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Improving the Water Retention Characteristics of Sandy Soil using Food Waste Compost Amendment and Indigenous Microorganisms

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The ability of soil to promote plant development is mostly governed by its hydraulic properties, namely its water retention capacity. Sandy soils are the least fertile because of their poor moisture capacity, high water permeability, and low nutrient concentration. Adding food waste (FW) compost to sandy soil can improve its water retention capacity. The FW compost can enhance soil organic matter, which improves water and nutrient retention in sandy soils for plant growth and health. This study aims to identify the best composition amendment for FW compost to enhance soil water retention in sandy soil (sand 76 %, silt 8 %, clay 10 %, pH 4.8, and EC 142.4 dS/m). Indigenous microorganisms (IMOs) collected from bamboo leaves (*Gigantochloa albociliata*) were added to the FW compost to supply nutrients and stimulate plant growth. Five treatments were applied experimentally, with FW compost amendment rates of (5,15, 25, 35 and 100) % w/w, compared to unamended sandy soil as the control. 100 % FW compost provided the largest increase (169 %) in the amount of readily accessible water in sandy soil, raised total porosity to 6 % and reduced bulk density by 64 %. The FW compost with 25 % w/w compost significantly increased the seed germination of Dwarf Pak Choy (*Brassica campestris sp. chinensis*) to 125 %. This short-term study highlights the benefits of using FW compost and its potential to improve water retention when a low amendment rate (25%) is used.

1. Introduction

The retention curve, also referred to as the soil-water characteristic curve, explains the relationship between soil water content and soil water suction and is a significant part of establishing soil hydraulic characteristics. It is defined by the texture and the structure of the soil. Moisture content is a key physical aspect to consider during the composting process (McCartney and Tingley, 1998). Microorganisms will become inactive if the moisture concentration is too low, whereas too high a moisture content will result in anaerobic zones because water displaces air from pore gaps. High moisture content can weaken the material matrix, allowing it to be compacted more easily, limiting porosity, and leading to the formation of anaerobic zones (Agnew and Leonard, 2003).

Indigenous microorganisms (IMOs) and green manures serve as a nutrient reserve. Both improve soil fertility by increasing organic matter in the soil. Plants inoculated with IMOs show improved plant growth, a high nutritional status, particularly phosphorus, and resistance to harmful and disease-causing microorganisms (Sumathi et al., 2012). An IMO suspension contains a wide spectrum of naturally chelated plant nutrients and trace elements, as well as sugars, amino acids, and growth-promoting compounds, which function as a soil conditioner by encouraging microbial activity in the soil, thereby improving air-water interactions and soil fertility (Saran et al., 2020).

About 1.3 billion tonnes of food waste is produced each year worldwide, with households accounting for the majority of these food wastes (Palaniveloo et al., 2020). It is not acceptable to dispose of FW in landfills or

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incinerators because FW has high organic and moisture contents and low calorific value (Xin et al., 2020). A viable biotechnological method for disposing of FW is composting, which transforms organic waste into a secure, stable, and humus-rich soil fertiliser (Lin et al., 2018).

Amending the composition of FW compost, i.e. composition amendment, is an interesting agronomic activity and a good waste management approach, as it helps reduce the emission of greenhouse gases (GHGs) from landfills. Besides, applying FW compost to soil also improves the properties of the soil. Food waste compost is characterised by its high bonding capacity to water, nutrient, and organic matter (OM), as it consists of humic acid and its structural aggregates, allowing nutrients and water to be retained and released gradually into the soil (Lim et al., 2021). Moisture retention pF curves provide information on the capacity of available moisture, allowing us to conclude when and how much water the plant wants. This method is the most effective way to understand the link between water, soil, compost, and plants. To the best of the author's knowledge, only a few studies have investigated the effect of FW compost rate on the hydraulic properties of soil.

The present study aims to measure the influence of IMOs in FW compost to determine the best amendment composition to beneficially impact soil water retention.

2. Methodology

The The experiments in this study were performed using samples of sandy soil taken from Universiti Teknologi Malaysia, Pagoh Campus, located at 2º 16' 0" N latitude and 102º 73' 0" W longitude based on GPS Tracker 2.8 software. The soil contains 10 ± 0.17 g kg^{-1} of clay, 8 ± 0.06 g kg^{-1} of silt, and 76 ± 0.32 g kg^{-1} of sand. The soil organic carbon content is 6.62 g kg^{-1}. For this research, 1 kg of compostable food waste (leftover rice, vegetables, fruits and eggshells) was used. All these compostable wastes were collected from Café UTM, Pagoh, twice a week and were sorted into a container for 30 d (Cai et al., 2019). The container layered the food waste by alternating wet waste (food scraps, vegetables, and fruit peels) and dried leaves to create a favourable environment for microbes to break down the collected material over time. The container was then checked every 3 days and sprinkled with water when the pile appeared to be too dry. The organic carbon content of the compost was 43.3 g kg^{-1}.

The sandy soil and the compost were prepared in six different ratios: (S100, S95:C5, S85:C15, S75:C25, S65:C35 and C100) in weight over weight (w/w) to determine the water retainment capacity of each sandy soil-to-compost ratio. The moisture content of the sandy soil and the compost were determined at 0.1 bara, 0.33 bar, 1 bar and 3 bar using a pressure limiter with a 5-bar Plate Extractor (1600F1, Equipment Corp., Santa Barbara, CA, USA). The higher-pressure conditions (5 bar, 7 bar, and 9 bar) were measured using a 15-Bar Plate Extractor (1500F2, Equipment Corp., Santa Barbara, CA, USA).

Total Nitrogen and total Organic Carbon tests were subcontracted to SAMM accreditation laboratory by using MS 1120 (2004) and MS678:Pt I to IV:1980.

A standard dilution-plating process was used to measure the densities of cultivable bacteria. One gram of the soil, the soil–compost mixture, or the compost was suspended in 9 mL of peptone water for 10 s and shaken. Dilutions were made eight times. Each treatment was replicated three times.

Seed germination was tested for 20 Dwarf Pak Choy seeds in Petri dishes (diameter 10 cm, depth 1.5 cm) with filter paper soaked in 5 mL compost extract and incubated in the dark for 6 d at 22 ± 3 °C. The soil-compost extract was prepared using 20 g of soil mixture and 200 mL of distilled water. The mixture was then stirred for 3 h and then centrifuged for 20 mins at 8,000 rpm. A blank sandy soil filled with distilled water was used as a control. The germination index (GI) percentages were obtained based on Eq(1) below, as explained by Malakahmad et al. (2017):

$$Germination\ Index\ (\%) = \frac{Relative\ seed\ germination\ x\ relative\ root\ growth}{100} \quad (1)$$

The statistical significance of the treatment effects of different concentrations of compost was determined via one-way Analysis of Variance (ANOVA) using SPSS software version 26.0.

3. Results and discussion

3.1 The Effect of the FW compost on soil moisture retention

Sandy soils have low water retention capacity and low irrigation water drainage beneath the root zone, so plants grown on such soil will inefficiently use the water and nutrients (Andry et al., 2009). Seed germination and plant development are also severely hindered due to the low moisture level of the soil. In Figure 1, the FW compost amendments retain more water than soil due to the high organic matter content of the FW compost.

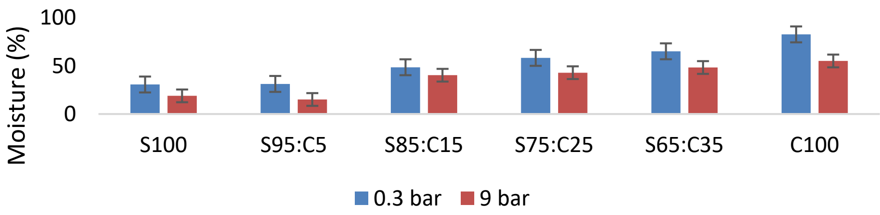

Figure 1: Moisture retention of the sandy soil and FW compost amendment. (Treatments are 100% soil, 95% soil:5% compost, 85% soil:15% compost, 75% soil:25% compost,65% soil:35% compost and 100% compost)

Microbial activity would be restricted at moisture levels below 40%, whereas at higher levels (> 70 %), the process is likely to turn anaerobic and smelly. The initial moisture contents for S75:C25 and S65:C35, respectively, were 58 % and 65 %, both of which are within the ideal range of 55 %–70 % for FW compost (Yeh et al., 2020). The treatment was neither too dry nor too moist; an ideal range for the microbial populations to grow. The moisture content was maintained at 42 %–48 % at 9 bar, indicating the essential circumstances for the successful function of the microbial population. An optimal moisture level strikes a balance between ensuring a consistent supply of oxygen and appropriate structure while also giving as much water as is practicable for microbial activity.

3.2 Effect on physical properties

The effect of varying FW compost compositions on the physical parameters of sandy soil is shown in Table 1.

Table 1: Effect of different concentrations of FW compost on the physical properties of sandy soil (P<0.05)

Soil: Compost ration	Porosity (%)	Bulk Density (kg/cm^3)	Soil pH	Organic Carbon (%)	C/N ratio
S100	91.97±0.11	212.72	4.77±0.00	0.6	5.9
S95:C5	92.34±0.11	202.93	6.86±0.05	0.9	7.2
S85:C15	94.26±0.11	152.22	6.88±0.04	2.8	8.8
S75:C25	94.42±0.19	147.89	6.98±0.03	4.2	8.9
S65:C35	95.00±0.20	132.85	7.03±0.01	6.9	11.1
C100	97.40±0.01	79.11	6.76±0.01	17.7	10.8

A substantial difference between the control and all the treatments can be seen from the changes in the bulk density (BD) of the FW compost amendment. The most notable reductions in BD were observed with treatments C100, S65:C35, and S75:C25, with corresponding reductions of 63.0 %, 37.9 %, and 30.8 %. The decrease in BD (and rise in total porosity) as a function of amendment rate follows a similar pattern for enhanced FW compost treatments. Several studies have noted a comparable reduction in BD following the FW compost amendment (Seyedsadr et al., 2022). The C100 treatment was associated with the greatest increases in total porosity, at 5.9%. The FW compost have influenced soil porosity directly through pores within the FW compost and the formation of packing or accommodation holes between the FW compost and the surrounding soil aggregates (Blanco-Canqui, 2017). This effect may also be due to an increase in SOM and aggregate stability afforded by the soil amendments (El-Naggar et al., 2019). The overall findings are consistent with past research, which has demonstrated that treated soil samples with elevated total pore volume also saw a substantial reduction in BD.

The amount of organic carbon relies on the amount of moisture in the FW compost. FW are readily degradable, and the loss of organic carbon during the composting process is caused by the increasing humidity. The nitrogen loss during the composting process increases with a decreased C/N ratio. The amount of nitrogen lost during the composting process increases with a lower C/N ratio. The higher the C/N ratio, the slower the rate of decomposition and the likelier that nitrogen would be immobilised during the composting process as well. The highest C/N ratio (11.1) seemed to correlate to a proper compost amendment (S65:C35), which is comparable to the values reported in the study of Vázquez et al. (2015).

3.3 Effect of different composition of FW compost on determination of viable cell count

The level of stability of the compost is the fundamental prerequisite for its safe usage in the soil. The stability of the compost is defined as the lack of phytotoxic substances and animal and plant pathogens in organic waste

(Cesaro et al., 2019a). The microbial activity in the compost is often linked to the stability of the compost. The microbial activity can be determined by using the microbial count as shown in Figure 2.

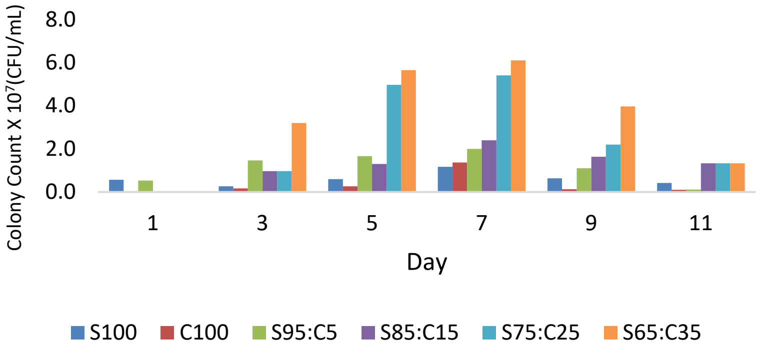

Figure 2: Total bacterial cell numbers in different soil/compost mixtures after compost amendment.

The treatment type and the effect of time on heterotrophic bacterial cell numbers were significant ($P < 0.05$). The number of bacterial cells was shown to be positively proportional to the amount of compost added to the soil. There was no resilience in the bacterial cell number 9 d after amendment. A dry compost mixture (S95:C5) would inhibit nutrient mobility, while a very wet mixture (C100) would hinder oxygen penetration, leading to anoxic conditions (Zailani et al., 2017). These two extreme moisture conditions would result in lower aerobic microbe activities and negatively affect the composting process.

The decreased cell number reported in C100 compared to other soil treatments could be attributed to the fact that (1) IMOs do not survive or are inactive in soil/compost mixtures when environmental circumstances are considerably different, and (2) following compost sterilisation, there is enhanced accessibility to organic carbon or nutrients. Irradiation of soil or compost has been shown to alter the chemical equilibrium of the sterilised material because it releases nutrients and destroys organic materials (Rawls et al., 2003).

3.4 Effect of compost on seed germination and root growth of Dwarf Pak Choy

According to Cesaro et al. (2019b), germination index (GI) values lower than 60% indicate significantly different phytotoxic effects from the control. The GI results for the current study are shown in Table 2. The experimental results show that the GI for S95:C5 and C100 were 51% and 44%, respectively, indicating phytotoxicity, whereas the highest GI was attributed to S75:C25, which indicates the most stability. These findings are consistent with prior research on the impact of compost on the vegetative growth of moringa seedlings (Wasiu Babatunde et al., 2019). It has been shown that applying a soil-FW compost amendment slightly raised GI values in comparison to the control. Higher seedling GI in compost amended treatments could be related to two factors: i) direct nutrient entry into the soil: as the compost frequently undergoes quick oxidation after being applied to the soil, more nutritional ions are released from their surfaces (Laghari et al., 2015); and ii) the increased water availability improves the bioavailability of soluble nutrients in the topsoil.

The literature has shown that FW compost amendments promote soil moisture retention as well as seed germination and seedling growth (Malakahmad et al., 2017). Figure 3 shows germinated Dwarf Pak Choy seeds in the control and the different compositions of compost.

Table 2: The effect of different composition of FW compost on the seed germination and the seedling growth of Dwarf Pak Choy (Brassica campestris sp chinensis) in sandy soils.

Treatments	Number of Seeds Germinated*	Relative Seed Germination (%) [a]	Mean Root Length	Root Growth (%)** [b]	Germination Index (%) [a × b]
S95:C5	17	94.44	1.6	53.96	51
S85:C15	16	88.89	2.5	87.28	78
S75:C25	17	94.44	3.8	131.85	125
S65:C35	15	83.33	3.0	104.83	87
C100	7	38.89	3.3	112.32	44

*Amount of seed germination for control: 18

**Mean of root growth for control: 2.9

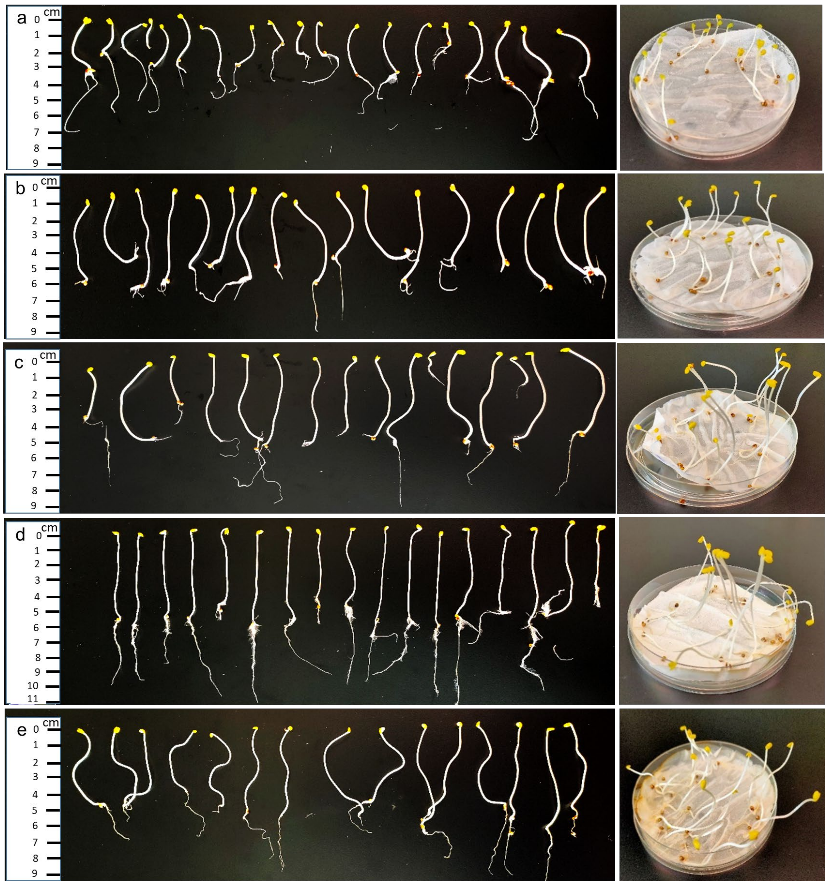

Figure 3: Total Seed Germination of (a) control (b) S95:C5 (c) S85:C15 (d) S75:C25 (e) S65:C35

Although FW compost amendment positively influenced Dwarf Pak Choy growth, C100 had no significant impacts, similar to other previously reported results (Kavitha et al., 2018). For example, the salt level of the soil-compost combination may limit the amount of compost that may be applied. If the salt concentration exceeds the tolerance of the plants to be cultivated, a better compost source must be obtained, or lower rates must be used (Cogger, 2005). The 100 % compost amendment, which rejects the study's hypothesis that compost amendment may boost seed germination, could be linked to a minor immediate gain in the bioavailability of nutrients following compost amendment in soil due to the almost neutral pH of the tested soil (pH 6.8). It was discovered that using a compost amendment rate of 25 % (as an organic amendment) could be the most effective way to produce high-quality Dwarf Pak Choy seedlings, while the 35 % compost amendment rate failed to enhance overall seed germination most likely due to the limited compost application rates.

4. Conclusions

Adding FW compost to soil increased not only the physicochemical features of the soil such as organic matter, porosity, and moisture retention but also its abiotic variables. The FW compost can positively affect the soil's microbial population and encourage plant development due to the availability of growth agents. The present study demonstrated that the amended soil response can vary greatly depending on the amendment rate used. This short-term study highlighted the benefits of using FW compost and its potential effects on the water and nutrient improvements of sandy soil while using a low amendment rate (25%), which also resulted in a higher GI (125%). This research reflects the need to further study soil management effects utilising a multi-parameter approach. Composting enhances agricultural production, soil protection, biodiversity, waste management, and soil C sequestration in general. Long-term field experiments would better explain the effects of FW compost rate applications on carbon dioxide efflux and soil respiration.

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