# Supplemental Information: Alkaline Mineral Residues from Pulp Mills as a Sustainable and Economical Alternative to Lime Fertilizers

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## Methods

### Soil Collection and Preparation

To identify these soil types, we combined mapped soil classification data(Cook et al., 2024) with recent satellite-derived maps of existing cotton fields (USDA, 2020) and managed pine stands (Thomas et al., 2021) across the southeastern US. We ranked each soil type by the total acreage of cotton or loblolly each hosted and selected the top 100 soil types for each crop (out of approximately 42,000 unique soil types present in the southeastern US). After excluding soil types with an average pH > 6 (Soil survey staff, 2020), we searched for qualifying top-100 soil types within up to approximately 100 miles of any of the identified pulp mills, then contacted landowners managing either cotton or plantation pine covering any of these soil types to arrange for site access and sample acquisition.

### Life Cycle and Techno-Economic Analysis

$$\frac{g\ of\ carbonate}{g\ of\ metal} = molar\ mass\ of\ carbonate\left(\frac{g}{mol}\right) * \frac{1\ mole\ of\ carbonate}{\#\ moles\ of\ metal\ in\ carbonate} * \frac{1\ mol\ of\ metal}{mass\ of\ 1\ mol\ of\ metal\ (} \quad (S1)$$

$$\frac{mass\ of\ carbonate\ (g)}{mass\ of\ DG\ (g)} = Mass\ fraction\ of\ metal\ in\ DG\ (\%) * \frac{mass\ of\ carbonate\ (g)}{mass\ of\ metal\ (g)} \quad (S2)$$

$$\frac{mass\ of\ CO_2\ (g)}{mass\ of\ DG\ (g)} = \frac{mass\ of\ carbonate\ (g)}{mass\ of\ DG\ (g)} * \frac{molar\ mass\ of\ CO_2\left(\frac{g}{mol}\right)}{molar\ mass\ of\ carbonate\left(\frac{g}{mol}\right)} \quad (S3)$$

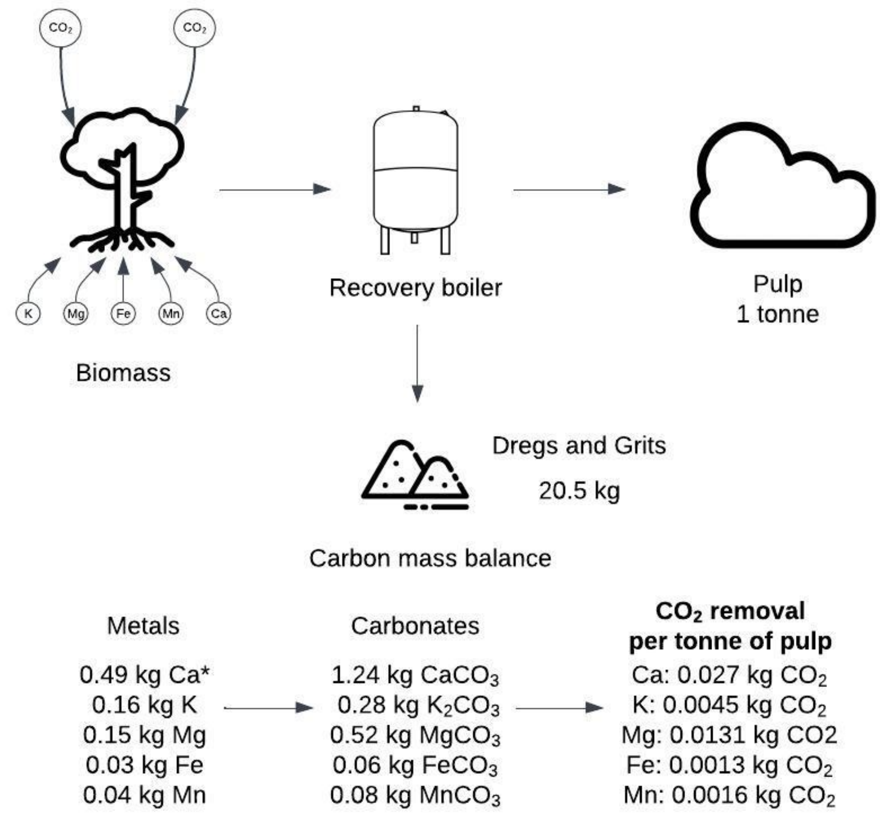


**Figure S1. Process flow diagram and mass balance of carbon within dregs and grits**

For every 1 tonne of pulp produced, 20.5 kg of DGs are produced as byproduct. Within the DGs, a certain percentage of the mass is made up of metals that are capable of forming carbonates in the recovery boiler, namely calcium, potassium, magnesium, iron, and manganese. Using the mass of metals in the DGs, the mass of their respective carbonates, and the ratio of the molar mass of $CO_2$ to the molar mass of carbon, we were able to calculate the mass of $CO_2$ that is drawn down for every tonne of pulp or DGs produced (Figure S1). For calcium, several additional steps (shown in equations S4-S5) were taken to calculate the calcium that originates in tree biomass as opposed to the mineral $CaCO_3$ used in the pulping process.

$$\frac{CaO\ in\ pine\ biomass}{K_2O\ in\ pine\ biomass} = Ash\ content\ of\ pine\ chips\ (\%) * \frac{Mass\ fraction\ of\ CaO\ (\%)}{Mass\ fraction\ of\ K_2O\ (\%)}\ (S4)$$

$$\frac{Mass\ of\ Ca\ from\ biomass\ in\ DG\ (g)}{1\ g\ of\ K\ in\ DG} = \frac{CaO\ in\ pine\ biomass}{K_2O\ in\ pine\ biomass} * \frac{Molar\ mass\ of\ Ca\left(\frac{g}{mol}\right)}{Molar\ mass\ of\ CaO\left(\frac{g}{mol}\right)} * \frac{Molar\ mass\ of\ K_2O\left(\frac{g}{mol}\right)}{Molar\ mass\ of\ K\left(\frac{g}{mol}\right)} \quad (S5)$$

The mass fraction of the carbonates within the ash content of trees was used in order to determine the amount of calcium relative to the other previously mentioned metals (Vassilev et al., 2010). Using this ratio, the mass fraction of $Ca^{2+}$ within DGs that originated in the tree biomass can be calculated which enabled us to repeat equations S4-S5 to finish off the carbonate mass balance and resulting levelized $CO_2$ removal. Following the calculation of the $CO_2$ drawdown attributed to DGs, the emissions released by preparing DGs for soil application were then modeled.

We assumed a transport distance of 50 miles to the agricultural fields, and the emissions of the trucks returning to the pulp mill are accounted for. The cost of the industrial crusher was calculated based on the amount of DGs processed per year (Breunig et al., 2024). The cost of the dryer was based on an industry quote (FEECO International, 2025). The plant utilization, indirect capital costs, capital cost contingency, return on equity, project life, and capital recovery factor were chosen based on standards found in industry and literature (Humbird et al., 2011; Keith et al., 2018; Pett-Ridge et al., 2023). The overall costs of the proposed system were calculated using equations S6 – S12 listed below. The inputs required are capital recovery factor, facility utilization, return on equity, capital costs, and operating costs.

$$Levelized\ cost\ of\ DG\ production = net\ operating\ cost + levelized\ capital\ cost\ (S6)$$

$$Levelized\ capital\ cost = capital\ intensity \times \frac{capital\ recovery\ factor}{biorefinery\ utilization} (S7)$$

$$Capital\ intensity = \frac{total\ capital\ cost}{CO_2\ capacity} (S8)$$

$$Total\ capital\ cost = direct\ capital\ cost + indirect\ capital\ cost + contingency\ cost\ (S9)$$

$$Direct\ capital\ cost = \sum_i reference\ cost\ of\ equipment\ or\ material_i \times \left(\frac{cost\ year\ index_i}{reference\ index_i}\right) \times\times\ instal$$

$$Capital\ recovery\ factor = \frac{weighted\ average\ cost\ of\ capital\ (i) \times\ (i+1)^{project\ life}}{(1+i)^{project\ life} - 1} (S11)$$

$$Weighted\ average\ cost\ of\ capital\ (i) = (return\ on\ equity\ \times\ equity\ financing\ (\%)) + (interest\ on\ debt\ \times\ debt\ financing)\ (S12)$$

**Material Characterization**

X-Ray diffraction (XRD) was used to identify the diffraction patterns of the various materials, specifically the DGs to compare to calcite. A PANalytical Empyrean X-ray diffractometer was used for data collection in the 2Θ range of 10° - 80°. Diffraction was scanned at 0.1313-degree intervals. Scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy (EDS) was used for elemental analysis and backscattered electron images. A variable pressure Hitachi SU3900 at a voltage of 20 kV and a resolution of 4.0 nm was used for SEM imaging. The North Carolina Department of Agriculture (NCDA) analyzed the 22 soils using a Mehlich-3 soil extraction test which provided information on common nutrients such as phosphorus and calcium, heavy metals such as arsenic and nickel, and chemical properties including cation exchange capacity and base saturation. The NCDA also provided nutrient measurements, chemical properties, and heavy metals content of the DGs.

| Plot | State Name | Recent Crop | Number of Buckets | W/V | HM | CEC | p H | BS | Bp H | Ac |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | g/cc | % | meq/100cc | | % | | meq/100cc |
| AL_1 | Alabama | Either winter wheat or rye, previous crop was cotton | 4 | 1.36 | 0.41 | 5.3 | 5.9 | 76 | 6.29 | 1.2 |
| AL_2 | Alabama | Grass and cotton both | 2 | 1.42 | 0.36 | 3.7 | 5.7 | 72 | 6.34 | 1 |
| GA_1 | Georgia | Cotton | 2 | 1.54 | 0.36 | 3.6 | 6.3 | 83 | 6.45 | 0.6 |
| GA_2 | Georgia | Cotton | 4 | 1.54 | 0.46 | 4.2 | 6.1 | 83 | 6.42 | 0.7 |
| LA_1 | Louisiana | clover (cover), but recently had cotton in cotton-corn-pea nut rotation | 2 | 1.29 | 0.71 | 7.6 | 6.6 | 93 | 6.46 | 0.6 |
| MF_1 | Georgia | Loblolly | 2 | 1.09 | 2.92 | 6.8 | 4.4 | 23 | 5.29 | 5.2 |
| PC_10 | Alabama | Loblolly | 2 | 0.98 | 0.81 | 4.4 | 4.5 | 18 | 5.71 | 3.6 |
| PC_3 | Louisiana | Loblolly | 2 | 1.08 | 0.51 | 12.7 | 6.4 | 90 | 6.28 | 1.3 |
| PC_5 | Arkansas | Loblolly probably (based on aerial) - clearcut right now | 2 | 1.18 | 0.22 | 5.2 | 4.8 | 52 | 5.98 | 2.5 |
| PC_9 | Alabama | Loblolly | 2 | 1.24 | 0.09 | 4 | 5.1 | 57 | 6.18 | 1.7 |
| RW_19 | Louisiana | Loblolly | 4 | 1.41 | 0.86 | 4.1 | 4.6 | 31 | 5.89 | 2.8 |
| RY_1 | Georgia | Loblolly | 4 | 1.46 | 1.14 | 5.9 | 3.4 | 12 | 5.3 | 5.2 |
| RY_2 | Georgia | Loblolly | 2 | 1.27 | 1.61 | 6.6 | 3.3 | 14 | 5.17 | 5.7 |
| TR_1 | Georgia | Loblolly | 2 | 1.36 | 0.46 | 4.2 | 4.8 | 52 | 6.1 | 2 |
| TR_10 | Arkansas | Loblolly | 2 | 1.25 | 0.32 | 5.9 | 4.8 | 66 | 6.09 | 2 |
| TR_11 | Texas | Loblolly | 4 | 1.19 | 0.32 | 9.4 | 4.9 | 74 | 6 | 2.4 |
| TR_2 | Georgia | Loblolly | 2 | 1.27 | 0.32 | 4 | 5.4 | 67 | 6.27 | 1.3 |
| TR_3 | Alabama | Loblolly | 4 | 1.47 | 0.41 | 2.7 | 4.9 | 52 | 6.27 | 1.3 |
| TR_4b | Alabama | Loblolly | 2 | 1.42 | 0.46 | 2.4 | 5.1 | 44 | 6.26 | 1.4 |
| TR_4g | Alabama | Loblolly | 2 | 1.39 | 0.51 | 3.5 | 5.3 | 59 | 6.24 | 1.4 |
| TR_5 | Alabama | Loblolly | 2 | 1.4 | 0.51 | 2.8 | 4.5 | 24 | 6.07 | 2.1 |
| TR_7 | Mississippi | Sweetgum | 2 | 1.05 | 1.25 | 3.8 | 4.6 | 27 | 5.91 | 2.8 |

| Plot | State Name | Recent Crop | Ca | Mg | P | K | S | Zn | Cu | Mn | Na |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ---mg/dm-3--- | | | | | | | | |
| AL_1 | Alabama | Either winter wheat or rye, previous crop was cotton | 580 | 109 | 48 | 111 | 21 | 2.52 | 1.36 | 156 | 7 |
| AL_2 | Alabama | Grass and cotton both | 360 | 61 | 91 | 145 | 12 | 2.4 | 2.68 | 95 | 10 |
| GA_1 | Georgia | Cotton | 420 | 49 | 82 | 180 | 7 | 3.88 | 0.46 | 31 | 8 |
| GA_2 | Georgia | Cotton | 500 | 61 | 83 | 170 | 11 | 4.6 | 0.76 | 33 | 10 |
| LA_1 | Louisiana | clover (cover), but recently had cotton in cotton-corn-pea nut rotation | 1180 | 85 | 84 | 184 | 8 | 2.84 | 1.06 | 63 | 10 |
| MF_1 | Georgia | Loblolly | 220 | 49 | 14 | 57 | 22 | 4.64 | 0.22 | 4 | 19 |
| PC_10 | Alabama | Loblolly | 100 | 24 | 5 | 39 | 15 | 0.64 | 0.36 | 2 | 9 |
| PC_3 | Louisiana | Loblolly | 1780 | 243 | 13 | 207 | 10 | 5 | 1.2 | 501 | 19 |
| PC_5 | Arkansas | Loblolly probably (based on aerial) - clearcut right now | 380 | 85 | 12 | 70 | 11 | 1.96 | 1.06 | 32 | 10 |
| PC_9 | Alabama | Loblolly | 300 | 73 | 2 | 41 | 22 | 0.44 | 0.4 | 60 | 9 |
| RW_19 | Louisiana | Loblolly | 180 | 24 | 5 | 31 | 8 | 0.92 | 0.34 | 41 | 9 |
| RY_1 | Georgia | Loblolly | 80 | 24 | 19 | 37 | 7 | 0.68 | 0.08 | 2 | 14 |
| RY_2 | Georgia | Loblolly | 80 | 49 | 6 | 35 | 5 | 1.64 | 0.08 | 1 | 20 |
| TR_1 | Georgia | Loblolly | 340 | 49 | 17 | 35 | 9 | 0.6 | 0.22 | 20 | 7 |
| TR_10 | Arkansas | Loblolly | 600 | 85 | 6 | 61 | 8 | 1.56 | 0.42 | 25 | 9 |
| TR_11 | Texas | Loblolly | 1080 | 158 | 6 | 82 | 16 | 1.08 | 1.22 | 265 | 21 |
| TR_2 | Georgia | Loblolly | 380 | 73 | 5 | 68 | 9 | 0.44 | 0.4 | 194 | 8 |
| TR_3 | Alabama | Loblolly | 220 | 36 | 32 | 39 | 7 | 1.32 | 0.26 | 34 | 9 |
| TR_4b | Alabama | Loblolly | 180 | 12 | 5 | 29 | 9 | 0.4 | 0.36 | 106 | 8 |
| TR_4g | Alabama | Loblolly | 340 | 36 | 7 | 29 | 7 | 1.8 | 0.48 | 143 | 7 |
| TR_5 | Alabama | Loblolly | 100 | 12 | 7 | 20 | 10 | 0.84 | 0.34 | 17 | 9 |
| TR_7 | Mississippi | Sweetgum | 120 | 36 | 8 | 47 | 30 | 0.92 | 1.1 | 13 | 19 |

| Plot | State Name | Recent Crop | As ppm | Cd ppm | Cr ppm | Ni ppm | Pb ppm | Se ppm |
|---|---|---|---|---|---|---|---|---|
| AL_1 | Alabama | Either winter wheat or rye, previous crop was cotton | 0.6 | BDL | 0.2 | 0.13 | 5.8 | 0.1 |
| AL_2 | Alabama | Grass and cotton both | 0.2 | BDL | 0.2 | 0.12 | 3.5 | BDL |
| GA_1 | Georgia | Cotton | 0.8 | 0.1 | 0.2 | 0.13 | 2.8 | BDL |
| GA_2 | Georgia | Cotton | 0.6 | BDL | 0.2 | 0.13 | 4.1 | 0.1 |
| LA_1 | Louisiana | clover (cover), but recently had cotton in cotton-corn-pea nut rotation | 0.9 | 0.1 | 0.2 | 0.51 | 2.2 | 0.1 |
| MF_1 | Georgia | Loblolly | 0.1 | 0.1 | 0.1 | 0.31 | 5.0 | 0.1 |
| PC_10 | Alabama | Loblolly | 0.1 | BDL | 0.3 | 0.15 | 3.4 | 0.1 |
| PC_3 | Louisiana | Loblolly | 0.2 | 0.2 | 0.1 | 2.16 | 3.7 | 0.3 |
| PC_5 | Arkansas | Loblolly probably (based on aerial) - clearcut right now | 0.1 | BDL | 0.2 | 0.42 | 4.8 | BDL |
| PC_9 | Alabama | Loblolly | 0.1 | BDL | 0.2 | 0.09 | 3.0 | 0.2 |
| RW_19 | Louisiana | Loblolly | 0.1 | BDL | 0.1 | 0.19 | 4.0 | 0.1 |
| RY_1 | Georgia | Loblolly | BDL | BDL | BDL | 0.14 | 1.2 | BDL |
| RY_2 | Georgia | Loblolly | BDL | BDL | BDL | 0.13 | 1.0 | BDL |
| TR_1 | Georgia | Loblolly | 0.1 | BDL | 0.1 | 0.22 | 3.1 | BDL |
| TR_10 | Arkansas | Loblolly | 0.2 | 0.1 | 0.2 | 0.34 | 4.8 | 0.1 |
| TR_11 | Texas | Loblolly | 0.1 | BDL | 0.2 | 0.63 | 4.5 | 0.3 |
| TR_2 | Georgia | Loblolly | 0.2 | BDL | 0.2 | 0.12 | 3.7 | 0.1 |
| TR_3 | Alabama | Loblolly | 0.1 | BDL | 0.2 | 0.13 | 1.6 | 0.2 |
| TR_4b | Alabama | Loblolly | 0.1 | BDL | 0.2 | 0.15 | 2.7 | 0.1 |
| TR_4g | Alabama | Loblolly | 0.1 | BDL | 0.1 | 0.17 | 2.5 | 0.1 |
| TR_5 | Alabama | Loblolly | 0.1 | BDL | 0.2 | 0.15 | 1.9 | BDL |
| TR_7 | Mississippi | Sweetgum | 0.2 | BDL | 0.1 | 0.17 | 6.6 | 0.2 |

**Figure S2. North Carolina Department of Agriculture soil report data**

**Report Abbreviations**

| | |
|---|---|
| **Ac** | exchangeable acidity |
| **B** | boron |
| **BS%** | % CEC occupied by basic cations |
| **Ca%** | % CEC occupied by calcium |
| **CEC** | cation exchange capacity |
| **Cu-I** | copper index |
| **ESP** | exchangeable sodium percent |
| **HM%** | percent humic matter |
| **K-I** | potassium index |
| **$K_2O$** | potash |
| **Mg%** | % CEC occupied by magnesium |
| **MIN** | mineral soil class |
| **Mn** | manganese |
| **Mn-AI1** | Mn-availability index for crop 1 |
| **Mn-AI2** | Mn-availability index for crop 2 |
| **Mn-I** | manganese index |
| **M-O** | mineral-organic soil class |
| **N** | nitrogen |
| **Na** | sodium |
| **$NO_3$-N** | nitrate nitrogen |
| **ORG** | organic soil class |
| **pH** | current soil pH |
| **P-I** | phosphorus index |
| **$P_2O_5$** | phosphate |
| **S-I** | sulfur index |
| **SS-I** | soluble salt index |
| **W/V** | weight per volume |
| **Zn-AI** | zinc availability index |
| **Zn-I** | zinc index |

**Figure S3. North Carolina Department of Agriculture soil report abbreviations**

| | Nutrient Measurements (ppm) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Material** | **N** | **P** | **K** | **Ca** | **Mg** | **S** | **Fe** | **Mn** | **Zn** | **Cu** | **B** | **C** | **Al** | **Na** |
| Dregs | 443 | 1230 | 7910 | 299000 | 8840 | 10200 | 1430 | 2850 | 266 | 60.7 | 16.5 | 103000 | 2010 | 37200 |
| Dregs | 1070 | 1200 | 7190 | 315000 | 9210 | 12300 | 1400 | 3030 | 274 | 63.8 | 15.2 | 105000 | 2100 | 34400 |
| Grits | 992 | 2030 | 911 | 373000 | 3310 | 1320 | 1870 | 26.6 | 48.1 | 4.64 | 10.7 | 74200 | 5130 | 6630 |
| Grits | 833 | 1820 | 863 | 362000 | 3430 | 1280 | 2150 | 26.5 | 46.6 | 4.49 | 10.1 | 76500 | 4980 | 6500 |

| Material | SS (10^-5 S/cm | EC (mS/cm) | pH | CCE (%) | ALE (tons) | C:N | DM (%) |
|---|---|---|---|---|---|---|---|
| Dregs | 3450 | 34.5 | 12.63 | 93.9 | 0.96 | 232:1 | 99.8 |
| Dregs | 3550 | 35.5 | 12.54 | 94 | 0.96 | 97.4:1 | 99.9 |
| Grits | 1290 | 12.86 | 12.57 | 94.8 | 0.95 | 74.9:1 | 100 |
| Grits | 998 | 9.98 | 12.57 | 93.8 | 0.96 | 91.9:1 | 100 |

| | Heavy Metals (ppm) | | | | | |
|---|---|---|---|---|---|---|
| **Material** | **As** | **Cd** | **Cr** | **Ni** | **Pb** | **Se** |
| Dregs | 0.61 | 1.88 | 13 | 30 | 129 | 1.64 |
| Dregs | 0.67 | 1.98 | 13.1 | 31.2 | 9.07 | 1.7 |
| Grits | 0.87 | 0.01 | 5.31 | 6.51 | 0.47 | 0.18 |
| Grits | 0.79 | 0.01 | 5.3 | 6.83 | 0.27 | 0.13 |

**Figure S4. North Carolina Department of Agriculture waste report data for dregs and grits**

| | | | | |
|---|---|---|---|---|
| **ALE** is Agricultural Lime Equivalence. The ALE indicates the amount of the waste material that provides a limiting effect equivalent to one ton of agricultural grade limestone.<br>**BD** is Bulk Density in lb/yd³.<br>**CCE** is Calcium Carbonate Equivalence and is used to determine ALE.<br>**C:N ratio** is the Carbon:Nitrogen ratio. | **DM%** is percent Dry Matter [for semi-solid and solid waste, this value facilitates conversion of dry-basis concentrations (ppm) back to wet-basis of original sample].<br>**EC** (Electrical Conductivity) measures salinity, or soluble salts (SS).<br>**pH** measures basicity/acidity. | **Al** = Aluminum<br>**As** = Arsenic<br>**B** = Boron<br>**Ca** = Calcium<br>**Cd** = Cadmium<br>**Cl** = Chloride<br>**Cr** = Chromium | **Cu** = Copper<br>**Fe** = Iron<br>**K** = Potassium<br>**Mg** = Magnesium<br>**Mn** = Manganese<br>**Mo** = Molybdenum<br>**N** = Nitrogen<br>**Na** = Sodium | **$NH_4$-N** = Ammonium -N<br>**Ni** = Nickel<br>**$NO_3$-N** = Nitrate -N<br>**P** = Phosphorus<br>**Pb** = Lead<br>**S** = Sulfur<br>**Se** = Selenium |
| **meq/L** = milliequivalent per liter; **mS** = millisiemens; **ppm** = parts per million or mg/L; **S** = siemens; T = trace (<0.005 lb/unit) | | | | |

**Figure S5. North Carolina Department of Agriculture waste report abbreviations**

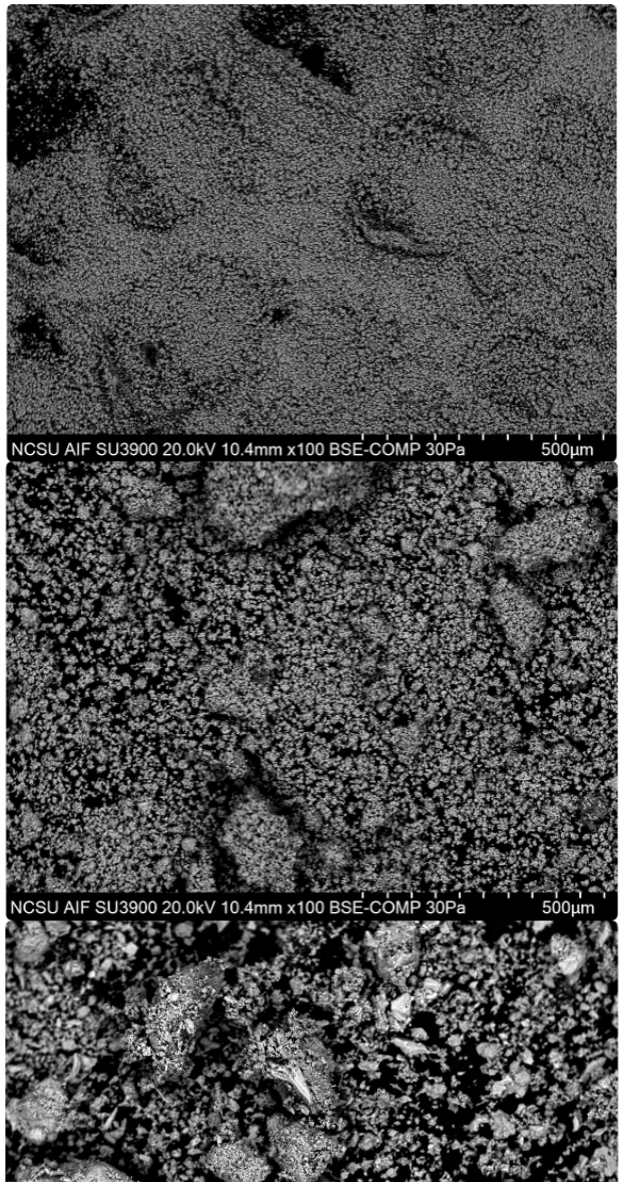


**Figure S6. Scanning electron microscopy images of calcite (top), dregs (middle), grits (bottom)**

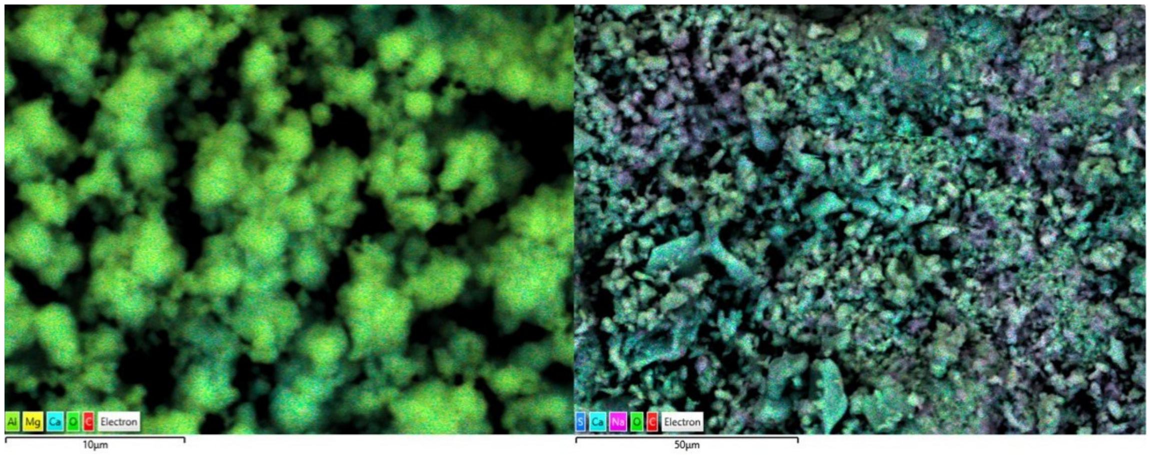


**Figure S7. SEM Results with elemental mapping for calcite (left) and grits (right)**

**Table S1. Heavy metal concentration of DGs and limits established by EPA for soil amendments**

| | Maximum allowable concentration of industrial solid waste applied to soil (ppm) (USDA, 2000) | Dregs (ppm) | Grits (ppm) |
|---|---|---|---|
| Arsenic | 75 | 0.64 | 0.83 |
| Cadmium | 85 | 1.93 | 0.01 |
| Chromium | 3000 | 13.1 | 5.31 |
| Nickel | 75 | 30.6 | 6.7 |
| Lead | 420 | 69 | 0.4 |
| Selenium | 100 | 1.69 | 0.16 |

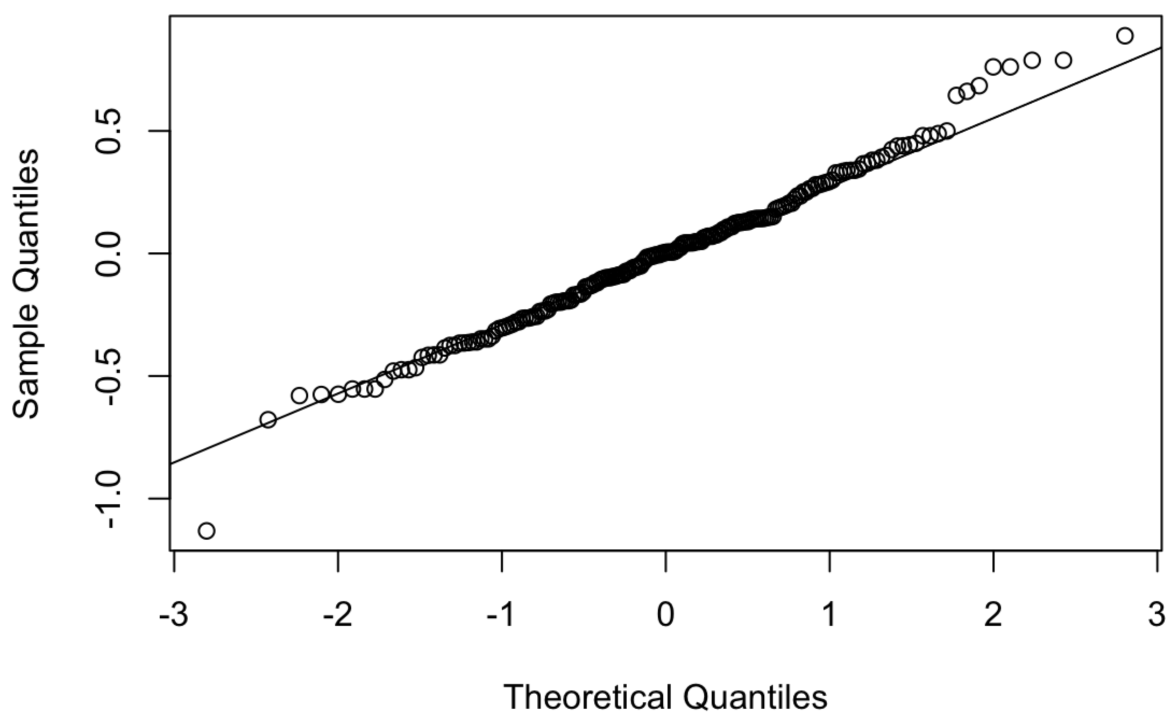


**Figure S8. Testing of Normality for soil pH change data (Q-Q Plot)**

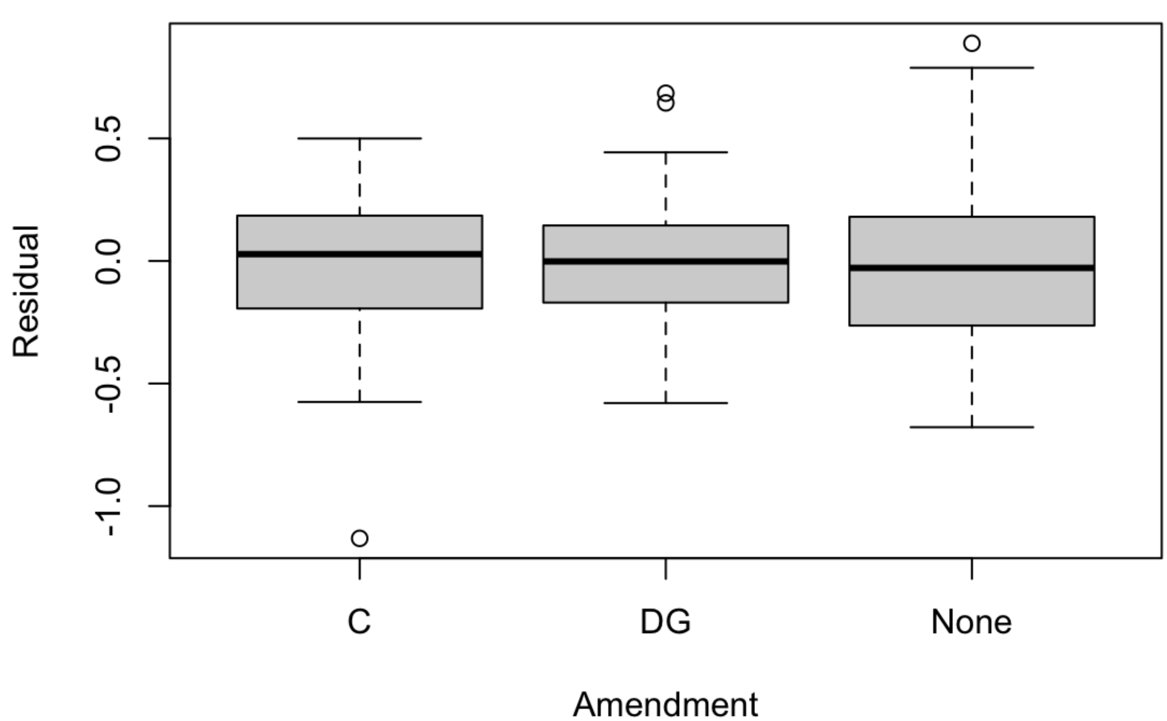

**Figure S9. Testing of Homogeneous Variance for soil pH change data**

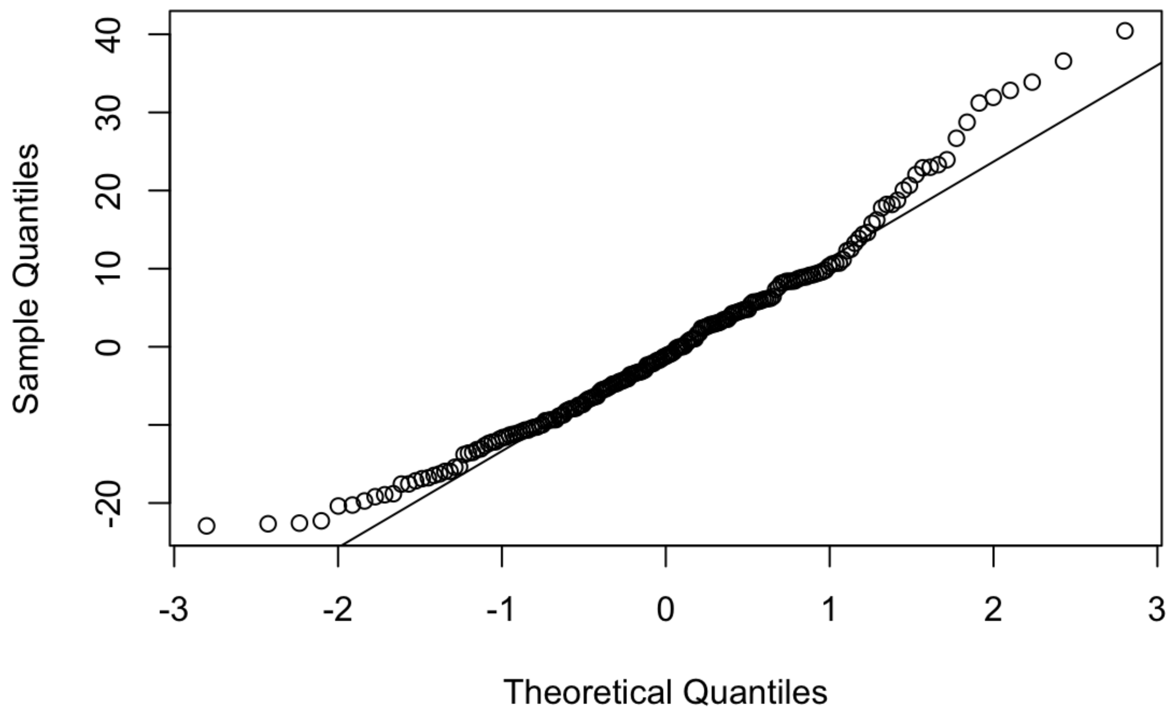


**Figure S10. Testing of Normality for soil carbon change data**

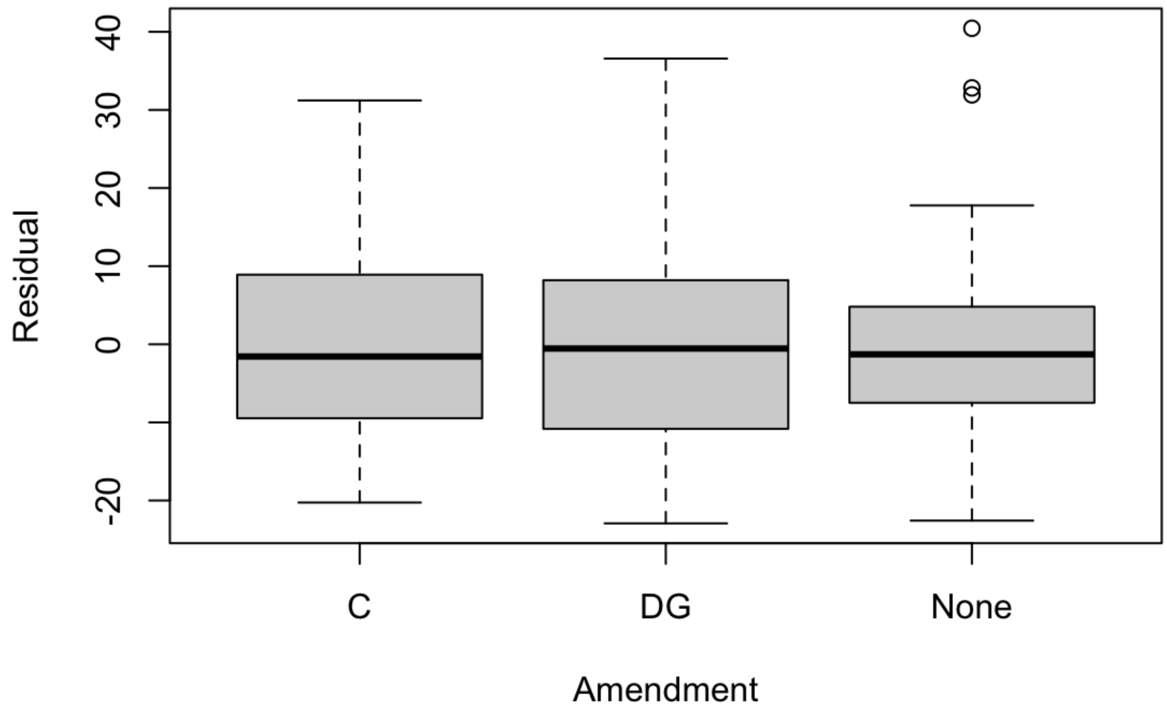


**Figure S11. Testing of Homogeneous Variance for soil carbon change data**

**Table S2. Emissions associated with the post-production drying, crushing, and transport of dregs and grits following generation at a pulp mill without drying**

| **Process step** | **Emissions ($tCO_2$/year)** | **Levelized emissions ($tCO_2$/tDG)** |
|---|---|---|
| Atmospheric fixation of $CO_2$ | -1818 | -0.17 |
| Crushing | 4 | 0.00 |
| Embodied equipment emissions | 293 | 0.04 |
| Front end loading DGs | 476 | 0.07 |

| | | |
|---|---|---|
| into trucks and transport to fields | | |
| Field weathering of DGs | -1 | 0.00 |
| Total | -498 | -0.07 |

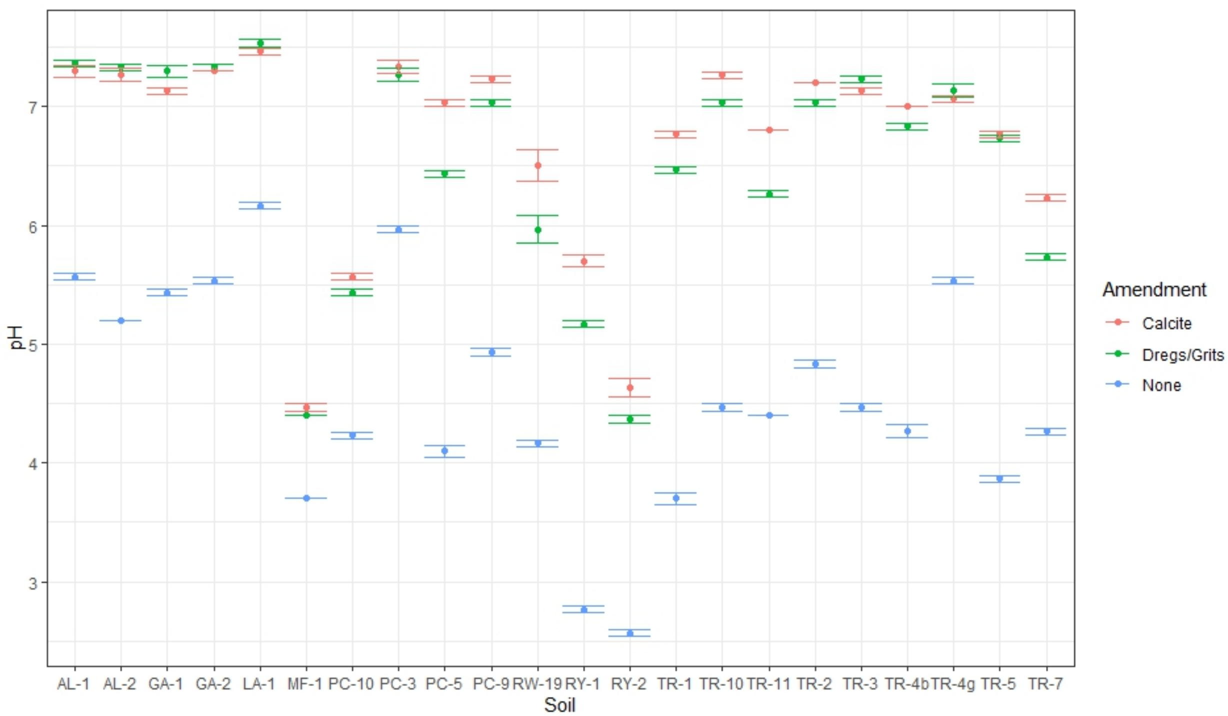


**Figure S13. 0-day soil incubation results**

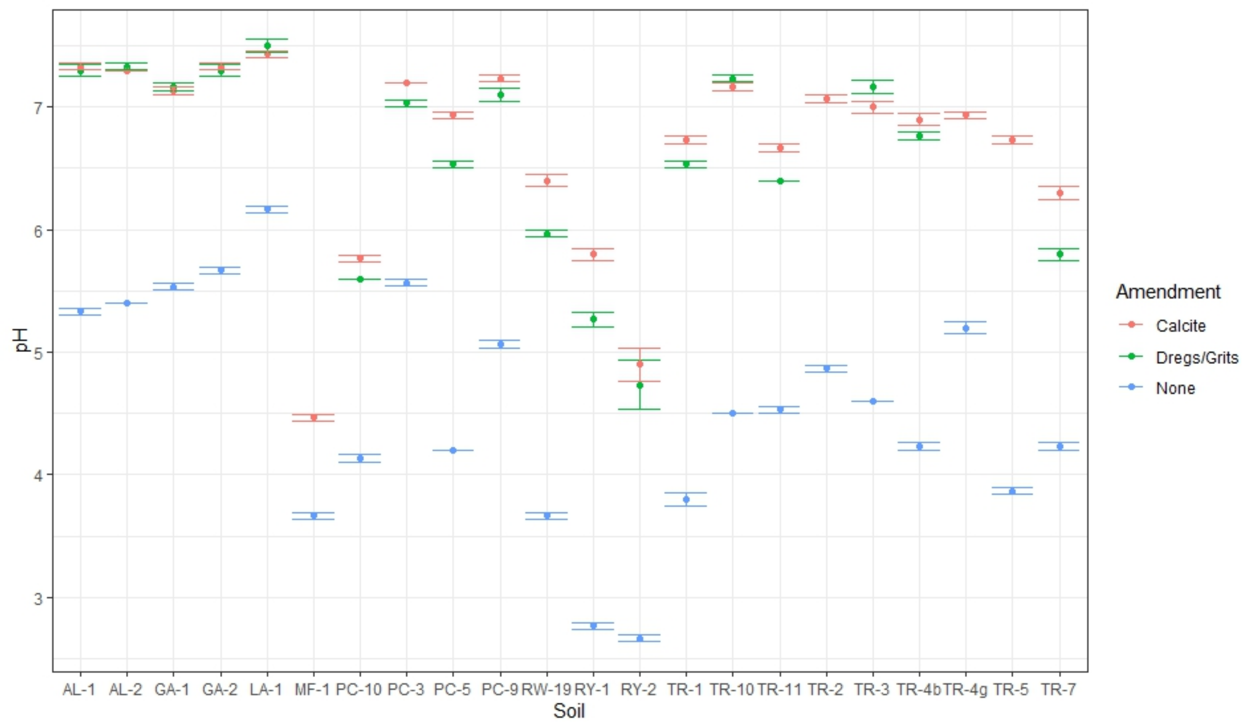


**Figure S14. 1-day soil incubation results**

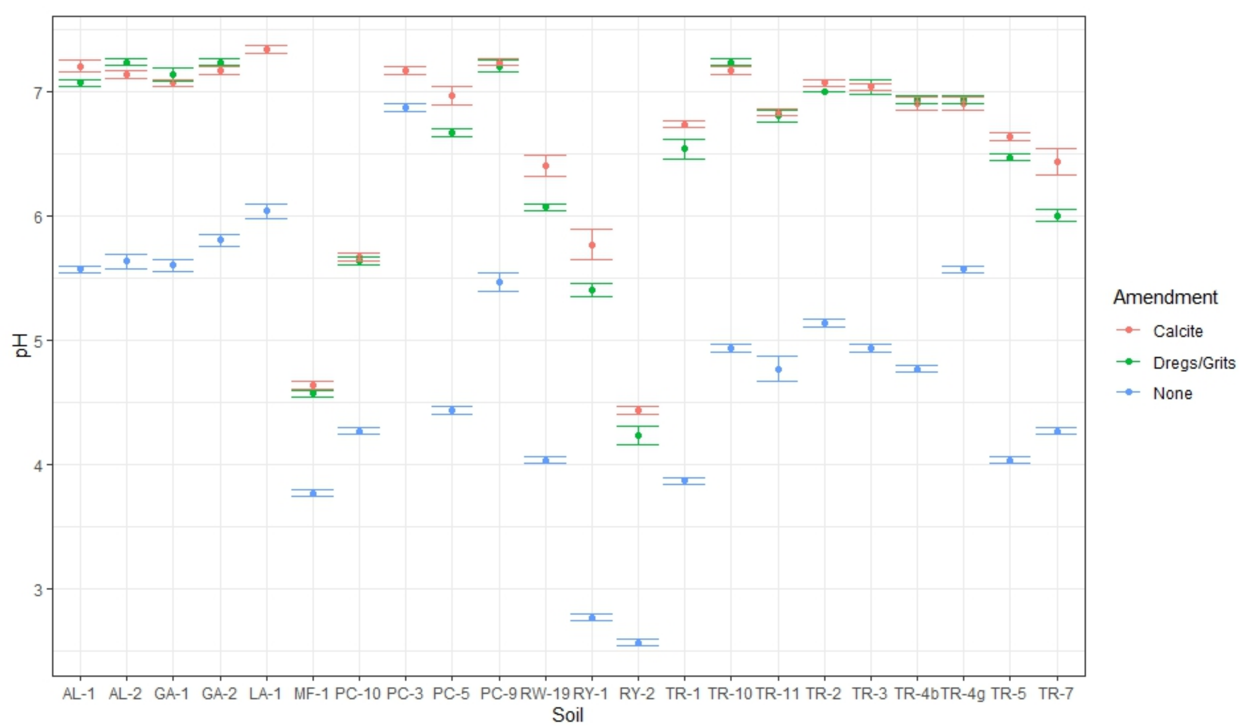


**Figure S15. 7-day soil incubation results**

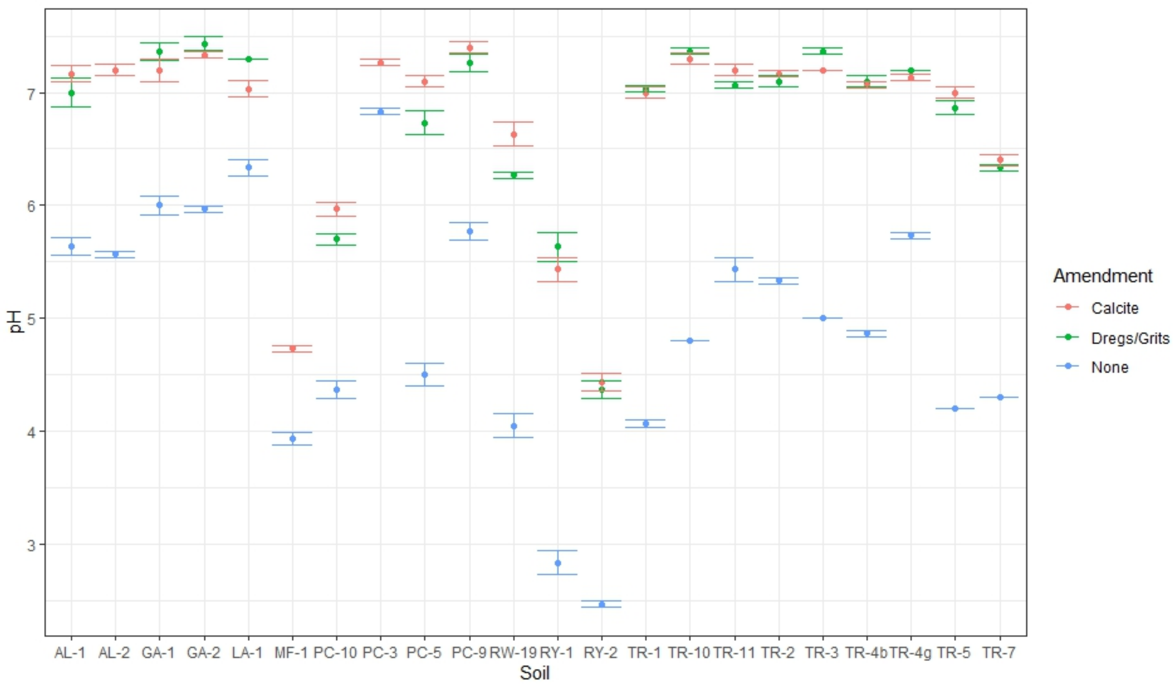


**Figure S16. 30-day soil incubation results**

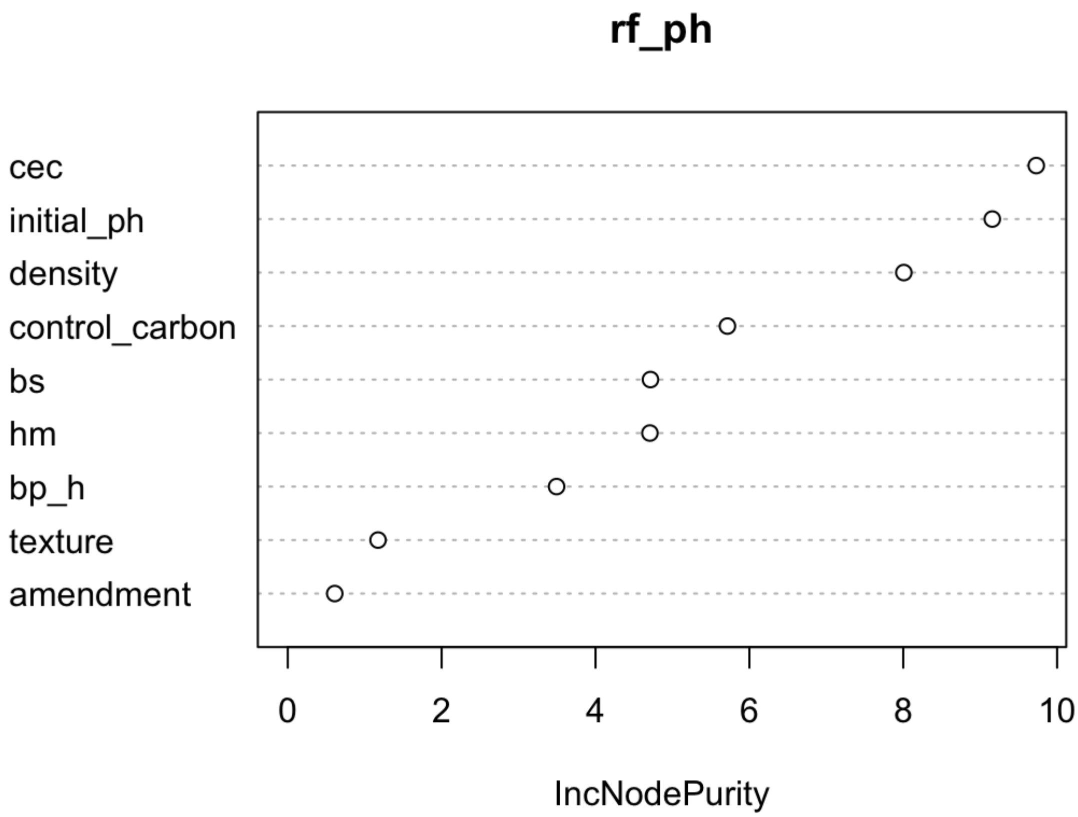


**Figure S17. Variable Importance Plot – Soil pH Random Forest Model**

```
               Type of random forest: regression
                     Number of trees: 500
No. of variables tried at each split: 3

          Mean of squared residuals: 0.04403721
                    % Var explained: 88.56
```

**Figure S18. Random Forest Model Out-Of-Bag Estimates**

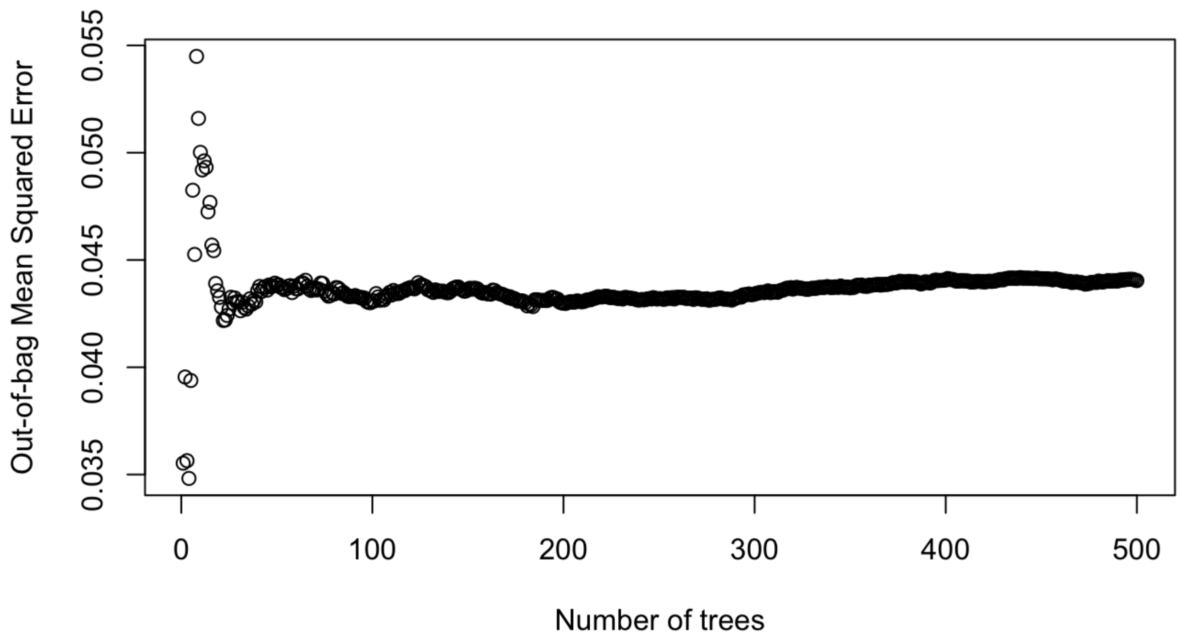


**Figure S19. Random Forest Model Out-Of-Bag Error Plot**

| Soil | Initial Carbon (%) | Initial Absolute Carbon (g-C/kg-soil) |
|---|---|---|
| GA1 | 0.537 | 5.37 |
| GA2 | 0.618 | 6.18 |
| TR3 | 0.654 | 6.54 |
| RY1 | 2.519 | 25.19 |
| AL2 | 0.525 | 5.25 |
| TR4B | 1.194 | 11.94 |
| RW19 | 1.733 | 17.33 |
| TR5 | 1.478 | 14.78 |
| TR4G | 1.117 | 11.17 |
| AL1 | 0.592 | 5.92 |
| TR1 | 1.441 | 14.41 |
| LA1 | 0.672 | 6.72 |
| RY2 | 3.104 | 31.04 |
| TR2 | 1.394 | 13.94 |
| TR10 | 1.092 | 10.92 |
| PC9 | 0.922 | 9.22 |
| TR11 | 1.359 | 13.59 |
| PC5 | 1.323 | 13.23 |
| MF1 | 6.822 | 68.22 |
| PC3 | 2.003 | 20.03 |
| TR7 | 2.082 | 20.82 |
| PC10 | 3.026 | 30.26 |

**Figure S20. Pre-incubation carbon contents of all 22 soils**

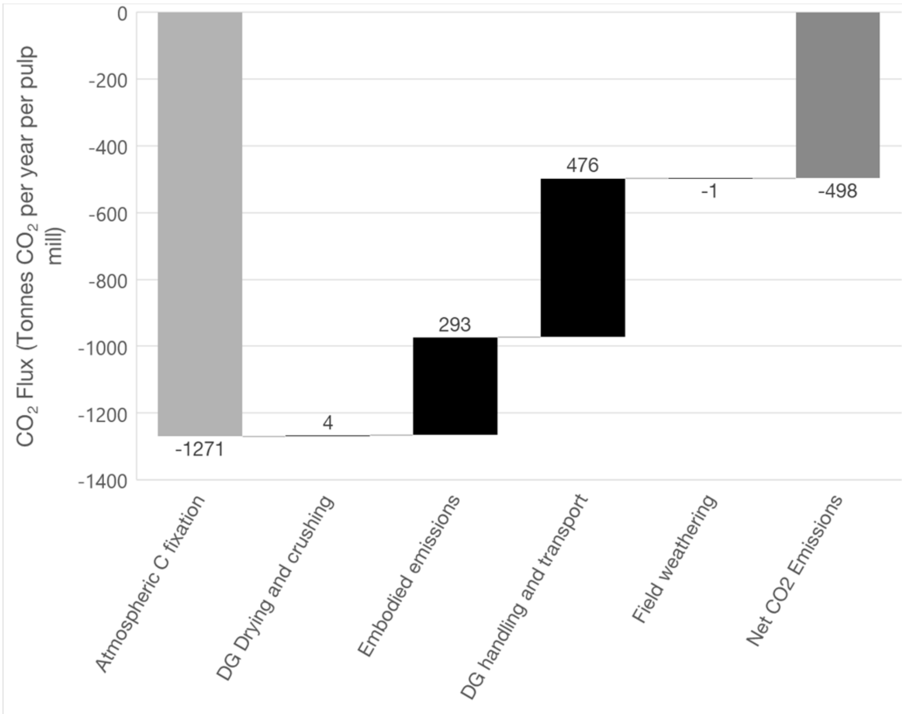


**Figure S21. Waterfall plot of annual life cycle emissions associated with the production of dregs and grits as a soil amendment without drying. Gray bars represent carbon drawdown, black bars represent carbon emissions to the atmosphere.**

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