

Advancing the Circular Bio-Nutrient Economy with a Focus on Open-Field Small Farm Systems

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Abstract

Nutrient circularity has garnered significant media attention due to its far-reaching effects, which include reducing nutrient depletion in soils, eutrophication in waterways, reliance on synthetic fertilizers, and greenhouse gas emissions. The Circular Bio-Nutrient Economy Association, based in Kenya, along with its affiliated organizations, is collecting nutrient-rich human waste and recycling it into fertilizer to reduce nutrient runoff into the already eutrophic Lake Victoria and to protect public health. The Nelson lab at Cornell is supporting the project by investigating the efficacy of circular nutrient inputs, including human urine, on crop yield and quality compared to conventional practices. The research conducted for the 2026 Laidlaw Summer Research Experience focused on open-field small farm systems, the most prominent agricultural system globally. The research compares the efficacy of circular soil amendments and urine-based top dressings to conventional soil amendments and top dressings on the growth of Blue Jade Dwarf sweetcorn. The preliminary results using height, germination, and chlorophyll content as response variables suggest that circular soil amendments and urine-based top dressing are viable alternatives to conventional practices.

Background

Current single-stream nutrient systems, which rely on commercial fertilizers and produce wastewater runoff, are creating oversaturated nutrient conditions in waterbodies while leaving soils depleted. This reduces crop nutrient content and yields while degrading aquatic ecosystems by creating hypoxic and anoxic conditions due to eutrophication.

Additionally, single stream nutrient systems create a reliance on synthetic fertilizers, which account for 2% of global greenhouse gas emissions (Menegat, 2022). The production of ammonia in fertilizers relies on the Haber-Bosch process, which requires high heat and high pressure, usually powered through fossil fuels (Moghadam et al. 2). As fertilizer runs off into waterways, it is broken down by microbes and oxidized to create nitrous oxide, a greenhouse gas with a warming potential 300 times greater than carbon dioxide (Kanthiram and Gribkoff, 2025).

In addition to a single-stream nutrient system, the current agricultural system flows through a single-stream economy that produces significant quantities of degradable and non-degradable waste. These wastes, if degradable, may wind up in the anoxic conditions of landfills and emit methane through anoxic decomposition (Scarpelli et al., 2024). If non-degradable, the waste retains its chemical form in the environment and can be incorporated into animal and human tissues (Roslan et al., 2024).

The Nelson Lab at Cornell University, in partnership with the Circular Bio-Nutrient Economy Association, is working to reduce wastewater runoff and reliance on commercial fertilizers by repurposing urine and diverting industrial waste products to revitalize soils and support public health. The experiments conducted at the Nelson Lab at Cornell directly support the Circular Bio-Nutrient Economy Association and its affiliated organizations in Kenya, which seek to remediate eutrophication in the Lake Victoria Basin caused by wastewater and fertilizer

runoff (Nakkazi et al., 2024). Additionally, the project seeks to improve public health outcomes by collecting and diverting waste into usable forms while improving nutrient quality of crops.

Alongside waste collection, the Nelson lab is supporting the Association through research projects that investigate the processing and efficacy of various urine-based fertilizers, as well as nutrient-rich products recycled from industrial waste streams, across a variety of agricultural systems, compared to conventional practices. During the Summer 2026 Laidlaw Experience, two experiments were conducted to compare the effects of circular and conventional inputs on two distinct agricultural systems: an urban raised-bed system and an open-field small farm system. The research presented in this report compares conventional and circular nutrient inputs within open-field small farm systems, the most ubiquitous agricultural system globally (Vatistas et al., 2022). The work is guided by two research questions: whether urine is an effective top-dressing in open-field farming systems compared to conventional alternatives, and how soil amendments from organic under-utilized resources (OURS), particularly biochar-based urine-derived fertilizers (BUF), compared to conventional products.

Methods

The study was conducted on Caldwell Plot E (34 x 58 m) at Cornell University during the summer of 2026. Blue Jade Sweet Corn (*Zea mays*) was planted on June 12th, 2026, a dwarf variety growing to about 3 to 4 feet tall. It produces shoots and miniature ears and has a maturation period of about 70 to 80 days. For maintenance, irrigation was limited to seasonal rain patterns, and the plots were weeded weekly.

Caldwell Plot E was divided into 4 ranges, each containing 7 treatment groups whose locations were randomized using a random number generator (Figure 1). Each treatment

plot consisted of 80 plants divided into 4 rows of 20 plants each. The 7 treatment groups varied based on soil amendments planted with the corn seed and the top dressings, which were applied twice throughout the growing season. The soil amendments included Gene's Starter Mix (10:20:20) - a conventional soil amendment, Pine char - a byproduct of the timber industry which is high in carbon, biochar - pyrolyzed organic matter from agricultural residue and biological waste which supplies nutrients including potassium and phosphorus, BUF+ - biochar enriched with urine which supplies nitrogen as well as nutrients present in biochar, potash - a non-circular soil amendment that supplied potassium, and bone char - pyrolyzed bone material that supplies calcium and phosphorus. The top-dressings included a conventional dressing as well as pasteurized and processed urine.

Treatment group 1 was the blank control, which did not receive soil amendments or top-dressing and serves as the negative control. Treatment group 2 received Gene's starter Mix (10:20:20), a conventional soil amendment, as well as a Conventional top-dressing; it constituted the positive control. Treatment 3 received Pine char and urine as a top-dressing. It was compared to treatment group 4, which received Pine char and the conventional top-dressing. Treatment 5 received pine char and Gene's starter mix as soil amendments and received the conventional top dressing. Treatment 6 received the soil amendment biochar and urine as a top-dressing. Treatment 7 received BUF+ along with potash and bone char in amounts that would garner an NPK ratio of (10:20:20) to control for the nutrient ratios within Gene's Starter Mix.

Treatments		
#	Starter amendment	Top-dress
1	Blank control	None
2	Gene's starter mix (10:20:20)	Conventional
3	Pine char	Urine
4	Pine char	Conventional
5	Pine char + Gene's starter mix (10:20:20)	Conventional
6	Biochar	Urine
7	BUF+ + potash + bone char (10:20:20)	Urine

Figure 1. Allocation of soil amendments and top-dressings between treatment groups

Rep 4y = 85–100	T5Pine char + 10:20:20	T7BUF + potash + bone char	T4Pine char	T1Blank control	T6BUF	T2Gene's 10:20:20	T3Pine char	15-ft plots
Alley10 ft								Walk / access
Rep 3y = 60–75	T7BUF + potash + bone char	T3Pine char	T2Gene's 10:20:20	T6BUF	T4Pine char	T1Blank control	T5Pine char + 10:20:20	15-ft plots
Alley10 ft								Walk / access
Rep 2y = 35–50	T2Gene's 10:20:20	T5Pine char + 10:20:20	T1Blank control	T7BUF + potash + bone char	T3Pine char	T6BUF	T4Pine char	15-ft plots
Alley10 ft								Walk / access
Rep 1y = 10–25	T4Pine char	T1Blank control	T6BUF	T3Pine char	T7BUF + potash + bone char	T2Gene's 10:20:20	T5Pine char + 10:20:20	Front block

Figure 2. Experimental Design. Each treatment is replicated four times using a randomized complete block design (RCBD). Each replication range is separated by a 10ft alley.

Statistical analysis included four response variables: relative chlorophyll content measured via SPAD readings, height in centimeters, percent germination, and yield. SPAD readings and height measurements were collected twice throughout the experiment. Both response variables were measured on the same plants for both measurement days. Eight plants from each treatment group plot were randomly selected, totaling 32 plants for each treatment group out of 80. Percent germination for each treatment group was measured three times during the growing season. Data collection on yield is ongoing.

The data were analyzed in R version 4.5.1. ANOVA Tests evaluated the differences in height and chlorophyll content among treatment groups. Before analysis, Q-Q plots verified data normality, and Levene's test confirmed homoscedasticity. An ANOVA test on a Generalized Linear Model (GLM) with a quasi-binomial family was used to evaluate differences in percent germination. A GLM was used due to the proportional nature of the percent germination data and its non-Gaussian distribution. The data were tested for overdispersion by calculating the Dispersion Estimate, which yielded 3.60883, exceeding the cutoff of 2. Due to the overdispersion in the data, a quasi- binomial instead of a binomial family was used to construct the GLM.

Results

There were significant differences in corn height between treatment groups from data collected on August 7th, 2026. Seed germination and Chlorophyll Content did not indicate significant differences between groups from data collected on July 16th, 2026.

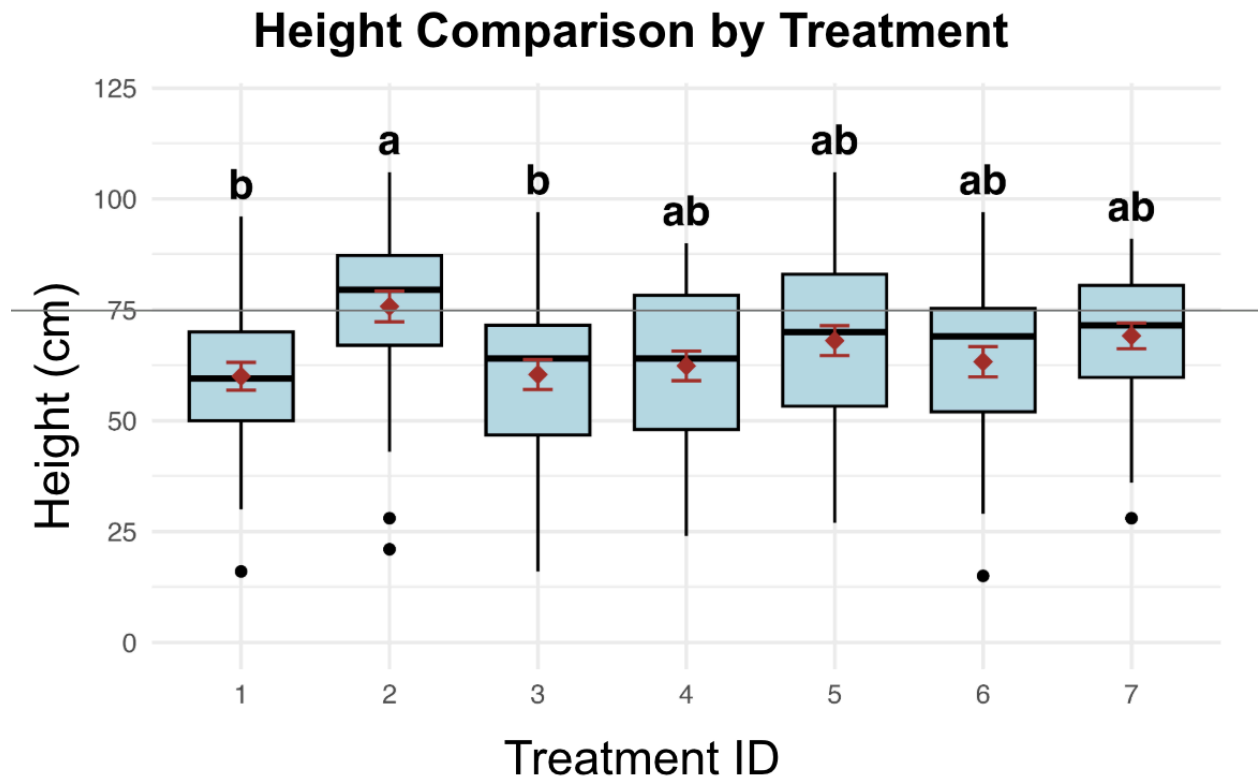


Figure 3. Anova Test of height produced a $\text{Pr}(> F) = 0.00751$, indicating significant height differences between the treatment groups. Matching letters indicate treatment groups that were not significantly different.

The ANOVA test conducted on height produced a $\text{Pr}(> F) = 0.00751$, indicating significant differences between groups. The TukeyHSD post-hoc test indicated a p-value = 0.015 between treatment groups 1 and 2, and a p-value = 0.019 between treatment groups 2 and 3. The mean values depicted in Fig. 3 indicate that treatment 2 significantly enhanced corn height compared to treatments 1 (blank control) and 3 (pine char + urine), which were the worst-performing groups. They also indicate that treatment 2 did not significantly enhance height compared to treatments 4, 5, 6, and 7.

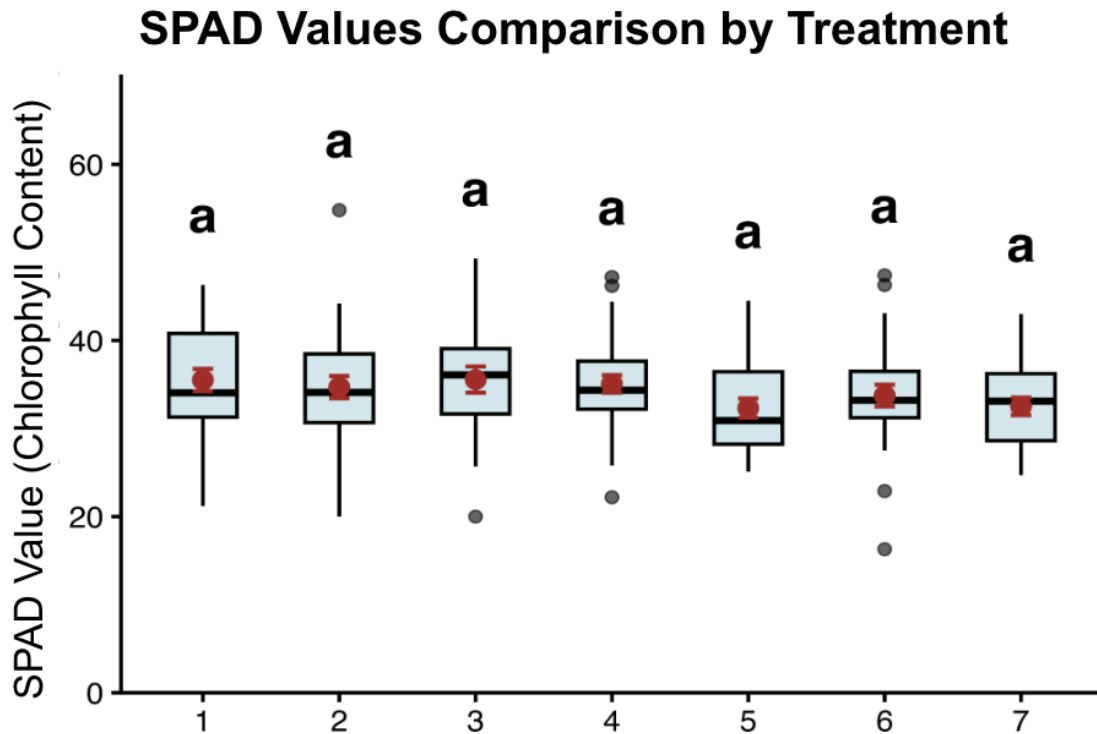


Figure 4. Boxplots of Chlorophyll Content with mean values and error bars overlaid. The same letter indicates no significant differences between treatment groups.

Chlorophyll content was recorded on 7/16/26, before the corn began to flower. The ANOVA Test for chlorophyll content produced a $\text{Pr}(> F) = 0.279$, indicating no significant differences among treatment groups. Figure 4 depicts the distribution of chlorophyll content among the treatment groups with the mean and error bars overlaid, confirming the null result.

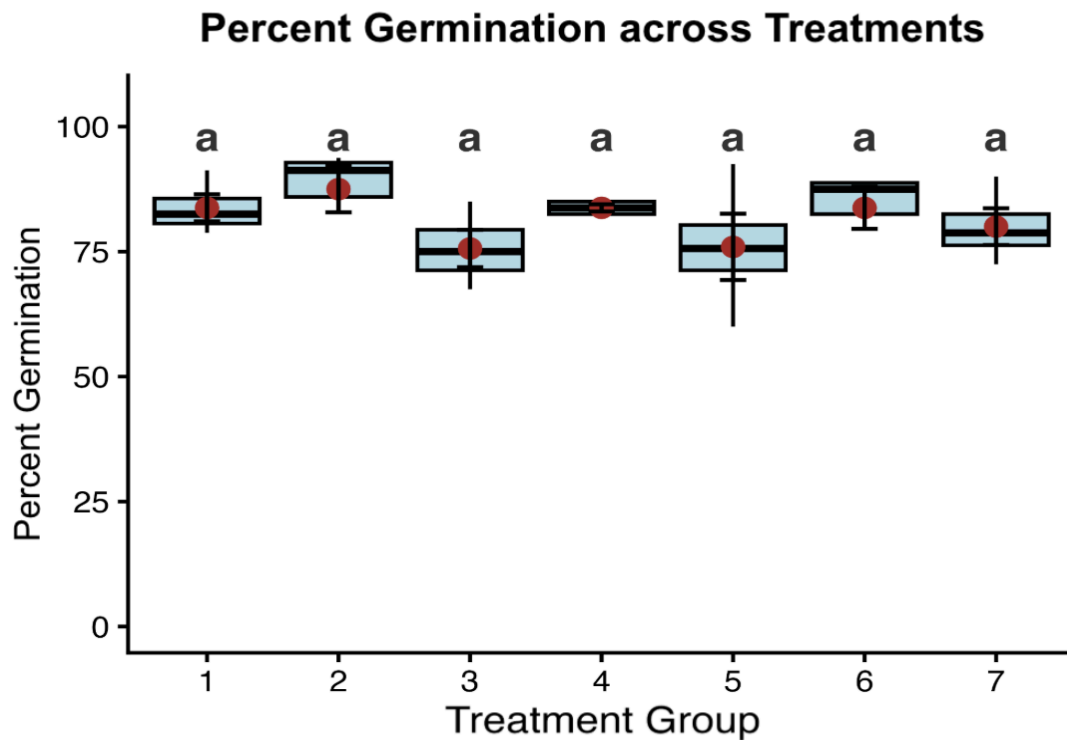


Figure 5. Boxplots of percent germination with mean and error bars overlaid. The same letter indicates no significant difference between treatment groups.

Percent Germination was recorded multiple times throughout the growing season, with the most recent data collected on 7/16/2026. The ANOVA Test for percent germination produced a $\text{Pr}(> \text{Chisq}) = 0.3214$, indicating no significant differences among treatment groups. Figure 5 depicts the distribution of percent germination among the treatment groups with the mean and error bars overlaid, confirming the null result.

Discussion

The significant differences in height provide insights into the combinations of soil amendments and top dressings that may enhance crop height. Crops in Treatment 2 (Gene's starter mix + conventional) were significantly taller than crops in the worst-performing groups:

Treatment 1 (blank control) and Treatment 3 (Pine char + Urine). The results indicate that pine char combined with urine limits crop growth when compared to the conventional treatment. The absence of a significant difference between treatments using conventional top dressing and treatments 6 (Biochar + Urine) and 7 (BUF+ + Potash + Bone char) indicates that processed urine as a top dressing is a viable alternative to conventional top dressings with regard to crop height. Additionally, the absence of significant differences between treatments 2, 6, and 7 indicates that the circular soil amendments in these treatments are viable alternatives to Gene's Starter Mix. Hence, the results indicate that urine as a top dressing, biochar, and the combination of BUF+ + Potash + Bone char affect corn height similarly to Gene's Starter Mix with conventional top dressing.

Further investigation into harvest yield is currently being undertaken. Along with yield, further investigation may focus on a diversity of crops to control for species-specific interactions with soil amendments and top dressings and a diversity of climates to control for environmental interactions with soil amendments.

Conclusion

The results obtained during the 2026 Laidlaw Research Summer Experience support the use of urine as a top dressing in combination with the circular soil amendments biochar and the combination of BUF+ + Potash + Bone char as alternatives to the non-circular conventional soil amendment Gene's Starter Mix and conventional top dressing. Ultimately, these results support adopting circular fertilizers on open-field small farms, the world's most common agricultural system, which has the potential to mitigate nutrient runoff into waterways, eliminate greenhouse

gases from synthetic fertilizer production, and protect public health by recycling biological waste.

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