Nutrient enhancement potentials of moringa (*Moringa oleifera*), neem (*Azadirachta indica*), and pawpaw (*Carica papaya*) fortified composts in contaminated soils

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Abstract This study assessed the nutrient enhancement potentials of moringa (*Moringa oleifera*), neem (*Azadirachta indica*), and pawpaw (*Carica papaya*) fortified composts in contaminated soils. The composts were formulated from poultry manure; leaves of moringa, neem, and pawpaw; and sawdust for a period of 8 weeks. Contaminated soil samples were collected from a dumpsite in Abeokuta, Ogun State. The contaminated soils were treated with the stabilized composts for a period of 4 weeks. Castor oil plants were introduced to assess the nutrient quality of the composts.

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Soil and compost parameters (pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (TN), C/N ratio, P, K, Na, Mg, and Ca) were determined using the standard procedures. Data collected were evaluated for simple descriptive and inferential statistics. Results showed non-significance ($p > 0.05$) of C/N ratios that ranged between 12.75 ± 2.43 and 12.96 ± 1.49. The pH values of moringa- and neem-fortified composts were slightly acidic, while the pawpaw-formulated compost was slightly alkaline. The levels of TN and OC were three times higher in moringa- and pawpaw-fortified composts than in the neem compost. Introduction of the composts to the contaminated soils decreased the soil pH but increased the nutrient quality parameters such as TN (33–50%), OC (56–77%), P (7–20%), Na (89–91%), K (12–25%), and Mg (10–13%). The three compost types increased the physiological properties of the castor oil plants. The study indicated the promising potentials of the three composts for nutrient enhancement of soil.

Keywords Nutrient enrichment · Contaminated soil · Soil properties · Plant · Compost types

Introduction

Soil pollution can threaten agricultural lands due to severe adverse effects on food quality and security. Soil contamination could arise from organic and inorganic pollutants such as metals, polycyclic aromatic

hydrocarbons, polychlorinated biphenyls, and total petroleum hydrocarbons (Bhabananda et al., 2008). These chemical impurities can initiate a number of illnesses and diseases including cancer, pulmonary diseases, cardiovascular diseases, genetic disorder, skeletal effect, and renal and peripheral neuropathy (Jurowski et al., 2021a, b, c, 2022; Muncke et al., 2020). Compost is applied to contaminated soil for a dual purpose of cleanup and nutrient enhancement (Taiwo et al., 2016). Composting is a natural process involving microbial degradation and stabilization of organic matter to a dark humus-like form (Taiwo, 2011; Taiwo et al., 2016). The *Moringa oleifera* (moringa) plant is an important source of food and herbal medicine. It has also been utilized for leachate treatment, for water purification, as a bio-fertilizer, and as green manure to increase the micro- and macronutrients in the soil (Ozobia, 2014; Taiwo et al., 2019). *Azadirachta indica* (neem) is another plant that plays a vital role in the prevention and treatment of diseases through many physiological and biological pathways (Alzohairy, 2016). Neem leaves and fruits possessed antimicrobial, nematocidal, and fungicidal properties, and hence had been applied as bio-pesticides (Gajalakshmi et al., 2004). Pawpaw is a unique plant with a proteolytic enzyme, chymopapain, that contained antifungal, antiviral, and antibacterial properties (Santana et al., 2019). The medicinal (anti-inflammatory, antiulcerogenic, and immunomodulatory actions) applications and biological (papain and chymopapain) activities of various parts of pawpaw have been demonstrated in published literature (Otsuki et al., 2010; Santana et al., 2019).

Moringa, neem, and pawpaw plants are rarely utilized as a source of green in composting. Few studies have adopted these plants as a sole material/supplement in composting (Adekiya et al., 2019; Agbede et al., 2018; Parmar & Shah, 2014; Shrinithivihahshini, 2009). However, the promising potentials of these three greens as nutrient enhancements of polluted soils are yet to be fully understood. The present study therefore utilized the composts made from moringa, neem, and pawpaw leaves to enhance the nutrient quality of contaminated soil samples collected from a dumpsite in Abeokuta, Ogun State.

Materials and methods

Experimental site

The study was carried out in a screen house located at the Federal University of Agriculture, Abeokuta (FUNAAB), that lies on latitude 7°30′N and longitude 3°54′E.

Compost formulation and composting

Composts were obtained after decomposition of organic wastes (Haouvang et al., 2017) from poultry manure, green leaves (moringa — *Moringa oleifera*, neem — *Azadirachta indica*, and pawpaw — *Carica papaya*), and sawdust, using the pile composting method. The compost materials were mixed at varying proportions of 35 kg poultry manure, 10 kg leaves, and 2 kg sawdust (Joyce, 2010). The composting operated under a controlled aerobic condition and close monitoring through regular wetting and turning for 8 weeks. The composts were determined for pH, electrical conductivity (EC), moisture content (MC), organic carbon (OC), total nitrogen (TN), phosphorus (P), potassium (K), sodium (Na), magnesium (Mg), and calcium (Ca) using the standard methods (AOAC, 2000) described in Official Methods of Analysis for "Chemical and physical parameters of compost/soil samples."

Soil collection

Contaminated soil samples were collected from the Saje dumpsite located in Abeokuta South Local Government, Abeokuta Ogun state (Fig. 1), an abandoned quarry mining site converted to a dumpsite in 1995 (Popoola & Adenuga, 2019). The Saje dumpsite is established on 4 Ha of land that daily receives about 150 t of municipal wastes (Popoola & Adenuga, 2019). The soil samples were collected randomly from four sampling points of the dumpsite at depth 0–30 cm. The samples were bulked together to form a composite that was subsequently air dried, sieved (<2 mm mesh), and homogenized. The homogenized contaminated soil samples were analyzed for important soil parameters using the procedures (AOAC, 2000) described in
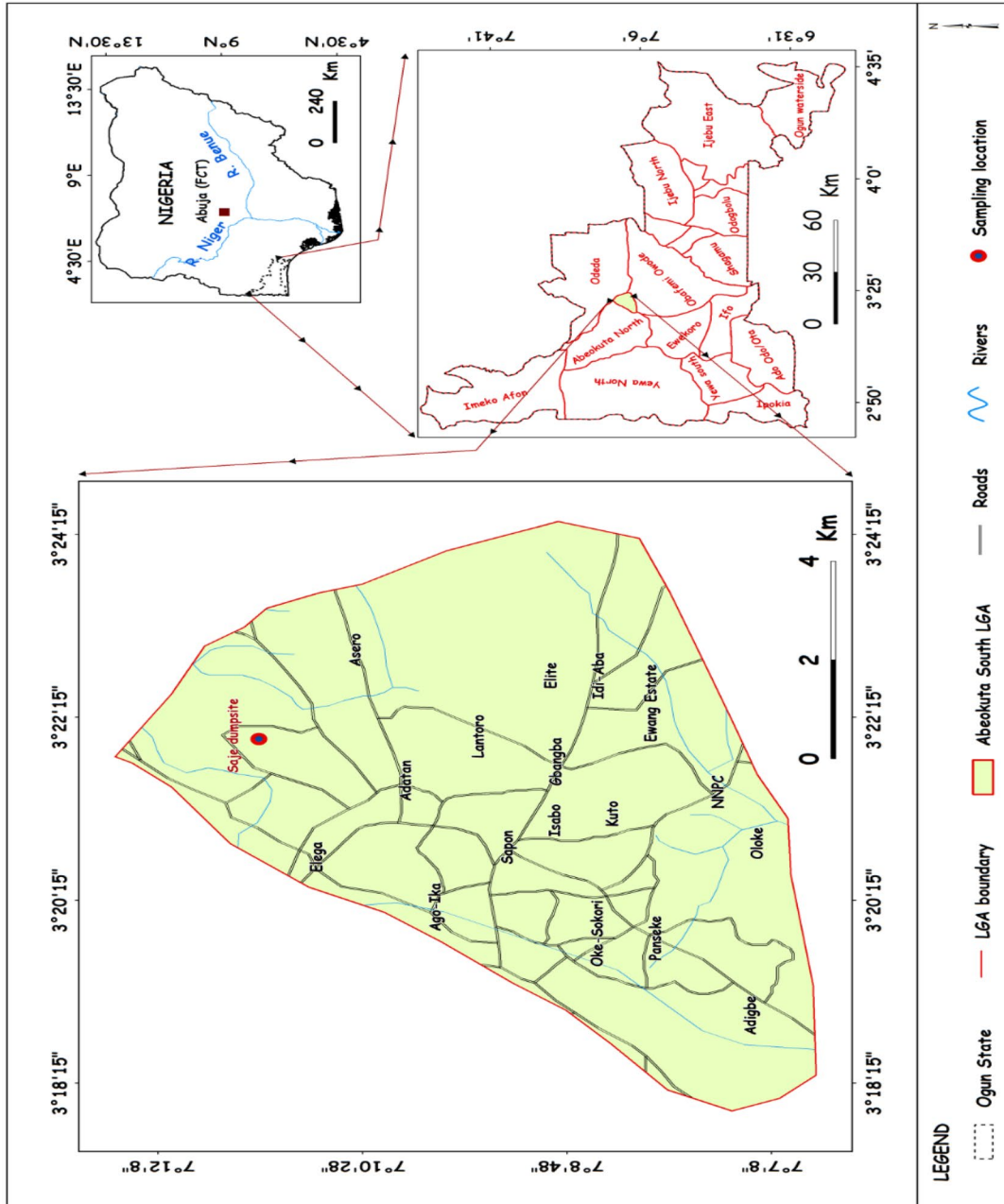
Fig. 1 The map of the Saje dumpsite in Abeokuta South Local Government, Ogun State

"Official Methods of Analysis fot Chemical and physical parameters of compost/soil samples."

Experimental design and treatments

The experiment was carried out in a randomized complete block design involving 12 treatments ($3 \times 4 \times 3!$) for "compost only" and 12 treatments ($3 \times 4 \times 3!$) for "compost + plant" for a period of 4 weeks. For the compost-only experiment, the three composts (moringa, neem, and pawpaw) were mixed with the air-dried and sieved contaminated soil samples in four mixing ratios. The ratios of mixing were 1:200 (5 g compost + 1 kg soil), 1:100 (10 g compost + 1 kg soil), 1:66 (15 g compost + 1 kg soil), and 1:50 (20 g compost + 1 kg soil). Each compost/soil mixing ratio treatment was further replicated into three samples. Similarly, a "compost + plant" experimental design was set up. Castor oil plants (*Ricinus communis*) were introduced into four separate compost/soil mixing ratios (1:200, 1:100, 1:66, and 1:50) that were further triplicated, for phytoremediation and physiological experiments. The physiological properties such as stem girth and height and leaf breath and length were measured on a weekly basis for 4 weeks. A total of 75 pots (36 for "compost only," 36 for "compost + plant," and 3 for control) were set up for the experiment.

Chemical and physical parameters of compost/soil samples

The compost, contaminated, and remediated soil samples were analyzed for physical and chemical parameters including pH, temperature, EC, MC, OC, TN, P, K, Na, Mg, and Ca using the standard procedure (AOAC, 2000). After the 6-week experiment, the treated soil samples were analyzed for important physical and chemical parameters.

The pH, temperature, and EC of compost/soil samples were assayed using a combined pH/EC probe (Combo HI, Model 9813). This method involves dissolving 2.0 g compost/soil sample in 10 mL distilled water. The mixture was swirled thoroughly, and the electronic meter probe was inserted for measurement of pH, temperature, and EC.

Moisture content was assayed gravimetrically using the procedure described in Aya El Zein et al. (2015). Organic carbon was determined by the Walkley–Black wet oxidation procedure involving the measurement of dichromate ion consumed in the process of organic matter oxidation (Taiwo et al., 2016). This method entails weighing 1.0 g compost/soil sample into a conical flask, followed by measurement of 10 mL 0.1 N $K_2Cr_2O_7$, and rapid introduction of 20 mL concentrated H_2SO_4. The mixture was shaken for 60 s, and 100 mL distilled water (after cooling) was added. Exactly 3 drops of indicator were introduced, and the solution titrated against 0.5 N ferrous sulfate solution till a color change to maroon.

The Bray I method was adopted for determination of phosphorus (Wu et al., 2013). The Bray 1 solution was added to the compost/soil sample, and vigorously agitated for 60 s, after which the resulting solution was centrifuged at 6000 rpm for 5 min. Reagent C was added to the supernatant product of the centrifuged solution. The final solution was measured for phosphorus using a Jenway UV/visible Spectrophotometer (Model 6405).

TN was assayed using the Kjeldahl distillation procedure following the details described extensively in Mylavarapu and Kennelley (2002). The distilled compost/soil digest was transferred into a clean Macro-Kjeldahl flask and analyzed with a Jenway UV/visible Spectrophotometer (Model 6405). The C/N ratio was calculated from the results obtained with Walkley–Black (C) and the TN determination.

The exchangeable cations (Na, K, Ca, and Mg) were analyzed using ammonium acetate (1 N NH_4O AC) buffer solution shaken with a mechanical shaker for 2 h to obtain a clear supernatant decanted into a 100-mL standard volumetric flask (Taiwo et al., 2016). This extraction cycle was repeated for another 30 min. The solution extract was made to the mark with 1 N NH_4O AC and then analyzed for Na, K, Ca, and Mg. Ca and Mg were determined with an Atomic Absorption Spectrophotometer (AAS, 210/211VGp Buck Scientific, E. Norwalk, CT, USA), while Na and K were analyzed using a flame photometer (Jenway, Model PFP 7).

Data analysis

The compost and soil data were evaluated for simple descriptive (mean, standard deviation, minimum, and maximum) and inferential (Duncan's multiple-range test, regression analysis) statistics using the Statistical Package for Social Sciences (SPSS) for Windows (SPSS 21.0).

The percent (%) nutrient increment by "compost only," and "compost + plant" treatments were calculated with the formula presented in Eq. 1.

$$\% \text{ Nutrient increment} = \frac{Nx - Ny}{Nx} * 100 \qquad (1)$$

where N_x is the concentration of nutrient in the remediated soil and N_y is the concentration of nutrient in the contaminated soil.

Results and discussion

Compost characteristics

The physical and chemical characteristics of composts after an 8-week maturity are shown in Table S1 (in the supplementary information). The pH of moringa (6.73 ± 0.14) and neem (6.83 ± 0.31) fortified composts were slightly acidic, while pawpaw-fortified compost (7.21 ± 0.10) was slightly alkaline. These pH values fell within the ideal pH variation of 5.5–8.0 prescribed for compost (Bernal et al., 2009), an indication of maturity and stability (Chaudhari et al., 2012; Smith et al., 2020). Moderate pH in compost ensures nutrient availability to plants, while high acidic and basic pH could make nutrient unavailable to plants (Chaudhari et al., 2012). The pH range obtained in this study was similar to the range of 6.74–8.02 reported by Smith et al. (2020) in neem compost formulated along with cow dung and corn stover. However, Taiwo et al. (2016) documented a higher pH value of 8.90 ± 0.02 in water hyacinth composted with cow dung and sawdust.

Figure 2 presents the temporal variations of compost parameters. Little variation was observed in pH values during the 2 months of composting. Generally, there were reductions in the levels of physical and chemical parameters of the three composts from weeks 1 to 8. The temperature of the finished composts ranged from 31.33 ± 1.15 (neem) to 42.00 ± 0.00 °C (pawpaw) (Table S1). Generally, the mesophilic temperature (25–40 °C) regime is mostly appropriate for compost stabilization in order to reduce excess carbon loss (Parma and Shah, 2014). The slightly higher temperature observed in pawpaw compost than other composts could therefore be attributed to vibrant activities of the decomposing microbes. The highest temperature (56.3–61.7 °C) was observed at week 3 of

the composting, indicating the modal peak of microbial activities, and elimination of pathogens that could be harmful to humans and plants (Waszkielis et al., 2013). Similarly, Shrinithivihahshini (2009) documented the highest temperature level of 50.1 °C during the first 3 weeks of composting involving pawpaw leaves and other organic wastes. The maximum temperature range for composting was given as 55–60 °C by Waszkielis et al. (2013).

The moisture contents (MCs) of composts decreased from 56.7% at week 1 to 31.5–34.3% at week 8 (Fig. 2). Moringa compost showed the highest significant mean level of MC (Table S1). MC is one of the vital factors that define the transportation of nutrients required by the microorganisms for their metabolic and physiological activities (Heyman et al., 2019). The MCs of composts produced in this study were within the suggested range of 45–65% (Chen and Haro-Marti, 2012), similar to the level of 65% reported at week 1 of pawpaw compost by Shrinithivihahshini (2009).

There was no significant difference ($p > 0.05$) in the mean values of EC (995 ± 3.06–1069 ± 10.47 μS/cm) in the three composts (Table S1), and thus comparable to the value of 1564 ± 208 μS/cm observed by Taiwo et al. (2016). However, Smith et al. (2020) observed higher levels of EC (3000–10,300 μS/cm), while a lower EC value (400 μS/cm) was documented by Shrinithivihahshini (2009). The EC value higher than the threshold limit of 4000 μS/cm in compost may be toxic to plants (Roig et al., 2012).

TN was measured at the lowest concentration in neem-fortified compost (0.75 ± 0.06%), while the highest value was observed in moringa compost (2.14 ± 0.26%) (Table S1). The TN level observed in neem-fortified compost was extremely lower than the range of 1.45–2.19% reported by Smith et al. (2020), while moringa- and pawpaw-fortified composts were within the range. The TN concentrations documented in this study were within the recommended range of 0.50–3.5% stipulated by the Penn State Agricultural Analytical Services Laboratory (Heyman et al., 2019). The temporal variations of TN showed little or no difference in the levels observed in moringa- and pawpaw-fortified composts from weeks 1 to 8 (Fig. 2). The neem-fortified compost indicated the highest level of TN reduction (by 50%) from weeks 1 to 8 (Fig. 2), probably due to vigorous microbial activities (El-Sharkawi, 2012).
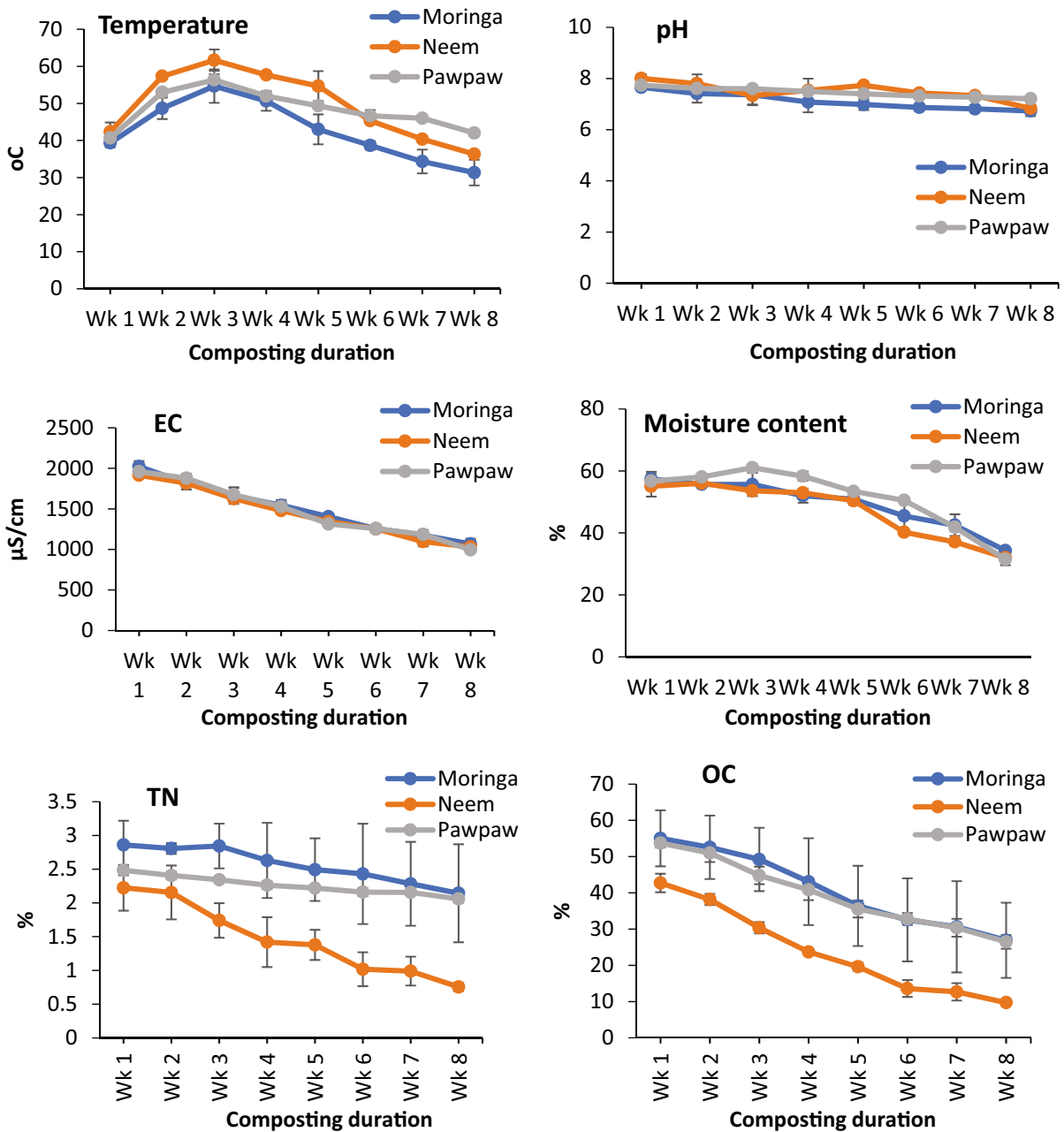
Fig. 2 Temporal variations of compost physical and chemical parameters; Wk — week

The concentrations of OC in the composts followed a similar pattern like TN, showing the varying values of 9.72 ± 0.49–$12.9 \pm 2.12\%$ (Table S1). OC can be converted directly to organic matter (OM) by multiplying with 1.729 based on the assumption that organic matter contains 58% OC (Taiwo et al., 2016). The conversion gives the OM range of 17.15–22.3%,

the values slightly lower than the recommended level usually greater than 24% (Heyman et al., 2019). This study established that moringa- and pawpaw-fortified composts were richer in OC than the neem compost.

Despite reduction in the C/N ratios of the three compost types by almost 50% from weeks 1 to 8 (Fig. 2), the mean C/N ratio of the final compost, which varied from
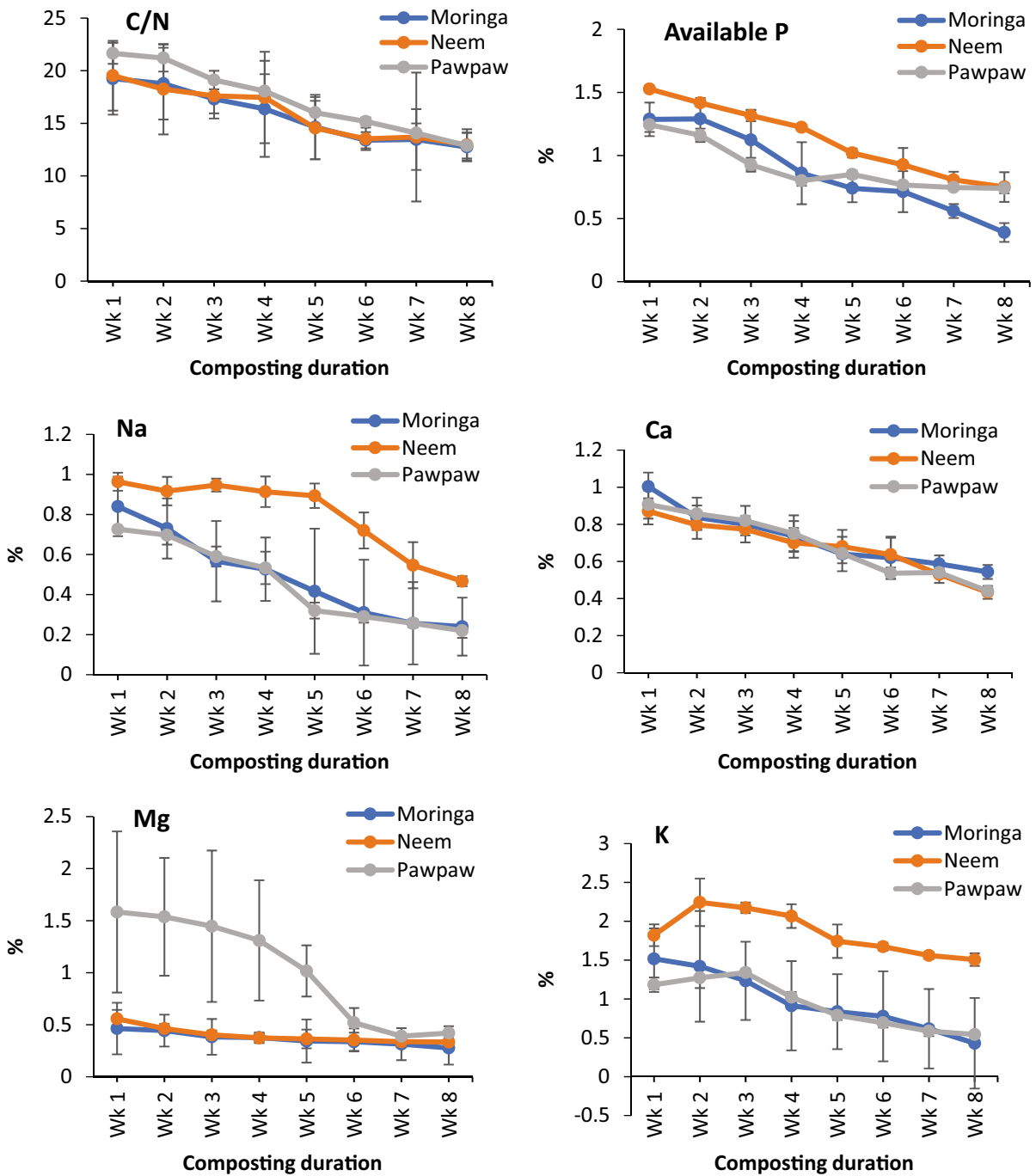
Fig. 2 (continued)

12.75±2.43 to 12.96±1.49 (Table S1), still fell within the recommended value of 10–20 (Sullivan et al., 2018). In our past study, the compost formulated from water hyacinth, cow dung, and sawdust produced a lower C/N ratio of 10.1±3.0 (Taiwo et al., 2016). Correspondingly, a lower C/N ratio of 7.5 was observed by Parmar and Shah (2014) in neem leaf compost. Similarly, a C/N ratio range of 12.9–16.7 was observed in a 9-week compost of

pawpaw leaves with organic wastes (Shrinithivihahshini, 2009). Furthermore, composting 50% pawpaw leaf extract with organic wastes produced the C/N ratio of 12.75 (Elmanda, 2014). Smith et al. (2020) also reported the C/N ratio of 10.9–13.6 in compost-formulated from neem leaves, cow dung, and corn stover. This study obtained the C/N ratios that fell within the range (12–18) suitable for agricultural purposes (Heyman et al., 2019). This therefore indicated the promising and sustainable potentials of the three compost types as biofertilizers for agricultural production of organic foods.

The available P (0.39 ± 0.04–$0.75 \pm 0.12\%$) contents (Table S1) in all the three composts were generally low, although the values appeared to be significantly higher in neem- and pawpaw-fortified composts than in moringa compost. The available P level observed in neem-fortified compost was similar to the value of 0.60% reported in compost made from the leaves of neem (Parmar & Shah, 2014). Green wastes are typically lower in P than the food scraps and biosolids (Heyman et al., 2019). The past study of Shrinithivihahshini (2009) observed a lower P concentration (0.08%) in pawpaw compost when compared to the present study.

Na indicated the highest significant ($p < 0.05$) concentration in pawpaw-formulated compost ($0.54 \pm 0.04\%$), while the lowest level of Na was observed in moringa-fortified compost ($0.24 \pm 0.02\%$) (Table S1). The highest amount of K was determined in neem compost ($1.51 \pm 0.08\%$), while no significance was observed in the mean concentrations of K for moringa and pawpaw composts. A past study established a higher K level (2.03%) in the compost of neem leaves (Parmar & Shah, 2014) than those obtained in the present study. The distributions of Mg in the composts followed a similar trend like K, where the neem-fortified compost had the highest level ($0.33 \pm 0.04\%$). Moringa-fortified compost revealed the highest level of Ca ($0.54 \pm 0.03\%$).

The summary of the nutrient composition of composts is shown in Figure S1 (in the supplementary information). Moringa- and pawpaw-fortified composts were richer in TN and OC than the neem compost, which had the highest level of K. The three composts appeared to produce similar values of Ca, while the neem- and pawpaw-fortified composts showed slightly higher concentrations of P and Mg.

Effects of composts on contaminated soil properties

Table 1 shows the compost resultant effects on the physical and chemical characteristics of contaminated soil before and after treatment. In all the treatments, introduction of composts decreased the mean pH of contaminated soil to significant levels (7.34 ± 0.21–7.78 ± 0.20) suitable for agricultural activities (Oshunsaya, 2019). The TN of contaminated soil increased significantly from $0.52 \pm 0.04\%$ to the highest value of $1.11 \pm 0.26\%$ in Pawpaw compost–amended soil. The concentration of P in the contaminated soil increased from 16.57 ± 1.25 to $22.64 \pm 3.57\%$ in Pawpaw compost–treated soil. Similar observations were established for OC, exchangeable Na, K, and Mg, indicating nutrient enhancement of the contaminated soils by the composts. However, the exchangeable Ca decreased in contaminated soils from 47.17 ± 4.74 to 4.22 ± 0.16 cmol/kg in the contaminated soil + moringa compost + plant treatment.

Effects of compost on contaminated soil pH

Figure 3 shows the compost effects on the pH of the contaminated soils. The pH of the contaminated soils decreased by 9–12% for pawpaw compost. This value was two times higher in the contaminated soils treated with moringa- and neem-fortified composts. A pH reduction was also observed in the "compost + plant" treatment. The experimental setup with pawpaw compost and castor oil plant showed the highest reduction value, especially at a 1:50 compost/soil mixing ratio. The reduction in pH by compost could suggest good potential for removal or cleanup of toxic metals (Taiwo et al., 2016). However, the pH values observed in all the treated soils depicted an alkaline environment (Table 2).

Nutrient enhancement potential of composts on contaminated soil

Figure 4 shows the nutrient enhancement ability of compost on contaminated soils. Moringa compost was able to raise the TN of the contaminated soil by 49–50%, while the other two composts increased the TN by 33–44%. The "compost + plant" experiment indicated lower TN incremental values, probably due to uptake by plants (Masclaux-Daubresse et al., 2010).

Table 1 Effects of composts on the physical and chemical parameters of the contaminated soils before and after remediation

		N 75	Mean	Std. deviation	Minimum	Maximum
pH	Contam. soil	3	8.37d	0.15	8.20	8.50
	Contam. soil + moringa compost	12	7.78c	0.20	7.45	8.10
	Contam. soil + moringa compost + plant	12	7.49ab	0.21	7.12	7.80
	Contam. soil + neem compost	12	7.67bc	0.30	7.15	8.10
	Contam. soil + neem compost + plant	12	7.49ab	0.21	7.15	7.85
	Contam. soil + pawpaw compost	12	7.40a	0.17	7.19	7.82
	Contam. soil + pawpaw compost + plant	12	7.34a	0.21	7.13	7.80
TN (%)	Contam. soil	3	0.52a	0.04	0.47	0.55
	Contam. soil + moringa compost	12	1.06d	0.11	0.89	1.25
	Contam. soil + moringa compost + plant	12	0.77bc	0.17	0.45	1.15
	Contam. soil + neem compost	12	0.84c	0.08	0.73	0.94
	Contam. soil + neem compost + plant	12	0.65ab	0.04	0.59	0.74
	Contam. soil + pawpaw compost	12	1.11d	0.26	0.80	1.42
	Contam. soil + pawpaw compost + plant	12	0.79bc	0.10	0.61	0.94
OC (%)	Contam. soil	3	5.15a	0.55	4.78	5.78
	Contam. soil + moringa compost	12	22.26d	8.97	14.10	37.20
	Contam. soil + moringa compost + plant	12	10.80b	2.50	8.53	14.22
	Contam. soil + neem compost	12	21.65d	3.47	12.34	23.92
	Contam. soil + neem compost + plant	12	11.54b	1.44	8.89	13.53
	Contam. soil + pawpaw compost	12	16.50c	4.07	10.90	23.34
	Contam. soil + pawpaw compost + plant	12	8.75ab	1.26	7.42	11.67
P (%)	Contam. soil	3	16.57a	1.25	15.30	17.80
	Contam. soil + moringa compost	12	19.23bc	1.23	17.40	21.60
	Contam. soil + moringa compost + plant	12	18.27ab	0.64	17.30	19.40
	Contam. soil + neem compost	12	20.45c	1.93	17.10	23.60
	Contam. soil + neem compost + plant	12	18.08ab	1.01	15.40	19.60
	Contam. soil + pawpaw compost	12	22.64d	3.57	17.10	27.60
	Contam. soil + pawpaw compost + plant	12	18.27ab	1.50	17.10	22.50
Exch. Na (cmol/kg)	Contam. soil	3	4.01a	0.81	3.43	4.94
	Contam. soil + moringa compost	12	29.69bc	7.25	22.60	47.50
	Contam. soil + moringa compost + plant	12	27.48 cd	6.46	20.20	42.50
	Contam. soil + neem compost	12	36.11b	7.74	22.20	46.50
	Contam. soil + neem compost + plant	12	28.82b	5.51	20.40	36.50
	Contam. soil + pawpaw compost	12	37.88d	7.66	24.20	47.50
	Contam. soil + pawpaw compost + plant	12	31.41abc	5.97	20.10	38.50
Exch. K (cmol/kg)	Contam. soil	3	1.65a	0.08	1.58	1.73
	Contam. soil + moringa compost	12	2.15bc	0.12	1.96	2.36
	Contam. soil + moringa compost + plant	12	2.19c	0.12	1.93	2.35
	Contam. soil + neem compost	12	2.01b	0.14	1.82	2.22
	Contam. soil + neem compost + plant	12	2.09bc	0.21	1.84	2.44
	Contam. soil + pawpaw compost	12	2.18c	0.10	1.96	2.30
	Contam. soil + pawpaw compost + plant	12	2.24c	0.16	1.96	2.55
Exch. Mg (cmol/kg)	Contam. soil	3	6.90a	0.45	6.63	7.42
	Contam. soil + moringa compost	12	7.84bc	0.16	7.50	8.02
	Contam. soil + moringa compost + plant	12	7.96bcd	0.07	7.86	8.10

Table 1 (continued)

		N 75	Mean	Std. deviation	Minimum	Maximum
	Contam. soil + neem compost	12	7.99 cd	0.16	7.65	8.25
	Contam. soil + neem compost + plant	12	8.07d	0.12	7.90	8.26
	Contam. soil + pawpaw compost	12	7.82b	0.16	7.55	8.10
	Contam. soil + pawpaw compost + plant	12	7.89bc	0.10	7.77	8.05
Exch. Ca (cmol/kg)	Contam. soil	3	47.17d	4.74	41.70	50.20
	Contam. soil + moringa compost	12	4.40a	0.24	4.03	4.80
	Contam. soil + moringa compost + plant	12	4.22a	0.16	4.00	4.60
	Contam. soil + neem compost	12	4.89ab	0.46	4.25	5.50
	Contam. soil + neem compost + plant	12	4.37a	0.21	4.15	4.85
	Contam. soil + pawpaw compost	12	5.89c	0.57	4.40	6.50
	Contam. soil + pawpaw compost + plant	12	5.53bc	0.48	4.50	6.40

Similar alphabets along the columns are not significant at $p < 0.05$

Exch. exchangeable, *Contam.* Contaminated

The reduction was more pronounced in moringa compost when compared to the remaining two composts. The reason might be due to the bioavailability of TN from moringa compost to the castor oil plant. Moringa and neem composts showed similar potentials in nutrient enhancement of the contaminated soils at the mixing ratios of 1:200 and 1:100, respectively. As the compost/soil ratios increased at 1:75 and 1:50, the neem compost showed a higher level of OC than the moringa compost–amended contaminated soils. The "compost + plant" treatment for OC exhibited similar trend like TN, where the moringa compost appeared to be more utilized by the plant than other composts. Even though both neem and pawpaw composts displayed greater potentials of P fortification in the contaminated soils than the moringa compost, it was observed that the enhancement of P by the three composts was generally low. The three composts were able to raise the P in the contaminated soils by 7–11% for moringa, 9–15% for neem, and 9–20% for pawpaw composts.
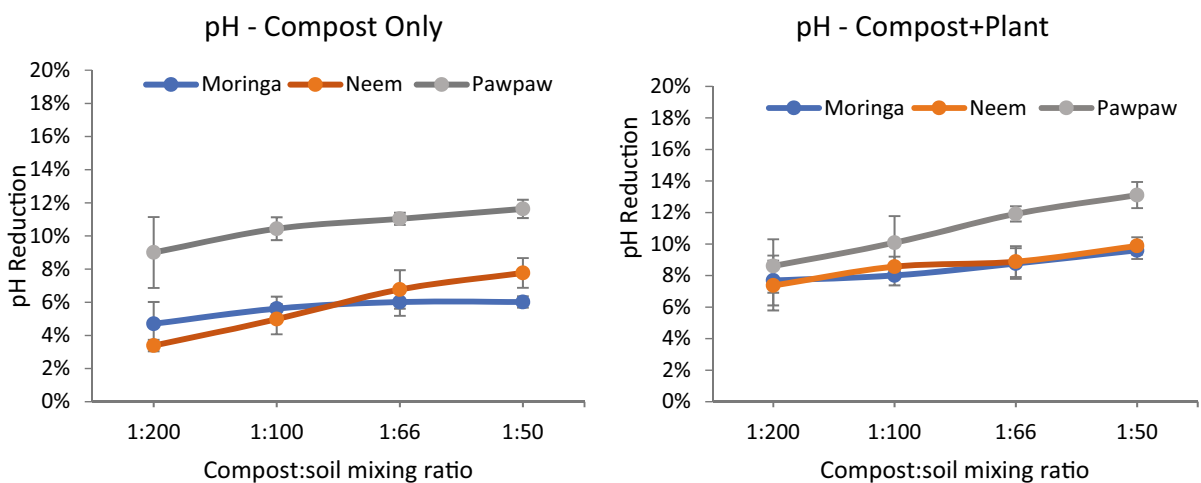

Fig. 3 Effects of composts on soil pH

Table 2 Regression analysis of different soil treatments

S/N	Treatment	Regression model	R	R^2	Sig
1	Contam. soil + moringa compost	$39.849 - 4.345\text{pH} - 0.844\text{TN} - 0.121\text{OC} - 0.020\text{P} - 0.021\text{Na} - 2.170\text{ K} + 0.185\text{ Mg} + 0.905\text{Ca}$	0.958	0.918	0.000
2	Contam. soil + moringa compost + plant	$8.201 - 4.074\text{pH} + 1.543\text{TN} + 0.088\text{OC} + 0.661\text{P} - 0.026\text{Na} - 0.313\text{ K} + 0.983\text{ Mg} + 0.987\text{Ca}$	0.997	0.994	0.030
3	Contam. soil + neem compost	$-19.814 - 1.661\text{pH} + 7.166\text{TN} - 0.162\text{OC} + 0.078\text{P} - 0.015\text{Na} - 1.972\text{ K} + 4.490\text{ Mg} - 0.076\text{Ca}$	0.968	0.937	0.092
4	Contam. soil + neem compost + plant	$-25.783 - 2.132\text{pH} + 6.120\text{TN} - 0.040\text{OC} - 0.008\text{P} - 0.021\text{Na} + 1.154\text{ K} + 4.849\text{ Mg} - 0.226\text{Ca}$	0.993	0.987	0.010
5	Contam. soil + pawpaw compost	$5.156 - 1.803\text{pH} - 0.065\text{TN} + 0.059\text{OC} + 0.042\text{P} - 0.048\text{Na} + 2.061\text{ K} + 0.534\text{ Mg} + 0.337\text{Ca}$	0.994	0.988	0.008
6	Contam. soil + pawpaw compost + plant	$-34.997 - 0.794\text{pH} - 1.261\text{TN} + 0.782\text{OC} + 0.082\text{P} + 0.071\text{Na} + 0.239\text{ K} + 4.010\text{ Mg} + 0.281\text{Ca}$	0.994	0.988	0.008

TN total nitrogen, *OC* organic carbon, *Sig.* significance, *Contam.* Contaminated

There were little variations in the Na enrichment of the contaminated soils by both "compost only" and "compost + plant" treatments. The introduction of the different compost types resulted into Na increment by 86–90%. The compost/soil mixing ratio showed no notable effects on the incremental levels of Na. The three composts are promising sources of Na to agricultural soils. These composts contributed less than 30% K to the contaminated soils. Pawpaw compost showed the highest contribution to the K level in the "compost only" treatment, which was two times higher than the neem compost at the 1:200 compost/ soil mixing ratio. For treatments with 1:66 and 1:50 compost/soil mixing ratios, the K increments by pawpaw and moringa composts in the contaminated soils were similar. In the "compost + plant" setup, K increased at the 1:50 compost/soil mixing ratio more than the values obtained in the "compost only" treatment at the same mixing ratio. This implies possible release of K into the soil by the castor plant. Adekiya et al. (2019) demonstrated a higher K enrichment of okra plant by green manure from moringa than those from neem and pawpaw.

There were no clear variations in the Mg contents released into the soil by the three composts. The contributions of the composts to Mg in the contaminated soils were lower when compared to other nutrients such as TN, OC, Na, and K. The "compost + plant" treatment revealed slightly higher Mg increment than the "compost only" experimental setup, similar to that of K. Addition of composts reduced the

Ca concentrations in both the "compost only"- and "compost + plant"-treated soils. This could indicate possible anthropogenic sources of Ca in the contaminated soils. Ca is a notable fingerprint for construction and demolition activities, iron and steel emission, cement production, and traffic (Taiwo et al., 2014, 2020; Thorpe & Harrison, 2008).

Effect of compost on the physiological parameters of castor oil seed plant

Compost effects on the physiological parameters of castor oil plants are presented in Fig. 5. The individual impacts of the compost/soil mixing ratios on the growth parameters of the plants are presented in Figures S2–S5 (in the supplementary information). All the growth parameters of the castor oil plant showed the highest performance in the neem compost–amended soils followed by the moringa compost–fortified soils. The treatments with "no compost" (controls) showed the lowest values of the growth parameters. The plant height increased from weeks 1 to 4 by 78% in neem and moringa composts, and 74% in pawpaw-fortified compost. In the previous study of Taiwo et al. (2016), the height of the kenaf plant treated with water hyacinth compost increased by 67%, after 4 weeks of planting. At week 4 of planting, the plant height of the plants in the neem compost–treated soils was 45% taller than the experimental setup with "no compost." The castor plant heights
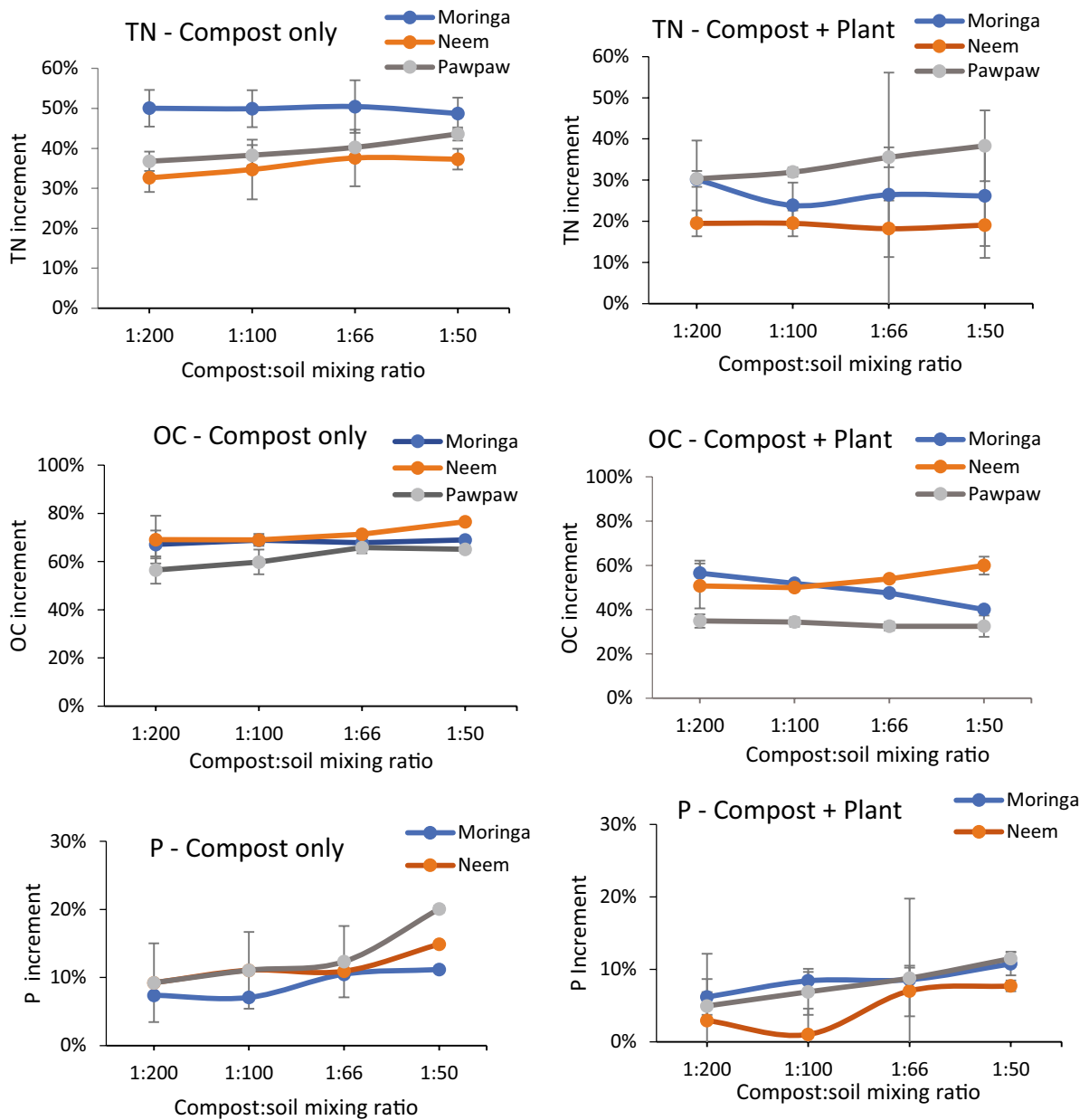
Fig. 4 Effects of composts on nutrient composition of the polluted soil at varying mixing ratios

were also 30 and 17%, taller in moringa and pawpaw composts than the control samples, respectively. The plants also indicated a higher increment girth size under the compost-treated soils than the controls by 36, 28, and 21% for neem, moringa, and pawpaw composts, respectively. Similar trends were observed for plant length and breadth, indicating the promising potentials of the composts as organic fertilizers.

Regression model of different treatments and soil parameters

Table 2 shows the regression data of different soil treatments (contaminated soil + moringa compost, contaminated soil + moringa compost + plant, contaminated soil + neem compost, contaminated soil + neem compost + plant, contaminated soil + compost, and
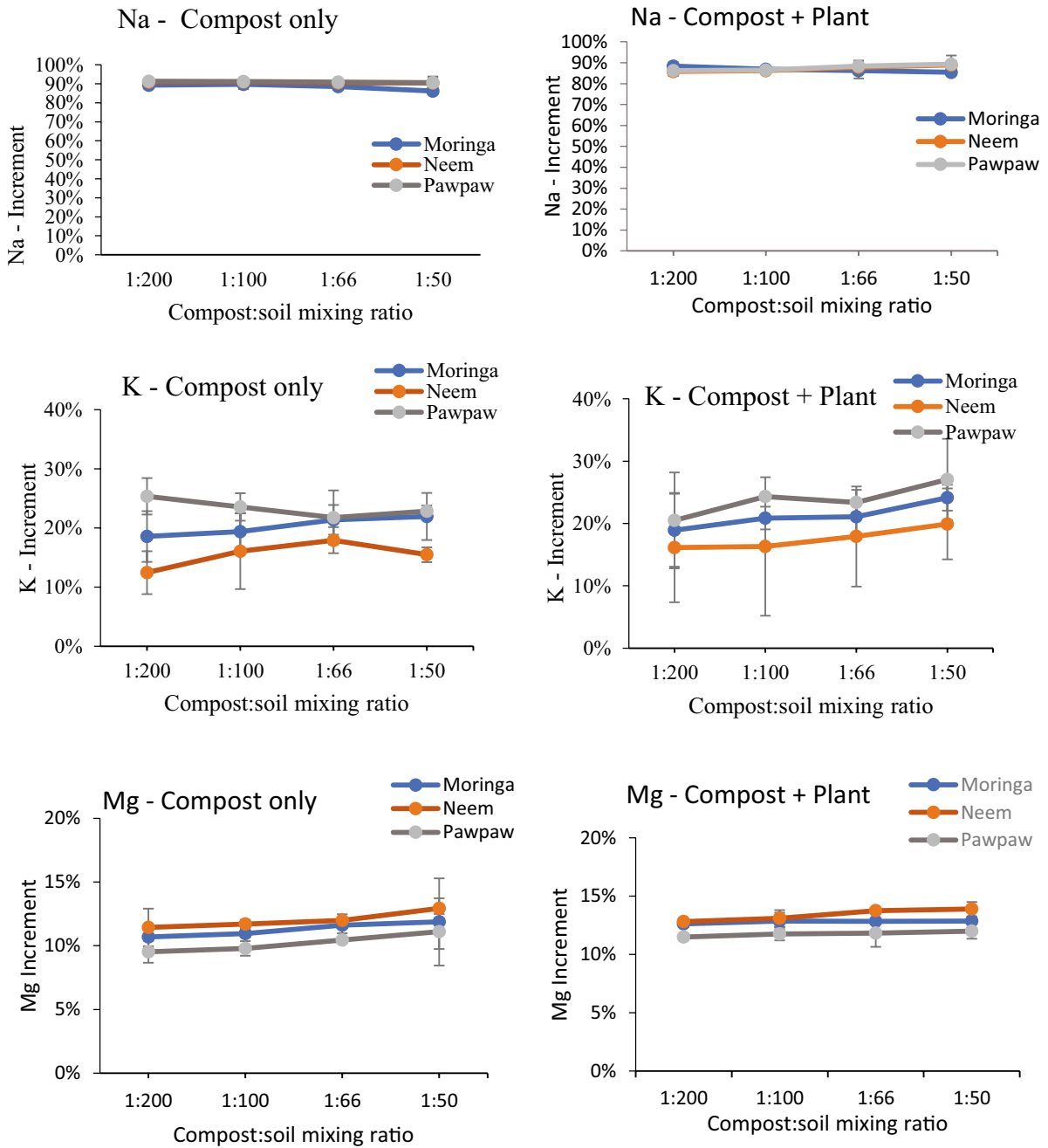
Fig. 4 (continued)

contaminated soil+pawpaw compost+plant). The model showed that all the compost treated soils performed well with R^2 ranging from 0.918 to 0.994, and significance levels varying from 0.000 to 0.092, therefore indicating good potentials of the compost for nutrient enrichment of contaminated soil. Positive associations were established for Ca (except in

contaminated soil+neem compost and contaminated soil+neem compost+plant) and Mg. The model also established that pawpaw compost contributed more to OC, K, and P in contaminated soil than other two composts. Neem compost indicated positive contribution to TN in contaminated soil.
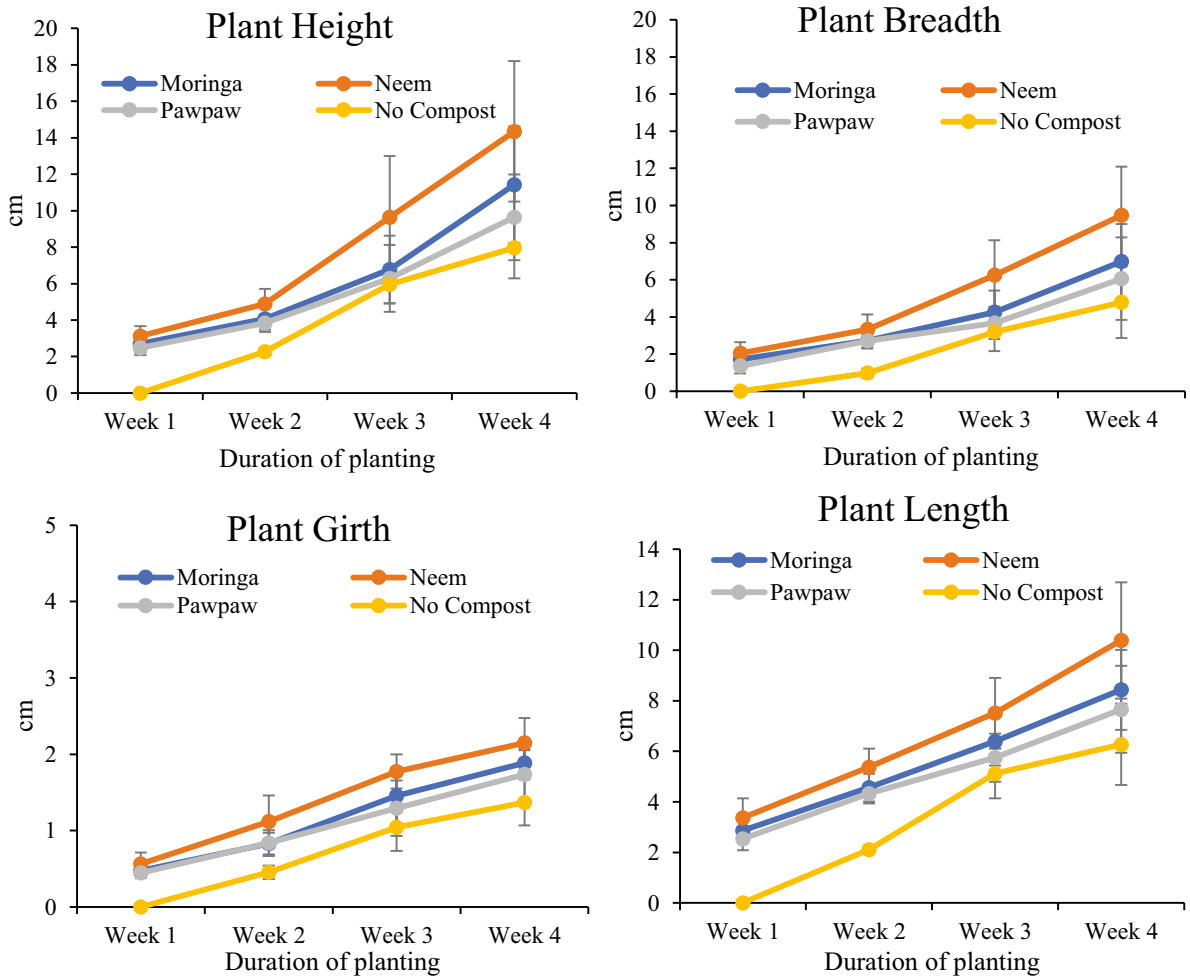
Fig. 5 Effects of compost on the physiological parameters of castor oil plant after 6 weeks of planting. Each point represents the average compost application rates

Conclusion

This is a novel study that adopted the leaves of moringa (*Moringa oleifera*), neem (*Azadirachta indica*), and pawpaw (*Carica papaya*) for co-composting with poultry manure and sawdust. The three composts possessed the C/N ratios that were in the range of 12–18 suitable for agricultural purposes, indicating promising potentials as biofertilizers. The study also revealed that the composts were able to boost the soil quality of the contaminated soils with essential nutrients including TN, OC, P, Na, K, and Mg. The nutrient enhancement ability of the three composts was evident in the growth parameters of the castor oil plants, which showed greater increment in the compost-amended contaminated soils than the "no compost" treatment.

The physiological growth of castor oil plants followed the pattern of neem > moringa > pawpaw. The regression model also established good relationships among the compost treated soils in relation to nutrient composition. This study therefore established the encouraging nutrient enhancement potentials of the three composts.

Availability of data and materials All data generated or analyzed during this study are included in this published article [and its supplementary information files].

Code availability Not applicable.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

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