# Sustainable production of engineered soils from local materials: A formulation, evaluation, and re-purposing of engineered soils

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# A formulation, evaluation, and repurposing of engineered soils

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# Project Summary

The government of Newfoundland and Labrador agriculture policy “The way forward on agriculture” has planned to increase local food production and diversify the economy by creating job opportunities. One of the opportunities is to expand and diversify crop production, an avenue to also increase crop profitability. Greenhouse producers are primarily importing potting soils from outside the province which affects the farm profitability and production sustainability. This project aimed to formulate and produce or repurpose engineered (potting) soils from locally available recipes. Engineered soil recipes and feedstock sources for vermicompost were identified. Three types of feedstocks: a green material (as nitrogen source) mainly from the kitchen and stores were mixed at 1:1 (v/v ratio) with three brown materials (as carbon source): new and spent engineered soil, and local peat moss. The new engineered soil was used for a comparison purpose with the same spent engineered soil. The currently in use engineered soil was imported from Ontario. *Eisenia fetida* and *Eisenia hortensis* were used for the composting experiment. A fully replicated vermicomposting experiment involving three feedstocks and two level of treatment (control and with worm) was conducted and monitored for 45 °C. *Eisenia hortensis* was very sensitive to our experimental conditions (slightly acidic feedstocks) and lost during the first week. The vermicompost system has a pH, temperature, and electrical conductivity within the recommended values. The physicochemical characteristics of vermicompost from all feedstock type confirmed its suitability to formulate engineered soil recipes from local material. Additionally, the project creates pathways for diverting a significant amount of community and agricultural organic waste from the landfill and reduce the greenhouse release from the landfill.

## 1. Background and project rationale

The need for sustainable and diversified agriculture in Newfoundland and Labrador (NL) is at the core of the “the way forward on agriculture” plan to increase locally grown fresh and healthy food products. This includes both food and industrial crops. Job creation and revenue generation is a central pillar of these activities aligned with the recent $13 million funding [1] to reduce the unemployment rate, which is higher in NL than in the Maritime provinces [2].

The availability of healthy and fertile soil is a critical limitation to agriculture in NL. Generally, NL soils are acidic, of low fertility, less than ideal for most agriculture uses, and require significant mineral and organic amendments to improve their physical, chemical, and biological properties. Preliminary data collected at MUN have shown that local soils are not an ideal base for building quality greenhouse soils.

However, it is possible to formulate engineered soil from local resources such as organic waste, agriculture waste, and peat moss to help grow fresh food and profitable crops. Greenhouse crops require precise growth conditions, including high fertility soils. For example, engineered soil for hemp and cannabis is currently imported at a high cost affecting the financial sustainability of local producers.

On the other hand, the province offers a wide range of high nutrient concentration organic waste types and peat resources. These may be employed to develop cheap but relevant potting mixes made from these locally available materials that can replace or minimize the use of imported commercial engineered soils. The abundant peat resources available in this province (about 5.4 million hectares) can be used to produce a NL potting soil which will benefit the expansion of indoor and outdoor horticulture and potential for revenue and job creation but gradual replacement with alternative material is required for environmental concerns.

The consistent production of quality engineered soils requires proper recipe selection, mixing ratio and characterization, production protocols, and thorough evaluation of the materials before the commercial use. This project thus aimed to formulate new engineered soils from local material and evaluate locally produced engineered soils by growing selected vegetable plants and possibly other controlled crops that may be integrated into a cropping system.

The specific objectives were: (a) to identify local recipes suitable to develop engineered soils, including vermicompost, (b) characterising the engineered soils, (c) repurpose the depleted potting soils as recipes, and (d) evaluate the new engineered and repurposed soils under pot experimental conditions (**first greenhouse trial is ongoing and to be continued, no data available**).

Standardized testing was employed throughout the life of the project to also allow the collection of information necessary (i.e., as per the federal Fertilizer Regulations) for any future off-farm commercial considerations.

## 2. More about engineered soils and recipes

Engineered soils are also known as potting soils, potting mixes, potting compost, and soilless culture. The history of growing plants in a pot or container has very old roots, racking back to about 4000 years, with the Egyptian civilization. The arable soil degradation, advances in science and technology, climate change, increased global population, and the increased and all-year-round demand for healthy and fresh organic food in developed countries are the major drivers for increased demand and production of engineered soils to grow food and industrial crops [3].

The production of quality and affordable engineered soils depends on the proper selection of locally available materials, their physical and hydraulic properties, the mixing ratios of the substrates, and nutrient content. There are organic materials such as peat, coir, compost, and wood products used to produce commercial potting soils. The mixing ratios of the recipes are greatly varied based on the intended use and the types of the potting ingredients [4].

Peat is the most widely used potting substrate in North America and Europe because of its availability and excellent physical and chemical properties, despite some environmental concerns related to the impact on carbon sequestration [3]. Peat is light, suitable for transport, a stable growth substrate (low degradation rate) with high porosity and water holding capacity, good aeration, and free of plant pathogens [3], [5]–[7]. Peats are acidic in nature. Newfoundland peats have pH ranges from 3.7 to 5, total nitrogen ranges from 7.7 to 26.7 g $kg^{-1}$, calcium from 15.8 to 108.0 ppm, and iron from 11.8 to 326.5 ppm [8]. Currently, an industry based at Bishop's Fall is producing sphagnum peat moss having a pH of 4, 98% organic matter on a dry basis, 50-58% water content, 1.3%, 0.02%, and 0.03% of total nitrogen, phosphorus, and potassium, respectively and 1.9% ash content [9]. Also, for comparison, commercial peat from central Finland has water soluble nitrogen ranging from 0.1 to 0.4 g kg$^{-1}$ and calcium chloride extractable phosphorus and potassium ranges from 10 to 80 mg kg$^{-1}$ and 0.1 to 1.5 g kg$^{-1}$, respectively [4].

In Newfoundland, peat mining was initiated in Bishop Falls area in 1970s to generate energy [10] and gradually shifted to horticultural and lately used for cleaning oil spills [11]. In 1999, Canada produced 10.3 million cubic metres of peat for horticultural, followed by Germany produced 9.5 million cubic metres of peat [12]. About 13% (5.4 million ha) of the NL area is occupied by peat, sphagnum peat moss is the abundant type [13]. Thus, peats are locally available as a potential ingredient for local engineered soil production.

Another potential potting recipe is compost, a commonly used ingredient in potting soils. It can be prepared onsite on the farm from available organic materials. Composts have good water retention capacity and nutrient availability but depending on the quality of the feedstocks and proper composting conditions such as temperature and moisture. Composting requires time, space, and proper composting conditions. A minimum temperature of 55 °C must be attained for at least 3 days to kill most pathogenic microorganisms and eliminate weed seeds in a traditional composting process. Also, the moisture content must be between 70% to 90% and well aerated in the case of vermicompost [14], [15]. The quality of the compost must be tested before mixing it with other potting recipes. The recommended compost proportion for the potting soil ranges from 20% to 50%, crop-dependent [16].

For local and on-farm potting, sterilized topsoil with no history of contamination with pesticides, inorganic chemicals, and free of GMO management can be used as potting substrates in combination with other recipes. The soil should be sourced from uncontaminated land and tested before mixing with other recipes.

There are several lists of organic fertilizers suggested by the USDA that can be used to boost the nutrient supply in potting soils. In Newfoundland, organic fertilizers can be obtained from composting, dairy, aquaculture waste, and seaweeds. Additionally, calcium carbonate and dolomitic limestones are applied to raise the pH of potting soil to between 6 to 7 depending on the crop need and also a source of calcium and magnesium plant nutrients.

The local production of potting mix depends on the availability of recipes, types of plant and size of the container. The recipes for all-purpose potting mixes include "peat moss, perlite, and/or vermiculite, an organic wetting agent, a liming agent, an organic fertilizer, and an array of organic amendments including compost, worm castings, organic fertilizers, and microbial inoculants". Lately, most producers replaced soil media with peat moss to prevent the risk of plant disease, but sterilized soils can still be used locally or onsite as potting mixes substrate. The rate of fertilizer amendment is depending on the intended use of the potting mixes (for seed starters, transplanting, and growing bigger plants). A unique source of compostable organic matter for maritime regions such as NL is fish waste, seaweed, and community organic waste. The former is a good source of phosphorus while all are a good source of nitrogen, variable among seas weed species [17], and have been confirmed to accelerate plant growth and enhance soil health. Their productivity parameters are in line with other composts [18]. The mixing proportions of the potting recipes vary among the producers based on the proposed application [3], [19], [20]. Studies evaluated the effect of varying the proportion of major ingredients such as peat moss and compost on plant growth [4], [21]. Upon proper formulation and successful certification, the locally produced potting mixes can be used to reduce or replace importing potting soils and contribute to local food production, also generating revenue and job creation.

Globally, the number of commercial potting soil suppliers is increasing to satisfy the demand to growing fresh food and industrial crops, China is the biggest importer of potting soils. An independent research organization (360researchreports.com) reported market share of 29% for potting soils in North America following 31% market share in Europe. Also, the global market for potting soil is projected to increase from 1.55 billion US$ in 2019 to 1.83 billion US$ in 2024. There are three types of engineered soils currently available on the market: all-purpose potting soils, lawn and garden soils, and professional soils for indoor gardening and greenhouse purposes [22]. The current online cost to purchase potting soils ranges between $1 and 6$ per litre including shipping (Figure 1).

Furthermore, the production of greenhouse-based food and industrial crops is increasing in Canada. For example, at national level the total sale of greenhouse products increased from 2.8 billion dollars in 2015 to about 3.2 billion dollars in 2019. The total sales of greenhouse products for Newfoundland and Labrador (NL) were 8.4 million dollars in 2015, increased to about 9 million dollars in 2017, slightly declined to 8.5 million dollars in 2019 [23] and accounts for 6.6% of the total farm sales [24]. Across Canada, there are about 32,000 seasonal and permanent greenhouse jobs created, but only 255 jobs are reported for NL. On the other hand, NL has the highest unemployment rate compared to national and maritime provinces [2]. Thus, this project aimed to formulate and produce potting soils from local materials, and rigorous testing of crop growth in the greenhouse will be performed in the next phases along with the formulation and production of potting soil; upon successful testing, it can be scaled up to large production scale for commercial purpose, which will create job opportunities and boost the provincial agriculture sector.

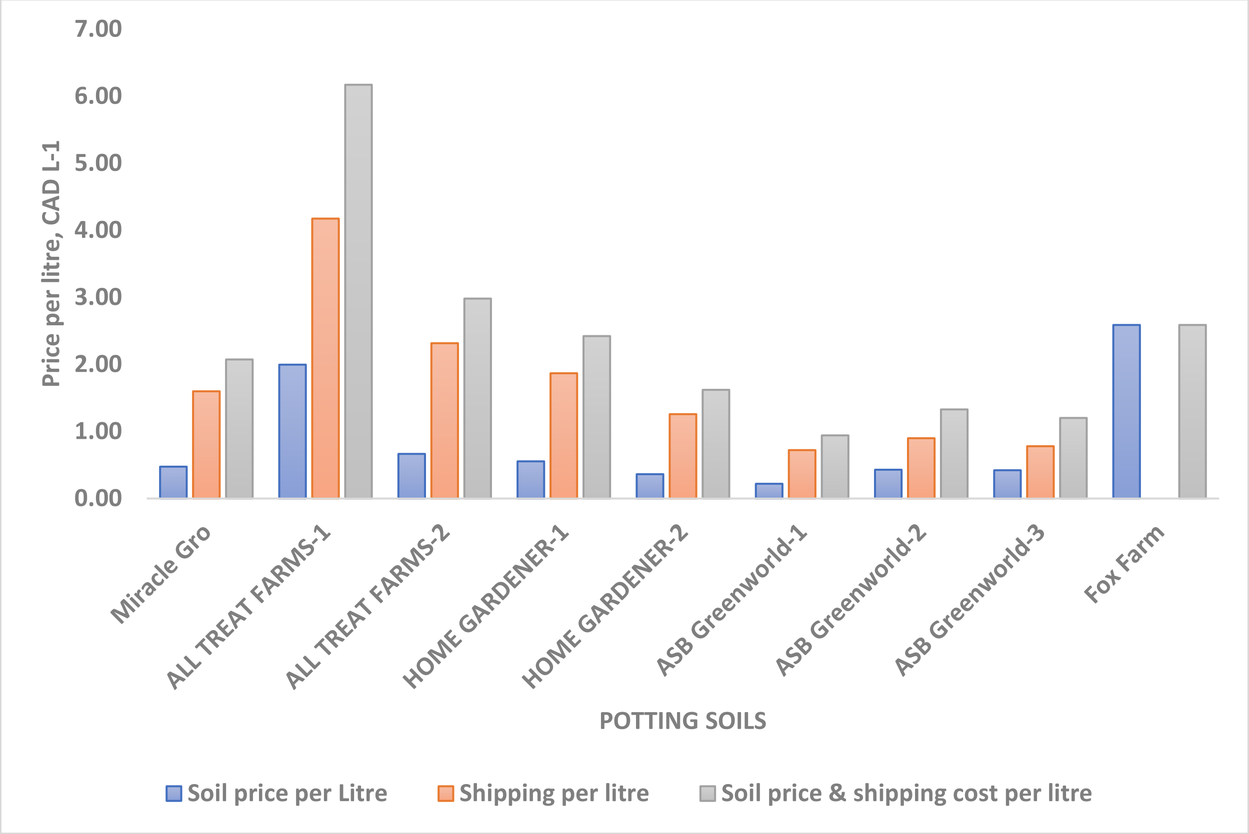


*Figure 1. Potting soil price, shipping cost, and potting soil price plus shipping cost per litre of selected potting soils based on the online Walmart store, Canada. The prices used in this figure are retrieved from* *https://www.walmart.ca/* *on October 19, 2020.*

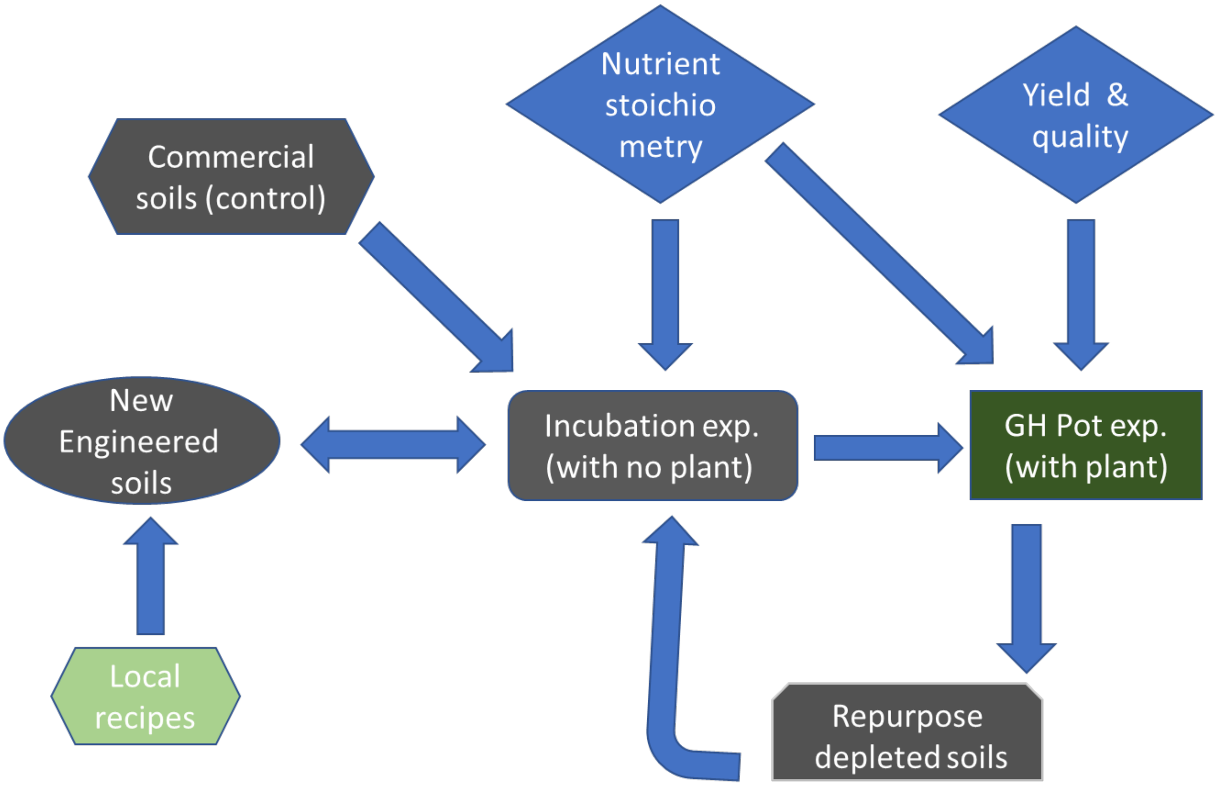


*Figure 2. Schematic diagram of the project.*

## 3. Materials and Methods

### 3.1. Study location and description

The experiment was conducted in G&M family farm facility located in the Placentia town, NL at 47°17'38.000" N, 53°59'36.000" W and has an elevation 19.0 m above sea level (Environment Canada). According to 2021 Canada Statistics the town has a total 3,289 peoples. Currently, the farm is producing industrial and food crops in the greenhouse and field. The farm is importing approximately 8 to 11 metric tonnes of potting soil every year from Ontario for greenhouse production.

### 3.2. Feedstock ingredients

**Green materials:** Undecomposed green materials (organic waste mainly food waste) were collected from voluntarily participated households and stores. Small amount of agriculture waste (mainly vegetables) was also collected from field G&M.

**Brown materials:** Fresh potting soil (as purchased), spent potting soil, and local peat moss were used as a source with higher carbon content to maintain C:N ratio of the vermicompost and support the earthworms' and microbial activities. Peat moss was purchased from a local commercial source in Bishop's Fall, NL. The most recent spent soil (summer 2021 greenhouse cultivation) was used as a source of carbon and also to investigate its reusability as a brown material, instead of discarded, or for minimizing the use of peat moss. The new potting soil (uncultivated) was used as a reference versus the spent soil.

### 3.3. Feedstock preparation

The ground green materials were further shredded to a smaller size to easily mix with brown materials. The shredded green materials were manually mixed with a brown material at 1:1 ratio (v/v) to attain uniform moisture before transferring about two kg of feedstock to 7.5 L pail. This produced three types of feedstocks: green material + new potting soil (Feedstock 1), green material + spent potting soil (Feedstock 2), and green material + peat moss (Feedstock 3). Feedstock 1, 2, and 3 has a bulk density of 0.622, 0.615, and 0.560 kg $L^{-1}$, respectively. The green materials had an average C:N of 24:1 while the brown materials had a C:N >30:1 (Table 2a-d).

### 3.4. Baseline characterization

Standard testing was performed to characterize shredded green materials, brown materials, and feedstocks (after the green and brown materials mixed at 1:1 ratio) and the product (vermicompost). Results of the baseline test are summarised in Tables 2a to 2c.

### 3.5. Experimental design

The study used three feedstocks and three experimental factors (control, *E. fetida*, and *E. hortensis*; Table 1). Each treatment had five replicates and resulted in a total of 45 experimental units. A total of nine treatments were randomly arranged in five blocks (replicates).

*Table 1. Treatment types and combinations. A ratio of 1:1 (v/v) was used to mix green and brown materials. Each treatment has five replicates and is randomly assigned in blocks.*

| Order# | Treatments combination |
|---|---|
| T1 | Green material: new potting soil (1:1) * control |
| T2 | Green material: new potting soil (1:1) * *E. fetida* |
| T3 | Green material: spent potting soil (1:1) * control |
| T4 | Green material: spent potting soil (1:1) * *E. fetida* |
| T5 | Green material: peat moss (1:1) * control |
| T6 | Green material: peat moss (1:1) * *E. fetida* |
| T7 | Green material: new potting soil (1:1) * *E. hortensis* |
| T8 | Green material: spent potting soil (1:1) * *E. hortensis* |
| T9 | Green material: peat moss (1:1) * *E. hortensis* |

Note: *E. hortensis* in treatment 7, 8, and 9 was not able to cop up with the feedstock conditions.

### 3.6. Vermicomposting trials

*Eisenia fetida* was obtained from local stores, and *E. hortensis* was obtained from Ontario, Canada. About two kg of well mixed feedstock were transferred to black pail in five replicates and about 180 g of *E. fetida* or 170 g of *E. hortensis* were added to pail and kept in room temperature between 15 to 20 ºC. Crashed eggshells were gradually added to the system to increase the pH to around 5.5 to 6.5. The experiment was conducted for 45 days (from February 1 to March 9, 2022). The system's pH, electrical conductivity, moisture content, system and room temperature were collected daily except on the weekend. The *E. hortensis* was sensitive to the freshly made feedstock conditions (lower pH and higher moisture content) and did not survive in the first week of the experiment.

### 3.7. Data analysis

The mean and standard deviation was calculated from the five replicates for treatment. A one-way ANOVA at 0.05 p-value was applied to compare the mean of selected physicochemical properties between the treatment groups.

## 4. Results and discussion

### 4.1. Baseline characterisation of recipes and feedstocks

The pH, organic matter, total carbon and nitrogen, cation exchange capacity, micro- and macro-nutrient for the new engineered soil (as purchased from the factory), with the plant (with 70 days old in the greenhouse), spent engineered soils of having different ages, ground green materials, and feedstocks are summarised in Table 2a to 2d. The spent soil was stored outside in an open area and exposed to local weather conditions; the oldest spent soil was covered with grass and weeds. The engineered soil planted for 70 days, receiving nutrients and regular watering. The analysis of these soil samples can inform on the reusability of spent soil for the same or different greenhouse crops.

The spent soils had a pH between 6.0 and 6.5, and organic matter (OM) from 9 to 33%; spent soil diluted with local soil had a lower OM (9%). The macro- and micro-nutrient content of the spent soil varies based on their age. The variation could be related to the duration and intensity of nutrients applied during greenhouse use and the decomposition of the organic matter. The baseline information of the spent soil will help us to repurpose the spent soil either as a recipe for vermicompost or engineered soil. Thus, one must test the nutrient distribution in the spent soil prior to repurposing it as they vary based on their greenhouse and storage management.

The ground green material has lower pH (5.2), higher moisture content (87%) and macronutrients (1.8% N, 0.2% P, 2.0% K, 2.6% Ca, and 0.2% Mg) and 871 mg $L^{-1}$ of sodium (Table 2c). The green material has a carbon to nitrogen ratio of 24.4. These values might vary greatly depending on the composition of the green materials. Thus, continuing work will account for the seasonal variability of community organic waste (green materials) available in the town of Placentia. The physicochemical properties of the peat moss used as a mixing recipe were provided above in section 2.

The new engineered soil was used as brown material to compare with the same spent soil. The local peat moss was used as a brown material to formulate a new engineered soil. All feedstocks had comparable physicochemical properties, except feedstock-3 which had lower pH and Mehlich-3-extractable phosphorus compared to the other two feedstocks (Table 2d). All feedstocks had a C:N ranging from 21 to 28%, >50% moisture content, and a bulk density of ≈ 0.6 kg $L^{-1}$.

*Table 2a. Baseline characteristics of new and spent engineered soil.*

| Soil types | n | pH | | OM (%) | | EC (mS/cm) | | M3-P (mg/L) | | M3-K (mg/L) | | M3-Ca (mg/L) | | M3-Mg (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std |
| New engineered soil (manufacturer report. test verification) | 1 | 6.00 | na | 60.2 | na | 14.20 | na | 134 | na | 338 | na | 1603 | na | 366 | na |
| New engineered soil (local lab; test verification) | 1 | 6.10 | na | 37.9 | na | 10.80 | na | 124 | na | 220 | na | 1162 | na | 254 | na |
| Spent engineered soil (70 days) | 1 | 6.70 | na | 24.3 | na | 21.80 | na | 586 | na | 1210 | na | 2756 | na | 411 | na |
| Spent engineered soil (summer 2021) | 3 | 6.03 | 0.46 | 32.33 | 1.42 | 14.40 | 4.25 | 101 | 65 | 96 | 18 | 1686 | 521 | 485 | 118 |
| Spent engineered soil (summer 2020) | 3 | 6.90 | 0.26 | 33.27 | 2.63 | 12.00 | 1.61 | 90 | 48 | 157 | 58 | 1288 | 179 | 467 | 64 |
| Spent engineered soil (summer 2020, mixed with native soil) | 3 | 5.97 | 0.12 | 9.07 | 1.01 | 18.93 | 1.10 | 67 | 2 | 151 | 54 | 1233 | 134 | 187 | 19 |
| Spent engineered soil (summer 2019) | 3 | 6.30 | 0.30 | 19.23 | 1.14 | 23.43 | 2.27 | 283 | 136 | 649 | 18 | 2587 | 223 | 648 | 66 |
| Native soil (Histosol) | 3 | 4.47 | 0.25 | 29.27 | 6.60 | 19.47 | 9.19 | 24 | 22 | 20 | 10 | 1289 | 1648 | 157 | 193 |
| Native soil (Luvisol) | 3 | 5.60 | 0.20 | 4.87 | 0.40 | 13.07 | 1.52 | 21 | 24 | 54 | 21 | 228 | 105 | 57 | 10 |

*Table 2b. Baseline characteristics of new and spent engineered soil.*

| Soil types | n | M3-Zn (mg/L) | | M3-Cu (mg/L) | | M3-Na (mg/L) | | M3-Fe (mg/L) | | M3-B (mg/L) | | M3-Mn (mg/L) | | M3-Al (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std |
| New engineered soil (manufacturer report. test verification) | 1 | 0.70 | na | 0.10 | na | 251 | na | 57 | na | 0.20 | na | 4.00 | na | 33 | na |
| New engineered soil (local lab; test verification) | 1 | 3.80 | na | 0.30 | na | 170 | na | 53 | na | 0.00 | na | 2.00 | na | nr | na |
| Spent engineered soil (70 days) | 1 | 20.00 | na | 1.80 | na | 345 | na | 86 | na | 0.20 | na | 36.00 | na | 17 | na |
| Spent engineered soil (summer 2021) | 3 | 3.90 | 0.60 | 0.43 | 0.15 | 79 | 44 | 39 | 6 | 0.07 | 0.06 | 1.67 | 0.58 | 2 | 0 |
| Spent engineered soil (summer 2020) | 3 | 6.07 | 1.88 | 1.03 | 0.35 | 161 | 73 | 56 | 12 | 0.15 | 0.07 | 8.00 | 8.72 | 19 | 22 |
| Spent engineered soil (summer 2020 mixed with native soil) | 3 | 14.47 | 1.31 | 4.23 | 0.40 | 30 | 3 | 195 | 6 | 0.73 | 0.15 | 29.33 | 3.06 | 1488 | 25 |
| Spent engineered soil (summer 2019) | 3 | 24.13 | 2.73 | 1.43 | 0.50 | 53 | 4 | 87 | 38 | 3.20 | 3.21 | 29.33 | 7.51 | 284 | 230 |
| Native soil (Histosol) | 3 | 7.87 | 3.00 | 2.83 | 1.31 | 40 | 23 | 132 | 70 | 0.20 | 0.35 | 131.00 | 97.12 | 1381 | 472 |
| Native soil (Luvisol) | 3 | 3.57 | 0.40 | 1.30 | 0.62 | 29 | 3 | 199 | 16 | 0.40 | 0.30 | 28.67 | 11.37 | 1908 | 173 |

Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), copper (Cu), sodium (Na), iron (Fe), boron (B), manganese (Mn), and aluminum (Al) are extracted in Mehlich-3 (M3) solution, soil organic matter (SOM), cation exchange capacity (CEC), sample size (n), standard deviation (SD), not available (NA).

*Table 2c. Baseline characteristics of ground green materials.*

| Analysis, per dry mass | Average | STD |
|---|---|---|
| Moisture content (as received), % | 87.17 | 0.35 |
| pH | 5.20 | 0.10 |
| Soluble salts, mS/cm | 8.99 | 0.39 |
| Total P, % | 0.24 | 0.02 |
| Total K, % | 2.03 | 0.15 |
| Total Ca, % | 2.60 | 0.16 |
| Total Mg, % | 0.18 | 0.02 |
| Total Fe, mg/L | 90.67 | 6.81 |
| Total Mn, mg/L | 53.00 | 3.00 |
| Total Cu, mg/L | 10.67 | 0.58 |
| Total Zn, mg/L | 16.67 | 1.53 |
| Total B, mg/L | 15.67 | 1.53 |
| Total Na, mg/L | 870.7 | 24.3 |
| Total C, % | 44.37 | 0.31 |
| Total N, % | 1.82 | 0.06 |
| C:N ratio | 24.40 | 0.82 |

*Table 2d. Baseline characteristics of feedstocks (FS) prepared by mixing ground green material and brown materials at 1:1 ratio v/v (FS1: ground green material + new engineered soil, FS2: ground green material + spent engineered soil, FS3: ground green material + peat moss).*

| Parameters | FD1-before VC | FS1-control | FS1-E.fetida | FS2-before VC | FS2-control | FS2-E.fetida | FS3- Before VC | FS3-control | FS3-E.fetida |
|---|---|---|---|---|---|---|---|---|---|
| **pH** | 6.4(±0.1) | 7.5(±0.1) | 7.2(±0.1) | 6.8(±0.2) | 7.2(±0.2) | 5.9(±0.2) | 5.3(±0.2) | 5.4(±0.1) | 6.5(±0.2) |
| **SOM,** % | 41.4(±4.9) | 38.7(±2.1) | 32.8(±2.1) | 39.4(±1.0) | 32.8(±3.5) | 32.9(±5.4) | 40.2(±6.8) | 54.9(±3.4) | 45.7(±1.9) |
| **CEC,** cmol/kg | 22.7(±0.9) | 19.9(±0.8) | 20.5(±2.3) | 20.7(±0.3) | 20.5(±2.7) | 33.0(±7.2) | 20.4(±2.1) | 12.1(±0.8) | 10.7(±0.6) |
| **M3-P,** mg/L | 199(±27) | 173(±11) | 300(±53) | 177(±6) | 300(±24) | 291(±40) | 108(±14) | 57.0(±6.0) | 168(±26) |
| **M3-K,** mg/L | 2178(±252) | 1745(±94) | 1842(±123) | 1828(±204) | 1842(±235) | 1982(±203) | 2324(±133) | 1171(±98) | 1265(±56) |
| M3-Ca, mg/L | 1761(±51) | 1992(±104) | 1954(±338) | 1649(±29) | 1954(±318) | 3372(±1174) | 1206(±169) | 721(±144) | 652(±83) |
| M3-Mg, mg/L | 359(±38) | 478(±13) | 475(±27) | 394(±13) | 475(±54) | 720(±66) | 224(±16) | 181(±13) | 175(±8) |
| M3-Zn, mg/L | 2.9(±0.3) | 2.4(±0.2) | 3.4(±0.2) | 3.7(±0.2) | 3.4(±2.1) | 5.7(±0.5) | 2.9(±0.1) | 1.8(±0.1) | 2.7(±0.2) |
| M3-Cu, mg/L | 0.9(±0.1) | 0.2(±0.1) | 0.2(±0.1) | 0.8(±0.1) | 0.2(±0.1) | 0.5(±0.2) | 0.8(±0.1) | 0.1(±0.1) | 0.1(±0.0) |
| **M3-Na,** mg/L | 178(±27) | 279(±6) | 3645(±22) | 226(±13) | 365(±56) | 545(±22) | 95.7(±5.7) | 74.0(±3.9) | 141(±11) |
| M3-Fe, mg/L | 31.3(±4.0) | 35.2(±1.5) | 33.8(±4.6) | 54.7(±1.2) | 33.8(±7.2) | 71.4(±9.4) | 12.3(±1.5) | bd | 4.0(±1.0) |
| M3-B, mg/L | 2.1(±0.2) | 0.9(±0.2) | 0.6(±0.1) | 1.9(±0.2) | 0.6(±0.3) | 0.5(±0.1) | 2. 2(±0.3) | bd | 0.1(±0.0) |
| M3-Mn, mg/L | 5.7(±0.6) | 4.2(±0.4) | 5.8(±0.4) | 8.0(±0.0) | 5.8(±0.9) | 5.2(±1.5) | 5.3(±0.6) | 2.8(±0.4) | 3.8(±0.4) |
| M3-Al, mg/L | 36.0(±4.4) | bd | bd | 46.3(±15.5) | bd | bd | 32.3(±5.8) | bd | bd |
| Nitrate-N, mg/L | 1.5(±0.1) | 2.2(±0.6) | 21.3(±36.8) | 1.7(±0.1) | 21.3(±2.3) | 73.5(±28.2) | 1.4(±0.0) | 0.9(±0.0) | 10.2(±8.4) |
| **Total Carbon,** % | 35.0(±2.1) | 32.2(±2.9) | 34.7(±1.7) | 37.8(±0.9) | 34.7(±1.0) | 32.3(±1.1) | 35.2(±3.8) | 38.7(±2.1) | 35.7(±1.6) |
| **Total Nitrogen,** % | 1.6(±0.1) | 1.5(±0.1) | 1.8(±0.1) | 1.5(±0.0) | 1.8(±0.1) | 1.9(±0.1) | 1.3(±0.1) | 1.3(±0.1) | 2.0(±0.0) |
| **C:N** | 26.3(±1.8) | 21.7(±0.9) | 19.1(±0.9) | 25.2(±0.6) | 19.1(±1.8) | 16.7(±1.0) | 22.3(±0.7) | 30.7(±0.8) | 17.7(±0.6) |

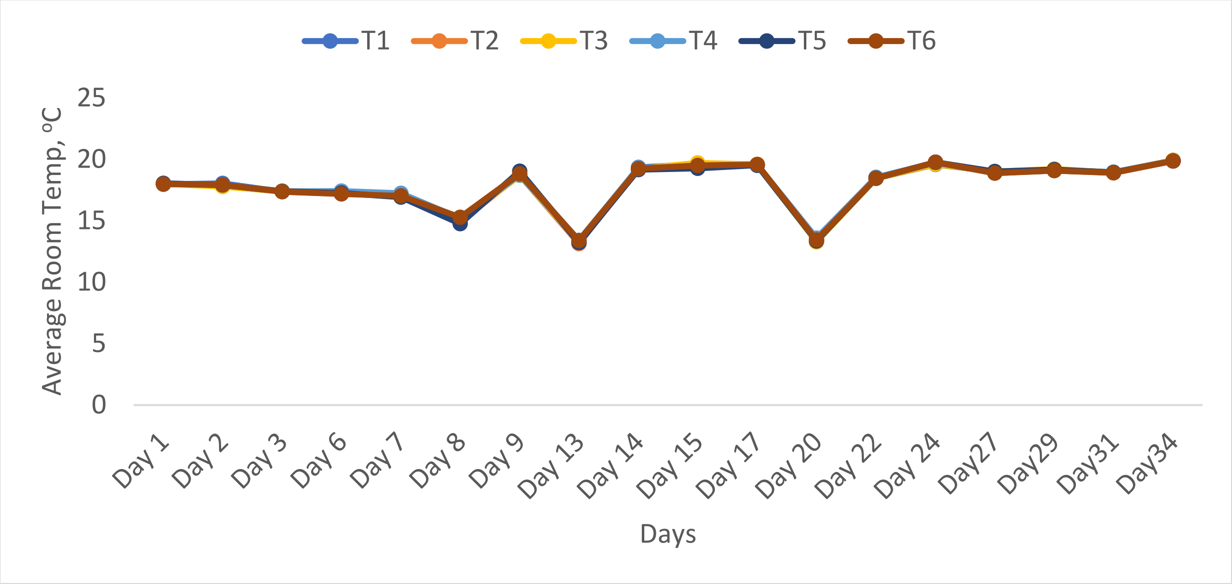
Below detection limit (bd), carbon to nitrogen ratio (C:N); M3 indicates elements extractable via the standard Mehlich-3 solution.

## 4.2. Monitoring of vermicompost system

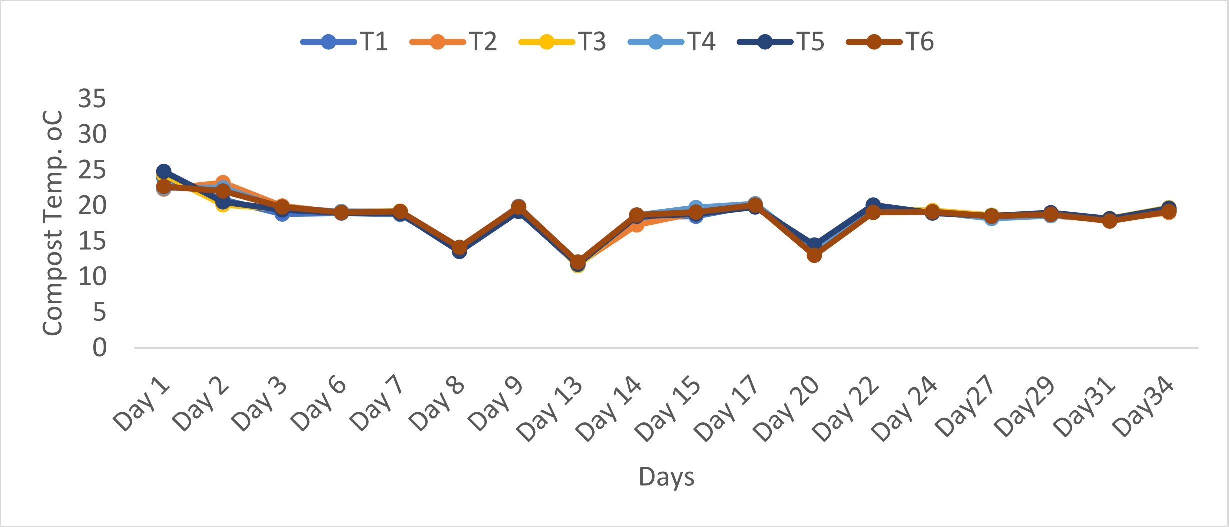
Figure 1a shows the summary of compost parameters monitored for 45 days. The average temperature of the vermicompost system and the room temperature were between 10 to 20 °C (Fig 1a and b). Another study reported a higher temperature between 25 to 35°C in the vermicompost related to relatively higher ambient temperature (20 to 30 °C) [25]. The temperature drop observed on days 8, 13, and 20 was related to the interruption of the heating system. However, the problem was corrected with in the same day. Despite the interruption, the recorded temperature was within the recommended range (0 to 35°C) [26].

The pH trend for feedstocks having new engineered soil (serve as a reference for spent soil) and spent soil was between 6.0 to 8.0. The higher pH observed for these treatments might be related to the application of eggshells and lower baseline acidity. Treatments having 50% (v/v) peat moss as brown material had a wide pH range (4 to 8; Figure 1c). The fluctuation was related to the pH property of the peat moss. Overall, the pH of all treatments was within the recommended pH value (4.0 to 8.0) [26].

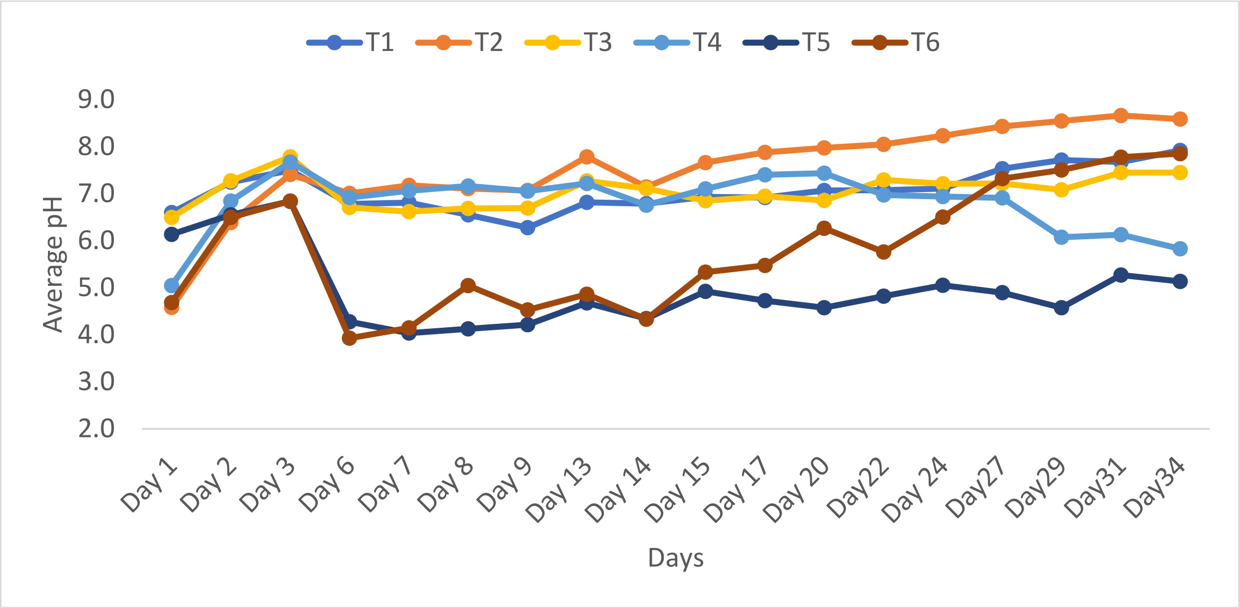
The electrical conductivity (EC) of all treatments ranged between 0.4 to 1.0 mS $cm^{-1}$ (Fig 1d), which is below the recommended EC value (1.3 mS $cm^{-1}$) for vegetable crops and might have lower nitrous oxide formation [27]. The EC variation was not feedstock dependent, most probably related to the moisture fluctuation. The moisture content greatly varied between experimental pots (replicates); data not presented. The moisture meter only measured up to 50%. Though the recommended moisture range for vermiculture is 50 to 75%, both *Eisenia fetida* and *Eisenia hortensis* did not like moisture above 50% in our setup. After adding feedstocks with lower moisture, *E. fetida* was able to normalize with their system and feed on the materials.



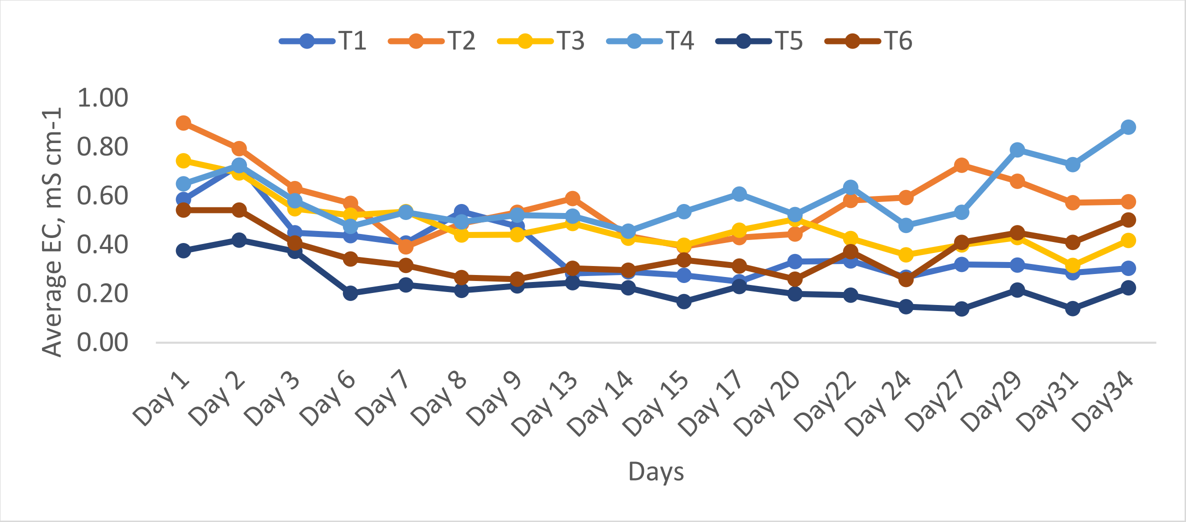
(a) Room temperature



(b) System temperature



(c) pH



(d) electrical conductivity

*Figure 3. Vermicompost monitored parameters (a) room temperature, (b) system temperature, (c), pH, and (d) electrical conductivity. The description for T1, T2, T3, T4, T5, and T6 are available in Table 1.*

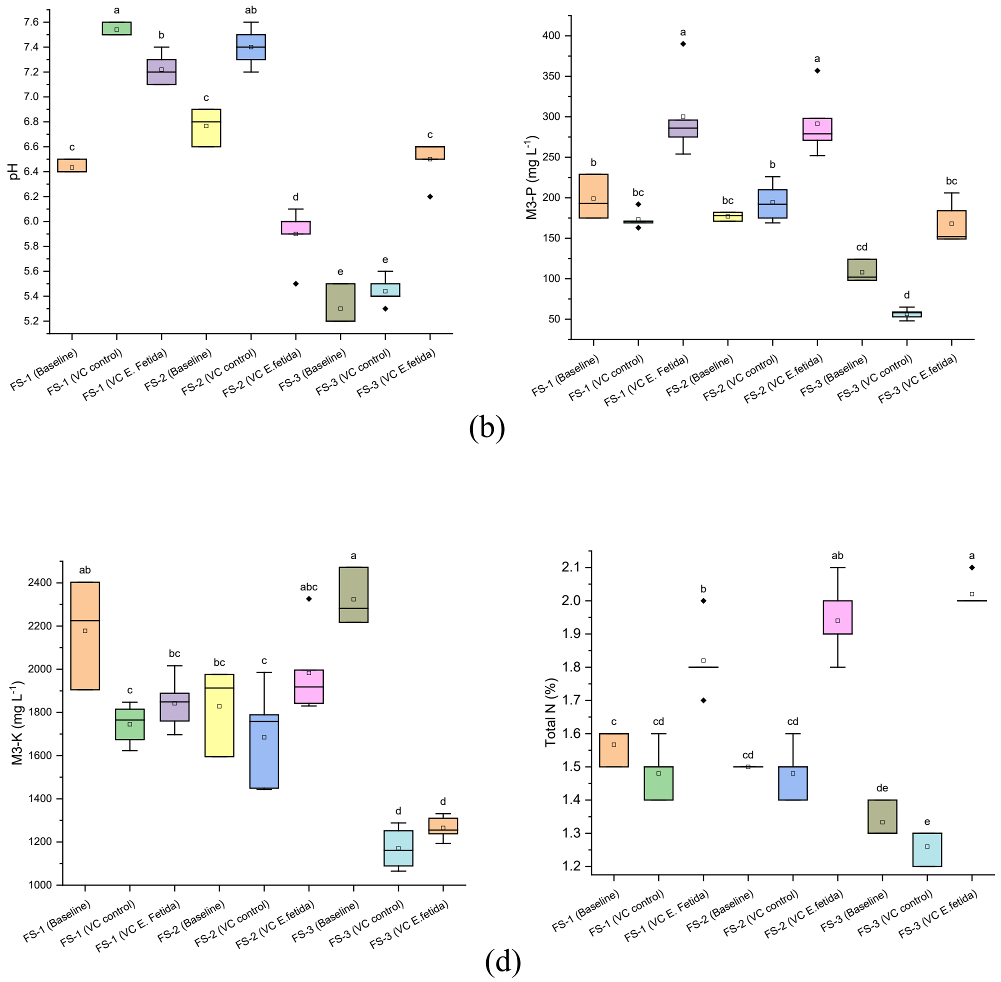
### 4.3. Comparing feedstocks and vermicompost properties

The vermicompost (with *E. fetida*) from all feedstocks had a pH between 6.0 to 7.2 while the controls (without *E. fetida*) had a pH of 7.5 for feedstock 1, 7.2 for feedstock 2, and 5.4 for feedstock 1. The vermicompost from feedstocks 1 and 2 had about 33% OM while feedstock 3 has higher OM (46%). The controls for feedstocks 1 and 2 have comparable OM with vermicompost while feedstock 3 control has slightly higher OM (55%). The vermicomposting process has decreased about 20% of the initial OM in feedstock 1, while only about a 7% decline was observed in the control treatment for the same feedstock. Feedstock 2 (having spent soil as a brown material) has a similar OM decline of about 17% in control and vermicompost samples (Table 2d). This implies that the spent soil (Feedstock 2) has higher microbial activities to break down organic materials compared to other feedstocks but requires further evaluation to understand their interaction with E. fetida. Surprisingly, feedstock 3 has an increase of about 37% and 14% of OM in control and vermicompost treatment compared to the initial OM in the same feedstock (before the start of composting or vermicomposting). The increase can be explained by the type and stability of OM in the peat moss or the assimilation of the OM in the green material and peat moss by the microbial and worm activities. However, the total carbon in all treatments ranges from 32% to 39%, which is comparable with other vermicompost prepared from feedstocks with cow manure and vegetable waste supplemented with macrophyte biomass[28]. Further assessment will be conducted to understand the carbon dynamics and sequestration potential of the vermicompost and traditional compost as a part of the same project.

The cation exchange capacity (CEC) of control and vermicompost for all the feedstock was comparable and not affected by the worm activities, except for feedstock 2 (Table 2d). Regardless of the feedstock types, total N was significantly higher in all vermicompost samples than in controls and baseline feedstocks (Table 2d). The increase was 16%, 29%, and 52% in vermicompost 1, 2, and 3, respectively. The total N increase in vermicompost agreed with other studies and related to aeration of the feedstock, resulting in a lower loss of $NH_3$ gas and nitrogen addition in the form of mucus [25], [26], [29]. The C:N in the vermicompost was between 17 to 19 regardless of the feedstock types, similar to another study [28] which indicates the stability of the product for plant growth upon repetitive evaluation (greenhouse trial is ongoing) [26].

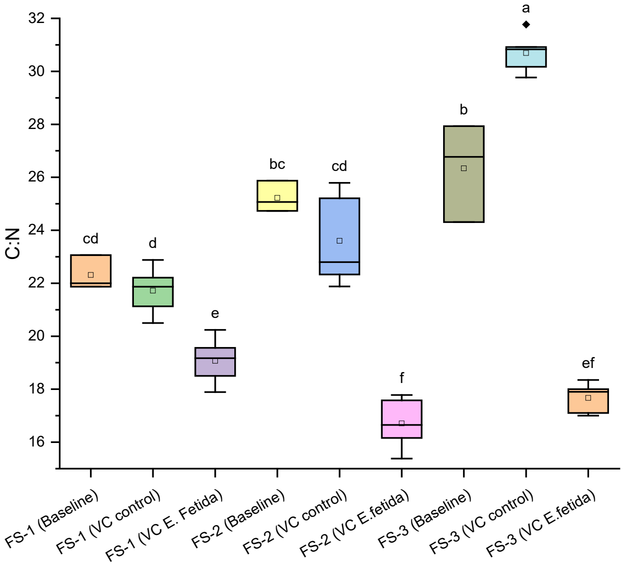
The Mehlich-3 P (M3-P) in vermicompost was significantly higher, by 51% and 65%, than the control in vermicompost 1 and 2, respectively, but no differences were observed between the two feedstocks. Similarly, vermicompost 3 had a significantly higher P than the control (Fig 4b). A similar trend was reported in other studies [30].

The sodium (Na) concentration in all vermicompost samples was higher than in control and initial feedstocks. Vermicompost 1 and 2 have an average Na of 365 and 545 mg $L^{-1,}$ while vermicompost 3 samples have an average Na of 141 mg $L^{-1}$. All vermicompost smaller quantities of boron, manganese, and zinc content and a trace amount of copper (Table 2d). The type of brown material and *E. fetida* activities influence the dynamics of carbon and nutrients in the vermicompost.



(a) (b)

(c) (d)



(e)

*Figure 4. Mean comparison of selected vermicompost properties (a) pH, (b) Mehlich-3 P, (c) Mehlich-3 K, (d) total N, and (e) C:N. Similar letter on the box-plots indicate no significance difference at $p = 0.05$. FS-1, 2, and 3 represent feedstock 1, 2, and 3, respectively. VC: vermicompost.*

## 5. Conclusion

This project assessed the potential of formulating engineered soil from local recipes using community and agriculture organic waste materials a source for N input (green materials) and spent potting soil and peat moss a source for C input (brown material) for the vermicomposting system. *Eisenia fetida* and *Eisenia hortensis* were applied to feed on the three types of feedstocks and monitored for 45 days. The pH of the feedstocks was adjusted using eggshell. Feedstocks were formulated from local recipes and evaluated for vermicompost formation. The produced vermicompost have acceptable physicochemical properties such as pH, EC, N, P, and C:N in comparison with other studies. The first trial of the greenhouse test (using lettuce) is ongoing. The current pilot vermicompost production will be scaled-up to increase production (the main recipe for engineered soil) to the level that allows replacing imported engineered soil. This will reduce the carbon footprint of farm products and divert the community and agricultural organic waste from landfill or other inefficient disposal options. Vermicomposting is known as an eco-friendly biotechnology solution for organic waste management and produces a nutrient-rich cast.

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