Int J Recycl Org Waste Agricult (2017) 6:99–106
DOI 10.1007/s40093-017-0156-8

ORIGINAL RESEARCH

Enriched cocoa pod composts and their fertilizing effects on hybrid cocoa seedlings

Chris Fidelis[1] · B. K. Rajashekhar Rao[1]

Received: 1 April 2016 / Accepted: 6 February 2017 / Published online: 16 February 2017

Abstract

Purpose Composting has the potential to recycle wastes as a means of conserving natural resources. The study was aimed at examining feasibility of producing nutrient-enriched composts from pest infested cocoa pods with chemical amendments and using manure composts as a fertilizing material in cocoa seedling nursery.

Methods Cocoa pod waste was composted in static vessels, aerobically, with chemical enrichments (triple super phosphate charged at 0.4% P or urea charged at 0.8% N or poultry manure charged at 22%) along with a control at the Cocoa and Coconut Institute, Papua New Guinea. The reaction (pH) of the composting mixtures (pH) and macro-nutrients dynamics was monitored at periodic intervals. Effect of soil incorporation of cocoa pod manure composts at 10 g kg^{-1} was assessed on the growth and foliar concentration of macro-nutrients in hybrid cocoa seedlings.

Results In the finished manure composts, dry matter loss ranged from 30.6 to 63.3%; greatest in composting mixtures charged with super phosphate and poultry manure. Besides, super phosphate enriched mixture lost small fraction of initial N (6.6%) compared to un-enriched cocoa pod waste (30.2%). Composting mixtures with greater pH values during composting process showed higher losses of N. Super phosphate charged manure compost outperformed the control, in terms of C/N ratio and concentration of macro-nutrients (P, K, Ca, Mg and S). Quality parameters for all the manure composts conformed to the Canadian Compost Guidelines indicating satisfactory standards. Waste cocoa pods enriched with superphosphate did not show any deleterious effects on cocoa seedlings' growth, rather, improved plant height, dry matter production and foliar N concentration.

Conclusion Waste cocoa pods, co-composted with triple super phosphate and poultry manure, produced composts of desirable quality and can be effectively used to fertilize the cocoa seedlings.

Keywords Composting · Infested cocoa pods · C/N ratio · Cocoa seedlings · Compost quality · Macro-nutrients

Introduction

Cocoa (*Theobroma cacao* L., family: Sterculiaceae) is a major cash crop in Papua New Guinea (PNG) and many tropical countries. Global annual production of dry cocoa beans exceeded 3.98 million tons in 2011–2012 (ICCO 2012). Each ton of dry beans produced generates approximately ten tons of cacao pod husks and the global burden of pod husk waste continues to increase well over 40 million tons (Vriesmann et al. 2012). Valorization of cocoa pod husk waste has been attempted by producing animal feed (Aregheore 2002; Alexander et al. 2008), black soap (Taiwo and Osinowo 2001), crude gums and pectins for food and pharmaceutical industries (Samuel 2006; Vriesmann et al. 2012) and as a fertilizer in crop production (Oladokun 1986; Iberemo 2010; Oyewole et al. 2012; Gusli 2013). PNG cocoa is known globally for its fine-flavored cocoa beans and country earns an annual export income of almost $100 million. The crop is grown in

✉ B. K. Rajashekhar Rao
rsraobk@rediffmail.com

[1] Department of Agriculture, PNG University of Technology, Private Mail Bag, Lae, Morobe Province 411, Papua New Guinea

100,000–130,000 ha area and exports over 47,000 t of cocoa (Nelson et al. 2011).

Generally, agro-wastes are converted into composts or farm yard manure before being used in crop production to improve soil fertility. Enrichments in composting improve nutritive value; augment disease suppressive activity and beneficial microbial populations in the composts (Postma et al. 2003; Biswas and Narayanasamy 2006; Pugliese et al. 2011; Diaz et al. 2011; Singh and Amberger, 1995; Nishanth and Biswas 2008; Biswas 2011; Meena and Biswas 2014). Such enriched composts partly substitute mineral fertilizer requirements (Adamtey et al. 2009), improve soil organic matter stocks, augument soil quality and most importantly prevent loss of nutrient N through volatilization (DeLaune et al. 2004; Steiner et al. 2010).

Soil fertility depletion and widespread nutrient deficiencies are matters of concern in tropical regions of the world due to lack of proper plant nutrient management. For example in PNG, N and Fe were deficient in >89% of the cocoa farms and P was deficient in about 25% (Nelson et al. 2011). Nutrient outflow through cocoa beans and husks have created large deficits in nutrient balance sheets. At the average yield of 0.4 t ha^{-1} y^{-1}, a total of 120 kg N, 24 kg P, 78 kg K, 9 kg Ca, and 21 kg Mg would be removed from each hectare in 15 years. These figures could be ten times more if cocoa pod husks are not recycled (Nelson et al. 2011; Fidelis 2014).

Proper waste recycling strategy has become all the more important with the outbreak of cocoa pod borer (*Conopomorpha cramerella* Snellen; family: Gracillariidae) (Yen et al. 2010). The cocoa pod borer (CPB) larva causes damage to cocoa by boring into the pod and disrupting the development of the beans. Although burial of infested pods is the recommended practice for the control of CPB infestation (DAFF 2014; Fidelis 2014), majority of growers find this as a cumbersome activity (Curry et al. 2011). Hence, of cocoa growers abandon CPB-infested pods and opened husks in piles scattered on the farms thus directly contributing to the multiplication of CPB. The husks and pods scattered on the farm, can also harbor and pre-dispose spread of black pod disease (*Phytophthora palmivora*) inoculum (Yen et al. 2010).

The study reported herein envisaged to generate nutrient-enriched composts from the CPB-infested pods. Although a few brief and inconclusive studies have been documented on the production of compost from cocoa husks or direct recycling of husks, no studies ever attempted using CPB-infested cocoa pods as feedstock for compost. The present study, therefore, aimed at evaluating pH and macro-nutrient dynamics during enriched composting of CPB-infested cocoa pods and at testing the fertilizing efficiency of composts on the growth and foliar nutritional status of hybrid cocoa seedlings.

Materials and methods

Study location

The composts were prepared at the Tavilo Research Centre, Papua New Guinea Cocoa and Coconut Institute (PNGCCI) located in Kerevat, East New Britain Province. The average annual rainfall of the area is 2700 mm per annum and daily mean temperature ranges from 30 °C during the day to 24 °C at night. The mean sunshine hour is 5.6 h day^{-1}.

Composting feed-stocks and enrichments

Cocoa pod borer (CPB) infested pods were collected from the field after a phyto-sanitary operation in 2013. The pest CPB attacks both young and mature pods (DAFF 2014) and therefore the pods used comprised of materials of diverse biochemical composition. Before initiating the composting processes, the pods were subjected to phyto-sanitation procedures for preventing possible spread of the CPB pest. The pods were enveloped in thick (500 μ) polythene sacks under sun for seven days. The heating of pods by solarization ensured elimination of CPB eggs, larvae and pupae (Upadhyay et al. 2009). After 7 days of solar treatments, the pods were uncovered and diced into small fragments (1.0–3.0 cm^3) using machetes to serve as the feedstock for composts.

The pods were co-composted with different combinations of mineral N or P sources or poultry manure to ensure improved compost quality and compost recovery. The details of the four treatments used are presented in Table 1. Fertilizer grade urea and triple superphosphate (TSP) were used as mineral N and P source for co-composting, respectively. The poultry manure was collected from layer cages under deep litter system at National Agriculture Research Institute, Kerevat, air-dried and stored in polyethylene sacks. The top soil (0–25 cm depth) served as a starter and was collected from the Tavilo plantation fields, air-dried and sieved to 2 mm.

Experimental set-up and procedure

Composting was done in polythene bins or vessels with diameter of 43 cm, height 41 cm and volume of ~50 L. A total of 30 small vents of ~1.3 mm diameter were made for air circulation at equal distance on the sides, lid and at the base of each bin. The composting vessels were filled with feedstock, enrichments and starter in layers. In brief, bottom of the bins were filled with 2 kg saw dust to absorb any excess moisture and also to act as a bulking agent. Subsequent layer had 5 kg shredded pod husks (1–3 cm^3

Table 1 Details of composting treatments with feedstock composition

Treatments and composition	Quantities of feedstock, starter and enrichments used	
	In a layer	In a vessel
Pod husk + top soil (CC1)	5 kg + 2 kg	15 kg + 6 kg
Pod husk + top soil + super phosphate (CC2)	5 kg + 2 kg + 133 g	15 kg + 6 kg + 400 g
Pod husk + top soil + urea (CC3)	5 kg + 2 kg + 133 g	15 kg + 6 kg + 400 g
Pod husk + top soil + poultry manure (CC4)	5 kg + 2 kg + 1.67 kg	15 kg + 6 kg + 5 kg

Table 2 Chemical properties and macro-nutrients in feedstock and other enrichments used in composting

Parameters	Topsoil	Cocoa pod	Poultry manure	Sawdust
pH in suspension	7.25 ± 0.85	5.66 ± 0.41	6.29 ± 0.23	3.45 ± 0.78
Total OC (mg g^{-1})	20.4 ± 6.77	409 ± 56.9	425 ± 44.1	561 ± 26.2
Total N (mg g^{-1})	2.41 ± 1.20	15.6 ± 3.51	21.0 ± 9.93	0.80 ± 0.33
C:N ratio	8.50 ± 4.72	26.2 ± 8.30	24.4 ± 11.6	701 ± 43.1
Total P (mg g^{-1})	1.15 ± 0.44	3.24 ± 0.72	10.2 ± 3.14	0.32 ± 0.15
Total K (mg g^{-1})	9.62 ± 3.97	25.2 ± 8.41	10.3 ± 4.55	0.14 ± 0.06
Total Ca (mg g^{-1})	24.2 ± 15.2	1.84 ± 0.57	10.0 ± 3.32	2.47 ± 0.88
Total Mg (mg g^{-1})	7.53 ± 4.61	2.62 ± 0.81	3.57 ± 1.12	0.32 ± 0.20
Total S (mg g^{-1})	0.64 ± 0.33	1.36 ± 0.55	2.48 ± 0.87	0.24 ± 0.17

size) with or without enrichments spread on the layer. The layer of shredded pods along with enrichments was enveloped by 2 kg of top soil layer. The enrichments were 130 g TSP powder and/or urea prills or 1.6 kg poultry manure to each layer of pods according to the treatment description outlined in Table 1. Thus, the pods were charged with TSP or urea or poultry manure at 0.4% P, 0.8% N and 22% mass of materials used for composting, respectively. The important properties of the pod husk, top soil, poultry manure and saw dust used are presented in Table 2. Moisture content of the composting mixtures was adjusted to 65% by weight with the addition of tap water. Composting process was terminated on day 90 by spreading the contents of the vessels on clean polythene sheets for air drying.

Sampling and physico-chemical analysis

Representative sample of pod husk, poultry manure, topsoil and saw dust were drawn in triplicates, oven dried at 65 °C for 48 h and analyzed for moisture content, pH and macronutrients content. Composting mixtures were turned once in ~10 days (on composting days 11, 16, 28, 32, 44, 53, 61, 70, 80 and 90). The turning frequency was chosen according to Nikaeen et al. (2015). Turning of compost materials gives the benefit of forcing aeration, homogenizing materials and adjusting water content. On days 17, 45, 61 and 90 samples were collected, fresh weight of the composting mass was recorded on a balance. Three subsamples (~200 g) were taken from the top, middle, and bottom of each vessel were combined to form one composite sample per composting vessel. Dried samples were ground with a grinding mill and sieved through a 1-mm sieve. Total organic C and total N were analyzed by the dry combustion and micro-Kjeldahl method, respectively. Total elemental composition (P, K, Ca, Mg and S) was estimated in *Aqua Regia* (concentrated HCl-HNO_3 at 3:1 v/v ratio) digested samples in an Inductively Coupled Plasma-Optical Emission Spectrophotometer (Varian 725ES model) (Chen and Ma 2001). The pH was recorded after suspending the feed-stocks and compost sample powders in deionized water (1:10 w/v) for 1 h using a pH meter. The mass loss of composting mixture at termination of experiment was calculated by gravimetric procedure on oven-dry weight basis (Frederick et al. 2004).

Assessment of fertilizing efficacy of composts

The efficacies of pod composts were assessed on hybrid cocoa seedlings were grown in polybags. Composts obtained at day 90 were tested as fertilizer in the nursery growth medium of hybrid cocoa seedlings in Oct–Dec, 2013.

Nursery preparation

The experimental site was situated in the Cocoa Breeding Nursery of Tavilo Research Center, PNG. The seedling bays were constructed with iron pickets and tire wire to hold the polybags in rows. The top surface of the seedling bays was covered with Visqueen® sheet. The seedling bay area was partially shaded with a green shade cloth (50% sunlight absorption property). The topsoil collected from a garden plot at the PNGCCIL's Raulawat plantation served as the growth medium. The topsoil was air-dried for five days under shade, sieved (<2 mm) and filled in standard size polybags (175 cm × 350 mm) at the rate of 2 kg topsoil per bag. A sub-sample of the topsoil analyzed for the physico-chemical properties revealed that top soil used as substrate for the experiment was slightly alkaline soil with a pH 7.29 (1:2.5 soil to water ratio), non-saline (electrical conductivity 0.05 dSm^{-1}) and poor in organic C and nitrogen contents (0.21 and 0.16%, respectively). Polybags with topsoil were arranged in the seedling bays for imposition of treatments.

Treatments, nursery management and monitoring

The topsoil in polybags was either amended with one of the cocoa pod composts at the rate of 20 g $polybag^{-1}$ to correspond a compost application rate of 20 t ha^{-1} (Adejobi et al. 2011). A control was also maintained with soil only. None of the polybags received any mineral fertilizer which is the usual practice by the farmers. Each treatment was replicated six times and was randomly (completely randomized design) arranged in the seedling bays. Disease free hybrid cocoa seeds of KA6-106 × KEE42 parentage (Upper Amazonian × Trinitario) were collected from ripe pods at Tavilo Cocoa Seed Gardens, PNGCCIL. The seeds were then pre-germinated by wrapping in a clean, moist cloth for 6 days and were then sown at three seeds per poly bag (Asare and David 2011). They were watered sufficiently and regularly with stored rain water. 2 weeks after planting seedlings were thinned to retain one healthy and uniform growing seedling per polybag. Seedlings were watered regularly with the stored rainwater. The experiment was terminated 75 days after planting by cutting the plants close to soil. Stem and leaf blades were separated, root portion was carefully removed from soil with a jet of water, rinsed with water and oven dried to record dry weight. Dried leaf blades were ground in an electric blender and assayed for macro-nutrients as explained in "Sampling and physico-chemical analysis".

Statistical analysis

One-way analysis of variance (ANOVA) was used to determine whether the chemical characters and macro-nutrient contents differed among the composts at different sampling intervals. Same test was employed to crop growth parameters upon compost application to the soil. When F-test was significant, means were separated by an LSD test. The samples collected from individual composting vessels were treated as replicates for each sampling time. All statistical analyses were performed with the Statistix 8.0 software.

Results and discussions

The pH values of the major feed-stocks were within the range of 3.45 and 7.25 (Table 2). Topsoil used as a starter had the highest pH (7.25) whilst poultry manure, pods and sawdust had pH of 6.29, 5.66 and 3.45, respectively. Poultry manure contained higher amounts of N, P and S nutrients than topsoil, cocoa pods and sawdust.

Mature composts were harvested on day 90 and the mass loss of wastes in un-enriched mixture (CC1) was significantly ($P < 0.05$) smaller and produced significant mass of compost than the other mixtures (Table 3). The dry matter loss% also differed significantly ranging from 30.6 to 63.3% among the mixtures with greatest losses from P-enriched mixture (CC2) and poultry manure-enriched mixtures (CC4). Mass loss depends on composting methods followed and the biochemical qualities of the feedstocks used for composting. For example, different methods of composting wheat straw and labile agricultural waste could result in 40–50% mass loss upon composting (Verma et al. 2014); our results were comparable to these findings. Decomposition and composting of cocoa pods depends on biochemical composition of wastes. Certain microbial inhibitors such as phenolic substances occurring in the cocoa pod husks, besides, higher lingo-cellulosic materials could retard the organic matter decomposition rates (Yapo et al. 2013). Besides saw dust with a wide C:N ratio was also used in the study. However, the major feedstock in the study, CPB-infested pods were mostly immature. Narrow C:N ratio of the waste pods, thus, possibly helped in the decomposition process. In co-composting treatments, top soil and sawdust also helped to circumvent the effect of phenolic substances through bulking or dilution.

Co-composting of CPB-infested pods with various additives significantly influenced ($P < 0.05$) evolution of pH (Fig. 1). The pH among the composting mixtures varied between pH 6.93 and pH 8.46. Generally, the pH values of CC1 and CC3 composting mixtures increased through sampling days 17–90. Enriching the pods with poultry manures and super phosphate prevented the upsurge of pH in the compost mixture. This could be due to increased accumulation of mineralized N as NH_4^+–N. The accumulated NH_4^+–N could be volatized as NH_3, incorporated into microbial cells, if sufficient readily degradable C is available or converted into NO_2^-—and then into NO_3^-—by the nitrifying bacteria depending on the stage of composting and chemical characteristics of the composting pile (Gibbs

Table 3 Compost mass, organic matter loss and C/N ratio of the manure composts (day 90.) Dry matter loss and C/N ratio are on dry weight basis

Composting mixture	Compost mass (kg)	Dry matter loss (%)	C/N ratio
Pod husk + top soil (CC1)	13.3[b]	30.6[a]	11.1[b]
Pod husk + top soil + super phosphate (CC2)	6.80[a]	62.2[c]	10.4[b]
Pod husk + top soil + urea (CC3)	8.24[a]	54.4[b]	6.35[a]
Pod husk + top soil + poultry manure (CC4)	8.05[a]	63.3[c]	7.46[a]
P value	0.02	0.04	0.001
LSD (0.05)	2.70	7.30	1.50

Treatment means with different lower case letters in a column indicates significant difference at $P = 0.05$

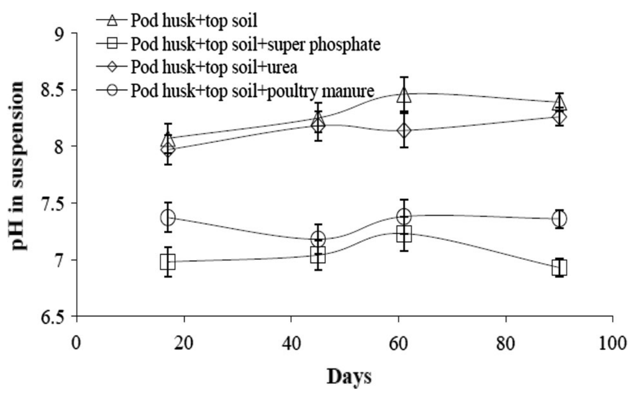

Fig. 1 Profile of pH in composting mixtures during the composting process. *Error bars* indicate LSD values at $P = 0.05$

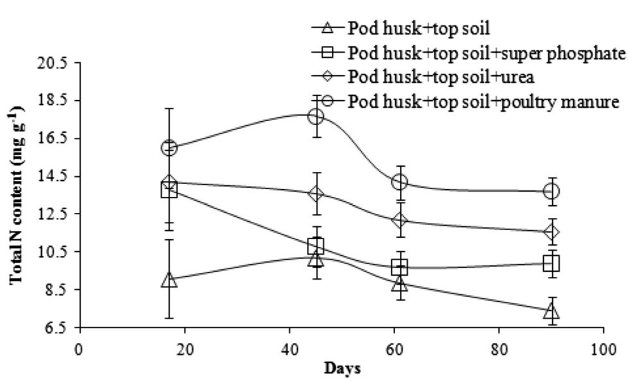

Fig. 2 Changes in total N content of composting mixtures during the composting process (on dry weight basis). *Error bars* indicate LSD values at $P = 0.05$

et al. 2002). Lowering of the pH in N-enriched compost could be due to acidification associated with production of NO_3^-–N during the nitrification process.

The total N concentration of composting mixtures progressively declined during composting (Fig. 2). The NH_4^+–N produced during mineralization could be lost through volatilization process and by leaching (Gibbs et al. 2002; Frederick et al. 2004; Tripetchkul et al. 2012). Gaseous emissions as nitrous oxide through denitrification and nitrogen volatilization have also been common (He et al. 2000; Veeken et al. 2002). The total N loss over 90 day was 30.2, 6.6, 28.8 and 9.7% of the initial N contents for CC1, CC2, CC3 and CC4 composts, respectively. Similar findings were made by Tran et al. (2012) with rice straw compost charged with super phosphate. The extent of volatile N loss was comparable to values reported by Wu et al. (2010). Enrichments improved the N content of the final composts; prominent effects were noticed in CC3 and CC4 mixtures (Fig. 2). Chemical enrichment agents such as phosphogypsum, phosphate rocks, phosphoric acid, alum and simple/single superphosphate have been traditionally used to reduce volatilization losses of N. Findings of the study indicate that triple superphosphate is effective to prevent volatilization loss of N from cocoa pod composting mixtures.

Frequently, the decomposition of composting feed-stocks might experience N or P limitations and enrichment of the feedstock with mineral N and/or P could have improved the decomposition rates as evidenced by maximum mass loss in TSP and poultry manure enrichments. However, in the current study, possibility of N limitation is very remote as the cocoa pods had a C/N ratio of 26, which could be an easily decomposable material. C/N ratio has been used as an indicator of the potential of compost stability. A mature compost should have an C/N ratio $\leq$25 (Sangamithirai et al. 2015). The C/N ratio of the final composts was also lower than 12 (Table 3). When enrichment with mineral N and/or poultry manure was made, final compost products showed C/N ratio $\sim$7. One of the consequences of using such composts with low C/N ratio is the possible phytotoxic effects on sensitive crops but might have nematicidal value (Rodriguez-Kabana et al. 1987).

The total P content of the composting mixtures were significantly ($P < 0.05$) different amongst the compost treatments (Fig. 3). As expected, the pod wastes fortified with 0.6% P (CC2) produced composts with higher total P content compared to other composts generated. The P concentration increase in all composting mixtures is attributed to loss of carbon (C) during decomposition and addition of P through co-composting substrates. Poultry manure is a P- rich source and used widely to improve the

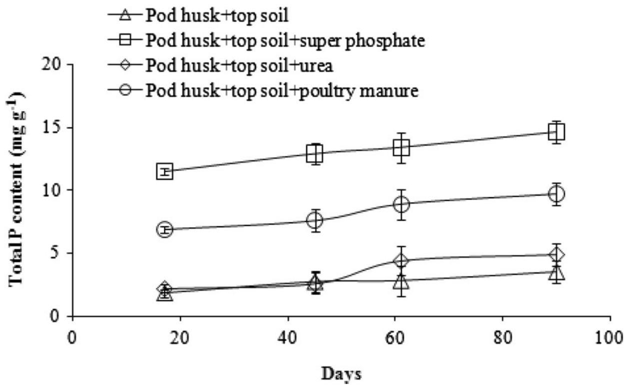

Fig. 3 Changes in total P content of composting mixtures during the composting process. *Error bars* indicate LSD values at $P = 0.05$

P content of composts (Ch'ng et al. 2013). Similar results were observed for other macro-nutrients (K, Ca, Mg and S) (Table 4). Enrichments significantly improved the macro-nutrient concentration of compost mixtures. Among the manure composts, CC2 was superior to control, in terms of K, Ca, Mg and S concentration. The elevated concentrations of Ca and S nutrients were a result of nutrient contributions from triple superphosphate besides the mass loss. Triple superphosphate contains 15% Ca and small amounts of S (∼1%) thereby enhanced the nutritive value of the final compost (Mudahar 2013). Although, K content in CC3 and Mg content in CC4 composts were higher than that from CC2, the differences were not statistically significant. All the composts produced from waste pods and used in the study met the quality standards of Canadian

Table 4 Nutrient composition of composting mixtures at the beginning and at maturity

Composting mixture	Total K ($mg\ g^{-1}$)		Total Ca ($mg\ g^{-1}$)		Total Mg ($mg\ g^{-1}$)		Total S ($mg\ g^{-1}$)	
	17 days	90 days	17 days	90 days	17 days	90 days	17 days	90 days
Pod husk + top soil (CC1)	51.7^{c}	62.4^{b}	25.3^{a}	34.9^{a}	8.61^{a}	9.10^{a}	0.40^{a}	0.80^{a}
Pod husk + top soil + super phosphate (CC2)	72.3^{a}	86.8^{a}	88.7^{c}	94.0^{c}	10.6^{a}	14.2^{b}	1.50^{b}	1.90^{c}
Pod husk + top soil + urea (CC3)	63.2^{b}	89.2^{a}	26.3^{a}	43.8^{b}	9.33^{a}	16.3^{b}	0.70^{a}	1.40^{b}
Pod husk + top soil + poultry manure (CC4)	67.4^{ab}	85.1^{a}	36.5^{b}	39.2^{ab}	14.9^{b}	16.7^{b}	0.80^{a}	1.30^{b}
P value	0.004	0.04	0.0001	0.03	0.004	0.001	0.01	0.03
LSD (0.05)	8.50	9.10	6.50	5.07	3.10	4.20	0.60	0.12

Treatment means with different lower case letters in a column indicates significant difference at $P = 0.05$

Table 5 Growth response of hybrid (F1) cocoa seedlings to the soil amendment of different pod manure composts

Fertilization treatments	Plant height (cm)	Total dry matter (g $plant^{-1}$)
Control (without compost)	29.4^{ab}	11.9^{b}
Soil + un-enriched compost (CC1)	28.3^{bc}	11.5^{b}
Soil + P-enriched compost (CC2)	28.3^{bc}	12.7^{a}
Soil + N-enriched compost (CC3)	26.3^{c}	11.4^{b}
Soil + Poultry manure-enriched compost (CC4)	30.9^{a}	12.8^{a}
P value	0.01	0.01
LSD (0.05)	2.4	0.51

Treatment means with different lower case letters in a column indicates significant difference at $P = 0.05$

Table 6 Effect of different pod composts on the foliar nutrient content ($mg\ g^{-1}$ dry matter) of hybrid cocoa seedlings

Fertilization treatments	Total N	Total P	Total K	Total Ca	Total Mg	Total S
Control (without compost)	20.6^{a}	1.81	20.1	9.03	3.15	1.90
Soil + un-enriched compost (CC1)	24.9^{bc}	1.50	19.4	9.50	2.90	1.63
Soil + P-enriched compost (CC2)	26.7^{c}	1.82	22.4	11.3	3.44	1.95
Soil + N-enriched compost (CC3)	21.5^{a}	1.74	22.7	9.24	3.02	1.92
Soil + Poultry manure-enriched compost (CC4)	23.0^{ab}	1.70	20.2	10.2	3.16	2.10
P value	0.04	0.62	0.64	0.83	0.98	0.07
LSD (0.05)	3.37	–	–	–	–	–

Treatment means with different lower case letters in a column indicates significant difference at $P = 0.05$

Compost Guidelines (1996)—C/N ratio below 25, pH 5.5–8.5, a minimum concentration of total N, P, K, Ca and Mg at 0.60, 0.25, 0.20, 3.0 and 0.30%, respectively.

The growth response of hybrid cocoa seedlings differed significantly ($P < 0.05$) among the soil incorporation of various enriched manure composts (Table 5). CC3 compost addition to soil suppressed the plant height by 10.5% compared to the soil that did not receive any compost. Crop growth suppression in CC3 compost could be due to phytotoxic consequences of using compost with low C/N ratio (Rodriguez-Kabana et al. 1987). Suppression effects in terms of plant height were not visible in seedlings grown on soils amended with CC4 compost. Suppressive effects on dry matter production were not prominent in composts CC1 and CC3. In summary, two manure compost formulations (CC2 and CC4) encouraged cocoa seedlings dry matter production. These findings were similar to that of observations made by Moyin-Jesu (2015) in cabbage crop supplemented with poultry manure.

Soil incorporation of various manure composts significantly ($P < 0.05$) affected the foliar N concentration in cocoa seedlings (Table 6). Soil amendment with CC2 compost evinced the greatest N concentration in foliage followed by CC1, CC4, CC3 and control. Nutrient concentration of P, Ca and Mg were also greater in CC2 compost amendment. Contrary to our findings, N-enriched compost increased N concentration and uptake in wheat crop (Akhtar et al. 2011). This could be partly due to N dilution in the actively growing biomass. In the current study, the nutrient contents were measured at active growing stage (vegetative) when significant nutrient dilution can occur. Secondly, in the current study no mineral fertilizers were used along with manure composts in accordance with local farmer's practices. Phosphorous-enriched cocoa pod compost improved N concentration in cocoa leaves due to possible improvement in absorption and accumulation of N. The results were in line with previous work done by Kavitha and Subramanian (2007).

Conclusions

The results clearly showed that borer infested cocoa pods can be effectively used to produce nutrient-enriched composts of acceptable quality. Composting without any adjuvant and urea resulted in composts with high pH values with the potential for some N loss through volatilization process. Co-composting cocoa pods with super phosphate and poultry manure prevented the upsurge of pH and conservation of N during composting process. Super phosphate charged cocoa pod compost was also superior in respect of P, S and Ca nutrients.

Nutrient-enriched cocoa pod composts can be successfully used as a nutrient supplement in the growth medium of the cocoa seedlings. Fertilization of cocoa seedlings with enriched cocoa pod composts (charged with superphosphate or poultry manure) improved growth (dry matter) through improved N uptake.

However, before the infected pod composts are widely used, further studies are needed. Results of the study indicate some losses of N through volatilization during cocoa pod composting without any amendments. Cheaper alternatives to superphosphate need to be identified that prevent upsurge of pH and possible losses of N from composting mixture. Such studies must also focus on microbiological parameters to ensure destruction of dormant stages of CPB and pathogens.

Acknowledgements First author (CF) wishes to thank CCIPNG for allowing him to conduct this study and for all the logistic supports.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Adamtey N, Cofie O, Ofosu-Budu GK, Danso SKA, Forster D (2009) Production and storage of N-enriched co-compost. Waste Manage 29:2429–2436

Adejobi KB, Famaye AO, Adeniyi DO, Orisajo SB, Adeyemi EA (2011) Effect of cocoa pod husk ash and goat dung on nutrient content and growth performance of cashew (*Anacardium occidentale*). Adv Environ Biol 5(7):1536–1542

Akhtar M, Naeem A, Akhter J, Bokhari SA, Ishaque W (2011) Improvement of nutrient uptake and yield of wheat by combined use of urea and compost. Soil Environ 30(1):45–49

Alexander J, Benford D, Cockburn A, Cravedi JP, Dogliotti E, Dominico AD et al (2008) Theobromine as undesirable substances in animal feed: scientific opinion of the panel on contaminants in the food chain. Eur Food Safety Auth J 725:1–66

Aregheore EM (2002) Chemical evaluation and digestibility of cocoa (*Theobroma cacao*) byproducts fed to goats. Trop Anim Health Prod 34:339–348

Asare R, David S (2011) Good agricultural practices for sustainable cocoa production: a guide for farmer training. Manual no. 1: planting, replanting and tree diversification in cocoa systems, sustainable tree crops programme. International Institute of Tropical Agriculture, Accra

Biswas DR (2011) Nutrient recycling potential of rock phosphate and waste mica enriched compost on crop productivity and changes in soil fertility under potato-soybean cropping sequence in an

Inceptisol of Indo-Gangetic Plains of India. Nutr Cycl Agroecosys 89:15–30
Biswas DR, Narayanasamy G (2006) Rock phosphate enriched compost: an approach to improve low-grade Indian rock phosphate. Bioresour Technol 97:2243–2251
Canadian Compost Guideline (1996) Guidelines for compost quality. CCME documents, PN1340, Manitoba, Canada
Ch'ng HW, Ahmed OH, Kassim S, Majid NMA (2013) Co-composting of pineapple leaves and chicken manure slurry. Int J Recycl Org Waste Agricult 2:23
Chen M, Ma LO (2001) Comparison of three aqua-regia digestion for twenty Florida soils. Soil Sci Soc Am J 65:491–499
Curry G, Lummani J, Omuru E (2011) Socioeconomic impact assessment of cocoa pod borer in East New Britain province, Papua New Guinea. Project no. ASEM/2008/034, Final report no. FR2010-25. Australian Centre for International Agricultural Research (ACIAR), Canberra
DAFF (Queensland Department of Agriculture, Fisheries and Forestry) (2014) Cocoa pod borer. Queensland Department of Agriculture, Fisheries and Forestry (DAFF), Queensland, Australia. http://www.daff.qld.gov.au/plants/health-pests-diseases/a-z-significant/cocoa-pod-borer#. Accessed 02 Nov 2015
DeLaune PB, Moore PA Jr, Daniel TC, Lemunyon JL (2004) Effect of chemical and microbial amendments on ammonia volatilization from composting poultry litter. J Environ Qual 33(2):728–734
Diaz LF, de Bertoldi M, Bidlingmaier W (2011) Compost Science and Technology. Elsevier, The Netherlands
Fidelis C (2014) Development of composting protocols of cocoa *(Theobromae cacao)* pod-based composts and their efficacy. Dissertation, PNG University of Technology, Papua New Guinea
Frederick C, Michel JA Jr, Pecchia JR, Keener HM (2004) Mass and nutrient losses during the composting of dairy manure amended with sawdust or straw. Compost Sci Util 12:323–334
Gibbs PA, Parkinson RJ, Misselbrook TH, Burchett S (2002) Environmental impacts of cattle manure composting. In: Insam H, Riddech N, Klammer S (eds) Microbiology of composting. Springer Verlag, Heidelberg, pp 445–456
Gusli S (2013) Zero-waste integrated cocao production system (ZWICP). In: Rangga I (ed) Coklat. Cocoa Sustainability Partnership, Indonesia, p 12
He Y, Inamori Y, Mizuochi M, Kong H, Iwami N, Sun T (2000) Measurements of N_2O and CH_4 from the aerated composting of food waste. Sci Total Environ 254:65–74
Iberemo OS (2010) Effect of organic fertilizer fortified with phosphate fertilizers and arbuscular mycorrhizal fungi inoculation on the growth of cashew in two ecologies in Nigeria. J Agric Sci 1(2):101–107
ICCO (International Cocoa Organization) (2012) Quarterly bulletin of cocoa statistics, vol 39, London, UK
Kavitha R, Subramanian P (2007) Effect of enriched municipal solid waste compost application on growth, plant nutrient uptake and yield of rice. J Agron 6:586–592
Meena MD, Biswas DR (2014) Changes in biological properties in soil amended with rock phosphate and waste mica enriched compost using biological amendments and chemical fertilizers under wheat-soybean rotation. J Plant Nutr 37:2050–2073
Moyin-Jesu EI (2015) Use of different organic fertilizers on soil fertility improvement, growth and head yield parameters of cabbage (Brassica oleraceae L). Int J Recycl Org Waste Agricult 4:291–298
Mudahar MS (2013) Fertilizer sulfur and food production. Springer Science and Business Media, The Netherlands
Nelson P, Webb M, Berthelsen S, Curry G, Yinil D, Fidelis C, Fisher M, Oberthür T (2011) Nutritional status of cocoa in Papua New Guinea. Better Crops 95:18–20
Nikaeen M, Nafez AH, Bina B, Nabavi BF, Hassanzadeh A (2015) Respiration and enzymatic activities as indicators of stabilization of sewage sludge composting. Waste Manage 39:104–110
Nishanth D, Biswas DR (2008) Kinetics of phosphorus and potassium release from rock phosphate and waste mica enriched compost and their effect on yield and nutrient uptake by wheat (*Triticum aestivum*). Bioresour Technol 99(9):3342–3353
Oladokun MAO (1986) Use of cocoa pod husk as fertilizer for maize production. Nigerian J Agron 1:103–109
Oyewole OS, Omueti I, Ajayi J, Rotimi RI (2012) Growth of cocoa (*Theobroma cacao L.*) seedlings on old cocoa soils amended with organic and inorganic fertilizers. Afr J Agric Res 7:3604–3608
Postma J, Montanari M, van den Boogert PHJF (2003) Microbial enrichment to enhance the disease suppressive activity of compost. Eur J Soil Biol 39:157–163
Pugliese M, Liu B, Gullino ML, Garibaldi A (2011) Microbial enrichment of compost with biological control agents to enhance suppressiveness to four soil-borne diseases in greenhouse. J Plant Dis Protect 118:45–50
Rodriguez-Kabana R, Morgan-Jones G, Chet I (1987) Biological control of nematodes: soil amendments and microbial antagonists. Plant Soil 100:237–247
Samuel YKC (2006) Crude gum from cocoa of Malaysian origin: part I: rheological properties. Malaysian Cocoa J 2:28–31
Sangamithirai KM, Jayapriya J, Hema J, Manoj R (2015) Evaluation of in-vessel co-composting of yard waste and development of kinetic models for co-composting. Int J Recycl Org Waste Agricult 4:153–165
Singh CP, Amberger A (1995) The effect of rock phosphate-enriched compost on the yield and phosphorus nutrition of rye grass. Am J Altern Agric 10:82–87
Steiner C, Das KC, Melear N, Lakly D (2010) Reducing nitrogen loss during poultry litter composting using biochar. J Environ Qual 39(4):1236–1242
Taiwo OE, Osinowo FAO (2001) Evaluation of various agro-wastes for traditional black soap production. Bioresour Technol 79:95–97
Tran TM, Bui HH, Luxhøi J, Jensen LS (2012) Application rate and composting method affect the immediate and residual manure fertilizer value in a maize–rice–rice–maize cropping sequence on a degraded soil in northern Vietnam. Soil Sci Plant Nutr 58:206–223
Tripetchkul S, Pundee K, Koonsrisuk S, Akeprathumchai S (2012) Co-composting of coir pith and cow manure: initial C/N ratio vs physic-chemical changes. Int J Recycl Org Waste Agricult 1:15
Upadhyay RK, Mukerji KG, Chamola BP, Dubey OP (2009) Integrated pest and disease management. APH Publishing Corporation, New Delhi
Veeken A, de Wilde V, Hamelers B (2002) Passively aerated composting of straw-rich pig manure: effect of compost bed porosity. Compost Sci Util 10(2):114–128
Verma R, Badole WP, Deewan P, Meena VS (2014) Carbon and weight loss during composting of wheat straw by different methods. Ann Biol 30(2):354–357
Vriesmann LC, Teófilo RF, Petkowic CLV (2012) Extraction and characterization of pectin from cacao pod husks (*Theobroma cacao* L.) with citric acid. LWT Food Sci Technol 49:108–116
Wu D, Liu P, Luo Y, Tian G, Mahmood Q (2010) Nitrogen transformations during co-composting of herbal residues, spent mushrooms, and sludge. J Zhejiang Univ Sci B 11(7):497–505
Yapo BM, Besson V, Koubala BB, Koffi KL (2013) Adding value to cocoa pod husks as a potential antioxidant–dietry fibre source. Am J Food Nutr 1(3):38–46
Yen JD, Waters EK, Hamilton AJ (2010) Cocoa pod borer (*Conopomorpha cramerella* Snellen) in Papua New Guinea: biosecurity models for New Ireland and the autonomous region of Bougainville. Risk Anal 30(2):293–309