Optimizing rock phosphate incorporation rate for efficient vermidegradation of cow dung waste paper mixtures

F.O Unuofin[a], P. N. S. Mnkeni[a]*

[a]Department of Agronomy, Faculty of Science and Agriculture, University of Fort Hare, PBX1314, Alice 5700, South Africa.

E-mail: funmifrank2009@gmail.com; pmnkeni@ufh.ac.za.

*Corresponding author, e-mail: pmnkeni@ufh.ac.za, cell: +27822004688.

Abstract:

Incorporation of rock phosphate (RP) into cow-dung paper-waste mixtures at rates of 2% P and above was earlier shown to accelerate the bioconversion and humification of the waste/waste mixtures but the optimum rate of RP incorporation was not established. This study sought to establish an optimal RP application rate for efficient vermidegradation of cow- dung paper-waste mixtures. A range of RP incorporation rates (0, 0.5, 1.0, 1.5, 2, and 4% P as RP) were mixed with cow-dung paper- waste mixtures with an optimized C: N ratio of 30 and allowed to vermidegrade following introduction of *Eisenia fetida* earthworms at a stocking density of 12. 5 g worms kg^{-1}. The bioconversion of the waste mixtures was monitored by measuring C: N ratios, polymerization index (PI), and humification index (HI). An application rate of 1% P as RP resulted in the fastest bioconversion and maturation of cow- dung paper-waste mixtures. The final vermicompost had a C: N ratio of 7, PI of 14.4, and HI of 27.1%. A P-fractionation study revealed that the extractability of P increased linearly with the rate of RP application with the water soluble P fraction making the largest (1002.4mg P kg-^{1}) contribution to the mineralized P. An RP incorporation rate of 1% P is therefore recommended for efficient vermidegradation of cow dung paper-waste mixtures but

higher rates of RP incorporation should be considered where greater P enrichment in final vermicomposts is desired.

Keywords: Vermicompost, carbon to Nitrogen ratio, Humification indices, Phosphorus fractions, Rock phosphate.

1 Introduction

Vermicomposting has proved to be a suitable technique of processing biodegradable organic wastes and converting them to organic fertilizers, because of its low cost and the large quantity of wastes that can be processed. However, the nutritional values of most compost/vermicompost products are erratic and determined principally by the types of the substrates used and the degree of composting [13, 16 and 24]. In order to increase the acceptability of vermicompost products as sources of nutrients or as growing media, it is essential to increase their P contents. Biswas and Narayanasamy [3] were able to increase the total P content of straw compost from 0.37% in control to 2.20% by adding 4% P as RP, while [24] were able also to increase the total P of rice straw vermicompost from 0.392% to 0.82% by adding 2% P as RP. Matiullah and Muhammad [16] also increased the total P content in poultry litter from 0.3% to 1.02% by adding 4% P as RP.

In addition to increasing the P contents of composts the incorporation of RP has also been shown to improve the humification of organic wastes. Singh and Amberger [23] reported that organic solid waste compost inoculated with RP not only increased its P content but also enhanced the humification of the resultant vermicomposts. Similarly [15] obtained highly humified compost from plant wastes composting by adding 25% Mussoorie RP. This prompted [16] to investigate the effect of RP incorporation on the vermicomposting of cow-dung waste paper mixtures. He investigated rates of RP incorporation ranging from 2 to 8% P as RP. The results showed that the vermicomposts were highly humified and had high total P and N contents as well as available P and N contents compared to the control. All rates of RP incorporation > 2% P improved humification to more or less the same extent suggesting that lower rates of RP incorporation could possibly be effective in improving the vermidegradation of cow dung waste paper mixtures. This study, therefore, investigated the effectiveness of using low RP application rates of less than 2% P in improving the vermidegradation of cow-dung paper-waste mixtures.

Edwards *et al* [6] postulated that a range of P forms could be produced during the co-composting of RP with organic wastes which could impact the subsequent bioavailability of P. There is little or no information on P transformations during the vermicomposting of RP enriched wastes. The objectives of this study were therefore to determine: (i) the minimum amount of rock phosphate necessary for efficient vermidegradation of cow- dung paper-waste mixtures, and (ii) the effects of rate of RP application on total P, Bray 1 extractable P, and different P fractions in the final cow-dung paper-waste vermicomposts.

2. Materials and Methods

2.1 Site description, wastes and earthworms utilized

The vermicomposting experiment was performed in a closed shaded yard at the University of Fort Hare Teaching and Research farm located (32^{o}46'S and 26^{o}50'E) in the Eastern Cape Province of South Africa under an ambient mean temperature of 25^{o}C. Waste papers used for the study were collected from the University printing press (Xerox) and Faculty offices, while RP was obtained from Phalaborwa in Limpopo Province, South Africa, which is granitic in nature. *Eisenia fetida* (*E. fetida*) earthworms used in the study were collected from a local wormery at the University of Fort Hare Teaching and Research farm. Cow dung was obtained from Keiskammahoek Dairy Project located about 60 km North East of the University of Fort Hare.

2.2 Experimental procedure

2.2.1 Phosphorus enrichment of vermicomposts with RP

The P enrichment treatments consisted of 6 rates of 0, 0.5, 1, 1.5, 2 and 4 % (elemental P basis) as ground RP. Each was thoroughly mixed with enough feedstock (5kg on dry weight basis) prepared together by mixing 2.16kg shredded paper and 2.84kg cow dung to achieve an optimized C: N ratio of 30. The resultant mixtures were loaded into worm boxes having capacity measuring 0.50 m x 0.40 m x 0.30 m (length x width x depth) with an exposed top surface area of 0.2 m^2 in a well-ventilated farm building at an average mean ambient temperature of about 25^0C. Mature *E. fetida* earthworms were introduced into the vermireactors at a stocking density of 12.5g worms kg^{-1} feed established by [25] as the optimum for the bioconversion of cow-dung paper-waste mixtures. Treatments were arranged in a completely randomized experimental design (CRD) with three replications. The moisture content was determined on a weekly basis according to [22] and maintained at about 80% moisture content by sprinkling water when necessary throughout the 56 days vermicomposting period.

Sample collection was carried out at day 0, 14, 28, 42 and 56 of vermicomposting and analyzed for volatile solids, ash content, total C, total N, organic and inorganic phosphorus. Samples collected at day zero and day 56 were also subjected to sequential P fractionation as described below. A germination index bioassay was performed on final vermicompost samples collected on day 56.

2.2.2 P Fractionation of vermicomposts

Vermicompost samples that were collected at the beginning (0 day) and at termination (56 days) of vermicomposting were sequentially fractionated to determine different P fractions using a modified version of the [8] procedure as described by [5]. Briefly, moist vermicompost samples were successively extracted with de-ionized water, 0.5 M $NaHCO_3$, 0.1 M NaOH, and 1 M HCl. In the first extraction with de-ionized water, 0.3g (oven dry basis) of vermicompost samples was weighed into a 50 ml centrifuge tube along with 30 ml of de-ionized water and shaken for 1h at room temperature on an end-to-end shaker at 150 excursions per minute. The samples were centrifuged at 10,000 g for 15 min and filtered using Whatman No 42 filter paper.

The compost residues that remained in the centrifuge tubes were afterwards successively extracted using 30 ml each of 0.5 M $NaHCO_3$ (pH 8.5), 0.1 M NaOH and 1.0 M HCl. Following shaking with each extractant for 16 h, centrifugation of the suspensions was done and afterwards filtered. A part of the $NaHCO_3$ and NaOH extracts were acidified to precipitate out the extracted organic matter and the resultant supernatant was then analysed for inorganic P (Pi). The remaining portions of the $NaHCO_3$ and NaOH extracts were digested with acidified potassium persulphate and analyzed for total P (Pt). The organic P (Po) in $NaHCO_3$ and NaOH extracts was determined as the difference between the Pt and Pi contents. The P concentration in all extracts and digests was determined by the molybdenum blue colorimetric method of [17] on a San 2++ Skalar Continuous Flow Analyser (CFA) (Skalar Analytical B.V. the Netherlands).

2.2.3 Physico-chemical analyses

The resultant vermicompost samples were analyzed for volatile solids (VS), ash content, total carbon and total nitrogen, extractable phosphorus P and humic substances. These vermicompost were first air dried until constant weight was achieved and subsequently pulverized (< 2mm) to offer a uniform sample for analysis. The (VS) were determined as sample weight loss (previously oven-dried at 105^{o}C) upon ashing at 550^{o}C for 4h in a muffle furnace [18] while total nitrogen (N) and carbon (C) were determined using a Truspec CN Carbon/ Nitrogen analyser [11].

Total phosphorus was determined by digesting 0.5 g of air-dried composts samples in a MARS 5 microwave digester (CEM Corporation, Matthews, North Carolina) using aqua regia followed by the determination of phosphorus concentration in the digests by means of the reduced phosphomolybdenum blue method on a continuous flow analyser (San 2++ Skalar Continuous Flow Analyser, Skalar Analytical B.V. the Netherlands). Humic substances were determined following extraction as described by [4]. To the composted samples 0.1 *M* NaOH (1:20 w/v ratio) was added and continuously shaken on a horizontal shaker for 4 h, followed by centrifugation of the resultant solution at 8,000 x g for 15 min. After that, the supernatants were separated into two portions, one portion was analysed for total extractable carbon fraction (C_{EX}) through the [26] rapid titration method as described by [1] and the remaining portion was adjusted to pH 2 using concentrated H_2SO_4 and set aside to coagulate for 24 h at 4°C. The resulting precipitates that were formed comprised the humic acid–like carbon (C_{HA}) while fraction that remained in solution constituted the fulvic acid-like carbon (C_{FA}). The C_{HA} was calculated by subtracting the C_{FA} from the C_{EX}. The humification indices were calculated using the following equations [16].

Humification ratio (HR) $= \left(\frac{CEX}{C}\right) x\ 100$

Polymerization index (PI) = (C_{HA}/C_{FA}) x 100

Humification index (HI) $= \left(\frac{CHA}{C}\right) x\ 100$.

2.2.4 Morphological assessment of the resultant vermicomposts

Scanning Electron Microscopy (SEM) images of the samples were taken using a scanning electron microscope model JOEL (JSM-6390LV, Japan). Briefly, the samples were oven dried and ground to pass through a 2 mm sieve. A small representative portion of the samples were coated with gold and mounted on SEM. Samples were imaged by scanning it with a high energy beam of electrons in a raster scan pattern.

2.3 Statistical analysis

Data reported herein are the means of three replicates (n=3). Statistical analysis was done using repeated measures analysis of variance (ANOVAR) since sampling was done non-destructively. Fisher's protected least significant difference (*LSD*) test at $p<0.05$ was used for means separation. All statistical analyses were done using JMP® Release 10.0 statistical package (SAS Institute, Inc., Cary, North Carolina, USA, 2010).

Results and Discussion

3.1. Effects of RP rate on ash and volatile solids contents

One of the main aims of this study was to explore the possibility of enhancing the vermidegradation of cow-dung paper-waste mixtures with lower rates of RP incorporation. Both percent ash and volatile solids contents of cow-dung paper-waste vermicompost were significantly affected by added RP (Table 1). The percent ash increased significantly with time at each added RP rate with the 4 % P rate of RP application resulting in consistently the highest ash content and the absolute control where no RP was added the lowest ash levels (Fig.1). The other rates of RP application resulted in intermediate ash contents which followed the order 2%P ≈ 1.5%P ≈ 1%P > 0.5%P (Fig.1). Final percent ash content ranged from 42% to 49% in vermicompost where RP was added, while in the control where no RP was added the ash content was 40% (Fig.1). The ash content was lowest for each RP treatment at day 0 but increased as time progressed with wide differences between treatments occurring on days 28 and 42. This observed significant increase in ash and decrease in volatile solids contents with time at each rate of added RP indicated degradation of organic matter (OM) in the vermicomposting mixtures as also reported by [10, 14 and 25]. This trend was confirmed by the maturation parameters used to monitor the stabilization of the vermicomposts, namely C: N ratio, polymerization index (PI) and humification index (HI), and SEM imagery.

The (VS) in cow-dung paper-waste vermicompost followed the same but opposite trend to ash content whereby the VS decreased significantly with time at each added RP rate (Fig.2). The decrease with vermicomposting time of the VS contents of the waste mixtures vermicomposted could be attributed to the loss in organic matter. Similar results have been reported by [12, 16], they demonstrated that decrease in VS contents in dairy manure waste paper mixtures vermicompost and agricultural waste compost was due to loss in organic matter.

[Table 1]

[Fig. 1]

[Fig.2]

3. 2. Effect of RP rate on the carbon to nitrogen ratio

Both added RP rates and time significantly affected C: N ratio of cow-dung paper-waste vermicompost (Table 1). The C: N ratio decreased significantly with time at each added RP rate but pronounced differences between rates of RP application were only observed up till day 28 beyond which differences were minimal (Fig. 3).The highest decrease in C: N ratio at day 14 occurred where RP was added at a rate of 1% while the least decline in C: N ratio was observed where no RP was added.

Further decline in C: N ratio was observed beyond day 28 till the termination of the experiment but the effects of added RP rates were not significantly different except for 0% and 0.5% P at days 42 and 56, respectively. Final C: N ratios ranged from 6.9 to 10.6 in vermicompost where RP was added, while in the control where no RP was added the C: N ratio was 12 (Fig. 3). Thus the incorporation of RP hastened the vermidegradation of cow - dung paper-waste mixtures during the early stages of vermicomposting up to 28 days but beyond this the RP effect was minimal. Time required to vermicompost maturity was 56 days where no RP was added but it was 42 days or less where RP was added (Table 2). The shortest time to vermicompost maturity was 33 days and was realized with the application of 1% P as RP which shortened the time to vermicompost maturity by 28% (Table 2).

This could be attributed to the decomposition of organic matter as a result of microbial action [2]. The C: N ratio results (Fig. 3) confirmed the findings of [16], that incorporation of RP accelerated the vermidegradation of the cow dung waste paper mixtures in that by day 42 the C: N ratio of the waste mixtures had declined from 30 when the experiment was initiated (Day 0) to less than 14 where RP was incorporated compared to 18 where it was not. The researcher findings further revealed that the improved degradation was fastest when RP was added at a rate of 1% P which allowed vermicompost maturity to be achieved within 33 days.

This indicated that a rate lower than the lowest rate of 2% P as RP used by [3, 13, 16 and 24] could be used to improve the speed of biodegradation of cow-dung paper-waste mixtures using *E. fetida*. The possibility of using lower rates of RP incorporation to enhance the vermidegradation of cow-dung paper-waste mixtures and possibly other waste will mean less transportation costs to places far from the Limpopo province of South Africa where RP is mined.

[Table 2]

[Fig. 3]

3.3. Effect of RP rate on humification parameters

Polymerization index (PI) and Humification index

Addition of RP into cow-dung paper-waste mixtures during vermicomposting had significant effects on the polymerization index (PI) of the vermicompost with significant interaction between added RP and time (Table 1). The (PI) increased significantly with time at each added RP rate ($P < 0.0001$). Whereas all RP rate treatments had the same (PI) at time 0, differences started to emerge as time progressed. These differences between rates of RP application were not pronounced up to 28 days, but wider significant differences were observed on days 42 and 56 (Fig. 4). The highest increase in PI at both day 42 and 56 occurred where RP was added at a rate of 1% P while the lowest increase occurred where no RP was added. The addition of RP at 1.5, 2 and 4% P had more or less the same effect on (PI) on these two days. Thus the trend of the (PI) of the waste mixtures on days 42 and 56 is summarized as 1 % P > 1.5%P ≈ 2%P ≈4%P >> 0.5%P >0%P (Fig. 4).

However, The HI of the resultant vermicompost (Table 1, Fig 5) followed the same pattern as the (PI). The HI increased significantly with time at each added RP rate ($P < 0.0001$) with no striking differences between rates of RP application up to 28 days (Fig 5). However, wide differences on HI were observed on day 42 and 56 (Fig 5) consistent with the observed significant RP x time interaction (P< 0.0001) (Table 1). The differences on HI followed the order of 1%P=4%P >2%P >1.5%P >0.5%P >0% P at day 42, whereas for day 56, the order was 1%P.>2%P=4%P=1.5%P> 0.5%P >0%P, respectively (Fig.5).

The increase in the HI with time indicated that the vermidegradation increased humification of the cow-dung paper-waste mixtures. The observed increase in humic acids demonstrated by the humification index could also account for the enhanced mineralization and dissolution of P. According to [23], the researcher pointed out that humic acids can absorb significant quantities of calcium ions and release H^+ ions which further facilitate the dissolution of RP. In addition, the functional groups in humic acids such as carboxylic and phenolic groups can also chelate Ca^{++} ions providing a driving force for the mineralization and dissolution of P from RP. Corresponding increases in the PI with time (Fig. 4) indicated that the lower molecular weight of fulvic acid fraction was progressively converted to the more recalcitrant molecules of higher molecular weight which make up the humic acid fraction [7, 9, 19 and 20]. This transformation was influenced by rate of RP application and interestingly it was highest at the 1 % P rate of RP application.

[Fig. 4]

[Fig. 5]

3.4. Effect of RP rate on total P, Bray 1 extractable P and different P fractions

Addition of RP to cow-dung paper-waste mixtures resulted in increases in both total P and Bray 1 extractable P contents with each increment of added RP (Table 3). The total P content of the final vermicomposts ranged from 0.18% where no RP was added to 2.31% P when RP was added at a rate of 4 % P is consistent with results of [3] who reported increases in the total P content of straw compost from 0.37% in control to 2.20% by applying 4% P as RP. Yan *et al*.[24] also reported an increase in the total P of rice straw compost from 0.392% to 0.82% by applying 2% P as RP.

Corresponding values for Bray 1 extractable P increased from 80 mg P kg^{-1} to 207 mg P kg^{-1} (Table 3) demonstrating an increased effect in the extractable P and thus implies significant increases in the effectiveness of vermicompost in providing P nutrition to plant [23] and increased significantly with time at each rate of added RP rate with the 4%P rate of RP application resulting consistently in the highest Bray-1 P and the absolute control where no P was added had the lowest Bray-1P (Fig. 6). This increased sharply up to day 14 at each added RP rate but declined sharply thereafter up to day 28, afterwards there was a sharp increase up to day 42 followed by a gradual decline up to day 56, suggesting that after 42 days the mineralized P underwent precipitation reactions hence the decreased extractability (Fig. 6) . This P release is due to the mediated activities of phosphate enzymes produced by microorganisms in the earthworm guts and those in the earthworm casts [24].

The sequential fractionation results revealed that total inorganic P (P_i) and organic P (P_o) were not affected by rate of RP application at the beginning (time 0) but after 56 days of vermicomposting the rate of RP application had contrasting effects on the two P fractions (Fig. 7). The total inorganic P (P_i) fraction increased with rate of RP application whilst the total organic (Po) fraction declined (Fig. 7). Examination of the sequential P fractionation results of individual fractions showed that the H_2O-P_i fraction made the largest contribution to total Pi while $NaHCO_3$- P_i made the least contribution (Fig. 8). The other Pi fractions also increased with rate of RP applications but only marginally (Fig. 8).The Pi content of the four vermicompost fractions at each added RP rate followed the order H_2O-P_i >> NaOH-P_i > HCl-P_i > $NaHCO_3$- P_i (Fig. 9). With the exception of the H_2O–Po fraction, the other organic

P fractions (NaOH, HCl, and $NaHCO_3$) declined with rate of RP application (Fig. 9) suggesting that these fractions were responsible for the observed decline in total (Po). This implies that most of the mineralized P during the vermicomposting of the cow-dung paper-waste mixtures enriched with RP would be available for plant uptake and thus indicate that vermicomposting cow-dung paper-waste mixtures enriched with phosphate rock improves the solubilisation of the Phalaborwa RP used in this study and thus improved its fertilizer value. According to [6] RP is an acceptable source of P for organic agriculture but its use is limited by its slow rate of P release. The high total P and extractable P contents observed in the cow-dung paper-waste vermicomposts enriched with RP point to their potential as organic P fertilizers.

[Table 3]

[Fig. 6]

[Fig. 7]

[Fig. 8]

[Fig. 9]

3.5. Changes in the morphological structure of cow-dung paper-waste mixtures during vermicomposting

Figure 10 shows the effects of rate of RP application on the morphological structure of cow-dung paper-waste mixtures during vermicomposting recorded using scanning electron microscopy (SEM). The SEM images of the cow-dung paper-waste mixtures at the beginning of the experiment (not shown) showed compacted aggregates of cellulose and protein fibres. However, inoculation of earthworm and RP facilitated the breakdown of the recalcitrant fibre in the paper and the cow dung to produce degraded vermicompost to varying degrees depending on the rate of added RP and vermicomposting time (Fig. 10). The SEM images show that degradation of the cow-dung paper-waste mixtures intensified with time at each rate of RP application. Wide differences in extent of degradation at different rates of RP application are seen on days 14 and 28 but by day 56 the vermicomposting mixtures appear to be equally degraded visually except where RP was added at a rate of 1% P where greater degradation was observed (Fig. 10). On day 28 there were pronounced differences in the segregation of the wastes mixture aggregate particles which appeared to follow the order 1%P>4%P>2%P>1.5%P>0%P>0.5%P, respectively. Generally, the incorporation of RP at the rate of 1% P resulted in consistently greater vermidegradation of the cow-dung paper-waste mixtures at each sampling date compared with the other RP treatments. This was reflected in higher segregation of the waste mixtures aggregate particles. The wide differences in extent of degradation at different rates of RP application observed on days 14 and 28 which coincided with the period of maximum microbial activity is a further proof that the observed improved vermidegradation of waste mixtures mixed with RP could be related to its stimulatory effect on soil microorganisms [21 and 25].

[Fig. 10]

4. Conclusions

The results of this study have confirmed that incorporation of rock phosphate improves the biodegradation of cow-dung paper-waste mixtures and further revealed that optimal vermidegradation can be achieved with the application of 1% P as RP. At this rate of RP incorporation, the vermicomposting mixtures required only 33days to reach maturity. The improvement in vermicomposting occurred mostly between days 14 and 28. Although a 1% P rate of RP application is all that was needed for fast maturation of the vermicompost, higher rates of RP application are necessary for enhanced P fertilizer value of the resultant vermicompost. Therefore, higher rates of RP incorporation may be necessary where final composts with higher P contents and thus better P fertilizer value are desired. Future studies will need to examine the agronomic value of these composts. Nevertheless, the results of the present study have shown that cow dung waste paper vermicomposts enriched with phosphate rock have potential as organic fertilizers which would be acceptable in organic farming.

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Figure Captions

Figure 1: Effect of added RP rates and vermicomposting time on ash contents during vermicomposting of cow dung-waste paper mixtures. [Error bars are standard deviations]

Figure 2: Effect of added RP rates and vermicomposting time on volatile solids contents during vermicomposting of cow dung-waste paper mixtures [Error bars are standard deviations]

Figure 3: Effect of added P as rock phosphate (RP) and vermicomposting time on the C: N ratio of cow dung- waste paper mixtures during vermicomposting with *Eisenia fetida*.. [Error bars are standard deviations]

Figure 4: Effects of added RP rate and vermicomposting time on Polymerization index. Bars indicate standard deviations

Figure 5: Effects of added RP rate and vermicomposting time on Humification index of cow dung waste paper vermicompost. Bars indicate standard deviations

Figure 6**:** Effects of added RP on Bray 1 extractable P during vermicomposting of cow dung-waste paper mixtures. Bars represent standard deviation.

Figure 7: Effects of added RP on total Pi and Po fractions of initial and final vermicompost. Bars indicate standard deviation.

Figure 8: Effects of added RP on individual Pi fractions of final vermicompost. Bars indicate standard deviation.

Figure 9: Effects of added RP on individual Po fractions of final vermicompost. Bars indicate standard deviation.

Figure 10: Scanning electron microscope images showing effects of RP application rate and time on vermicompost morphological properties.

Tables

Table 1 Repeated measures ANOVAR for C: N ratio, PI, HI, Total P, Total N, Bray1 extractable P, VS, Ash content

	Effect					
	Added RP rates		Time		Added RP rates X Time	
	$F_{(5, 60)}$	P	$F_{(4, 60)}$	P	$F_{(20, 60)}$	P
C: N ratio	1023.3	<0.0001	22341.2	<0.0001	460.3	<0.0001
Polymerization index (PI)	42.8	<0.0001	376.8	<0.0001	30.1	<0.0001
HI (%)	425.1	<0.0001	2357.6	<0.0001	101.7	<0.0001
Total P (g kg^{-1})	2332.1	<0.0001	1064.1	<0.0001	894.4	<0.0001
Total N (%)	201	<0.0001	540	<0.0001	25	<0.0001
Bray 1P (mg kg^{-1})	1895.5	<0.0001	1637.5	<0.0001	1034	<0.0001
VS (%)	314.2	<0.0001	903.4	<0.0001	17.9	<0.0001
Ash content (%)	396.3	<0.0001	784.3	<0.0001	16.2	<0.0001

F values and probabilities are shown for each effect. P < 0.05 in italics is significant. n=3, C: N=carbon to Nitrogen ratio, PI = Polymerization index, HI= Humification index, HR= Humification ratio, VS=Volatile solid, MBC= Microbial biomass carbon NH_4^+-N= Ammonium- Nitrate, NO_3^-- N = Nitrate- Nitrite, NH_4^+ : NO_3^-= Ammonium: nitrate ratio

Table 2**: Effect of rate of RP application on the vermidegradation time of cow dung waste paper mixtures as reflected by C: N ratio**

Treat. No.	Treatment % P as RP	Regression Equations (C:N ratio VS Incubation time in days)	Days required to maturity (i.e. at C/N ratio=12)	% improvement in reducing time to vermicompost maturity
1	0	$y = -0.0026x^2 - 0.2072x + 30.8$	46	
2	0.5	$y = 0.002x^2 - 0.1234x + 31.0$	42	9*
3	1.0	$y = 0.0066x^2 - 0.7714x + 29.229$	33	28*
4	1.5	$y = 0.005x^2 - 0.6458x + 31.6$	41	11*
5	2.0	$y = 0.0059x^2 - 0.7038x + 30.4$	41	11*
6	4.0	$y = 0.007x^2 - 0.7646x + 29$	40	13*
		P>F	<0.0001	

*Relative to treatment 1 (where cow-dung-waste paper mixtures were only inoculated with *Eisenia fetida* and no RP addition).

Table 3: Effects of added RP on Total P and Bray 1 extractable P contents of the final cow dung waste paper vermicomposts

Added RP	Total P (%)	Bray 1 P (mg kg^{-1})	Increase in Extractability of P (%)
0% P	0.18	80	
0.5% P	0.55	101	26
1% P	0.97	141	76
1.5% P	1.32	152	90
2% P	1.76	170	113
4% P	2.31	207	159
CV	5	3	
P-Value	<.0001	<.0001	

Figures

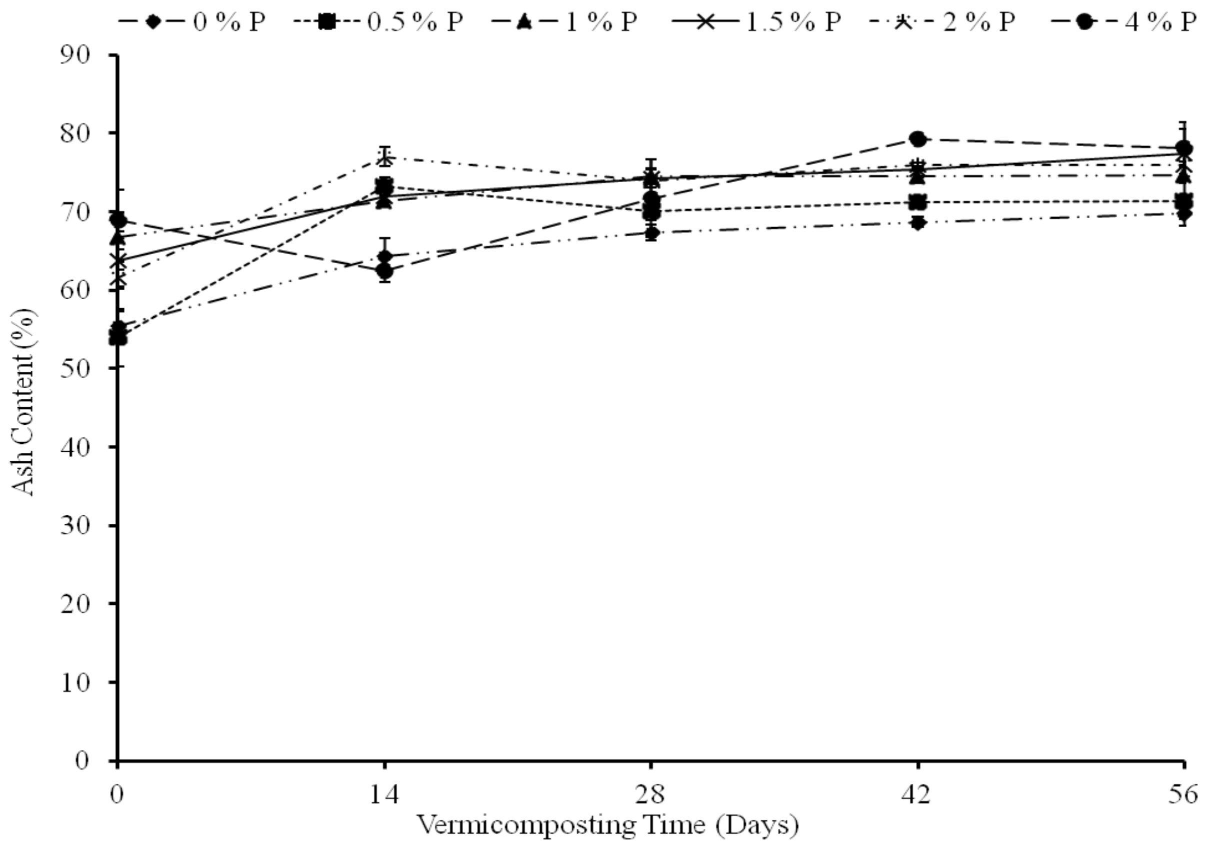


Fig. 1

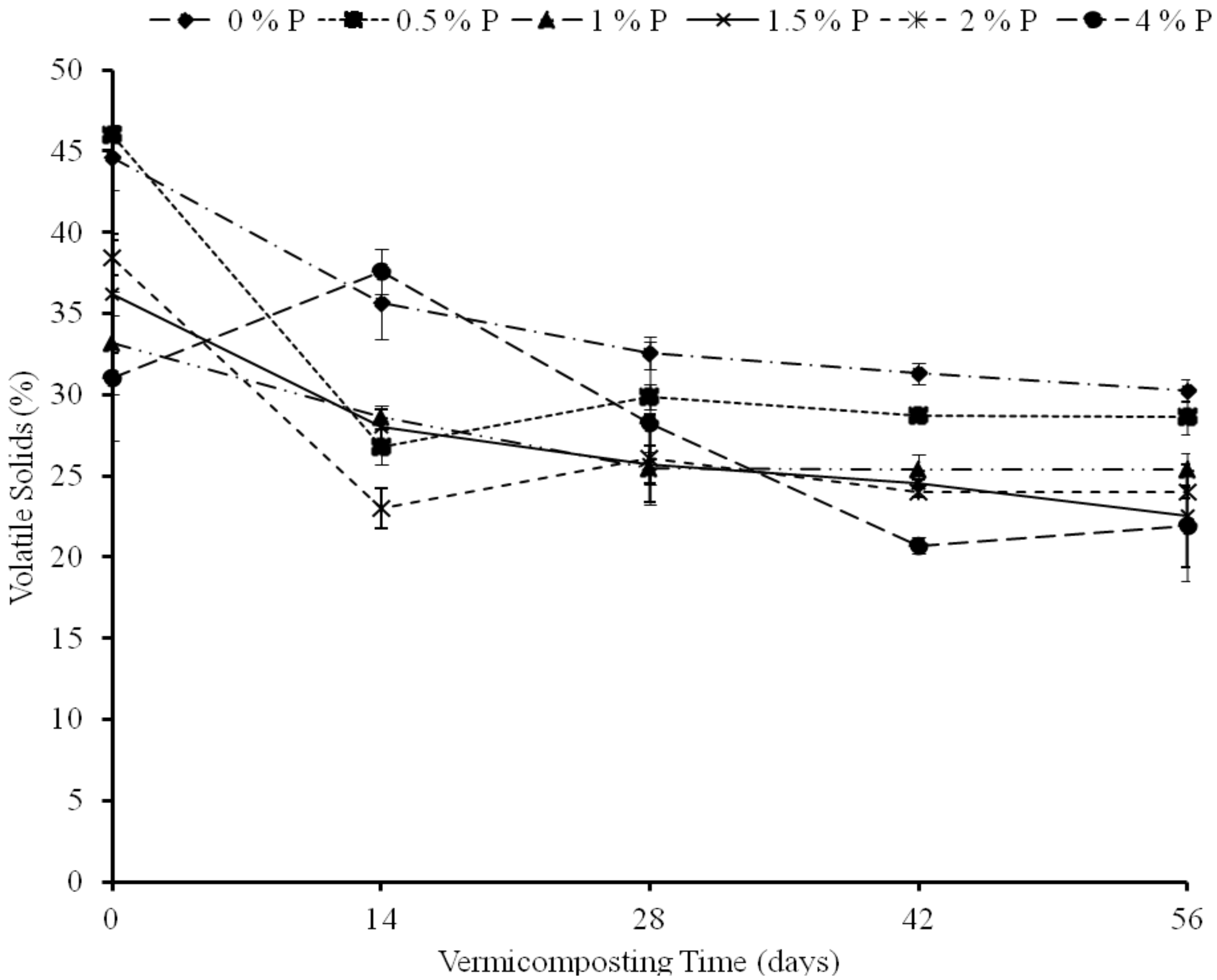

0 % P
0.5 % P
1 % P
1.5 % P
2 % P
4 % P
Volatile Solids (%)
Vermicomposting Time (days)
0
5
10
15
20
25
30
35
40
45
50
0
14
28
42
56

Fig. 2

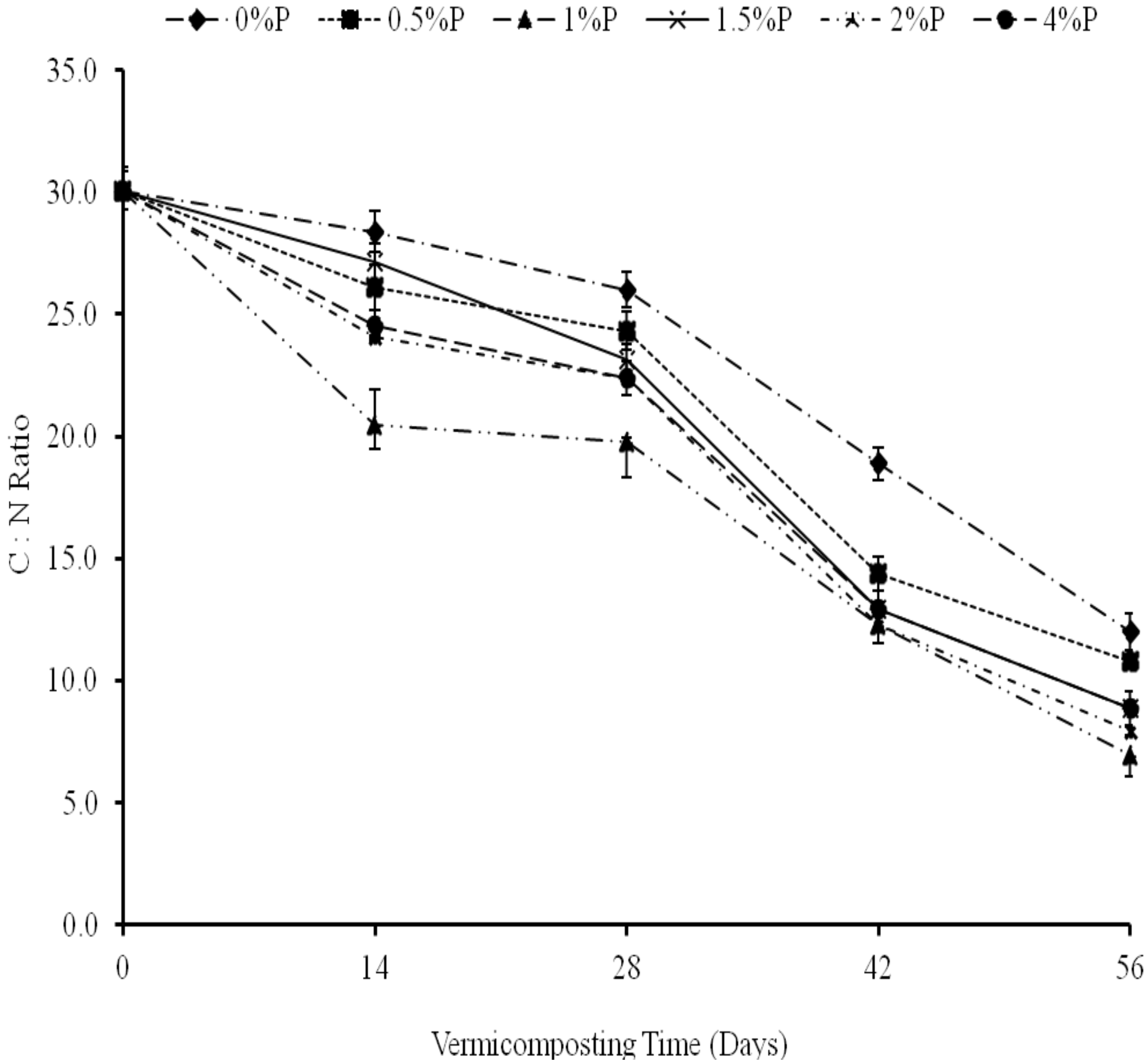
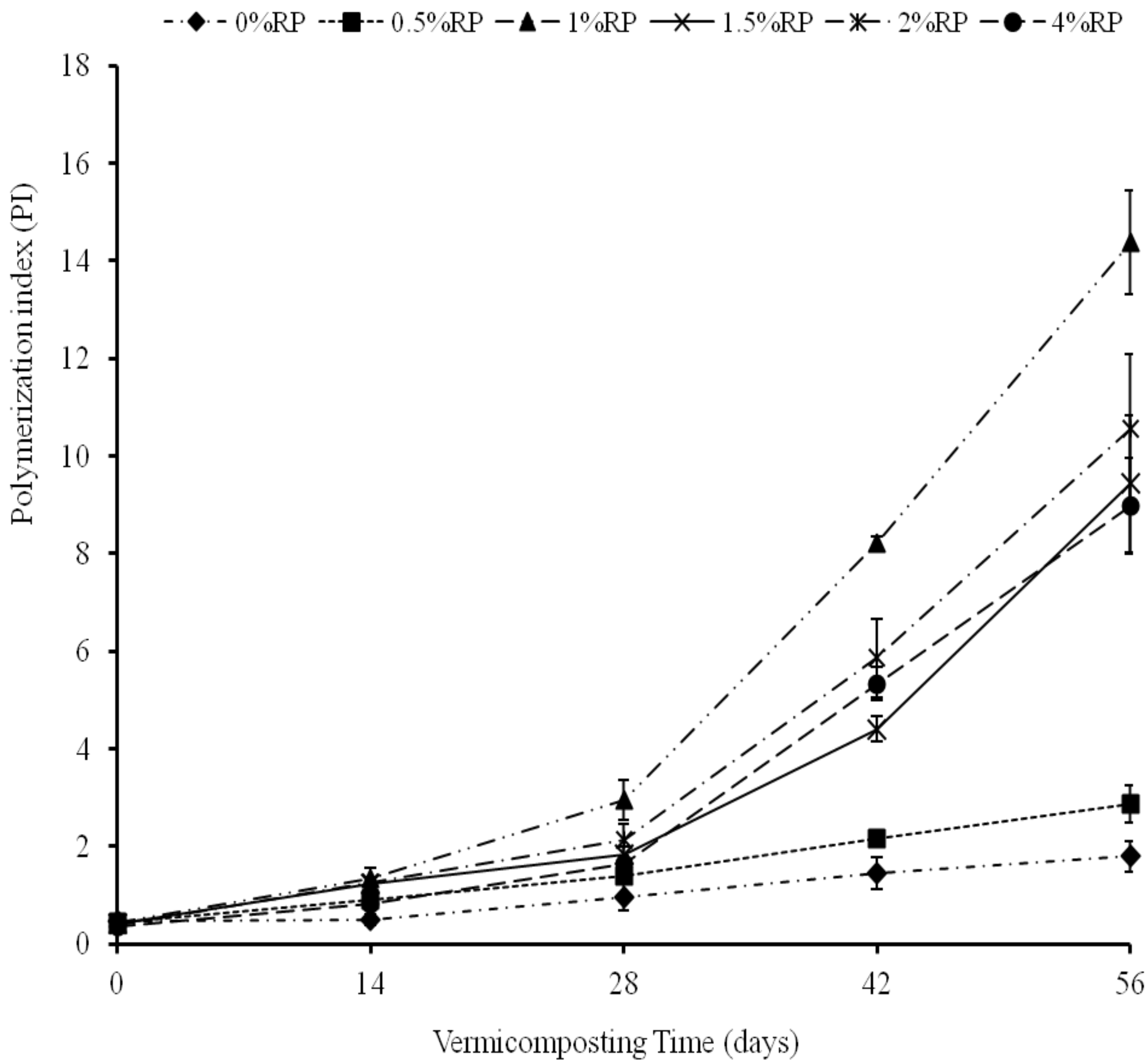
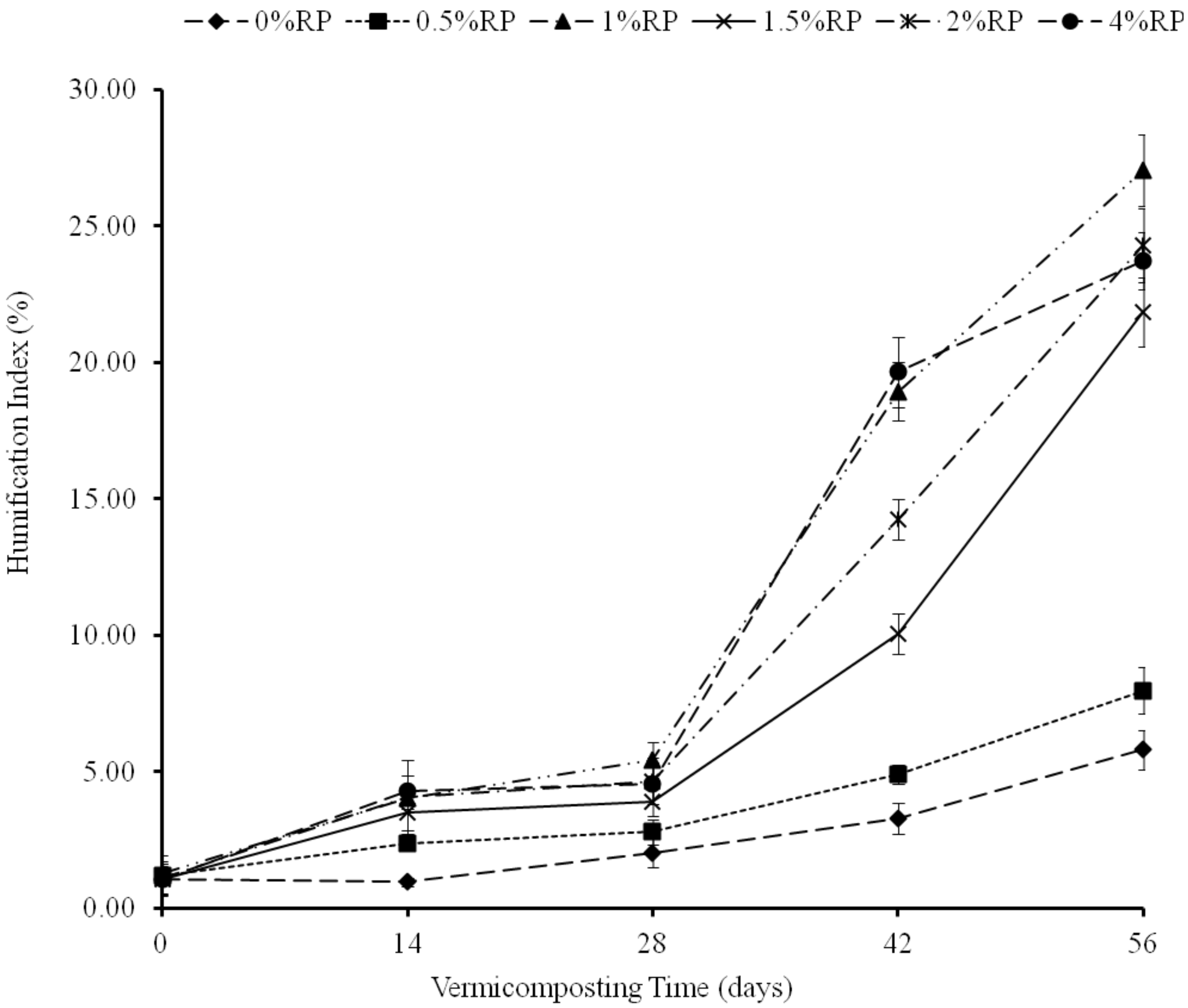

0%P
0.5%P
1%P
1.5%P
2%P
4%P
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
C : N Ratio
0
14
28
42
56
Vermicomposting Time (Days)

Fig . 3



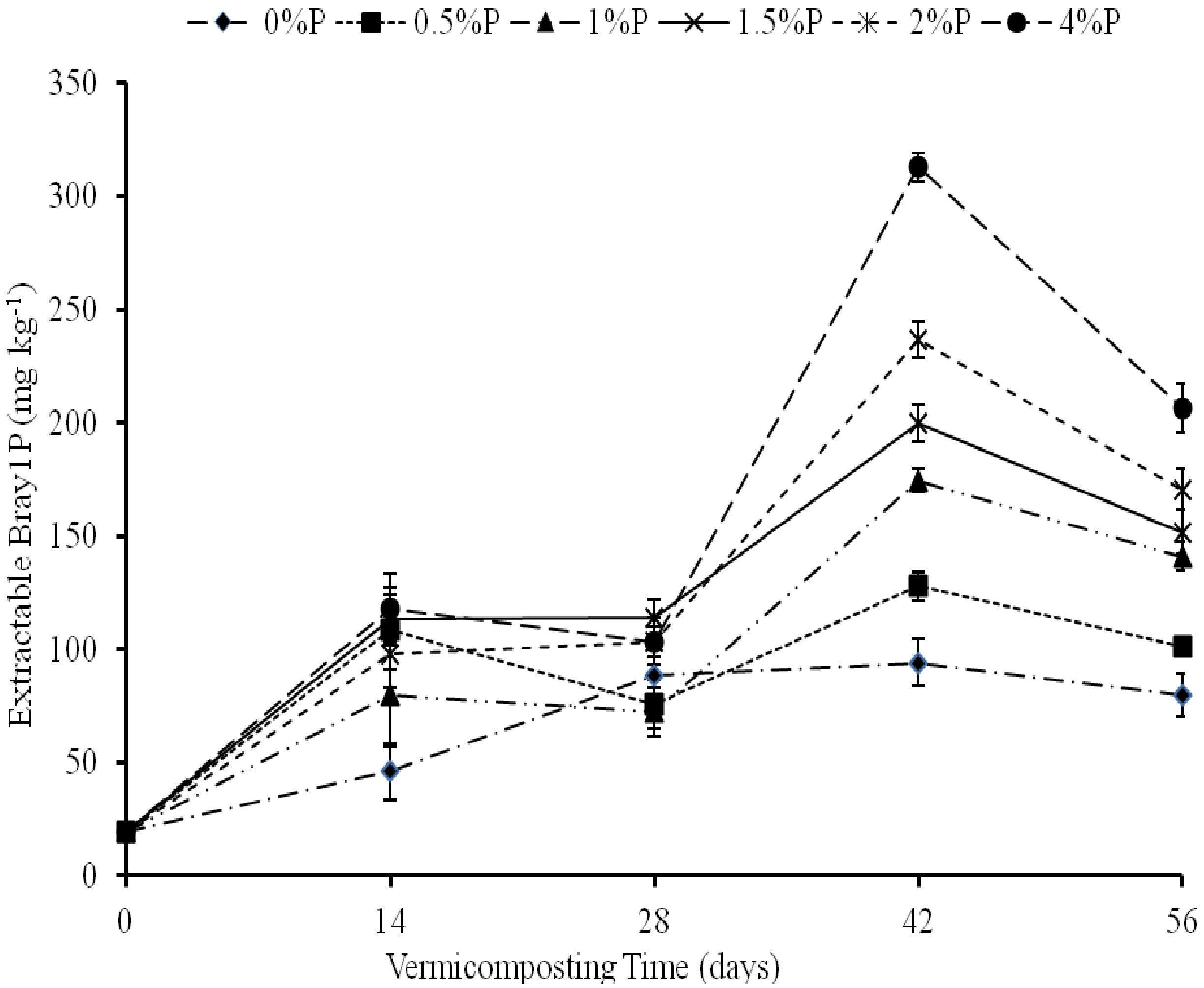
0%RP
0.5%RP
1%RP
1.5%RP
2%RP
4%RP
Polymerization index (PI)
18
16
14
12
10
8
6
4
2
0
0
14
28
42
56
Vermicomposting Time (days)

Fig. 4



0%RP
0.5%RP
1%RP
1.5%RP
2%RP
4%RP
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Humification Index (%)
0
14
28
42
56
Vermicomposting Time (days)

Fig. 5



0%P
0.5%P
1%P
1.5%P
2%P
4%P
350
300
250
200
150
100
50
0
Extractable Bray1 P (mg kg-1)
0
14
28
42
56
Vermicomposting Time (days)

Fig. 6

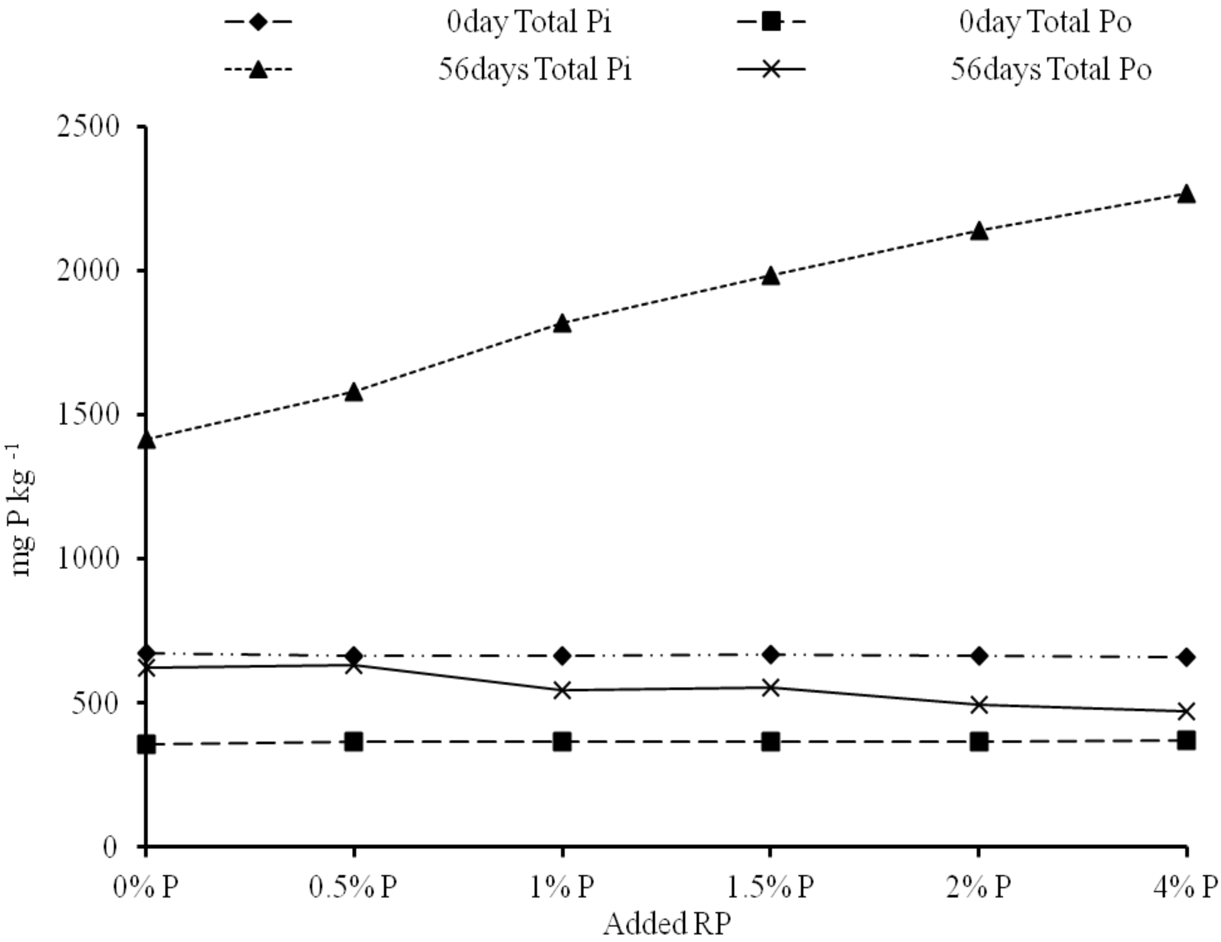
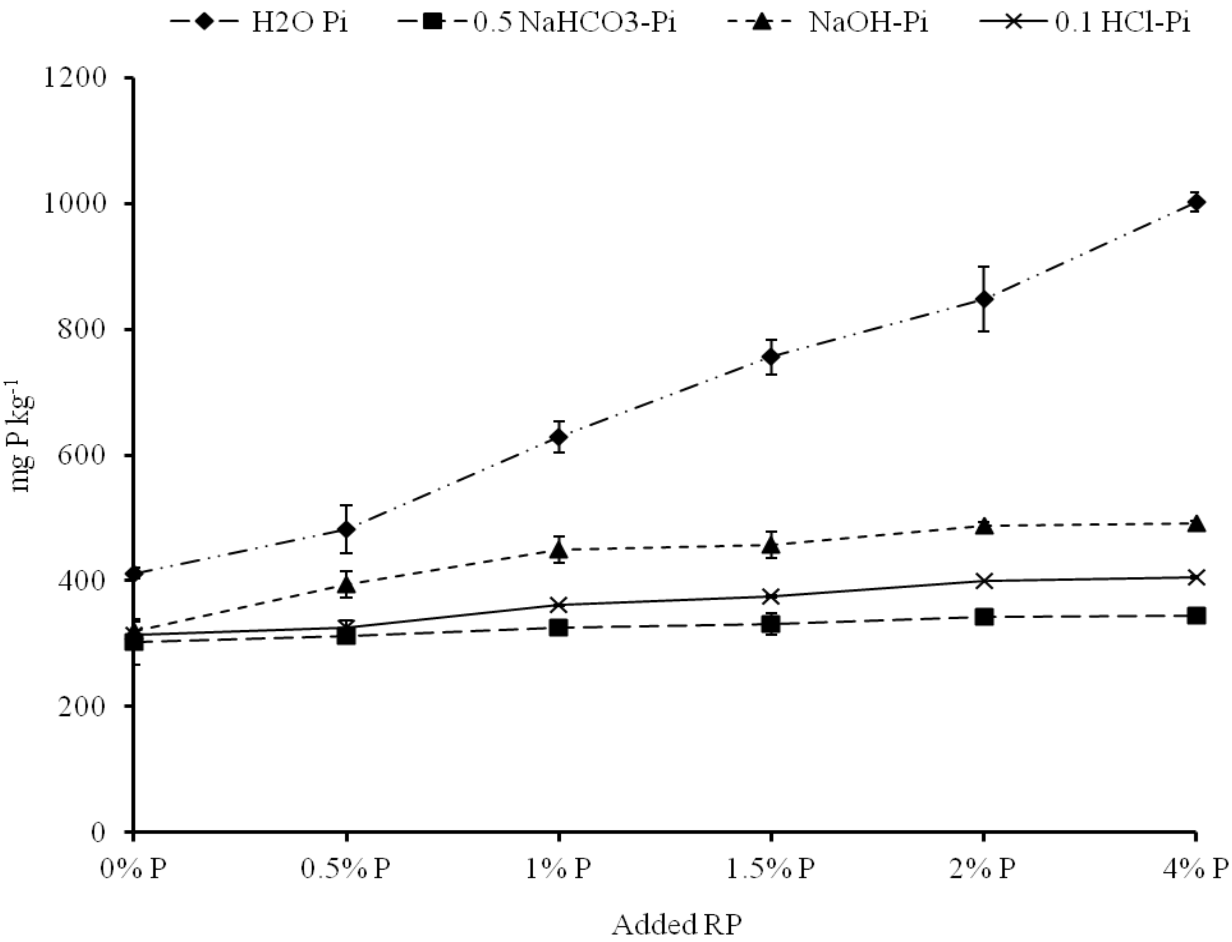

0day Total Pi
0day Total Po
56days Total Pi
56days Total Po
2500
2000
1500
1000
500
0
mg P kg -1
0% P
0.5% P
1% P
1.5% P
2% P
4% P
Added RP

Fig 7



H2O Pi
0.5 NaHCO3-Pi
NaOH-Pi
0.1 HCl-Pi
1200
1000
800
600
400
200
0
mg P kg-1
0% P
0.5% P
1% P
1.5% P
2% P
4% P
Added RP

Fig. 8

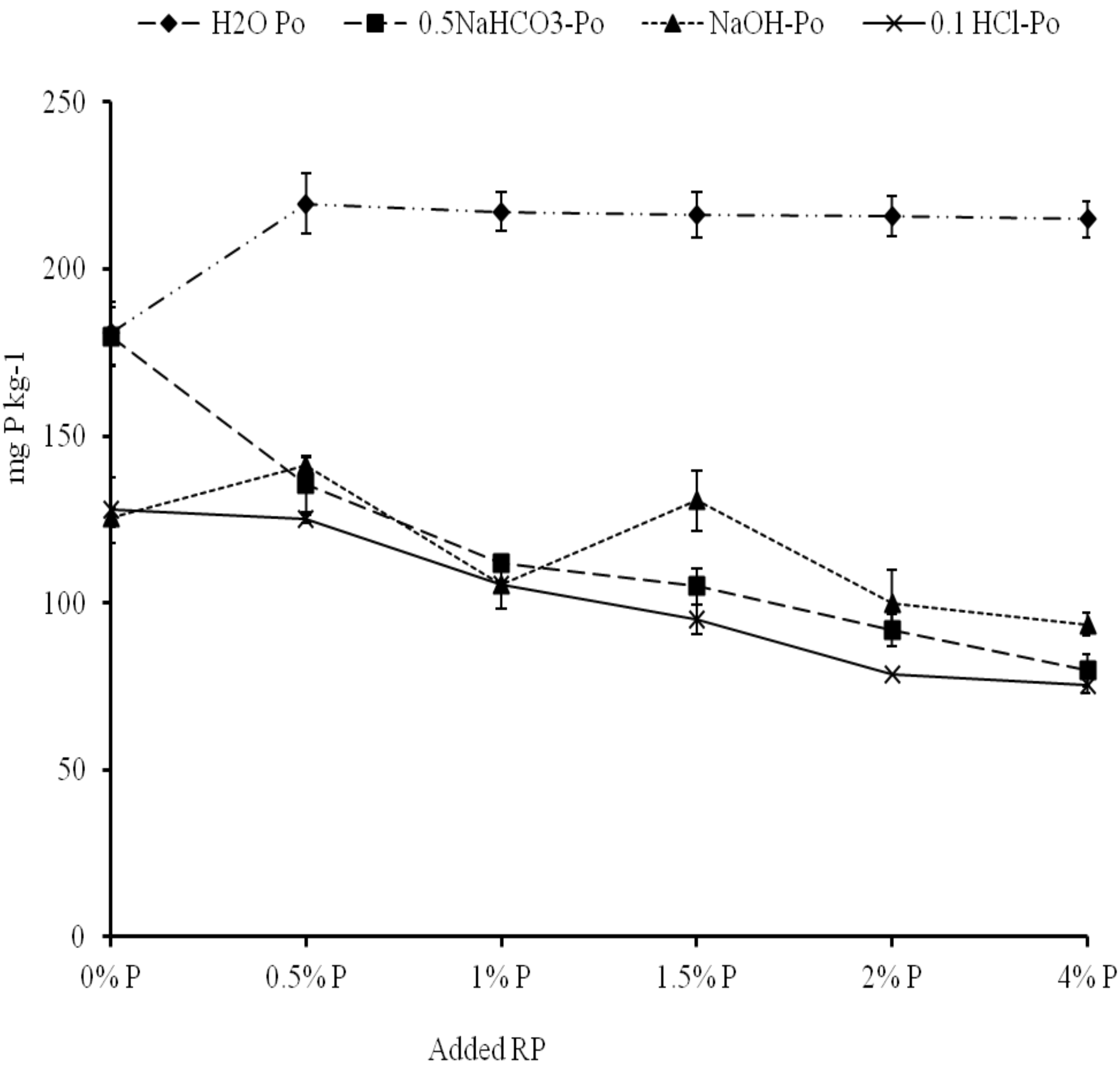

H2O Po
0.5NaHCO3-Po
NaOH-Po
0.1 HCl-Po
250
200
150
100
50
0
mg P kg-1
0% P
0.5% P
1% P
1.5% P
2% P
4% P
Added RP

Fig.9

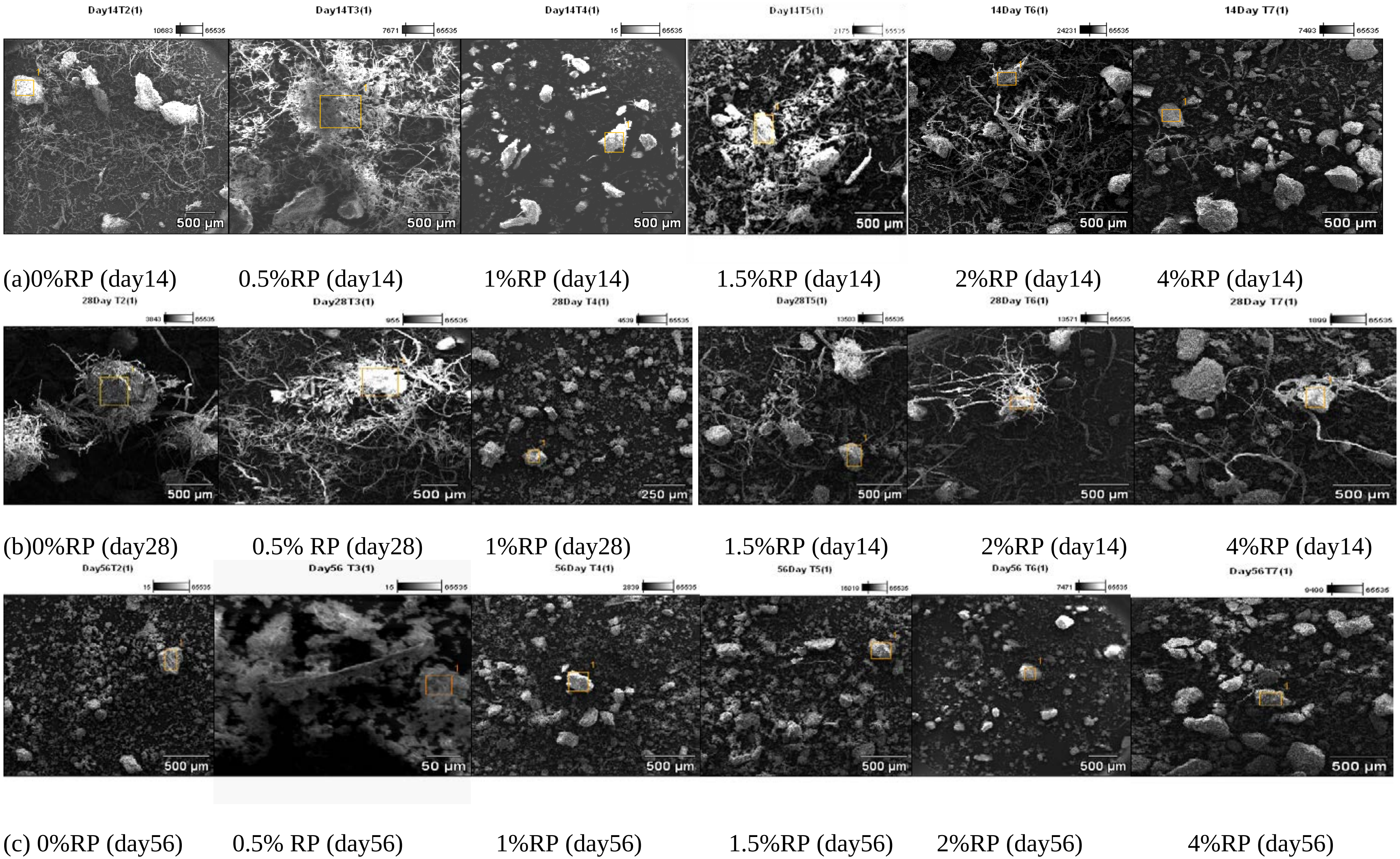


Fig. 10 .Scanning electron microscope images showing effects of RP application rate and time on vermicompost morphological properties