

## **Original Research Article**

# **Accumulation and Potential Remediation of Copper in Golf Course Putting Greens**

---

### **ABSTRACT**

The objective of this study was to determine the potential accumulation of copper (Cu) within a USGA golf green profile and analyze potential remediation techniques of soils containing toxic Cu concentrations. Accumulation study utilized: copper phthalocyanine pigment (Par), copper hydroxide (Junction DF), varying concentrations of copper sulfate ( $\text{CuSO}_4$ ) within irrigation, and combinations of each. Products were applied over 13 weeks at Clemson University horticulture greenhouses with samples taken at thatch depth, 0-5.1 cm below thatch, and 5.1-10.2 cm below thatch at conclusion of study. Average Cu concentrations in thatch layer was  $634.7 \text{ kg Cu ha}^{-1}$ , with 0 - 5.1 cm and 5.1 - 10.2 cm depth concentrations of 11.26 and  $6.84 \text{ kg Cu ha}^{-1}$ , respectively. Remediation studies exposed 5 mg Cecil sandy loam to 15 ml 1000 ppm of  $\text{CuSO}_4$ -Cu followed by 4 sequential 20 ml filtration cycles of 1 N ammonium sulfate, 1 N calcium nitrate, 1 N gypsum, or water. Single filtration of ammonium sulfate removed similar or greater amount of Cu than cumulative impact of 4 filtrations of any other products with  $2064 \text{ mg Cu kg}^{-1}$ . Studies suggest that the management or removal of thatch may alleviate toxic accumulation of copper, however the use of ammonium sulfate in irrigation water may provide additional remediation options to turfgrass managers.

**Comment [u1]:** This study

Keywords: turfgrass; thatch; copper toxicity; remediation; accumulation; adsorption.

**Comment [u2]:** Use comma (,) instead of semicolon (;). E.g. turfgrass, thatch,....

## 1. INTRODUCTION

Hybrid bermudagrass [*Cynodondactylon* (L.) Pers. x *C. transvaalensis* Burt-Davy] is the most commonly used warm-season turfgrass in the southeastern United States in both sports turf and golf course turf areas due to its ability to withstand high temperature and humidity associated with the climate as well as its aggressive rhizomatous and stoloniferous growth habits allowing for very low mowing heights (3.2 – 4 mm) and relatively quick turf recovery, if damaged (1). As a  $C_4$  plant, bermudagrass experiences a state of dormancy normally associated with consistent temperatures below 10°C in which the plant ceases active growth and exhibits an aesthetically undesirable yellow to brown appearance (2). Applications of pigmented products, of which copper (Cu) is often a component, is common in high visibility locations in place of traditional overseeding practices (3). Copper is also used in fungicides and algaecides, often as copper sulfate ( $CuSO_4$ ) or copper hydroxide ( $Cu(OH)_2$ ), due its ability to denature proteins and enzymes in fungi. The use of Cu in agriculture can be traced back to 1885 in Bordeaux, France in vineyards to prevent downy mildew development. The continued use of Cu-based fungicides is the largest contributor of soil Cu in the agriculture industry (4).

**Comment [u3]:** Use square bracket throughout [ ]

**Comment [u4]:** [ ]

**Comment [u5]:** [ ]

**Comment [u6]:** [ ].

Healthy turfgrass leaves typically contain Cu between 5 to 38 ppm depending on grass species. Toxicity symptoms can develop at 20 to 30 ppm Cu (5-6). Due, in large part, to its oxidation-reduction potential, Cu is required for specific enzymatic conversions of amino acids to proteins, cell wall metabolism, electron transport, along with other processes. Excessive Cu cycling can lead to creation of free radicals via Fenton reactions, damaging plant structures (7-8). Weekly foliar applications of 250 ppm Cu have been reported to reduce turf quality in as few as 28 days (9).

**Comment [u7]:** [ ]

**Comment [u8]:** [ ]

**Comment [u9]:** [ ]

In soils, Cu is adsorbed to charged surfaces of clay, and iron (Fe), aluminum (Al), and manganese (Mn) oxides using oxygen as an intermediary in these surface bonds (10).

Comment [u10]: []

Cupric copper ( $\text{Cu}^{2+}$ ) is absorbed by roots either individually in solution or as a component in natural or synthetic complexes. Absorption is greatly affected by Cu immobility associated with increases in soil pH, cation exchange capacity (CEC), and percentage of organic content (11). When exposed to the equivalent of  $50 \text{ kg Cu ha}^{-1}$  followed by eight soil pore volume replacements of water, some Florida soils yielded less than 3% of total Cu in leachate. Further research indicated up to 98% of total Cu remained in the upper 5 cm of soil columns for those containing a greater percentage of organic matter (12). Decreases in bentgrass (*Agrostis palustris* L.) dry clipping weight and root mass were reported when Cu levels in soil were increased from 0 to  $600 \text{ mg kg}^{-1}$  (13).

Comment [u11]: []

Comment [u12]: []

Comment [u13]: italicise

Comment [u14]: []

Accumulation of various ions to toxic levels and buildup of organic and inorganic substrates are longstanding issues faced by turfgrass managers, with concerns of excessive soil salinity, pH, and thatch management being commonplace (2). When tackling issues of salinity, whether caused by poor irrigation water quality, natural soil occurrence, or product applications, organic substrates including humic acid and calcium-containing products such as gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) have been evaluated for ability to improve turfgrass quality. These materials also have been examined for their role in flushing and/or binding metallic salts such as sodium chloride which otherwise may cause soil dispersion (14-16).

Comment [u15]: []

Comment [u16]: []

The removal of thatch by the processes of verticutting, fraze mowing, or hollow tine aerification is a common practice by turfgrass managers striving to maintain a thin layer of living and dead stems, leaves, and roots of grass between the actively growing shoots of grasses and the soil surface (17). Danneberger and Turgeon (18) reported core cultivation and vertical mowing could reduce the overall content of a thatch layer while causing an increase in the overall cation exchange capacity (CEC) on a per volume basis.

Comment [u17]: []

Comment [u18]: []

Studies were conducted at Clemson University, Clemson SC, to assess zones of Cu accumulation in a bermudagrass USGA specification putting green, and to evaluate various products ability to remove Cu from the rootzone.

## 2. MATERIAL AND METHODS

Comment [u19]: MATERIALS

### 2.1. Copper Profile Accumulation.

TifEaglebermutagrass plugs (10 cm diameter x 10 cm deep) were removed from a two-year-old USGA-standard constructed green at the Clemson University Turfgrass Research Facility in Clemson, South Carolina (34.670682, -82.834950) and placed into a 100% sand rootzone meeting USGA particle size specifications contained within 15.24 cm diameter x 15.24 cm deep greenhouse pots. Turf was established for 3 weeks in the Clemson University greenhouse facility at a temperature of 23.9°C (75°F) until reaching 15 cm diameter and maintained at 1.3 cm height. Pots were then treated over the span of 13 weeks with varying species, compounds, and concentrations of Cu. Treatments consisted of an untreated control and various Cu-containing products, rates, and combinations (Table 1) with four pots per treatment being the replications. Due to the presence of mancozeb, a zinc, manganese, and nitrogen containing fungicide, in Junction DF, mancozeb (Fore 80WP) (Dow Agrosiences LLC., Indianapolis, IN) was applied at 2.29 kg ha<sup>-1</sup> (0.75 oz 1,000 ft<sup>2</sup>) to all plots not containing Junction DF as a treatment. Treatments of the commercial pigment Cu phthalocyanine (Par) (Harrell's LLC, Lakeland, FL) and copper hydroxide (Junction DF) (SePro Corporation, Carmel, IN) were applied at respective rates and timings via foliar application delivered at 187.3 L ha<sup>-1</sup>. Treatments of CuSO<sub>4</sub> (copper sulfate pentahydrate, LabChem, Zelienople, PA) were applied via 1-inch (2.54 cm) equivalents of irrigation water weekly.

**Table 1. Treatments and rates applied to 'TifEagle' hybrid bermudagrass**

Treatment <sup>†</sup>	Rate
Phthalocyanine pigment (Par)	1.17 L ha <sup>-1</sup> (0.37 oz 1,000 ft <sup>-2</sup> ) <sup>A</sup>
Par (2X)	1.17 L ha <sup>-1</sup> (0.37 oz 1,000 ft <sup>-2</sup> ) <sup>B</sup>
Copper hydroxide + mancozeb (Junction DF)	12.21 kg ha <sup>-1</sup> (4.0 oz 1,000 ft <sup>-2</sup> ) <sup>C</sup>
0.25 ppm CuSO <sub>4</sub>	0.25 mg CuSO <sub>4</sub> L <sup>-1</sup> B*
2.0 ppm CuSO <sub>4</sub>	2.0 mg CuSO <sub>4</sub> L <sup>-1</sup> B*
50 ppm CuSO <sub>4</sub>	0.05 g CuSO <sub>4</sub> L <sup>-1</sup> B*
100 ppm CuSO <sub>4</sub>	0.1 g CuSO <sub>4</sub> L <sup>-1</sup> B*
200 ppm CuSO <sub>4</sub>	0.2 g CuSO <sub>4</sub> L <sup>-1</sup> B*
Par + 0.25 ppm CuSO <sub>4</sub>	01.17 L ha <sup>-1</sup> (0.37 oz 1,000 ft <sup>-2</sup> ) <sup>A</sup> + 0.25 mg CuSO <sub>4</sub> L <sup>-1</sup> B*
Par + 2.0 ppm CuSO <sub>4</sub>	1.17 L ha <sup>-1</sup> (0.37 oz 1,000 ft <sup>-2</sup> ) <sup>A</sup> + 2.0 mg CuSO <sub>4</sub> L <sup>-1</sup> B*
Junction DF + 0.25 ppm CuSO <sub>4</sub>	12.21 kg ha <sup>-1</sup> (4.0 oz 1,000 ft <sup>-2</sup> ) <sup>C</sup> + 0.25 mg CuSO <sub>4</sub> L <sup>-1</sup> B*
Junction DF + 2.0 ppm CuSO <sub>4</sub>	12.21 kg ha <sup>-1</sup> (4.0 oz 1,000 ft <sup>-2</sup> ) <sup>C</sup> + 2.0 mg CuSO <sub>4</sub> L <sup>-1</sup> 1 B*
PAR + Junction DF	1.17 L ha <sup>-1</sup> (0.37 oz 1,000 ft <sup>-2</sup> ) <sup>A</sup> + 12.21 kg ha <sup>-1</sup> (4.0 oz 1,000 ft <sup>-2</sup> ) <sup>C</sup>
PAR + Junction DF + 0.25 ppm CuSO <sub>4</sub>	1.17 L ha <sup>-1</sup> (0.37 oz 1,000 ft <sup>-2</sup> ) <sup>A</sup> + 12.21 kg ha <sup>-1</sup> (4.0 oz 1,000 ft <sup>-2</sup> ) <sup>C</sup> + 0.25 mg CuSO <sub>4</sub> L <sup>-1</sup> B*
PAR + Junction DF + 2.0 ppm CuSO <sub>4</sub>	1.17 L ha <sup>-1</sup> (0.37 oz 1,000 ft <sup>-2</sup> ) <sup>A</sup> + 12.21 kg ha <sup>-1</sup> (4.0 oz 1,000 ft <sup>-2</sup> ) <sup>C</sup> + 2.0 mg CuSO <sub>4</sub> L <sup>-1</sup> B*

<sup>†</sup>All treatments not including Junction DF received mancozeb (Fore 80 WP) (Dow Agrosciences LLC., Indianapolis, IN) at a rate of 2.29 kg ha<sup>-1</sup> (0.75 oz 1,000 ft<sup>-2</sup>).

<sup>A</sup> Applied bi-weekly

<sup>B</sup> Applied weekly

<sup>C</sup> Three applications applied bi-weekly

\*Applied as 1-inch irrigation equivalent

At the conclusion of 13 weeks, 5 cores (2 cm diameter x 15 cm deep) were extracted from each pot and divided by depths: thatch (approximately 1.27 cm), 0 - 5.08 cm below thatch layer, and 5.09 – 10.16 cm below thatch layer. Cores were submitted to Clemson University Ag Services Laboratory for Cu concentration analysis using Mehlich I extractant.

## 2.2. Copper Remediation

Five g (approximately 4 ml) of a Cecil sandy loam were mixed with 15 ml of solution containing 1,000 ppm CuSO<sub>4</sub>-Cu within 50 ml test tubes at a constant rate of 180 oscillations per minute with 3-inch stroke for 24 hours. Contents were centrifuged at 1500 revolutions per minute for 1 hour. Supernatant was extracted and analyzed for Cu concentrations by Clemson University Agricultural Services Lab to develop an average concentration of adsorbed copper.

Soil in test tubes was then exposed to treatments consisting of 20 ml of tap water, 20 ml 1 N gypsum (CaSO<sub>4</sub>•2H<sub>2</sub>O) (SoftCal Pellets, Austinville Limestone Co., Austinville, VA), 20 ml 1 N calcium nitrate (Ca(NO<sub>3</sub>)<sub>2</sub>) (15.5-0-0) (Hi-Yield, Voluntary Purchasing Groups, Bonham, TX), and 20 ml 1 N ammonium sulfate ((NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>) (21-0-0) (Hi-Yield, Voluntary Purchasing Groups, Bonham, TX) (AMS). Soil and solutions were shaken for 5 minutes at a rate of 180 oscillations per minute with a 3-inch stroke and placed in a Damon/IEC HN-SII centrifuge (Thermo Scientific, Waltham, MA) at a rate of 1500 revolutions per minute for 1 hour. Supernatant was extracted for analysis. Soil samples were retreated with 20 ml of the same

**Comment [u20]:** Citation pls.

**Comment [u21]:** Whose method is this? Citation is needed.

solution they were initially treated with, shaken, centrifuged, and supernatant extracted 3 more times. Supernatants were analyzed for Cu concentration by Clemson University Agricultural Services Lab. All treatments had 4 soil sample replications.

### 2.3. Statistical Analysis

Studies were designed as two factor treatments and completely randomized. Greenhouse pot locations were rotated weekly to remove potential for localized microclimate impact. Due to high variability probability of soil chemical and physical characteristics within a given area as well the potential impact of Type II errors in environmental studies, analysis of soil samples was performed using 2-way Analysis of Variance and Fisher's Protected LSD ( $P=.10$ ) (19-20).

Comment [u22]: []

## 3. RESULTS AND DISCUSSION

### 3.1. Results

#### 3.1.1. Copper Profile Accumulation

Comment [u23]: Remove underline

Statistical differences were present between thatch and underlying soil depths with average Cu concentrations of 634.7, 11.26, and 6.842 kg ha<sup>-1</sup> for thatch, 0 – 5.08 cm, and 5.08 – 10.16 cm sampling intervals, respectively (Figure 1). This corresponds to a 58-100X increase in Cu between the predominantly organic thatch and the mineral component of the soil. Within each sampling interval, irrigation treatments containing 200 and 100 ppm CuSO<sub>4</sub> resulted in greater Cu accumulation than all other treatments. Within the thatch layer 200, 100, and 50 ppm CuSO<sub>4</sub> treatments were an order of magnitude greater than all other treatments, averaging 3763.9, 3274.6, and 1321.4 kg Cu ha<sup>-1</sup>, respectively. Samples from the 200 and 100 ppm treatments were statistically higher than 50 ppm. In 0 – 5.08 cm and 5.08 – 10.16 cm depth intervals below thatch layer, 200 ppm treatments were statistically

higher than 100 ppm (Figure 2). While 50 ppm was higher than all treatments except 200 and 100 ppm, it was not statistically greater than other treatments in intervals below thatch layer.

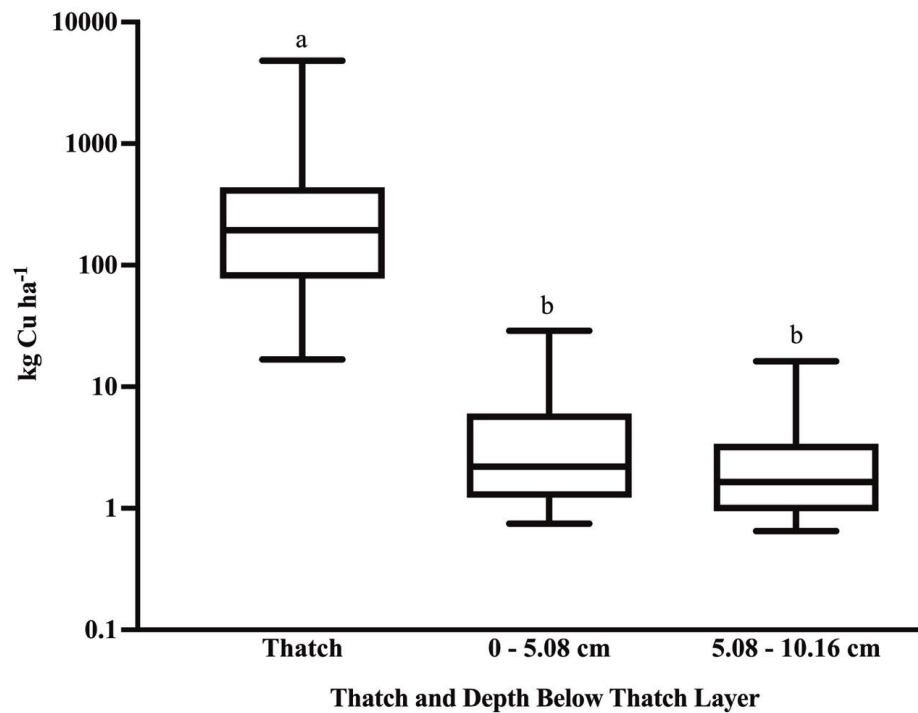


Fig. 1. Concentration of copper within subsurface layers following 13 weeks of treatments with various copper-containing products. Verticals lines represent 10 and 90 percentiles. Different letters indicate significant differences between treatments using Fishers Protected LSD ( $P=0.10$ )



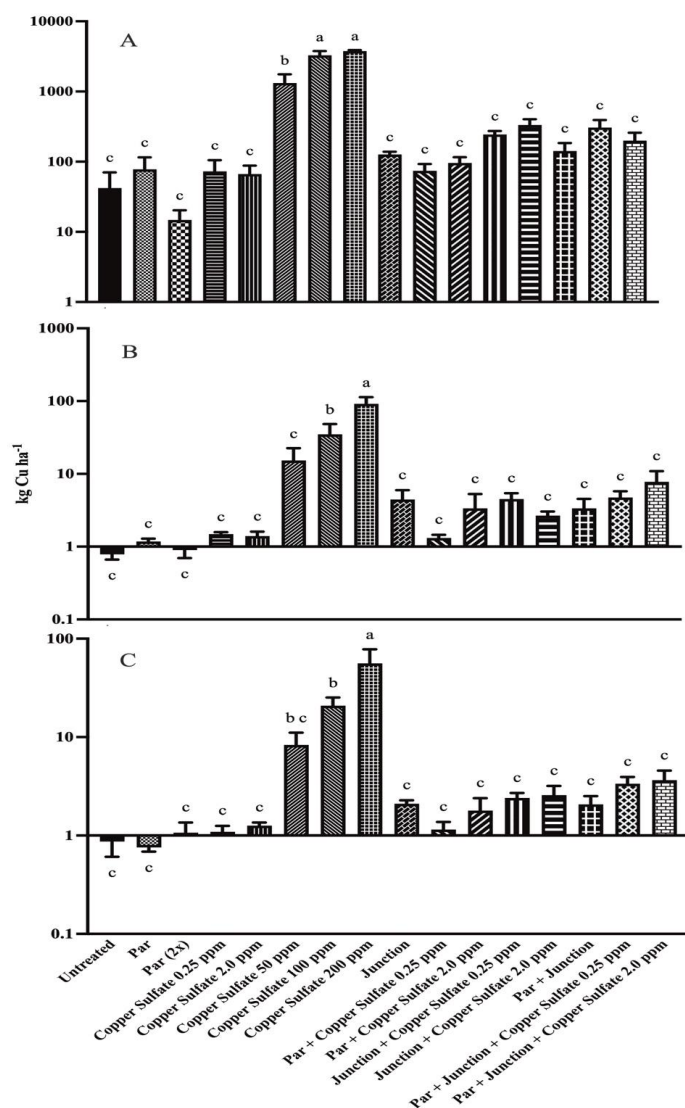


Fig. 2. Copper concentration of hybrid bermudagrass rootzone within (A) thatch layer (B) 0 – 5.08 cm below thatch layer (C) 5.08 – 10.16 cm below thatch layer after being exposed to copper-containing products. Vertical bars represent standard errors. Different letters indicate significant differences between treatments within depths using Fishers Protected LSD

( $P=10$ )

### **3.1. Copper Remediation**

**Comment [u24]:** Remove underline

Replacement treatments were analyzed by individual treatment filtration and cumulative impact of sequential filtrations. Individually, first filtration AMS resulted in the greatest concentration of Cu removed from soil, extracting an average  $2064 \text{ mg kg}^{-1}$  (Figure 3). First filtration  $\text{CaNO}_3$  was similar to first filtration  $\text{CaSO}_4$  removing  $958$  and  $715 \text{ mg kg}^{-1}$ , respectively. With the exception of water treatment, first filtrations resulted in the greatest amount of displaced Cu.

Ammonium sulfate resulted in the greatest cumulative impact removing  $2628$ ,  $2744$ , and  $2804 \text{ mg Cu kg}^{-1}$  after 2, 3 and 4 filtration cycles, respectively. These cumulative averages were statistically greater than all other treatments and their respective cumulative impact (Figure 4). A single filtration of AMS was statistically similar to all cumulative AMS amounts, and also to four filtrations of  $\text{CaSO}_4$ , and cumulative effect of three and four filtrations of  $\text{CaNO}_3$ . Water by itself resulted in the lowest Cu displacement with one filtration yielding  $496 \text{ mg kg}^{-1}$  of Cu, and four filtrations yielding a combined  $831 \text{ mg kg}^{-1}$ , approximately 43% of the predicted quantity of Cu added to the soil.

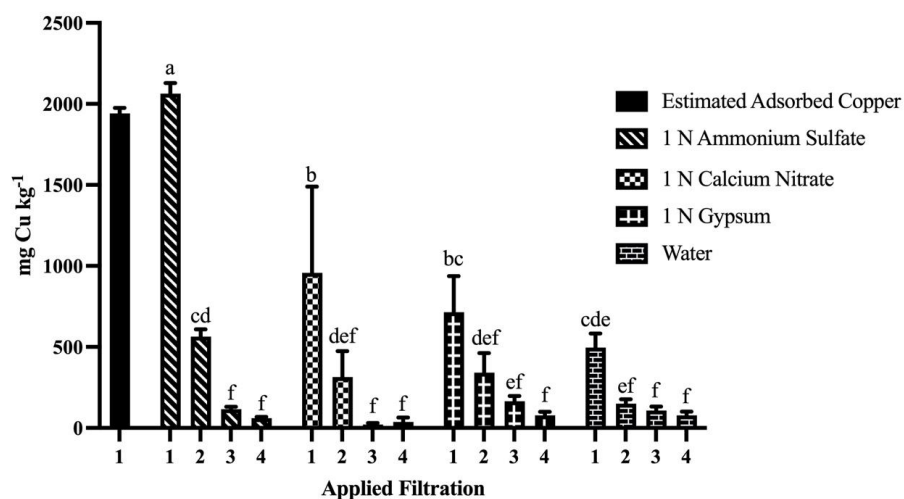


Fig. 3. Copper concentration of sequential filtration treatments to Cecil sandy loam previously exposed to 1000 ppm  $\text{CuSO}_4\text{-Cu}$ . Vertical bars represent standard errors. Different letters indicate significant differences between treatments using Fishers LSD ( $P=0.10$ )

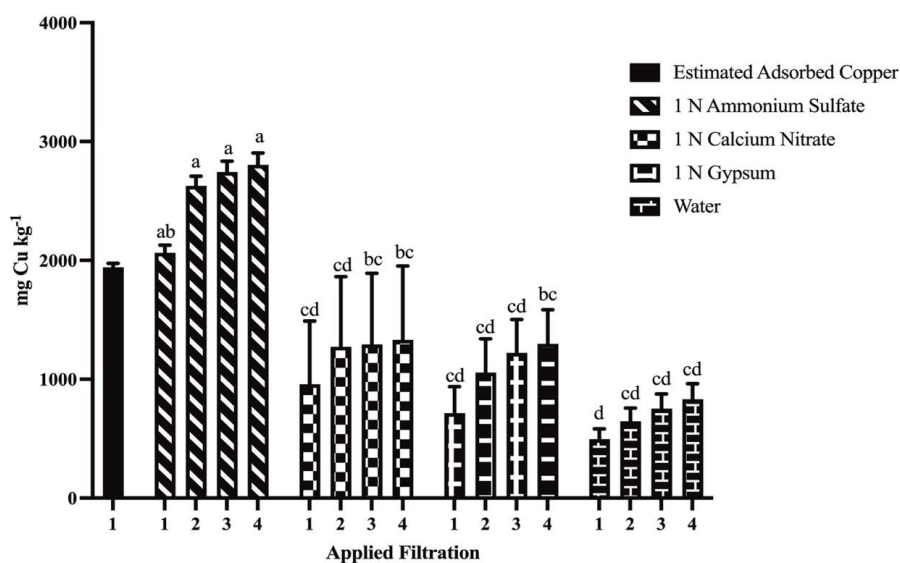


Fig. 4. Cumulative extracted copper concentration of sequential filtration treatments to Cecil sandy loam previously exposed to 1000 ppm  $\text{CuSO}_4\text{-Cu}$ . Vertical bars represent standard errors. Different letters indicate significant differences between treatments using Fishers LSD ( $P=0.10$ )

### 3.2. Discussion

Elevated levels of Cu within the thatch layer are consistent with similar findings in vineyards where Cu concentrations were highest in soil profiles with high organic matter content (21-22). Thatch is a collection of dead and decaying organic material, which provides many potential preferred negative binding sites for Cu. Below the thatch layer within a golf green built to USGA specifications, there is potential for other binding sites depending on use of organic substrates such as peat moss during construction process; however, pure sand greens lack this organic material, thus, Cu adsorption in these situations is reliant on various organic compound complexes (22). Results from this study indicate the thatch layer should

Comment [u25]: []

Comment [u26]: []

be the part of the rootzone turfgrass managers should focus on when trying to remediate effects of excess Cu.

Of particular interest is the efficacy of AMS compared to that of products containing calcium in removing Cu. Lyotropic series suggest that divalent calcium should be more apt in removal of  $\text{Cu}^{2+}$ , however the acidification of solution corresponding with AMS compared to that of  $\text{CaNO}_3$  or  $\text{CaSO}_4$  likely encourages increased solubility and disassociation of Cu from soil. With AMS providing potential Cu displacement from soil profiles, turf managers may have a viable option for removal of Cu. More evaluation is needed to determine minimum necessary amount of AMS required for efficient removal of Cu to avoid unwanted fertility or phytotoxic effects associated with excess soluble nitrogen fertilizer. There is a potential for turfgrass managers to incorporate AMS into their fertility program to remediate high levels of Cu plus provide a nitrogen source. Gypsum is not a source of nitrogen providing an alternative with minimum impact to turfgrass fertility programs; however, it is not as effective at removing Cu as AMS. Additionally, water carrier volume must be evaluated to assess the necessary volume of water for displacement.

**Comment [u27]:** I suggest that, the researcher should look for more relevant works to support the findings of this study.

#### 4. CONCLUSION

As a result of its potential adsorption of excessive levels of Cu, management practices aimed at reduction of the thatch layer such as hollow tine aerification, fraze mowing, and vertical mowing, may also result in reduction of Cu in soil profile. Aggressive aerification has been reported to reduce thatch content by approximately 10% (17). These practices can be impractical for golf course superintendents and other turf managers at times due to the potential temporary damage to a facility's aesthetics and playability. In situations where mechanical removal is impractical or rootzones contain higher percentages of clay particles, the use of AMS may serve as an alternative to aid in flushing heavy metals from turfgrass rootzones in practice similar to salinity flushing.

Continued research is needed to evaluate Cu absorption dynamics in dormant grasses to determine critical thresholds prior to plant death. Further research should build upon the potential use of AMS to aid in removal of Cu ions from soil profiles by investigating the minimum required AMS to avoid turfgrass damage in addition to irrigation water volume necessity

## REFERENCES

1. Turgeon AJ. Turfgrass management. 8th ed. Upper Saddle River (NJ): Pearson/Prentice Hall; 2008.
2. McCarty LB. Best golf course management practices. 3rd ed. Upper Saddle River (NJ): Pearson/Prentice Hall; 2018.
3. Shearman RC, Wit LA, Severmutlu S, Budak H, Gaussoin RE. Colorant effects on dormant buffalograss turf performance. American Society Horticulture Science. 2005;15:244-246.
4. McBride M, Tiller K, Merry R. Copper in soils and plants. Sydney: Academic Press; 1981.
5. Robson AD, Reuter DJ. Diagnosis of copper deficiency and toxicity. In: Loneragen JF, Robson AD, Graham RD, editors. Copper in soils and plants. London: Academic Press; 1981.
6. Jones Jr JB. Turf analysis. Golf Course Management. 1980;48(1):29-32.
7. Printz B, Lutts S, Hausman JF, Sergeant K. Copper trafficking in plants and its implication on cell wall dynamics. Front Plant Sci. 2016;7:601.
8. Yruela I. Copper in plants: acquisition, transport and interactions. Functional Plant Biology. 2009;36:409-430.
9. Gore A, McCarty LB, Brown P. Heavy metals effects on warm-season turfgrass golf greens. Golf Course Management. 2021;89(4):68-72.

10. Mitra GN. 2015. Copper (Cu) uptake. In: Regulation of nutrient uptake by plants. New Delhi: Springer; 2015.
11. Havlin JL, Tisdale SL, Nelson WL, Beaton JD. Soil fertility and fertilizers: an introduction to nutrient management. 7<sup>th</sup> ed. Upper Saddle River (NJ): Prentice Hall; 2005.
12. Sun, Li T, Alva AK, Li YC. Mobility and fractionation of copper in sandy soils. Environmental Pollutants & Bioavailability. 2019;31(1), 18–23.
13. Faust MB, Christians NE. AB-DTPA and Mehlich III soil tests unable to predict copper available to creeping bentgrass. Communications in Soil Science and Plant Analysis. 1999;30(17-18), 2475–2484.
14. Bello SK, Alayafi AH, AL-Solaimani SG, Abo-Elyousr KAM. Mitigating soil salinity stress with gypsum and bio-organic amendments: a review. Agronomy. 2021;11(9):1735
15. Rahayu R, Mo YG, Soo CJ. Amendments on salinity and water retention of sand base rootzone and turfgrass yield. Sains Tanah Soil Science Agroclimatology. 2019;16(1):103-111.
16. Sekar S. Efficacy of salinity mitigation on warm season turfgrasses. Thesis of Degree of Master of Science, Cornell University. 2016
17. Atkinson JL, McCarty LB, Bridges WC. Effect of core aerification frequency, area impacted, and topdressing rate on turf quality and soil physical properties. Agronomy. 2012;104(6):1710-1715.
18. Danneberger TK, Turgeon AJ. Soil cultivation and incorporation effects on the edaphic properties of turfgrass thatch. Journal of the American Society for Horticultural Science. 1986;111(2): 184-186.
19. Pennock DJ. Designing field studies in soil science. Canadian Journal of Soil Science. 2004;84(1):1-10.

20. Peterman RM. Statistical power analysis can improve fisheries research and management. Canadian Journal of Fisheries and Aquatic Sciences. 1990;47(1): 2-15.
21. Sonoda K, Hashimoto Y, Wang SL, Ban T. Copper and zinc in vineyard and orchard soils at millimeter vertical resolution. The Science of the Total Environment. 2019;689,958–962.
22. Duplay J, Semhi K, Errais E, Imfeld G, Babcsanyi I, Perrone T. Copper, zinc, lead and cadmium bioavailability and retention in vineyard soils (Rouffach, France): The impact of cultural practices. Geoderma. 2014;230-231,318–328.

**Comment [u28]:** Use Square bracket when numbering the references, as it is in the Text (citation).  
E.g. [1]. Turgeon AJ