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Characterization and Efficacy of a Novel Poultry-Derived Fertilizer for Container Production

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Summary

The poultry industry is a major rural economic industry within the Southern US. Raw poultry litter, a waste product of the industry, is facing increasing regulation for its use as a broadcast fertilizer. Alternatively, poultry litter can be processed utilizing aerobic digestion to produce a new product with potentially fewer negative environmental and health consequences. A novel digested litter-based fertilizer produced by Cleaned and Green, LLC (C&G) was assessed for nutrient release characteristics and plant responses to gauge its efficacy for container production. Rapid water incubation tests demonstrated that the majority of C&G nutrients released within 10 min, similar to traditional synthetic fertilizers. In soil-based incubation tests, ammonium release occurred in two phases, at Day 1 and Day 35. Nitrate concentration remained low through Day 15 but increased dramatically through Day 55. Potassium was immediately available upon application. Phosphorus concentrations were not significantly higher than control soil, indicating this product may help alleviate some environmental concerns. Tomatoes grown with C&G and C&G blended fertilizers showed improved vitality at higher N rates.

However, tomatoes growth with poultry litter at higher rates produced larger plants. Growth assays on tomatoes was recorded. Due to its rapid release, this novel fertilizer appears best fit for short-term floriculture crops.

INTRODUCTION

Extended-release fertilizers fall into two categories: slow-release and controlled-release. Controlled-release products often contain synthetic, plastic-coated prills that rely on environmental factors to mediate release (Vejan *et al.*, 2021). Slow-release fertilizers often lack a synthetic coating and rely on microbial processes to release nutrients (Fu *et al.*, 2018). Poultry litter falls into the rapid-release fertilizer category; nutrient release and availability begin upon release (Wang *et al.*, 2015). Controlled-release fertilizers are common in container production to meet plant requirements over time and limit excess leaching (Chen and Wei, 2018). The rapid release of high nutrient amounts may lead to environmental concerns and require multiple applications for desired plant nutrition in the growing season (Vejan *et al.*, 2021).

The United States Department of Agriculture estimates the value of poultry products at $46 billion, with Georgia (1.3 billion birds) and Alabama (1.2 billion) overtaking Arkansas (1 billion) in total birds (USDA, 2022). Poultry litter (PL) applications can enhance plant growth, demonstrating generally positive relationships within soils (Wang *et al.*, 2015). However, concerns pertaining to the eutrophication of aquatic environments have brought on renewed legislation and regulation of its applications. Raw PL may undergo the process of aerobic digestion to slow nutrient release and reduce the risk of disease. Aerobic digestion utilizes microbial activity or thermophilic heat from an acid to break down the litter (Zhang *et al.*, 2022). Aerobic digestion may be combined with additional processes, such as that utilized by Cleaned & Green (C&G), to produce a PL-based fertilizer with N-P-K ratios similar to fertilizers in container production (USPO, 10,723,665 B1).

The objectives of this study were two-fold: first, to characterize the nutrient release patterns of C&G, and second, to conduct a growth assay with C&G and other nutrient sources. Physical prill characterization, chemical composition, and microbial viability were also tested (data not reported).

MATERIALS AND METHODS

Incubation Test. Water-based incubation assessments were conducted to determine the nutrient release patterns of a novel, PL-derived fertilizer, C&G (12 N - 2 P_2O_5 - 2 K_2O - 12 S), a synthetic fertilizer (herein referred to as “Synthetic”) blended to contain similar nutrient values, and a polymeric resin-coated fertilizer (17-5-11; Osmocote, Scotts Miracle-Gro, Marysville, OH). One gram of each fertilizer product was added to 100 mL DI water (n=3). Solutions were stirred at 60 rpm and maintained a temp of 20 C. Electrical conductivity (EC) measurements occurred at set time intervals over a 24-hour period.

Soil-based incubation tests were performed with a clay soil (pH=6.6). The soil was homogenized by drying, pulverizing, and sieving to exclude particles >2 mm. Incubation jars (n=80) were filled with 100 g of dry soil. C&G was incorporated at a rate of 1.5 lbs. N/yd^3 in half of the jars. Soil samples were maintained at a volumetric water content of 0.3 cm^3/cm^3 and 30 C. On each sample date, four replications per treatment (C&G and Control) were removed, air-dried, homogenized, and partitioned for nutrient extraction. Ammonium and nitrate concentrations were determined using 2M KCL extraction, fluorimetry, and colorimetry on a multimode plate reader. Total P and K were determined using a Mehlich 1 extraction (Mehlich, 1953).

Plant Assays. Tomatoes (*Solanum lycopersicum* 'Celebrity') were transplanted into 1 gal containers (Classic 400; Nursery Supplies Inc., Fairless Hills, PA) filled with a pine bark: peat (3:1 v:v) amended substrate. Fertilizer treatments included the following: Synthetic, C&G, Blend (Synthetic+C&G), PL, and a control receiving no fertilization. Fertilizer treatments were applied at three rates: 0.75 lbs. N/yd^3, 1.5 lbs. N/yd^3, and 3 lbs. N/yd^3. Each treatment-rate combination included six replicants. Substrate pH and EC were monitored weekly using the Pour-Through method (Wright, 1986). Plant dry weight and foliar nutrient concentration were determined eight weeks after transplant.

Soil-based nutrient release data were analyzed via PROC Reg procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). Effects of fertilizer, rate, and the fertilzer*rate interaction on dry weight and foliar nutrient concentrations were analyzed via ANOVA with the PROC Glimmix procedure. Means were separated using Tukey's honest significant difference (HSD) at a 5% alpha level.

RESULTS

Incubation Tests. In rapid water release incubation, Synthetic released nutrients both quickest and in the greatest quantities (**Fig. 1**).

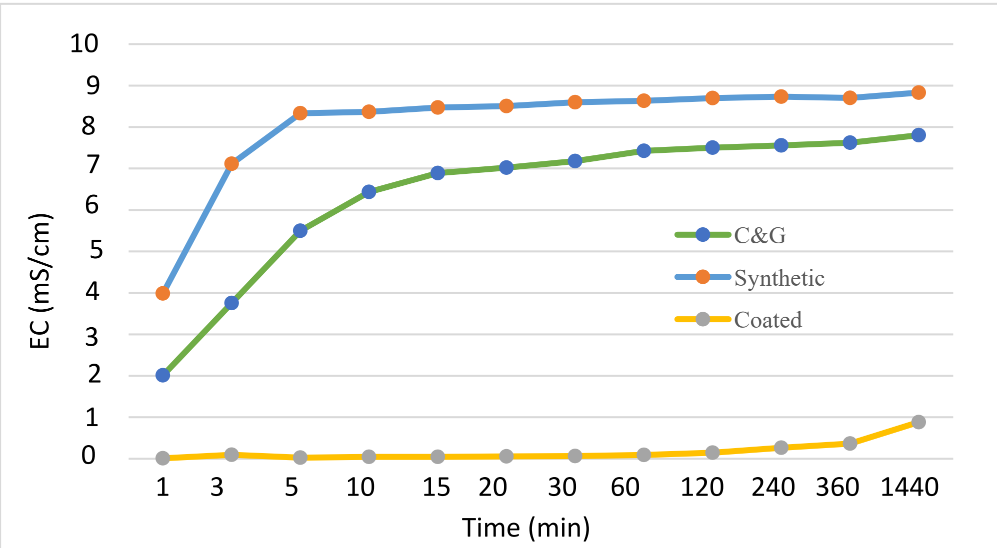

Figure 1. Nutrient release rates, determined by EC, of a novel poultry litter-derived fertilizer (C&G), a synthetic granular fertilizer (Synthetic), and a resin-coated fertilizer (Coated) over 24 hours in a water incubation.

Within 10 minutes, Synthetic released 95% of recorded nutrients compared to 82% for C&G. As expected, little to no change in EC was recorded in the resin-coated product after 24 hrs. C&G performed similarly to quick-release fertilizers and should be considered a quick-release product.

In soil, C&G immediately released ammonium at 65 ppm as compared to 14 ppm for the Control (**Fig. 2**). A secondary release of ammonium, nearly doubling the initial release, occurred on Day 45. By Day 55, ammonium concentration had declined from its peak to 119 ppm. Background ammonium concentrations were 6 ppm at Day 55. Nitrate concentrations increased slowly over the first two weeks before sharply increasing through Day 55. On Day 15, nitrate comprised 25% of the total nitrogen released from C&G (**Fig. 3**).

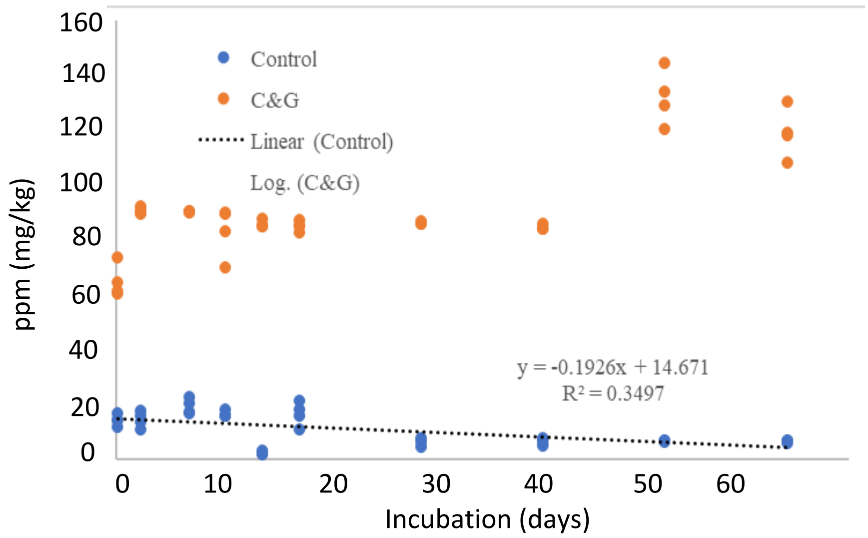

Figure 2. Recorded ammonium concentrations within soil after applying a novel poultry litter-derived fertilizer (C&G) over 55 days.

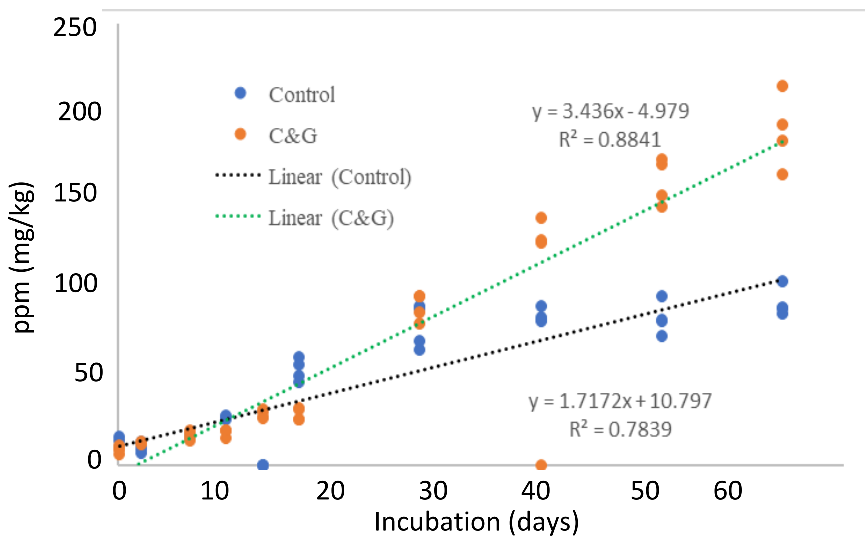

Figure 3. Recorded nitrate concentrations within soil after applying a novel poultry litter-derived fertilizer (C&G) over 55 days.

Nitrate concentrations surpassed ammonium on Day 35 and had a final concentration of 189 ppm. In contrast, the Control nitrate concentration on Day 55 was 92 ppm. Total nitrogen release at the conclusion of the trial was 308 ppm for C&G and 178 ppm for the Control (**Fig. 4**). Potassium was immediately released from C&G. By Day 9, 94% of the total K had been released (**Fig. 5**). Although C&G increased the mean soil-extractable P, concentrations of P were not significantly higher (p = 0.44) than the control soil (**Fig. 6**).

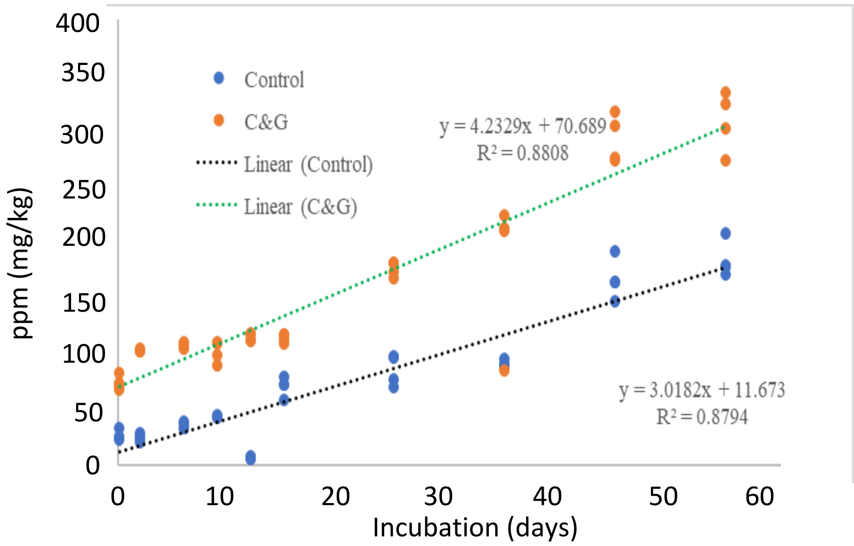

Figure 4. Total nitrogen (sum of nitrate and ammonium concentrations) within soil after applying a novel poultry litter-derived fertilizer (C&G) over 55 days.

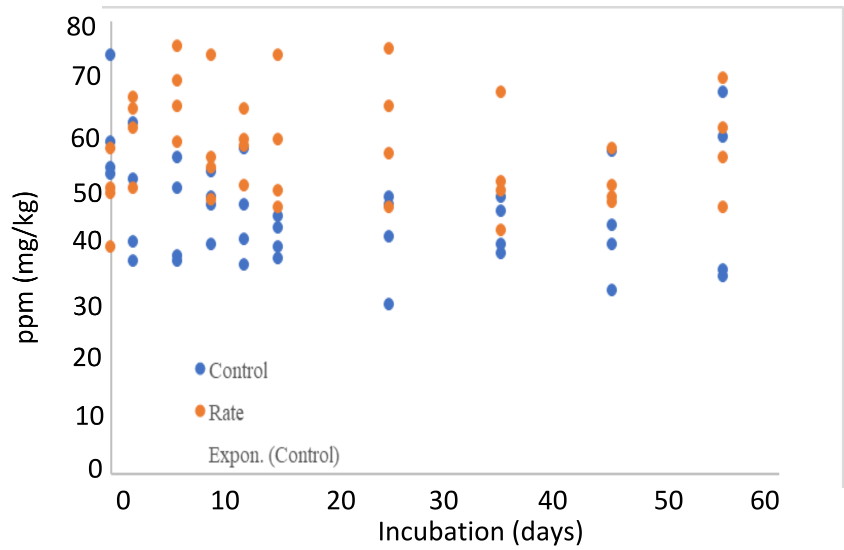

Figure 5. Recorded phosphorus concentrations within soil after applying a novel poultry litter-derived fertilizer (C&G) over 55 days.

Plant Assays. Electrical conductivity levels rapidly dropped from a high of ~8 mS/cm for all fertilizer applications within the first three weeks after transplant (**Fig. 7**). Poultry litter was the only treatment to maintain EC levels >1 mS/cm for eight weeks. By the conclusion of the study, Synthetic and Control recorded similar EC readings at 0.2 mS/cm. Containers with C&G and PL applied maintained higher EC levels by the conclusion of the study. Across all fertilizer treatments, substrate pH was reduced by approximately 1 unit but increased steadily to 6.5-7 (**Fig. 8**).

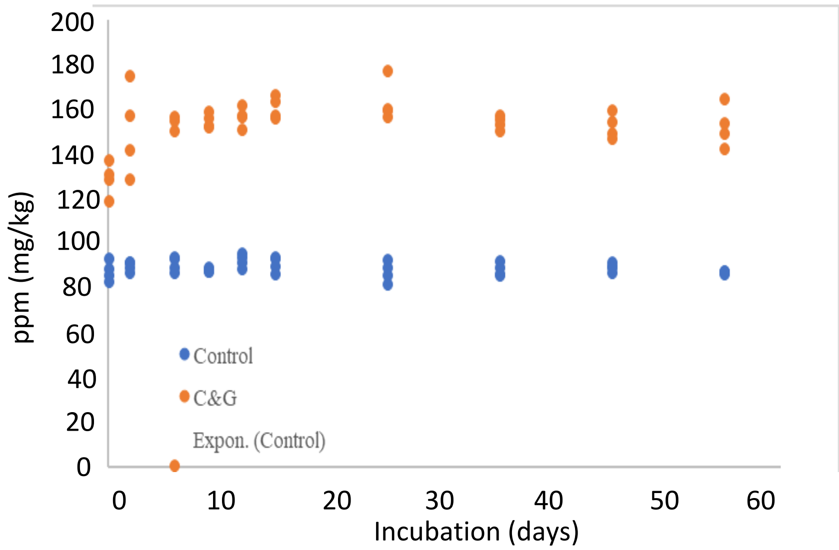

Figure 6. Recorded potassium concentrations within soil after applying a novel poultry litter-derived fertilizer (C&G) over 55 days.

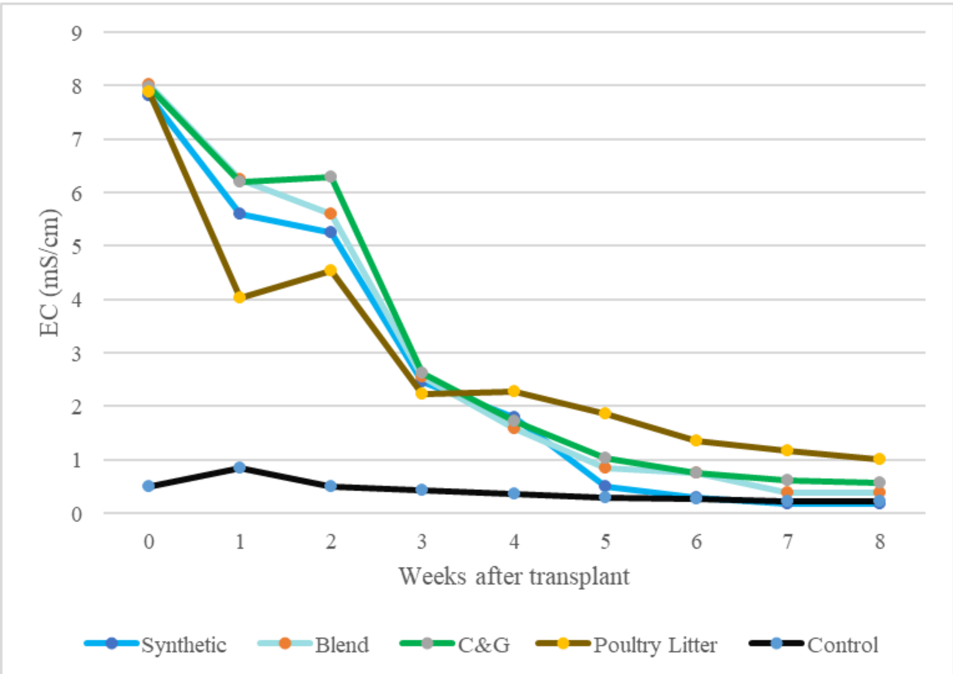

Figure 7. Measured electrical conductivity (EC) of container-grown tomatoes fertilized with a synthetic fertilizer (Synthetic), a novel poultry litter-derived fertilizer (C&G), Blend (Synthetic+C&G), poultry litter, and a control receiving no fertilization. All fertilizers were applied at a rate of 1.5 lbs. N/yd^3.

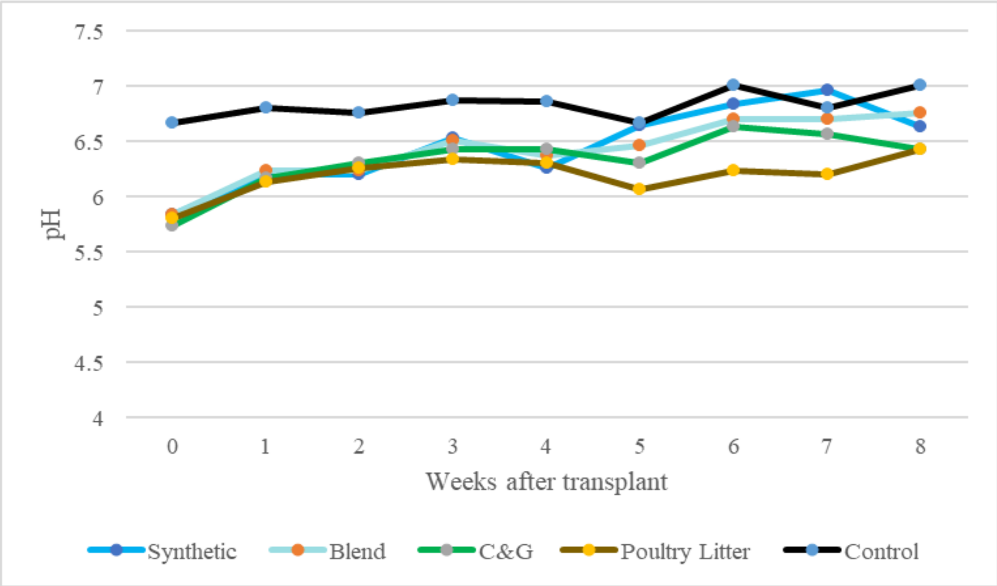

Figure 8. Effect of fertilizer treatments on substrate pH. Fertilizer treatments consisted of a synthetic fertilizer (Synthetic), a novel poultry litter-derived fertilizer (C&G), Blend (Synthetic+C&G), poultry litter, and a control receiving no fertilization.

Tomato dry weight was affected by rate, fertilizer type, and the interaction between rate and fertilizer type (p=< 0.0001). PL at 1.5 lbs N/yd^3 and 3 lbs. N/yd^3 produced the largest tomato plants (**Table 1)**. PL applied at 0.75 lbs. N/yd^3 produced plants similar in size to C&G or Blend applied at rates of 0.75 lbs. N/yd^3 and 1.5 lbs. N/yd^3. Increased mortality was observed in all fertilizers applied at 3 lbs. N/yd^3 except PL. Tomatoes receiving Synthetic at 3 lbs. N/yd^3 had an 83% mortality rate. Tomatoes receiving C&G or Blend at 3 lbs. N/yd^3 demonstrated improved vitality, only losing one specimen each. However, Blend applied at 3 lbs. N/yd^3 produced the smallest plants after eight weeks. Visually, tomatoes fertilized with PL exhibited greater nutrient deficiencies (**Fig. 9**).

Foliar N concentrations were affected by nutrient source, rate, and their interaction (p=< 0.0001). Products containing C&G contained the highest concentrations of nitrogen (**Table 2**). At 3 lbs. N/yd^3, C&G and Blend produced plants with foliar N of 2.47% and 2.56%, respectively. Synthetic applied at 0.75 lbs. N/ yd^3 produced plants with foliar N of 1.97%. Although PL tomatoes were the largest, foliar N was lowest at 0.86%, 0.96%, and 1.39% for rates of 0.75, 1.5, and 3 lbs. N/yd^3, respectively.

Foliar P concentrations were affected by nutrient source, rate, and their interaction (p=< 0.0069). Tomatoes fertilized by PL, all rates, Blend at 3 lbs. N/yd^3 contained the highest foliar P concentrations. Few differences were observed in other treatments. Foliar K concentrations were unaffected by rate, but differences were recorded by nutrient source (p=< 0.0001). However, no discernable trends in foliar K were observed.

Table 1. Plant assay dry weights.

Fertilizer	Rate (lbs. N/yd^3)	Dry weight (g) Tomato
Synthetic[y]	0.75	19.5cd[z]
	1.5	29.9bc
	3	--
Blend[x]	0.75	30.4b
	1.5	32.5b
	3	12.6d
C&G[w]	0.75	33.7b
	1.5	32.7b
	3	24.9bc
Poultry Litter	0.75	34.8b
	1.5	49.9a
	3	58.2a
Control	--	0.2e

[z] Data were analyzed using a one-way anova and subsequent means were compared using the Tukey honest significant difference ($p \leq 0.05$). Means within a column with the same letter do not significantly differ from each other.
[y] Synthetic, a rapid-release fertilizer blended to contain the same nutrient ratio and Cleaned and Green minus sulfur

[x] Blend is a 1:1 ratio of Synthetic and Cleaned and Green fertilizer

[w] Cleaned and Green (C&G) is a poultry litter derived product containing a similar N-P-K ratio as blend and Synthetic but with the addition of 11% Sulfur

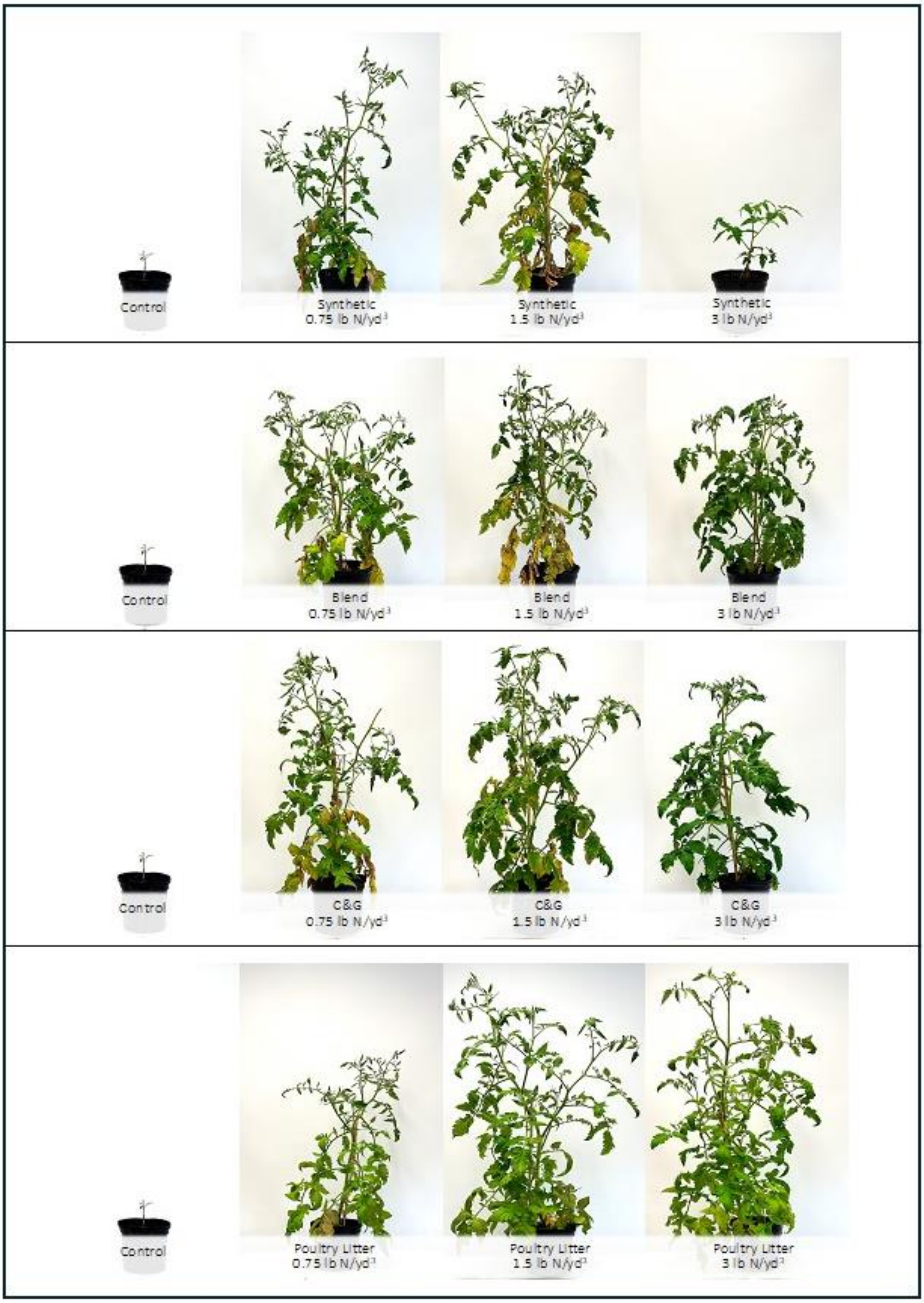

Figure 9. Tomatoes eight weeks after transplanting which received nutrients from a synthetic fertilizer (Synthetic), a novel poultry litter-derived fertilizer (C&G), Blend (Synthetic+C&G), poultry litter, and a control receiving no fertilization.

Table 2. Plant assay of plant macronutrient percentages within tissue.

Fertilizer	Rate (lbs. N/yd^3)	Nitrogen	Phosphorus	Potassium
	0.75	1.97abc[z]	0.07d	0.74ab
Synthetic[y]	1.5	1.53dc	0.19cd	0.53b
	3	--	--	--
	0.75	1.55cd	0.12 cd	0.46b
Blend[x]	1.5	1.78cd	0.17cd	0.39b
	3	2.56a	0.37ab	0.63b
	0.75	1.49cde	0.12cd	0.47b
C&G[w]	1.5	1.94bcd	0.19cd	0.34b
	3	2.47ab	0.26bc	0.4b
	0.75	0.86f	0.44a	0.79ab
Poultry Litter	1.5	0.96ef	0.46a	0.71b
	3	1.39def	0.38ab	1.32a

[z] Data were analyzed using a one-way anova and subsequent means were compared using the Tukey honest significant difference ($p \leq 0.05$). Means within a column with the same letter do not significantly differ from each other.

[y] Synthetic, a rapid-release fertilizer blended to contain the same nutrient ratio and Cleaned and Green minus sulfur

[x] Blend is a 1:1 ratio of Synthetic and Cleaned and Green fertilizer

[w] Cleaned and Green (C&G) is a poultry litter derived product containing a similar N-P-K ratio as blend and Synthetic but with the addition of 11% Sulfur

DISCUSSION

Both water- and soil-based incubation tests characterize C&G as a quick-release fertilizer. However, C&G did exhibit a delayed release of ammonium. Between Day 35 and Day 45, ammonium concentration rose 56%. Similarly, nitrate concentrations began to climb rapidly after Day 15. These mechanisms for delayed N release need to be studied further. While P and K were applied in similar concentrations, their releases and availability drastically differed. Potassium and phosphorus were quickly released after incorporation. The mean P concentrations were 61% less than K concentrations. Additional testing is required to determine the speciation of P and C&G potential implications to reduce the environmental burdens of raw PL applications.

Differences were observed between nutrient products and rates in container-grown tomatoes. The Synthetic fertilizer, a custom blend matching the macronutrients of C&G, was volatile at 3 lbs. N/yd^3, resulting in the death of most tomatoes by Week 4. Fatalities were also overserved, but to a lesser extent, in the Blend (Synthetic + C&G) and C&G fertilizers applied at 3 lbs. N/yd^3. Surviving treatments produced smaller plants but mostly recovered by Week 8. No fatalities occurred from PL applications, which produced plants 67% heavier than Synthetic and 53% heavier than C&G. By Week 8, all treatments experienced yellowing, purpling, or a combination of nutrient deficiency symptoms. Significant declines in measured EC occurred across all treatments through Week 8.

Tissue analysis revealed that C&G nutrient levels resemble the Synthetic fertilizer. Plant produced with PL contained higher levels of P and K, but lower N concentrations. Due to the mobility of N within the plant, the rapid growth observed in tomatoes grown in PL would predictably cause N in the most recently mature leaves to be reallocated to meristematic regions. Higher P and K concentrations were expected in tomatoes grown in PL due to its balanced N-P-K ratio.

Overall, C&G, both as a stand-alone and supplemental nutrient source, has shown positive effects on plant growth. It was less volatile than the ammonium sulfate blend of synthetic fertilizer, resulting in fewer plant fatalities. This novel, litter-based product has the greatest potential in short-duration production systems where irrigation and leachate fractions can be carefully controlled. However, further testing in container ornamental crops is needed.

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