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Impact of earthworm species and growth habitats on the quality of vermicompost

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Abstract

Environmental degradation is a major threat confronting the world, the vermicompost product one of the best organic manure to be used for enhancing soil, crop and environment. This study aimed to the evaluated effect of earthworm species on the availability of macronutrients in the vermicompost. In this direction, the possibilities of using different growth habitats with 4 different earthworm species in an experiment to produce an organic fertilizer (vermicompost) were studied. In conjunction with those from previous studies Ninety days vermicomposting experiment was conducted in polyethylene boxes contained a pre-composted (mixture of cow manure, market wastes, kitchen wastes, sawdust and bagasse). Each type of the followed vermicomposting habitats; 100% pre-composted (PC), 75% PC+ 25% cardboard waste (CB) and 75% PC+25% soil (S) were inoculated with one species of earthworms; *Allolobophora longa*, *Eudrilus eugeniae*, *Eiseia fetida* and *Perionyx excavatus*. The present study concluded that, *A. longa* could not survive in PC habitat, while other earthworms produced a high quality vermicompost under the same condition. On the other hand, the PC+S habitat was the best for *A. longa*, which was suitable for growing of the species. The PC+CB and PC+S vermicompost's of *E. fetida* and PC+S of *A. longa* had a lowest pH, EC and C/N ratio. The total NPK content and their available forms were enhanced in the vermicompost's of PC+CB and PC+S for all tested worms as compared with PC and untreated with earthworms (control) respectively. In conclusion, he total NPK content and their available forms were enhanced in the vermicompost's of PC+CB and PC+C for all tested worms in compared with PC vermicompost and control treatment, but E. fetida was the best.

Keywords: vermicomposting, earthworms, available nutrients, quality parameters, environment, organic manure.

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1. Introduction

Chemical fertilizers have played a significant role in agriculture around the world. However, condensing and continuous use of easily soluble chemical fertilizers disturbs soil health, leading to acidification, micronutrient depletion, soil degradation; reduce in the activity of soil micro flora and micro- fauna, poor crop health and lower crop quality. In view of this, it is desirable that we may have to return to less resource demanding agricultural practices viewing the gaps in domestic production as also nutrient depletion estimates. In this direction, vermicomposting offers immense scope to small and marginal farmers in creating their own organic manurial resources and ways to generate alternative income. They can recycle organic wastes using earthworms to make vermicompost. Earthworms are classified as the major decomposers of dead and decomposing organic waste and derive their nutrition from the bacteria and fungi that grow upon these materials. Therefore, they are essential not only for soil fertility but also for recycling organic wastes (Edwards and Lofty, 1977). Earthworms are found in a wide variety of habitats; organic matter such as manure, litter and compost are very attractive to earthworms, and they are found in highly hydrophilic environments near freshwater and fallow water. The species of earthworms contribute to the breakdown of plant-derived organic matter, but by different ways depending on degrade organic matter and specie of earthworm. Earthworms can be divided into three main types: anecolote, earthworm makes permanent vertical burrows in soil and feed on leaves on the soil surface that they drag into their burrows. They also cast on the surface, and these casts can quite often be seen in grasslands, Endogeic: earthworm makes horizontal burrows through the soil to move around and to feed, reuse the burrows again to a certain extent and has often pale colors, grey and pale pink, Epigeic: earthworm lives and feed on leaf litter of soil surface and tend not to make burrows, also often bright red or reddish-brown (Munroe, 2007). Different organic wastes can be used in vermicompost production by different species of earthworms (Abul-Soud *et al*., 2009). Yan *et al*. (2012), found that feed *Eudrilus eugeniae* with different plant residues grass clippings, sago waste and rice straw. Assessed major nutrient status of vermicompost of vegetable market waste (MW) and floral waste (FW) processed by three species of earthworms namely, *Eudrilus eugeniae*, *Eiseia fetida* and *Perionyx excavatus* (Pattnaik and Reddy, 2010). The organic matter when subjected to decomposition with the help of earthworms the resultant product is ‘vermicompost’ and the process is known as vermicomposting. The product is the result of organic waste consumed by earthworm, digested and passed through gut and excreted in the form of granules (Gupta, 2003; Palaniappan and Annadurai, 2003; Sharma, 2004; Singh and Singh, 2008). The use of earthworms for composting organic matter and the latest biotechnology which helps in giving bio-fertilizers for agricultural uses and a high quality for protein (earthworm biomass) for supplementing the nutritional energy needs of animals (Blouin *et al*., 2019). It is a better technology for recycling of solid wastes than that of sole composting (Pattnaik and Reddy, 2010). Vermicompost is a nutritive "organic fertilizer" rich in humus, macronutrients (nitrogen, phosphorus and potassium), micronutrients, minerals, nutrients, vitamins, proteins, and enzymes, beneficial soil microflora, actinomycetes and plant growth regulators, which is used as an alternative to agrochemicals (Adhikary, 2012; Sharma *et al*., 2017; Singh *et al*., 2013). The benefits of vermicompost include improving soil fertility and soil health, water holding capacity, soil productivity, soil biodiversity, and crop growth and yield, enhancing soil physical, chemical, and biological properties (Joseph, 2019; Zuhair, 2011). In addition, vermicompost is frequently considered a supplement to fertilizers and it releases the nutrients slowly with a significant reduction in C/N ratio, concurrent with the requirement of plants (Sharma and Garg, 2019). During vermicomposting process, the nutrients locked up in the organic waste are changed to simple and more easily available and absorbable forms such as nitrogen, phosphorus, soluble potassium, calcium and magnesium in worm's gut (Sharma *et al*., 2017). The aims of the study were Investigate effect of different vermicomposting habitats on the general characteristics of the final vermicompost product and showed the effect of earthworm species on the availability of macronutrients in the final product.

2. Materials and methods

2.1 Study location

A vermicomposting trail was conducted during autumn season of October 2021 for three months at the laboratory of Agricultural Zoology and Nematology department (27^{o}12'23''E and 31^{o}09' 51''N), Faculty of Agriculture, Al-Azhar University, Assiut governorate, Egypt. The temperature during the experiment was ranged between 11 to 29^{o}C with an average temperature of 20^{o}C.

2.2 Earthworms species

Different Four species of earthworm involved *Eisenia fetida*, *Allolopophora longa*, *Eudrilus eugeniae*, and *Perionyx excavatus* were used in the experiment. The species *E. eugeniae*, *P. excavatus* and *E. fetida* were brought from the Central Laboratory for Agricultural and climate, Cairo, Egypt. The fourth specie *A. longa* was collected from the Experimental Farm of the Agriculture Faculty, Al-Azhar University, Assiut, Egypt. General morphological characteristics obtained from average data of 10 adult earthworms belong the same species (Table 1).

Table (1): General morphological characteristics of the studied earthworm species.

Earthworm specie	Long (cm)	Weight (g)	Diameter	A yellowish striped end
A. longa	10	1.50	Thick	No
E. eugeniae	9	1.24	Thick	No
P. excavatus	7.5	0.70	Thin	No
E. fetida	6	0.68	Thick	Yes

2.3 Vermicomposting

Fifty kg of cow manure (fresh weight) + 50 kg of market waste and kitchen waste + 10 kg of sawdust + 10 kg of bagasse were composted in covered pile system for 30 days before vermicomposting setup. Cardboard waste (CB) was collected then crushed into small size (2-4cm). Also, Loamy sand textured soil (S) was sieved through a 2 mm sieve. The experiments were carried out in plastic boxes with a size of 50×30×30 cm in which it was purchased from vegetables market. The boxes were cleaned and carefully wrapped from the inside to protect the growing habitat from the bad conditions and draining excess water. Three types of vermicomposting habitat, PC, PC+CB and PC+S were inoculated with four different species of earthworms, *A. longa*, *E. fetida*, *E. eugeniae* and *P. excavatus*. The experiment was arranged in completely randomized design with three replicates for each treatment as fellows: *A. longa* + only pre-composted mixture*; A. longa* + pre-composted mixture + Cardboard (with ratio of 3:1 w/w); *A. longa* + pre-composted mixture + soil (with ratio of 3:1w/w); *E. eugeniae* + only pre-composted mixture; *E. eugeniae* + pre-composted mixture + paper (with ratio of 3:1 w/w); *E. eugena* + pre-composted mixture + soil (with ratio of 3:1w/w); *P. excavatus* + only pre-composted mixture*; P. excavatus* + pre-composted mixture + paper (with ratio of 3:1 w/w); *P. excavatus* + pre-composted mixture + soil (with ratio of 3:1 w/w); *E. fetida* + only pre-composted mixture*; E. fetida* + pre-composted mixture + paper (with ratio of 3:1 w/w); *E. fetida* + pre-composted mixture + soil (with ratio of 3:1 w/w). The control treatment was conducted for the three vermicomposting substrates without earthworms. The first group was filed with only 2 kg of pre-composted mixture (PC). The second group was filed with 1.5kg of pre-composted mixture + 0.5 kg of soil (3:1 w/w) (PC+S). And the third group consisted of 1.5kg of pre-composted mixture + 0.5kg of cardboard waste (3:1 w/w) (PC+CB). Each group of vermicomposting habitat divided into five subgroups (5 treatments × 3 replicates). Four of them were treated with one Specie of *E. eugeniae, P. excavatus, A. longa,* and *E. fetida*. The fifth group was filed without earthworm as a control treatment. Each box inculcated with 50 healthy adult earthworms with clear clitellum. The moisture content of the boxes was kept at 60-70% of the water holding capacity. After draining the excess water, the boxes were covered with pieces of burlap sacks to maintain the growing environment at the appropriate moisture level during the experiment. Humidification is done with water when the moisture content is lower than the suitable limit. The temperature was measured twice daily for 90 days, then the average temperature and relative humidity were recorded.

2.4 Chemical analyses

Represented samples were collected from each treatment at zero and mature stage (after 90 days) of the vermicomposting experiment to determine the quality and quantity of the final product. The collected samples were air dried, milled, and then sieved by a 2 mm stainless steel sieve. The fine samples were storage in glasses gars for the subsequent analyses. The pH was measured in water suspension sample at 1:10 using pH meter, Electrical conductivity (EC) was determined in a 1:10 of solid to water solution according to Falcon (1987). Available macronutrient (NPK) was measured and analyzed according to the methods described by Subbiah and Asija (1956), Olsen *et al*. (1954) and Page (1965), respectively. The total organic carbon (TOC) was determined using the loss ignition method in a muffle furnace at 550^{o}C for 4 h according to Nelson and Sommers (1996). Total Kjeldahl Nitrogen (TN) was determined according to Stevenson (1982). Carbon/nitrogen ration estimated from TN% and TOC%. Total potassium (TK) and total phosphorus (P) content were measured using flame photometer and spectrophotometer, respectively (Page *et al*., 1982). The chemical analysis of the vermicomposting substrates used in this study are listed in Table (2).

Table (2): Chemical analysis of the vermicomposting substrates used in this study.

Analysis	Pre-composted mixture	Soil	Cardboard
EC (dS m^{-1})	8.51±0.19	1.81±0.06	1.86±0.13
pH	9.29±0.01	8.36±0.06	10.92±0.03
TOC (%)	30.16±0.39	4.29±0.12	54.02±0.02
C/N ratio	16.57±0.40	21.45±1.13	49.09±0.66
Total nutrients			
N (g kg^{-1})	18.30±0.30	0.74±1.20	1.10±1.50
P (g kg^{-1})	9.29±0.18	2.07±0.81	1.42±0.54
K (g kg^{-1})	13.57±0.51	9.23±0.21	2.75±0.34
Available macronutrients			
N (g kg^{-1})	0.29±0.03	0.13±0.01	Nd*
P (g kg^{-1})	0.86±0.06	0.015±0.00	Nd*
K (g kg^{-1})	5.40±0.10	0.76±0.05	0.034±0.00

The testified values are mean ± standard error of three replicates, Nd*= means no detected.

2.5 Statistical analysis

The statistical analysis was performed using the software Minitab, version 17.3.1 (Informer Technologies Inc.). The significant differences between treatments were tested via ANOVA and completed by Fisher test at $P<0.05$ significance level. For data analysis and drawing, Microsoft Office Excel Corporation, USA) were used.

3. Results and Discussion

3.1 Effect of feeding substrate on the chemical characteristics of the vermicompost under the various earthworm species

3.1.1 pH values

The pH is a good parameter, which determines the alkalinity of compost and vermicompost (Majlessi *et al*., 2012). The lowest pH vermicompost is more suitable for plant growth. The pH values of the initial mixtures and in the vermicompost after treating with the different earthworm species as well as the control treatment (without earthworms) were explained in Figure (1). The pH was ranged from 8.21 to 8.82 and decreased by 6.24, 9.53, 5.06, 7.79, and 7.27% than that observed in PC at the starting time of vermicomposting; and 8.47, 3.95, 4.86, 6.66, and 7.29% than that of PC+S; and 8.93, 10.84, 8.93, 8.77, and 7.56% in vermicompost of *A. longa, E. fetida, E. eugeniae, P. excavatus*, and control, respectively. The final vermicompost of PC and PC+CB had the lowest pH values (8.41 and 8.39) when *E. fetida* was presented. While lowest value (8.10) was obtained in PC+S habitat of *A. longa*. The decreasing in the pH in the vermicompost may be due to the produced organic acids during the decomposition of the organic substances by earthworms and microorganisms.

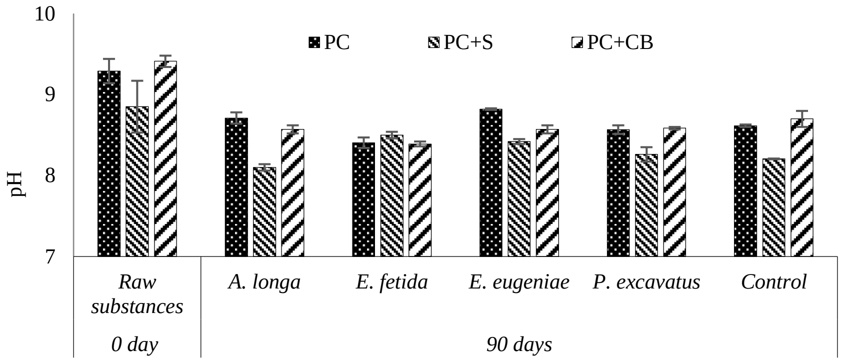

Figure (1): pH values of the feeding mixtures (PC, PC+S, PC+CB) before adding earthworms and their vermicomposts after treatments (90 days).

The low pH value might be attributed to the release of organic acids and CO_2 as well as NH_3 volatilization through the earthworms and microbial activity or could be due to the hydrogen ions that released during nitrification process. Moreover, it is a common phenomenon that the organic fatty acids produced during composting process can decrease the pH. In addition, it could be because of the effect of the decreasing in the EC values. The increases of the initial pH values of P substrate and the habitat of PC+CB is due the high content of sodium hydroxide, which applied into the pest of carton during the producing of carton boxes.

3.2 Electrical conductivity (EC)

Electrical conductivity (EC) indicates the salinity of the soil amendment (e.g., vermicompost, compost, manure, etc.), and reflect its validity as an amendment for soil fertility and agricultural production (Abd El-Rahim *et al*., 2021; Lim *et al*., 2014). The EC of the mature vermicompost ranged from 2.93 to 6.58 $dS.m^{-1}$and was decreased in the vermicompost processed by *A. longa, E. fetida, E. eugeniae, P. excavatus,* and control by 28.61, 35.14, 30.43, 35.30, and 22.74% more than that of the initial EC value of PC, and by 57.17, 55.49, 45.97, 35.72 and 5.81% less than the EC of PC+S at zero time, and by 14.01, 30.07, 26.13, 26.42, and 3.87%, less than that of PC+CB, respectively. In general, a significant decrease was observed in the EC of all the mixtures after vermicomposting under the various earthworm species (Figure 2). Also, EC of control treatment (compost) was also decreased (Figure 2).

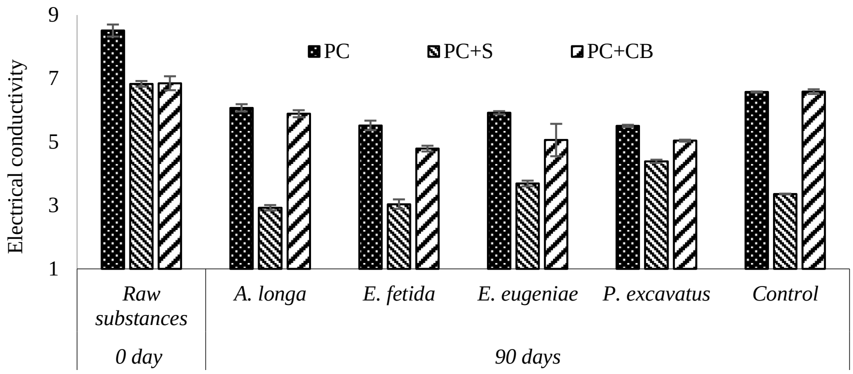

Figure (2): Electrical conductivity (EC) values of the feeding mixtures (PC, PC+S, PC+CB) before and after vermicomposting.

The decreases of EC value during the trial parallel with those obtained by Arora and Kaur (2019) could be due to the feeding of the earthworms on the soluble nutrients. The dissolution of salts and filtration it during the watering of the boxes could be the main reason of shifting EC during the vermicomposting. Mahaly *et al.* (2018), reported that, the changes in the EC during vermicomposting were attributed to the utilization of soluble salts by microorganisms for biosynthesis and also to the adsorption of soluble salts by earthworms. Increase in EC has been reported after vermicomposting due to the degradation of organic matter releasing minerals such as exchangeable Ca, Mg, K, and P in the available forms, that is, in the form of cations in the vermicompost and compost (Pattnaik and Reddy, 2010). A decrease in EC of vermicomposted paddy and wheat straw with farmyard manure (1:1 ratio) has been reported due to production of ammonium ions (NH_4^+), as well as loss of the dissolved salts in the environment (Singh *et al*., 2014).

3.1.3 Total organic carbon (TOC)

Organic carbon is an energetic element for the activity of microorganisms and earthworms during the vermicomposting process. Total organic carbon (TOC) assessment is a valuable test to access the performance of the earthworms in decomposition of organic substrates as compared with the TOC content. The results revealed a decrease in the TOC content in all of the tested growth habitats under the various earthworm species Table (3) and Figure (3). The decreases in TOC is due to feeding of the earthworms and the degradation of organic matter by microorganisms. Ramnarain *et al*. (2019), indicated that, the earthworms accelerate the decomposition of the organic materials during the vermicomposting.

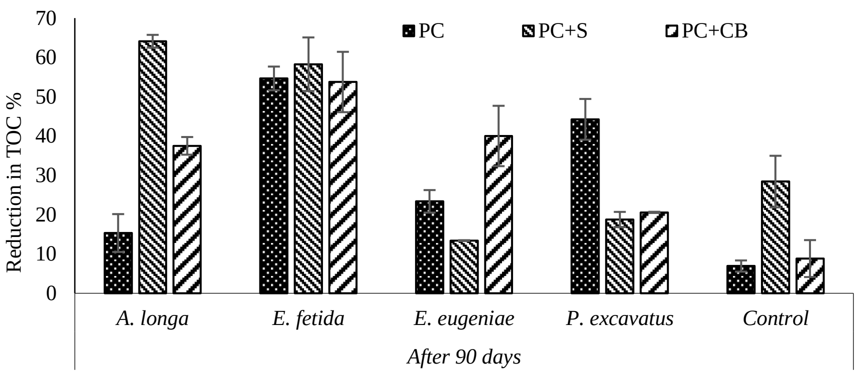

Figure (3): Reduction percentage of total organic carbon (TOC) content of vermicomposts, (PC, PC+S, PC+CB) after vermicomposting (90 days) under the different earthworm species.

Al-Assiuty *et al*. (2021), reported similar results for vermicomposts produced by *E. fetida* and *Aporrectodea caliginosa*. Reduction in the TOC content was ranged from 6.92% (PC compost), to 68.10% (PC+S) vermicompost of *A. longa*. Regarding to PC, vermicompost of *E. fetida* had a highest reduction in the TOC content (54.65%), while untreated had the lowest one (6.92%). Therefore, the reduction in TOC of PC vermicompost could be arraigned in the descending order of untreated > *A. longa* > *E. eugeniae* > *P. excavates* > *E. fetida*. In PC+S, an excellent behavior for *A. longa* in reducing TOC was observed more than other earthworms and compost treatment (Figure 3). The reaction could be due to existing of the soil (as an additive) in the vermiculture mixture, which is preverbal (as a natural growth habitat) for *A. longa*. The reduction in TOC content in PC+S vermicompost arraigned in the order of *A. longa* > *E. fetida* > *P. excavates* > *E. eugeniae* > control (Figure 3). In PC+CB, the TOC content of the vermicompost reduced by 53.74, 40.01, 37.49, 20.57, and 8.82% for *E. fetida*, *E. eugeniae*, *A. longa*, *P. excavates*, and control treatments (Figure 3). In general, *E. fetida* exhibited a good deal in reducing TOC in both PC and PC+CB vermicomposts, but *A. long* was the best in case of PC+S.

Table (3): The total organic carbon (TOC), total nitrogen (TN), phosphorus (TP) and total potassium (TK) content of the vermicompost when treated with different earthworm species at the initial and final product of vermicomposting.

Parameter		TOC (g/k)	TN (g/k)	TP (g/k)	TK (g/k)
0 day					
	PC	560.07±9.80	18.30±0.30	9.29±0.18	13.57±0.51
	PC+S	447.85±9.31	16.4±0.23	7.46±0.21	12.48±0.45
	PC+CB	657.84±16.85	15.60±0.23	7.31±0.04	10.87±0.52
90 days					
A. longa	PC	474.28±26.96[ab]	16.00±056[d]	11.19±0.26[c]	19.01±1.89[b]
	PC+S	160.77±7.28[c]	20.66±1.16[a]	14.82±0.23[a]	21.88±0.24[a]
	PC+CB	411.19±14.78[bc]	17.97±2.86[a]	13.04±0.56[b]	20.99±2.26[a]
E. fetida	PC	254.01±16.89[c]	19.01±0.36[bc]	12.96±0.03[b]	21.48±1.34[a]
	PC+S	186.94±30.53[c]	17.14±0.15[b]	13.74±0.10[ab]	19.14±1.01[bc]
	PC+CB	304.33±50.50[c]	19.35±0.16[a]	13.96±0.99[bc]	25.52±7.95[a]
E. eugeniae	PC	429.11±16.06[b]	20.70±0.16[a]	11.77±0.62[c]	21.47±0.57[a]
	PC+S	327.87±048[a]	14.94±3.26[c]	15.10±2.12[abc]	20.02±1.27[b]
	PC+CB	394.66±50.51[bc]	18.31±0.06[a]	17.35±0.42[ab]	21.14±0.64[a]
P. excavates	PC	312.30±29.05[c]	19.74±026[ab]	18.55±0.02[a]	19.83±1.24[b]
	PC+S	363.77±8.61[a]	18.52±0.36[b]	11.42±1.90[b]	18.16±0.40[c]
	PC+CB	522.51±0.98[ab]	18.68±1.86[a]	13.16±0.74[b]	20.62±0.05[a]
Control	PC	521.32±8.00[a]	18.07±0.46[c]	13.04±0.56[b]	18.30±0.64[bc]
	PC+S	274.08±17.16[b]	13.50±0.16[c]	13.94±0.55[b]	17.03±012[bc]
	PC+CB	629.82±30.91[a]	16.88±0.03[a]	21.72±0.00[a]	17.99±0.64[a]

PC = 100% pre-composted mixture, PC+S = 75% pre-composted mixture + 25% soil, PC+CB = 75% pre-composted mixture +25% cardboard, each value represents the mean of three replicates ±standard error, the small letters represent the significant differences (P<0.05).

Earthworms are classified as the major decomposers of dead and decomposing organic matter and derive their nutrition from the bacteria and fungi that grow upon these materials. They are essential not only for soil fertility but also for recycling organic wastes (Edwards and Lofty, 1977). In vermicomposting, the earthworm consumes organic residues and converts them through its gut into very fine particles and simplest constituents. Aalok *et al.* (2009) found that the reduction in the TOC indicates the ability of earthworm to decompose organic matter (Rahman *et al*., 2020).

3.1.4 Chemical composition in vermicompost

Total nitrogen (TN), phosphorus (TP), and potassium (TK) content as well as C/N ratio of the initial substrates and the mature vermicoposts of different organic additives for earthworm species are shown in Table (3). Data indicated significant effect on the chemical composition of the final vermicompost with growth habitats and species of earthworms as compared with initial substrates. The TN increased in final vermicomposts except with PC vermcompost of *A. longa*, PC+S of *E. eugeniae* and control of PC and PC+S (Table 3). In PC vermicompost, TN content increased by 2.60, 1.64, 0.91% for *E. eugeniae, P. excavates,* and *E. fetida*, respectively as compared with the initial PC. On the other hand, *A. longa* and control treatments were reduced the TN by 2.10 and 0.03%, respectively. However, the earthworm species show variable trend in their ability to conserve nitrogen element. Regarding to the vermicompost of PC+S, *A. longa* and *P. exacavatus* increased TN by 2.12 and 4.26%, respectively, but decreased by 0.94, 3.46 and 2.90% in *E. fetida*, *E. eugeniae* and control treatments. Referring to PC+CB, the TN of the vermicomposts produced with *E. fetida, P. exacavatus, E. eugeniae, A. longa, and* control was increased by 3.8, 3.1, 2.7, 2.4, and 1.3% than the initial substrates. The increasing of total nitrogen in the vermicompost is due to the reduction of dry mass in terms of carbon dioxide during the oxidation of organic matter. In addition, the earthworms can enhance nitrogen levels during vermicomposting through the digestion of substrate in their gut and simultaneous addition of nitrogenous excretory products, mucous, body fluid, enzymes which are retained to the vermicomposat as a casts; besides the decay of dead tissues of warms in the vermicomposting system (Joseph, 2019). Garg *et al*. (2006), Repoted that analyzed the nutrients content of the cast of *E. fetida* from different types of organic substances *i.e.*, textile sludge, textile fiber, institutional waste, kitchen waste, and agro-residues. They found that, the total nitrogen content increased in the presence of earthworms. In spite of the excellent nitrogen conservation behavior of *E. fetid* in the PC+CB and *A. longa* in the PC+S, the ability of *P. excavates* to maintain N in the three types of growth habitat was observed. The TP decreased in all of final vermicomposts comparing with the initial mixture except the PC+CB of *E. eugeniae* that was increased. Increases in TK were recorded for all treatments (Table 3). TK content ranged from 17.03 g/kg (the control of PC+S) to 25.22 g/kg (PC+CB of *E. fetida*). Generally, earthworms are arranged according to the TK content in their final vermicompost in descending order of *control* > *E. fetida* > *E. eugeniae* > *P. excavates* > *A. longa* for the PC final products, *A. longa* > *E. eugeniae* > *E. fetida* > control > *P. excavates* for the PC+S; and *E. fetida* > *A. longa* ≈ *P. excavates* ≈*E. eugeniae* ≈ control (Table 3). Similar result of TK was reported by Al-Assiuty *et al*. (2021).

3.2 Effect of feeding substrate and earthworm species on the available macronutrients in final vermicompost

Determining the available nutrients content of the mature vermicompost considered as a quality test, which is related to the maturity of the vermicomposting process. The data presented in Table (4) showed a reduction in the available nitrogen in the vermicompost produced from PC, PC+S, and PC+P, for all treatments of the earthworms species except the control treatment of PC, The PC+S vermicompost of *E. fetida* and the control one of PC+CB, which were increased the available nitrogen by 27.7, 32, and 14%, respectively, compared to the initial substrates (Table 4). In short, *E. fetida* exhibited the highest increases in the available N in PC+CB vermicompost.

Table (4): Available macronutrients content (Nitrogen, phosphorus, and potassium) in the vermicompost under different earthworm species in the initial and mature stage of vermicomposting.

Parameter		Available N	Available P	Available K
0 day				
	PC	0.29±0.03	0.86±0.06	5.40±0.10
	PC+S	0.22±0.01	0.65±0.00	4.24 ±0.05
	PC+CB	0.21±0.01	0.64±0.00	4.05±0.00
90 days				
A. longa	PC	0.19±0.02[bc]	0.47±0.03[d]	5.82±0.14[d]
	PC+S	0.22±0.01[a]	0.60±0.02[ab]	9.30±0.13[a]
	PC+CB	0.19±0.04[b]	0.48±0.01[a]	6.61±0.18[d]
E. fetida	PC	0.11±0.00[d]	0.67±0.00[c]	8.91±0.22[a]
	PC+S	0.16±0.01[ab]	0.64±0.01[a]	6.24±0.32[c]
	PC+CB	0.48±0.08[a]	0.54±0.02[a]	7.83±0.58[b]
E. eugeniae	PC	0.24±0.03[b]	1.04±0.04[a]	6.82±0.24[c]
	PC+S	0.21±0.04[a]	0.52±0.03[cd]	6.12±0.09[c]
	PC+CB	0.17±0.02[b]	0.66±0.01[a]	8.87±0.25[a]
P. excavates	PC	0.17±0.00[cd]	0.82±0.01[b]	8.16±0.11[b]
	PC+S	0.15±0.02[ab]	0.45±0.02[d]	7.02±0.09[b]
	PC+CB	0.12±0.02[b]	0.69±0.12[a]	8.25±0.12[ab]
Compost	PC	0.57±0.02[a]	0.71±0.02[c]	6.14±0.23[d]
	PC+S	0.11±0.00[b]	0.55±0.02[bc]	6.03±0.18[c]
	PC+CB	0.39±0.03[a]	0.57±0.00[a]	6.14±0.16[d]

PC = 100% pre-composted mixture, PC+S = 75% pre-composted mixture + 25% soil, PC+CB = 75% pre-composted mixture +25% cardboard, each value represents the mean of three replicates ±standard error, the small letters represent the significant differences (P<0.05).

The declining in the available nitrogen during the vermicomposting could be due to the mineralization of organic nitrogen by microorganisms and the earthworms. While, increasing of available N may be due to the decomposition of organic nitrogen during the process (Joseph, 2019). Comparing with the available phosphorus of the initial substrate, there was a reduction in the availability of phosphorus in all of the produced vermicomposts of PC, PC+S, and PC+CB under all tested earthworm species (Table 4). Regarding to available K (Available K), all the tested earthworms showed an increase in the extractable potassium (Table (4) and Figure (4)). Available K was ranged from 5.83 (*A. longa*) to 8.91 g/kg (*E. fetida*), from 6.3 (control) to 9.30 (*A. longa*), and from 6.14 (control) to 8.87 g/kg (*E eugeniae*) in vermicompost of PC, PC+S, and PC+CB, respectively. High available K value was detected in the vermicompost produced by *E. eugeniae* (114%) compared with initial mixture when the growth habitat was PC, while, *E. fetida* and *A. longa* showed a highest increases in the available K (89 and 56%) in the vermicompost of PC and PC+CB, (79 and 68%) for respectively. Therefore, increase in available K in PC vermicompost could be arranged in ordered of *E. fetida* < *P. excavates* < *E. eugeniae* < *A. longa* = control; were as *A. longa* < *P. excavates* < *E. fetida* = *E. eugeniae* = control in case vermicompost of PC+S; and *E. eugeniae* < *P. excavates* < *E. fetida* = *A. longa* = control in the PC+CB vermicomposts. Suthar (2007) reported that, vermicomposting showed to be an effective process for regaining higher potassium from organic wastes. Zuhair (2011) observed that the potassium content in the produced vermicompost was increased significantly with the advancement of vermicomposting periods.

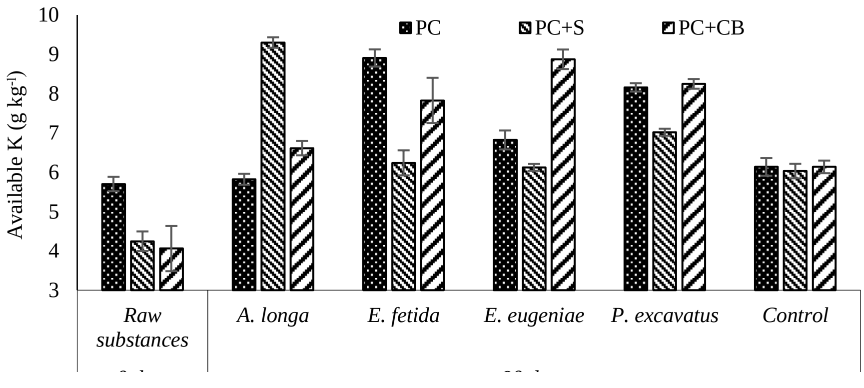

Figure (4): Available potassium (K) content in the feeding mixtures (PC, PC+S, and PC+CB) before and after vermicomposting under treatments by different earthworm species.

Comparing with the available phosphorus of the initial substrate, there was a reduction in the availability of phosphorus in all the produced vermicomposts of PC, PC+S, and PC+CB under all tested earthworm species (Table 4). Regarding to available K (Available K), all the tested earthworms showed an increase in the extractable potassium (Table (4) and Figure (4)). Available K was ranged from 5.83 (*A. longa*) to 8.91 g/kg (*E. fetida*), from 6.3 (control) to 9.30 (*A. longa*), and from 6.14 (control) to 8.87 g/kg (*E eugeniae*) in vermicompost of PC, PC+S, and PC+CB, respectively. High available K value was detected in the vermicompost produced by *E. eugeniae* (114%) compared with initial mixture when the growth habitat was PC, while *E. fetida* and *A. longa* showed highest increases in the available K (89 and 56%) in the vermicompost of PC and PC+CB, (79 and 68%) for respectively. Therefore, increase in available K in PC vermicompost could be arranged in ordered of *E. fetida* < *P. excavates* < *E. eugeniae* < *A. longa* = control; were as *A. longa* < *P. excavates* < *E. fetida* = *E. eugeniae* = control in case vermicompost of PC+S; and *E. eugeniae* < *P. excavates* < *E. fetida* = *A. longa* = control in the PC+CB vermicomposts. Suthar (2007) reported that, vermicomposting showed to be an effective process for regaining higher potassium from organic wastes. Zuhair (2011) observed that the potassium content in the produced vermicompost was increased significantly with the advancement of vermicomposting periods. The observed data as a result of microbial enzyme activity produced by the microorganisms in the earthworm's gut perhaps transformed insoluble potassium into a soluble form (Kaviraj and Sharma, 2003; Pattnaik and Reddy, 2010). Sharma (2003) showed that the acid production by the microorganisms was the main technique for solubilizing insoluble potassium and the promoted number of microflorae exists in the gut of the earthworms, vermicomposting may have played a significant role in transformed insoluble potassium and increased potassium over the control.

4. Conclusion

From all investigated results we can concluded that the PC+CB and PC+S vermicompost's produced by *E. fetida* and *P. excavatus* have the best results for quality measurements. The worms have a promising function in the recycling of organic wastes. Although *A. longa* did not survive in the full organic matter growing habitat, whoever adding soil into the growth habitat increased its ability in organic matter recycling. The total NPK content and their available forms were enhanced in the vermicompost's of PC+CB and PC+C for all tested worms in compared with PC vermicompost and control treatment, but *E. fetida* was the best. More research is required to understand the behavior of the earthworms with different bulking agents.

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