provide specific information on 1) how quickly nutrients are released from a CRF, 2) how much nutrients are immobilized, and 3) how N forms are transformed between inorganic forms (NH₄⁺ and NO₃⁻). The objective of this research was to determine over time how initial substrate moisture content and storage temperature affect the chemical properties and available nutrients derived from a CRF incorporated into a bagged peat-based substrate and stored for up to 180 d.

Materials and Methods

The base substrate was 60 sphagnum peat: 30 aged pine bark fines: 10 perlite (by vol.) amended with 5.5 g·L⁻¹ dolomitic limestone (ECOPHRST; National Lime and Stone Co., Findlay, OH) and 0.5 g·L⁻¹ granular wetting agent (AquaGro 2000G; Aquatrols, Paulsboro, NJ). The treatment design was a 3 × 3 factorial arrangement with three moisture levels and three fertilizer treatments. Water was added to the

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¹Research Assistant.

²Research Horticulturist.

³Corresponding author. E-mail: james.altland@ars.usda.gov.

base substrate to attain IMC of 25%, 45%, or 65%, calculated as the mass of water per mass of wet substrate.

The fertilizer treatments included the base substrate described previously with lime and wetting agent only as a nonfertilized control, or a CRF (Osmocote 18N–2.6P–9.96K, 8–9 months; The Scotts Co., Marysville, OH) in its original CRF-P or CRF-G before amendment. The prills for the CRF-G treatment were ground with a coffee grinder to physically break the coating layer and to induce immediate and complete nutrient release at the time of potting. Both CRF treatments were incorporated at $0.59 \text{ kg-m}^{-3} \text{ N}$. The CRF-G treatment served as a positive control to determine the maximum amount of nutrients that would be available without interference from the CRF coating.

After fertilizer treatments were mixed into the base substrate, 0.4 L of each was placed in $10 \times 15 \text{ cm}$, 2 mil sealable plastic bags (Royal Bag, Brooklyn, NY). Each bag was perforated with four holes to simulate the perforation of commercial bagged potting mixes. The bags were placed in a growth chamber (VWR Signature Diurnal Growth Chamber, Model 2015; VWR International, Radnor, PA) set to 20 or 40 °C. Because the growth chambers could not be replicated for practical reasons, differences in nutrient release from the substrates between the two storage temperatures will not be compared statistically, but will be discussed. There were four bagged replicates of each fertilizer, temperature, and moisture level combination for each of five harvest dates at 2, 14, 30, 90, and 180 d after mixing.

Two days after the substrate treatments were mixed, but before they were placed in growth chambers for storage, four replicate bags of each fertilizer and moisture treatment combination were analyzed for water extractable nutrients using a modified saturated media extraction procedure. Substrates were transferred each to a 1 L sealable plastic bag, and 350 mL of reverse osmosis water was added. The substrate slurry was allowed to come to equilibrium for 30 min. Afterward, a small hole was cut into the corner of the bag and placed immediately over PVC Buchner funnels (13.1 cm i.d., 6.6 cm tall; Thermo Fisher Scientific, Waltham, MA) fitted with a fiberglass filter paper (G6; Thermo Fisher Scientific). The Buchner funnels were attached to an erlenmeyer flask and placed under vacuum (maximum of 101 kPa) using an electric pump (Duoseal Vacuum Pump 1376; Welch Vacuum Technology, Inc., Skokie, IL) to facilitate extraction of the water from the substrate and through the filter paper. Filtrates were immediately placed in a refrigerator and stored at 2 °C until the time of analysis.

At analysis, pH was determined with a pH/ion analyzer (MA 235; Mettler Toledo, Columbus, OH) and EC with a conductivity meter (Fisher 06-662-61; Thermo Fisher

Scientific). Samples were subsequently filtered through GF/F binder-free borosilicate glass fiber filter paper (Whatman Ltd., Kent, UK) to remove particles greater than $0.7 \mu\text{m}$. The filtrate was poured into 5-mL autosampler vials, capped, and analyzed using ion chromatography (ICS 1600 Ion Chromatography System; Dionex, Bannockburn, IL) for concentrations of NO_3^- , NH_4^+ , and phosphate (PO_4^{2-}). Three additional bags for each moisture level treatment were analyzed for moisture content by weighing the contents of the bag, drying in an oven at 110 °C for 3 d, and weighing again. Nutrient concentrations determined by ion chromatography were converted to mass (mg) of each nutrient using the volume of water applied for the extraction process (350 mL) and the volume of water measured as moisture content.

Four replicates of each treatment combination were subsequently removed from each chamber at 14, 30, 90, and 180 d after the substrates were mixed and subjected to the same extraction and nutrient analysis described previously. Likewise, three bags for each temperature and moisture level treatment combination were measured for percent moisture content.

Data were subjected to analysis of variance and correlation analysis, when appropriate, using statistical software (SAS v9.3; SAS Institute, Cary, NC). Data were plotted as means with error bars representing the 95% confidence interval about the mean, using graphing software (SigmaPlot 12.5; SYSTAT Software, Inc., Chicago, IL).

Results and Discussion

Moisture content of the bagged substrates changed over time (Fig. 1). There were significant interactions between IMC and day for bags stored in both 20 and 40 °C chambers ($P < 0.0001$, data not shown). Although not compared statistically, bags stored at 40 °C seemed to have lost more moisture over the 180 d experiment than those stored at 20 °C. Over the duration of

the experiment, moisture in bags with 25%, 45%, and 65% IMC stored at 20 °C were reduced by 17%, 28%, and 13%, respectively, whereas those stored at 40 °C were reduced by 21%, 41%, and 60%, respectively. The forced-air feature of the growth chambers, along with the relatively small bag volume (compared with commercial sizes) resulted in accelerated moisture loss. The original intent of the holes was to prevent anoxic and anaerobic conditions in the media. Vent holes are also routinely used in commercial bagged potting media, although commercial bags are stacked and wrapped collectively on a pallet such that there is very little moisture loss over time (personal communication and several commercial sources).

Substrate pH was affected by fertilizer, IMC, and day for samples stored at both 20 and 40 °C (Table 1). Substrate pH increased with increasing IMC in both storage temperatures (Fig. 2). Dissolution of dolomitic limestone added to potting mixes can cause a gradual increase in media pH over time (Carlile, 2004). The calcium and magnesium carbonate [$\text{CaMg}(\text{CO}_3)_2$] in dolomitic lime dissociates in water to form exchangeable Ca^{2+} and Mg^{2+} , as well as carbon dioxide and additional water molecules (Lindsay, 1979). This reaction consumes two hydrogen ions (H^+) and thus causes pH to increase. While water is necessary for the reaction to occur, there is no literature addressing the impact of moisture level in soils or soilless substrates on lime reactivity. However, Altland and Jeong (2016) described how solubility of dolomitic lime and other weak bases is limited by pH, thus lime dissociation should increase with increasing water availability. Fertilizer treatment also affected substrate pH (Table 1). The two fertilized substrates (CRF-P and CRF-G) had similar or lower pH than the nonfertilized control. The CRF used in this experiment contained equal parts NO_3^- and NH_4^+ forms of N. NH_4^+ is readily oxidized to NO_3^- and in the process evolves H^+ ions

Fig. 1. Mean moisture content (% by weight) of bagged substrates composed of 60 sphagnum peat: 30 bark: 10 perlite by volume. Error bars represent 95% confidence intervals about the mean. Substrates had initial moisture contents (IMC) of 65%, 45%, or 25%, and the bagged substrates were stored in a growth chamber at temperatures of either 20 °C (left) or 40 °C (right) for 180 d.

Table 1. Probability values (*P* value) for main effects and interactions of fertilizer type, initial moisture content, and day of collection on the pH, electrical conductivity (EC), inorganic nitrogen (N), and phosphorus (P) recovered in bagged substrates stored at 20 or 40 °C.

Temp (°C)		pH	EC	N	P
20	F	0.0001	0.0001	0.0001	0.0001
	M	0.0001	0.1517	0.0001	0.0001
	F*M	0.1034	0.0001	0.0001	0.0001
	D	0.0052	0.0001	0.0001	0.0001
	D*F	0.0004	0.0001	0.0001	0.0001
	D*M	0.0001	0.0001	0.0001	0.0001
	D*F*M	0.1031	0.0001	0.0001	0.0001
40	F	0.0001	0.0001	0.0001	0.0001
	M	0.0001	0.0001	0.0001	0.0001
	F*M	0.0295	0.0001	0.0001	0.0001
	D	0.0001	0.0001	0.0001	0.1409
	D*F	0.0001	0.0001	0.0001	0.0010
	D*M	0.0001	0.0001	0.0037	0.3019
	D*F*M	0.0032	0.0001	0.0001	0.4361

D = day; F = fertilizer; M = moisture.

Fig. 2. Substrate pH of bagged substrates composed of 60 sphagnum peat: 30 bark : 10 perlite by volume. Substrates were amended with 5.5 g·L⁻¹ dolomitic limestone and had initial moisture content (IMC) of 65% (top), 45% (middle), or 25% (lower), and stored in a growth chamber set to 20 °C (left) or 40 °C (right) during 180-d storage period. Substrates were also either not amended with fertilizer (control), or amended with 0.59 kg·m⁻³ N of a controlled release fertilizer (CRF) (Osmocote 18N-1.3P-5K) that was either ground (CRF-G) or whole prills (CRF-P). Error bars represent the 95% confidence interval about the mean.

that lower pH. Zaccheo et al. (2013) also reported a strong acidification effect from two different CRF formulations that both

had 50% of its N as NH₄⁺. They attributed this substrate acidification to oxidation of NH₄⁺ from the CRF. The pH of the CRF-G

substrate was similar or lower than the CRF-P substrate throughout the experiment when stored at 20 or 40 °C. The total mass of NH₄⁺ would have been immediately available for oxidation in the CRF-G treatment, compared with the relatively slow and incomplete release of NH₄⁺ from the CRF-P treatment. While not compared statistically, there appeared to be little or no difference in pH response between the 20 and 40 °C chambers.

Moisture and fertilizer treatment affected EC in both 20 and 40 °C chambers either as a main effect or interaction with other factors (Table 1). Nonfertilized substrates had relatively low and stable EC over time in each of the six temperature and IMC treatment combinations (Fig. 3). Likewise, substrates with CRF-G had relatively high (>3 mS·cm⁻¹) and stable EC over time in each of the temperature and IMC treatments. Substrates with CRF-P, however, varied with IMC. At 25% IMC, EC in CRF-P substrates stayed relatively low (≤1 mS·cm⁻¹) throughout the experiment when stored at 20 or 40 °C. The low moisture levels in these substrates likely limited nutrient diffusion through the CRF coating (Fig. 1). At 45% IMC, EC of the CRF-P substrate increased over time in the 20 °C chamber, but plateaued after 90 d in the 40 °C chamber. This again was likely due to the extremely low moisture contents of the substrates in the 40 °C chamber, which dropped to below 10% moisture, while those in 20 °C were at 31% moisture. A similar pattern occurred in substrates with 65% IMC, in that EC increased steadily over time in substrates in 20 °C storage but plateaued after 90 d when stored at 40 °C. While not compared statistically, EC increased more rapidly in CRF-P substrates with 65% IMC stored at 40 °C compared with 20 °C. For example, EC of CRF-P substrates in the 65% IMC reached 2.76 mS·cm⁻¹ by 180 d, whereas the same treatment reached an EC of 2.85 mS·cm⁻¹ in just 90 d at 40 °C. Husby et al. (2003) showed that CRF products with a similar coating to that used in this experiment had increased nutrient release as temperature increased from 20 to 40 °C.

Fertilizer and IMC affected %N recovery over time (Table 1). The nonfertilized substrates did not receive N-fertilizers, so the %N recovery in these treatments represents the contribution of N from other substrate materials. Very little N was detected in the nonfertilized substrates, between 1% and 3% across all temperature and IMC combinations (Fig. 4).

On day 2, 90.2% of applied N was recovered in the CRF-G treatment averaged across the three IMC treatments. The CRF-G treatment served as a positive control to both validate our extraction method and document N-immobilization of the fertilizer. Percent N recovered would ideally be 100% in the CRF-G treatment because the coating layer along with the fertilizer content was finely ground before incorporation.

Fig. 3. Substrate EC of bagged substrates composed of 60 sphagnum peat: 30 bark : 10 perlite by volume. Substrates were either not amended with fertilizer (control) or amended with 0.59 kg·m⁻³ N of a controlled release fertilizer (CRF) (Osmocote 18N-1.3P-5K) that was either ground (CRF-G) or whole prills (CRF-P). Substrates had initial moisture content of 65% (higher), 45% (middle), or 25% (lower) and were stored in a growth chamber at temperatures of either 20 °C (left) or 40 °C (right). Error bars represent the 95% confidence interval about the mean.

Birrenkott et al. (2005) established a threshold of 90% for N recovery in CRF leaching systems for accurately documenting CRF release period, acknowledging that as much as 10% could be unrecoverable in sand or substrate systems. Thus, the 90.2% recovered on day 2 of this experiment suggests a thorough and accurate recovery rate. By day 14, only 64.8% to 69.4% of N was recovered from CRF-G in the 20 °C chambers and 61.6% to 66.6% in the 40 °C chamber. The decrease in %N recovered from day 2 to day 14 in the CRF-G treatment in each of the IMC and temperature combinations were likely the result of microbial N immobilization. Averaging across all six IMC and temperature combinations, there was a 25% reduction in detectable N from the CRF-G treatment by day 14. This represents a reduction of 0.15 kg·m⁻³ N from the substrate. Our observed values for N immobilization are similar to previously established rates. Scott (1985)

suggested a 0.035 kg·m⁻³ reduction in N because of microbial-induced N immobilization per 10% of the substrate composed of pine bark. That equates to 0.105 kg·m⁻³ for the substrate used for these experiments, which was composed of 30% pine bark. Others have suggested 0.14 kg·m⁻³ N to satisfy microbial populations acting on pine bark substrates (Pokorny, 1979). Birrenkott et al. (2005) reported that total N recovered from CRF in leachate solutions through a bark-based substrate was significantly lower than through a sand substrate due to N immobilization. Peat-based media have indigenous microbial populations of 10⁵ to 10⁶ bacterial colony-forming units (cfu) and 10² to 10³ fungal cfu, whereas bark-based substrates have 10⁶ to 10⁷ bacterial cfu and 10⁵ to 10⁶ fungal cfu (Carlile, 2004). Carlile (2004) warns that higher microbial populations in pine bark substrates can lead to greater N immobilization.

Percent N recovered from substrates receiving CRF-P was affected by IMC. Recovery of N from substrates with 25% IMC was only 16.5% and 15.9% after 180 d in 20 and 40 °C chambers, respectively, while recovery for those in 45% IMC was 42.5% and 20.5% N, respectively (Fig. 4). The lower values for %N recovered from CRF-P in 45% IMC and the 40 °C chamber compared with the 20 °C chamber are likely due to substrate moisture content. After 90 d, the moisture content of substrates that started with 45% IMC dropped to 6.1% moisture in the 40 °C chamber compared with 31.9% moisture in the 20 °C chamber (Fig. 1). Substrates receiving CRF-P with 65% IMC had similar release patterns in 20 and 40 °C chambers, with those in the 20 °C chamber reaching a maximum recovery of 50.0% and those in the 40 °C chamber attaining 45.7% recovery. While nutrient release from a resin or polymer-coated CRF is primarily a function of temperature (Birrenkott et al., 2005; Cabrera, 1997; De Oliveira et al., 2016), others have noted that moisture content in soil or soilless substrates will affect nutrient diffusion out of the CRF prill, and drier soils will reduce the overall rate of nutrient release (Chang-wen et al., 2006; Shaviv et al., 2003). It is not clear what substrate moisture level will slow or halt nutrient release from CRF prills, however, it is likely that the extremely low moisture levels in the substrates stored at 20 °C with 25% IMC or any of the samples stored in the 40 °C chamber reduced nutrient release.

Phosphorus recovery was affected by fertilizer type and IMC in both storage temperatures (Table 1). As expected, little or no P was recovered from nonfertilized substrates (Fig. 5). Percent P recovered from CRF-P responded similarly to N with respect to IMC and temperature. Percent P recovery was low in substrates receiving CRF-P and 25% IMC, whereas %P recovered increased from 2 to 180 d in substrates with 45% or 65% IMC. Among CRF-P treatments, %P recovery was generally lower than %N recovery. Huett and Gogel (2000) showed that across 17 different polymer-coated CRF products, including five formulations using a coating technology similar to the product in this experiment, the relative release rate was more rapid for N than P. More rapid release of N than P has been attributed to the greater solubility of N compared with P compounds (Chang-wen et al., 2006). The percent P recovered from CRF-G substrates was less than 40% in most cases with 45% and 65% IMC. Percent P recovery in CRF-G substrates with 25% IMC was higher than those with 45% or 65% IMC. As discussed previously, higher IMC likely resulted in greater lime dissolution. The higher levels of free Ca²⁺ might have formed precipitates with PO₄²⁻ from the CRF-G, thus reducing %P recovered in the water-extraction process. A more likely reason for low %P recovery rates is microbial P

Fig. 4. The recovered water extractable nitrogen ($\text{NH}_4^+ + \text{NO}_3^-$) from a substrate composed of 60 sphagnum peat: 30 bark : 10 perlite by volume. Data are expressed as mean percent of the total mass of 238 mg N applied via the controlled release fertilizer (CRF). Error bars represent the 95% confidence interval about the mean. Substrates were either not amended with fertilizer (control) or amended with $0.59 \text{ kg} \cdot \text{m}^{-3}$ N of a CRF (Osmocote 18N-1.3P-5K) that was either ground (CRF-G) or whole prills (CRF-P). Substrates had initial moisture contents of 65% (higher), 45% (middle), or 25% (lower) and were stored at temperatures of either 20 °C (left) or 40 °C (right).

immobilization. Handreck (1996) showed that 40% to 50% of extractable P was reduced in the first 5 d of a substrate incubation study solely as a function of microbial immobilization. The N:P ratio of all the N and P not recovered from the CRF-G substrates ranged from 3.3 to 5.4 with an overall mean of 4.8 (data not presented). The N:P ratio of bacteria is 4.7 on dry weight basis (Brookes et al., 1984; Todar, 2012), which further corroborates the likelihood that unrecovered P in the CRF-G treatments was due to microbial immobilization.

In summary, IMC and storage temperature affected pH, EC, and nutrient release. The typical moisture content of bagged potting substrates is 40% to 60% (personal communication and several commercial sources). Moisture content of our bags dropped below this typical level, revealing how severely moisture content can affect substrate chemical properties. Substrate pH increased with increasing IMC due to

greater lime reactivity. Because dolomitic lime reactions are chemical and not biological, storage temperature seemed to have minimal effect on pH. Bags stored at 40 °C dried out more quickly, and thus the secondary effect of temperature on moisture content over time affected lime dissolution, with very little effect from temperature directly. EC followed a trend similar to N release, such that the two variables were highly correlated with the CRF-P substrates across all dates ($r = 0.937$, $P < 0.0001$, $n = 120$). About 25% of N from CRF-G treatments was immobilized between 2 and 14 d of storage. Low moisture content of bags due to low IMC or storage at 40 °C, reduced the rate of N release from CRF-P treatments. Substrate P was rapidly immobilized by microbial communities. The percent of P immobilized in the CRF-G treatment was less in substrates with low IMC because of reduced microbial activity in low moisture substrates.

Demand for bagged substrates with CRF amendments is seasonal and in greatest demand during early spring. Because recommendations have been to use substrates amended with CRF within 30 d (Carlile, 2004; Hulme, 2011; Zaccheo et al., 2013), there is pressure on manufacturers to mix and bag substrates immediately before the sales period. Any strategy that would allow for early mixing and longer storage would ease some of this logistical pressure. Temperatures of 20 and 40 °C did not seem to differentially affect EC, N, or P. While the experiment was not designed for direct comparison of temperatures with statistical analysis, visual examination of the trends along with 95% confidence interval bars suggests minimal differences in EC, N, and P with respect to the two temperature regimes. It is possible that lower temperatures closer to 0 °C would have the intended effect of reducing nutrient release, but this approach might not be suitable for the growing media industry due to feasibility and cost of storing large volumes of bagged substrates in controlled environments. Currently, bagged substrates are stored outside (personal communications with numerous commercial sources).

Moisture content had a profound effect on nutrient release. Lower IMC reduced the dissolution of dolomitic lime resulting in lower substrate pH. Lower moisture contents, whether due to IMC or drying through vent holes, resulted in reduced N release from the CRF-P treatments. Contrary to this, higher moisture contents resulted in greater P immobilization due to greater microbial activity. Considering the dissolution of lime and release of N and P, the net effect on EC was primarily a function of N release. Thus, EC was also reduced with lower moisture contents. This suggests that manufacturers could use moisture content as a means to slow the release of nutrients in bagged substrates. This would have the added benefit of reduced shipping costs. Currently, substrate manufacturers do not control or modify the moisture content of the bagged substrates; moisture content of the bagged substrate depends solely on the moisture content of the organic matter at the time of mixing and bagging (personal communications with several commercial sources). An additional drawback to substrates with low moisture content is the perception of reduced quality by consumers. Drier substrates may be more dusty, more difficult to handle, and perhaps more difficult to wet (depending on wetting agent).

The objective of this research was to determine how moisture content and storage temperature affected the chemical properties and available nutrients derived from a CRF incorporated into a bagged substrate. Under the conditions of this experiment, temperature seemed to have the primary effect of drying substrates stored at 40 °C more quickly than those stored at 20 °C. Moisture content had more direct effect on nutrient

Fig. 5. The recovered water extractable phosphorus (P) from a substrate composed of 60 sphagnum peat: 30 bark : 10 perlite by volume. Data are expressed as mean percent of the total mass of 39.63 mg P applied via the controlled release fertilizer (CRF). Error bars represent the 95% confidence interval about the mean. Substrates were either not amended with fertilizer (control) or amended with 0.59 kg·m⁻³ N of a CRF (Osmocote 18N-1.3P-5K) that was either ground (CRF-G) or whole prills (CRF-P). Substrates had initial moisture contents of 65% (higher), 45% (middle), or 25% (lower) and were stored at temperatures of either 20 °C (left) or 40 °C (right).

release from CRF, as well as lime dissolution and thus pH.

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