Journal of Applied Horticulture, 16(2): 112-116, 2014

Effect of storage on some physical and chemical characteristics of vermicast

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Abstract

It is widely acknowledged that vermicast has beneficial effect on plant growth but little is known on how the manner and duration of storage affect the vermicast quality. In an attempt to cover this knowledge-gap we have carried out a study on changes in physical and chemical properties of vermicast as function of ageing when it is stored. The study revealed that most of the characteristics of the castings were retained during the first 60 days of storage. Further as storage was continued, the physical properties such as total and water filled pore space were reduced by 11 and 40%, respectively. The water holding capacity of castings also reduced about 82% and exhibited high degree of water repellency. Whereas, the bulk density and particle density of castings increased two-fold. These changes may impede the water availability, oxygen diffusion and plant root penetration in the field. The nitrogen loss of 49% was recorded due to intense ammonia volatilization. There was more than 75% loss in potassium and phosphorus content and a significant reduction in the concentration of minor and trace nutrients. These changes in the properties of castings reduced the beneficial impact of vermicast on plant growth.

Key words: Vermicast properties, vermicast storage, *Eudrilus eugeniae*, neem leaf litter, nutrient

Introduction

Vermicomposting is the term given to the process of conversion of biodegradable matter by earthworms into vermicast (Abbasi and Ramasamy, 2001). In the process, a major fraction of the nutrients contained in the organic matter is converted to more bioavailable forms. Application of vermicompost improves the soil structure by increasing porosity and reducing the bulk density. It improvises soil aeration, water-holding capacity, buffer capacity, and cation exchange capacity of soil (Nada *et al*., 2013). In addition, the vermicompost is also reported to contain biologically active substances such as plant growth regulators and have been shown to increase growth of many plants (Tomati *et al*., 1990, 1995; Abbasi and Ramasamy, 1999; Atiyeh *et al.,* 2002; Arancon *et al*., 2004; Gajalakshmi and Abbasi, 2004; Edwards, 2004; Sinha, 2009).

Although a considerable number of studies have been carried out on vermicomposting of various organic materials with different earthworm species and their impact on the soil and plant growth (Gajalakshmi *et al*., 2001a, 2002; Singh and Sharma, 2002; Gajalakshmi and Abbasi, 2003, 2004; Padmavathiamma *et al*., 2008), there is still a lack of knowledge on the change in the properties of vermicast during the course of storage. The castings of *anecics* and *endogeics* have been extensively studied in relation to the changes in the physico-chemical properties during ageing process (Hindell *et al.,* 1997; Decaëns *et al.,* 1999; Decaëns, 2000; Aira *et al.,* 2005; Mariani *et al.,* 2007). There are also few studies on the enzymes and microbial aspects of castings generated from the epigeic earthworms (Parthasarathi and Ranganathan, 1998, 1999; Scullion *et al.,* 2003). There is no study on changes in the characteristics of vermicast during the ageing as a function of manner of storage. Investigating this storage effect on castings is of great importance with respect to understanding the changes in nutrient status and physical properties of vermicast. The present work has been taken up to investigate the changes in the properties of the vermicast when stored so that the optimum age for best utilization could be understood. The present study was conducted with vermicast generated from neem leaves.

Materials and methods

Neem leaves were collected from Pondicherry University campus and its vicinity. The collected leaves were washed with water to remove adhering material and soaked for 48 hr in order to remove phenolic compounds and to make substrate softer and palatable to earthworms (Nath *et al.,* 1987; Agarwal *et al.,* 1991). Rectangular wooden boxes (depth 30cm, width 35cm, length 39cm) were used as vermireactors. The reactors were filled from bottom up with successive layer of coarse sand and soil to a thickness of 3 and 5cm, respectively. Neem leaves was added as feed with the earthworm species *Eudrilus eugeniae*, an epigeic worm. After 2 weeks, the vermicast was harvested. An aliquot of fresh castings was analyzed immediately whilst the rest were stored for <7, 14, 21, 60, 90 and >120 days. The casts were stored in the polyethylene bags of 20 micron thick and 7 x 10 inch size. Plastic bags filled with 500 g of vermicast were stored at room temperature in order to imitate the general way of storage of vermicompost in commercial sectors.

Moisture content of castings was determined by weight loss at 105 °C. To estimate bulk density (p_{bulk}) sample volume was measured with a graduated cylinder and its dry weight was determined by oven drying. The particle density ($p_{Particle}$) was determined by volumetric flask method (Bashour and Sayegh, 2007). The quotient value of weight of the sample and its volume which was measured through volume of water displaced by known amount of soil sample in the volumetric flask is reported as $p_{Particle}$. To measure the water holding capacity (WHC), the samples were filled in cylinders with a perforated base and immersed in water and drained. The quantity of water taken up by samples was determined by drying to constant mass at 105 °C (Margesin and Schinner, 2005). The total and water filled porosity were calculated from the particle and bulk density values of respective samples. The total porosity was calculated by subtracting quotient value of p_{bulk} and $p_{Particle}$ of the samples with 1. The calculated total porosity value was subtracted with multiplied value of gravimetric water content and quotient value of p_{bulk} and $p_{Particle}$ of the samples, and it is reported as WFPS (Carter and Gregorich, 2008). The electrical conductivity (EC) was measured with sample suspension prepared in 1:2 ratio (Bashour and Sayegh, 2007) by using EI™ 611E EC meter. Thin sections of casts were made after impregnating the samples in araldite using Bueller PetroThin™ thin sectioning system (FitzPatrick, 1993). The internal and external structures of thin sectioned castings were observed under the binocular microscope.

The total organic (C_{org}) content in the castings was measured by modified dichromate redox method according to Heanes (1984). In this method, external heating was applied during the oxidation process in order to quicken and complete oxidation of C_{org} in the sample. The total nitrogen (N_{tot}) content of the samples was determined by modified Kjeldahl method (Kandeler, 1993) using Kel Plus™ semi-automated digester and distillation units. In order to include nitrate, nitrite, nitro and nitroso groups, mixture of salicylic acid and sulphuric acid was used for digestion. All the elements present in the vermicast were analyzed by Bruker™ S4-Pioneer model wavelength dispersive X-ray fluorescence spectrophotometer (WD-XRF). The samples were ground to particle size well below 100 µm using ball mill in order to minimize the grain size interference on XRF-measurement. The concentration of major elements found in the vermicast is reported in this paper. The data were analyzed statistically with software SPSS 16 package and subjected to one-way ANOVA. Comparisons between means were tested with LSD test.

Results and discussion

Fresh castings of *E.eugeniae* produced from neem leaf litter were fine, long, slender and pellet-like in structure. The size was in the range of 0.1 to 2.0 mm length and 0.1 to 1.2 mm breadth. During storage, the casts had undergone significant changes in their physical and chemical properties (P< 0.001) (Table 1-2). The castings stored for prolonged period (>120 days), had its structure disintegrated and formed clod like aggregates. The initial moisture content of 77.4 ± 3.5% was reduced to 66.7 ± 2.5% in 60 days stored vermicast. Afterwards, the moisture content drastically decreased to about 20% in the 90 and >120 days of storage. Decrease in the moisture content of vermicast during the storage may exert a strong influence on the microorganisms (Nannipieri *et al.,* 2003) and their enzyme activity in the vermicast (Parthasarathi and Ranganathan, 1998). The microbiota and their enzymes in turn reflect on the mineralization of nutrient (Birch, 1964). The results indicate that the drastic loss in moisture content (>75%) after 90 days leads to reduction in microbial mediated activity in the vermicast.

In the first 3 weeks of storage, the particle density was stable, after that it increased and became two folds high at > 120 days stored vermicast compared to the fresh castings (P<0.001) (Table 1). Ruhlmann *et al.* (2006) has reported that the $p_{Particle}$ of castings varied considerably due to the degree of decomposition of organic matter present in it. In the present study the $p_{Particle}$ was ranging from 1.359 to 2 g cm^{-3}, which is very low than the soil $p_{Particle}$ range of 2.6-2.8 g cm^{-3} in relation to the plant growth. Low $p_{Particle}$ of the vermicast can be explained by their high C_{org} content. It has

Table 1. Physical characteristics (mean± SD) of castings of different period of storage and the calculated of F-values using one-way ANOVA

Days of storage	Water Content (%)	Bulk Density (g cm^{-3})	Particle Density (g cm^{-3})	Pore Space (%)	Water-Filled Pore Space (%)	Water Holding Capacity (%)	EC (mmhos cm^{-1})
<7	77.44 ± 3.46	0.307 ± 0.006	1.359 ± 0.034	77.41 ± 0.94	30.49 ± 1.77	651.0 ± 37.4	4.893 ± 0.210
14	76.67 ± 0.84	0.317 ± 0.009	1.349 ± 0.33	76.47 ± 0.70	31.63 ± 1.14	798.0 ± 9.0	3.673 ± 0.361
21	75.70 ± 3.86	0.334 ± 0.005	1.350 ± 0.012	75.26 ± 0.48	33.41 ± 2.06	592.1 ± 30.8	1.569 ± 0.023
60	66.73 ± 2.45	0.383 ± 0.014	1.435 ± 0.037	73.31 ± 0.86	34.65 ± 1.57	518.0 ± 20.6	1.526 ± 0.050
90	20.63 ± 3.49	0.524 ± 0.015	1.849 ± 0.028	71.68 ± 0.54	14.87 ± 2.94	132.7 ± 5.0	1.489 ± 0.029
>120	21.36 ± 2.82	0.603 ± 0.014	2.000 ± 0.037	69.86 ± 0.70	18.24 ± 2.94	117.8 ± 9.0	1.439 ± 0.040
F value	772.1***	1034.7***	774.6***	145.9***	135.5***	1441.1***	649.4***

$^{*}P$<0.05, $^{**}P$<0.01, $^{***}P$<0.001, $^{n.s}$ - not significant.

Table 2. Total nitrogen and organic carbon (mean±SD) of castings with different period of storage and the calculated of F-values using one-way ANOVA

Parameter	Days of storage						F value
	<7	14	21	60	90	>120	
Total kjeldahl nitrogen mg g^{-1}	21.77 ± 1.33	14.95 ± 0.35	14.33 ± 1.46	12.55 ± 2.19	13.94 ± 2.49	11.20 ± 0.83	239.5***
Total organic carbon mg g^{-1}	108.0 ± 2.1	115.2 ± 8.7	130.8 ± 2.5	144.6 ± 5.4	151.2 ± 1.7	90.0 ± 1.9	46.5***

$^{*}P$<0.05, $^{**}P$<0.01, $^{***}P$<0.001, $^{n.s}$ - not significant.

been reported that increase of C_{org} in the soil, decrease the $p_{Particle}$ at the rate of 0.04-0.06 g cm^{-3} per percentage of C_{org} (Ruhlmann *et al.,* 2006).

As the age of the vermicast progressed, there was a significant increase in bulk density (P<0.001) (Table 1). During the first week of storage, the bulk density was 0.307 g cm^{-3}, and then it increased, till the end of the experiment (0.603 ± 0.014 g cm^{-3}). There was 2 fold increase in bulk density in four months of storage. However, it is lower than the soil bulk density range of 0.7-1.8 g cm^{-3} in relation to the plant growth (Lal and Shukla, 2004). Low bulk density is desirable for plant growth, as it makes easier for plant root penetration and it posses high water infiltration rates. On the other hand, high bulk density would impede root penetration and reduce the air and water movement (Edwards, 2004).

Porosity of castings decreased distinctly (P<0.001) throughout the >120 days of storage and its range was between 69.9 to 77.4% (Table 1). Porosity directly influences water infiltration, hydraulic conductivity and water storage capacity in soils (Blanchart *et al.,* 2004). Moreover, it greatly influences the structure, function and interaction of microbial and microfaunal communities (Hattori, 1994). The percentage of water-filled pore space was high, but not significantly different in the first 21 days of storage, ranging between 30.5 and 33.4%. High WFPS may decline the microbial activity, presumably as a result of additional water, presenting a barrier for diffusion of oxygen to waste products away from microorganisms (Linn and Doran, 1984a,b; Doran, 1990). The castings stored for 90 and >120 days showed 14.9 and 18.2% of WFPS, respectively; this lower WFPS is also not suitable for the microbial activity. Usually excessive dryness is more prejudicial to microorganisms than an excess of water-filled pores (Tate, 1985; Paradelo and Barral, 2009).

WHC was the maximum in castings stored for 2 weeks and it was 651.0 ± 37.4 and 798.0 ± 9.0% in the first and second week, respectively (Table 1). High WHC of the castings during the initial period of storage may be due to the abundance of micropores present in the castings (Chaudhuri *et al.,* 2009). At the end of the experiment nearly 6 fold decrease in WHC was recorded compared to fresh castings (P<0.001). While estimating the WHC of the vermicast stored for 90 and > 120 days, it was observed that the vermicast did not absorb water for many hours, indicating high degree of water repellency. This may be due to conformational re-arrangements of the organic matter (Mashum and Farmer, 1985; Valat *et al.,* 1991; Roy *et al.,* 2000), and excess dryness (King, 1981; Ritsema *et al.,* 1998; De Jonge *et al.,* 1999; Bachmann and van der Ploeg, 2002; Quyum *et al.,* 2002).

Electrical conductivity indicates the concentration of total soluble salts in solution, thus reflecting the degree of soil salinity and it affects plants at all stages of development. The sensitivity may vary from one growth stage to another for some crops (Maas and Hoffman, 1977). In the neem castings of our study, maximum EC of 4.893±0.210 mmhos cm^{-1} was recorded in the fresh castings and it significantly declined during the storage (P<0.001) (Table 1). There was a maximum of about 68% reduction in EC during first 21 days of storage and thereafter there was a slow and steady decline till the end of the experiment.

The total nitrogen content in fresh castings was 21.77±1.33mg g^{-1} (Table 2). In the 14 days stored castings, 31% reduction in N_{tot} was observed. Afterwards the concentration decreased slightly during the entire storage process. The gaseous loss of nitrogen from the casts may be the reason for the maximum N_{tot} loss during 14 days of storage. A higher loss of N during the initial weeks was likely due to the intense ammonia volatilization. In general, NH_3 volatilization is strongly dependent on the NH_3 and NH_4^+ concentration. It has been reported that up to 30% nitrogen loss occurs in fresh castings by denitrification (Kharin and Kurakov, 2009). The organic carbon content of fresh castings was 108.0±2.1 mg g^{-1}. During the storage process, the C_{org} content in the castings significantly increased up to 29% in the course of 90 days. After 120 days, there was a drastic decrease and its concentration was near to those of fresh castings (Table 2).

Decaëns *et al*. (1999) observed same pattern of C_{org} increase but without any decline over prolonged ageing of vermicast of large species of anecic earthworm, *Martiodrilus carimaguensis.* They have also summarized a combination of several factors for C_{org} increase during the ageing process. Among those factors, the possible reasons that would be applicable in the present studies are fixation of atmospheric CO_2 from autotrophic microorganisms, such as algae or nitrification microorganisms (Vinceslas- Akpa and Loquet, 1997) and accumulation of organic matter by cast-dwelling macro-invertebrates. The significant decrease of C_{org} in vermicast stored for more than 120 days can be attributed to excessive dryness of castings, which is not suitable and beneficial to microbiota. The fresh castings are noted to be enriched in Ca, followed by K (Table 3). The concentration of these elements was almost stable until 21 days of storage. Afterwards, there was a decline throughout the study. Lal and de Vleeschauwer, (1981) and Schrader and Zhang (1997) ascribed the high Ca content of casts to the presence of calcite spheroids originating from worms' calciferous glands which regulates the CO_2 in their tissues (Briones *et al.,* 2008).

In the fresh castings, 12.9 % of K was recorded and there was 77% of loss at the end of 4 months storage. In the case of P, the initial concentration of 2.1% was reduced to 1.2%, at the end of 4 months. A maximum P loss of 73% was observed in the first two weeks of storage. After that, there was slow and steady decline of P content till the end of the experiment. Except Mg, the concentration of other elements such as Al, Fe, Na, Cl, S, Si, Ti and Zn decreased as the storage period increased (Table 3). Changes in Mg concentration did not show any trend as the age of the castings progressed. The overall results show that 60 days of storage did not show much variation; after that there was a significant decrease in the concentration of these elements. The reduction of K, P and other metals content may be due to nutrient assimilation by the bacterial and fungal grazing macro-invertebrates in the castings. Loss of these trace nutrients may slide down the positive impact of vermicompost on the plant growth.

The present study revealed that during storage of vermicast, the physical and chemical properties of castings get altered. The prolonged storage period reduced the nutrient concentration and in turn the beneficial properties required for plant growth. According to the results of this study, most of the characteristics of the castings were retained during the first 60 days of storage. Further as storage was continued, the nutrient status depleted. The changes in physical property are disintegration of the structure of

Table 3. Major elements present in the casting stored for different period.

Elements	Days of storage					
	<7	14	21	60	90	>120
Ca	60.18	60.14	60.09	48.91	17.444	15.56
Al	2.280	1.260	1.190	1.120	1.042	1.045
Cl	3.890	3.850	3.790	3.150	0.898	0.774
Fe	3.773	2.505	2.382	1.878	1.643	1.108
K	12.92	14.77	14.85	10.69	2.580	2.864
Mg	2.578	3.716	3.848	2.443	0.633	1.111
Mn	0.258	0.193	0.179	0.199	0.070	0.245
Na	0.429	0.428	0.428	0.397	0.394	0.436
P	2.090	1.460	1.430	1.430	1.425	1.230
S	5.360	4.169	4.146	4.058	1.060	1.480
Si	15.63	15.54	15.38	15.01	13.38	12.82
Ti	0.888	0.446	0.368	0.133	0.105	0.070
Zn	0.377	0.093	0.090	0.090	Nil	Nil

All the elements are in percentage (%).

the vermicast, increase in bulk density, water repellency, decrease in water holding capacity and water content. All these factors lead to adverse impact on plants when applied as manure. Therefore, utilization of vermicast before nutrient loss is recommended or castings need to be stored by appropriate methods which should prevent the loss of nutrient concentration and maintain the physical characteristics of vermicast. At present, there are no prescribed guidelines for storage of castings; hence comprehensive method of storage needs to be explored extensively.

Acknowledgment

AKH and MK are thankful to University Grants Commission, New Delhi for the research fellowship under the RGNF scheme.

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Received: November, 2013; Revised: January, 2014; Accepted: January, 2014