

Are the Enrichment Nutrient Feasible to the Vermicomposting Efficiency For Water Hyacinth (*E. Crassipes*)?

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**Are the enrichment nutrient feasible to the vermicomposting efficiency for water
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Abstract

In eutrophic environments, aquatic weeds reproduce quickly and occupy large areas, preventing multiple uses of water resources. The use of the biomass of these plants in vermicomposting represents a sustainable alternative. The enrichment of macrophyte biomass during vermicomposting was tested using inorganic NPK solution (1.75% and 3.5%) and organic solution (0.25 g/L and 0.5 g/L) to improve the quality of the compound. Biomass consumption increased as the experiment progressed, reaching the highest values at the end. The experiment without worms remained stable. The influence of *E. fetida* individuals the vermicomposting process of water hyacinth will depend nutrient addition. The additions improved subtly the compost quality and the consumption of biomass, besides its low-cost, easily obtained and applicable treatment. It does not have the necessary requirements for its use as a fertilizer. However, we suggest the use in association with other fertilizers, adding moisture and structuring to the soil.

Keywords: *Eisenia fetida*, priming effect, eutrophication, humification, sustainability

1. Introduction

Macrophytes are aquatic plants that colonized both aquatic environments and transitional with terrestrial ones (Chambers et al., 2008) with great plasticity and adaptability (Najar, 2017), offering a variety of ecosystem services (e.g., refuge for species, food and habitat) (Bento et al., 2007). The reproductive characteristics of this group are greater in eutrophic environments resulting in population explosions with the formation of vegetation mats, which promotes losses of multiple uses of water resources, causing several negative ecological and socioeconomic impacts (Villamagna

& Murphy, 2010; Chapungu et al., 2018; Zhang et al., 2019). Among the floating macrophytes that normally occur in eutrophic freshwater bodies, it stands the aquatic weed water hyacinth *Eichhornia crassipes* (Martius) Solms-Laubach (Pontederiaceae). This species is originally from South America with widespread invasive potential (Howard & Harley, 1997; Koutika & Rainey, 2015; Kurugundla et al., 2016; Cordeiro et al., 2020).

Due the high biomass production in eutrophic systems, the use of macrophyte biomass represents an ecological and sustainable alternative economic use of these vegetables. One of the main characteristics of the treatment is the possibility of using practically any organic material and the formation of a nutritious compound that can be used for fertilization. It is justify especially once weed water hyacinth as a source of macronutrients as nitrogen, phosphorus and potassium which improve the soil fertility (Kumari et al., 2021) However, there are few sustainable techniques applied, such as physical, chemical and biological methods that have undesirable impacts (e.g. contamination by herbicides) (Thomaz, 2002). The use of excess biomass as a raw material for vermicomposting thus consists of a possibility of reducing an environmental problem by applying this biomass in sustainable techniques (Najar, 2017). Composting consists in a treatment of waste regulated by microbial decomposition, featured by the oxidation of organic matter. A process similar to composting is vermicomposting, which is distinguished by the use of mesofauna, especially *Eisenia fetida* (Oligochaeta, Lumbricidae). The process of composting is facilitate by the combined action of earthworms with that of flora present in your digestive tract. During composting, part of the organic matter is mineralized in carbon dioxide, ammonia and water, while the other part is transformed into humic substances (Valente et al., 2009). Hamer (2004) observed that the positive effects of adding

different organic substrates are often related on the mineralization of organic carbon in the soil. Blagodatskaya et al. (2007) indicated that the addition of carbon-rich compounds can strongly change the turnover of native organic matter, causing the priming effect. As stated by Tótolá & Chaer (2002), a high-quality soil has intense biological activity that can be defined by microbiological indicators, therefore, the priming effect is beneficial to the mineralization process and increased soil quality.

Addition of exogenous organic matter in the soil can cause intensification or delay in the decomposition of organic matter (Chen et al., 2014). Decomposition requires a sequential breakdown of a variety of substrates (such as: waxes, phenols, lignin, and cellulose). The priming effect overcomes this limitation by availability of more nutrients from fresh organic matter. Kaspari et al. (2008) exemplifies this statement when describing the decomposition of litter, in which the decomposing microorganisms are presented as the main limiting factors. In that case, the provision of a greater amount of nutrients would accelerate this process since enzymes produced by different microbes are required. Laskowski & Berg (2005) showed that nitrogen-rich leaves decompose more quickly when compared to nitrogen-poor leaves. Incorporation of inorganic and organic elements as an additional source of nutrients for priming effect may improve the quality of the vermicompost generated by macrophyte biomass. This addition can be exemplified in similar studies by adding additional sources of nutritious organic compounds in studies such as animal waste. It is common to add manure to vermicomposting of macrophytes, mainly from cattle (Gajalashmi et al., 2000; Gajalashmi et al., 2002; Najar & Khan, 2013; Bernal et al., 2016; Suthar et al., 2016; Devi & Khwairakpam, 2020). This mixture is favorable to the adaptation of earthworms and beneficial for improving the consumption of macrophyte biomass by them. In a comparative experience, Bernal et al. (2016) vermicomposted *E. crassipes*, cattle

manure in a combined treatment of both in the proportion of 50%. The experiment achieved total conversion of macrophyte biomass in 110 days. Ansari & Rajpersaud (2012) vermicomposted *E. crassipes* with organic waste of grass clippings, and combined experiment of both. Vermicompost with *E. crassipes* had a conversion rate of 56.14% while the combined treatment obtained a conversion rate of 76.19%.

This study aimed to study vermicomposting using the biomass of *Eichhornia crassipes* as a source of organic matter, aiming to evaluate the compound generated after the addition of organic and inorganic substance (glucose and commercial fertilizer NPK) in two concentrations each. The specific objectives were: (i) to evaluate the kinetics of macrophyte consumption by *E. fetida*; (ii) evaluate the quality of the humus formed from the vermicomposting by means of particles; (iii) identify whether the addition of a pre-activator (organic and inorganic) will increase the quality of the generated humus and (iv) evaluate the consumption of macrophyte biomass by *E. fetida* using mathematical modeling. This study had the hypothesis that the incorporation of both substances as an additional source of nutrients may improve the quality of the vermicompost generated in the macrophyte biomass by priming effect.

2. Methods

2.1 Assembly and preparation of vermicomposting experiment

Specimens of water hyacinth were collected manually at the Departamento de Botânica (DB) of the Universidade Federal de São Carlos (UFSCar). After collected, the macrophytes were manually washed in running water to remove aggregate debris. All parts of the plant were used, which were cut after this process to facilitate the consumption. A portion of the specimens were kiln dried (ca. 50 ° C) until constant

mass. This procedure allowed composing the proportions of biomass (dry and fresh - 3:1).

The vermicomposting experiment occurred in three dark polypropylene boxes, previously cleaned, dried and stacked (total dimension: 32 cm long, 16 cm wide and 36 cm high). The system were composed of two digester boxes (total volume: 8 L) and a collection box (volume: 4 L). In the digester boxes a layer of ca. 2 cm of an inert substrate was set. This substrate consisted of a mixture of vermiculite and sand (1:1 ratio). Above the substrate, a polypropylene mesh (mesh: 1 cm) was placed for separation between the inert substrate and the macrophyte biomass. This procedure aimed to facilitate the final separation of the remaining macrophyte biomass after the end of the vermicomposting and, thus, to calculate the consumption efficiency of the water hyacinth biomass. Thirty specimens of *Eisenia fetida* (Oligochaeta, Lumbricidae) with varying sizes and masses were selected, contemplating all stages of life of the species. The individuals had their length (in cm) determined before and after each treatment using a millimeter rule. The initial and final biomasses of the specimens were determined on a precision scale (brand Bel Engineering, model M214Ai; precision 0.0001 g) and the number of individuals was counted at the beginning and after the end of the vermicomposting. Before the beginning of vermicomposting (n = 3 for each treatment), 30 individuals of *E. fetida* were kept in the digestion boxes for 24 h for adaptation. Some standards must be followed so the vermicomposting reaches its objectives and, at the same time, corresponds to the tolerance standard of the present macrofauna. Therefore, it was sought to keep earthworms at 25°C and 75% humidity (Venter & Reinecke, 1988). The added macrophytes must be in both fresh and dry form, with the addition of 10g of fresh biomass and 30g of dry biomass.

At the same time, mini systems (n = 24 for each treatment) were set up to observe the consumption kinetics of macrophyte biomass. The mini systems were prepared with *E. crassipes* biomass and *E. fetida* individuals in the same proportion as the previously described in the system (1 g of fresh biomass, 3 g of dry biomass and 3 individuals of *E. fetida*). The mini system were dismantled weekly (following the same procedures described) and the consumption efficiency of *E. crassipes* biomass was calculated (Equation 1).

$$E = \frac{B_e - B_s}{B_e} \times 100 \quad (1)$$

where: E = consumption efficiency (%); Be = input biomass; Bs = outgoing biomass.

Experiments without earthworms (n = 24) and without treatment were also set up to allow a comparison between the consumption of biomass by the annelids and the microorganisms. This experiment was done in the same proportions as the mini systems, but without *E. fetida* individuals.

The treatments contemplating the addition of nutrients were conducted by the application of commercial inorganic fertilizer (Casa Verde, foliar solution), containing nitrogen, phosphorus, and potassium (NPK) in the proportion 15-05-05 and the organic aquatic solution of glucose (C₆H₁₂O₆). The commercial fertilizer used was added as aqueous solution, in the concentrations 1.75% and 3.5%. The organic solution of glucose was added in the concentrations 0.25 g/L e 0.5 g/L. Both solutions were used as a way to maintain the humidity in the earthworms during the experimental time of 60 days. To verify the priming effect on the vermicompost three treatments (in replicas) were performed with *E. crassipes*: (i) Control - biomass without addition of inorganic compound; (ii) NPK 1.75%; (iii) NPK treatment 3.5%; (iv) Glucose 0.25 g/L and (v)

Glucose treatment 0.5 g/L. The first addition was made after finishing its assembly, being added 100 mL of the solution in each system and 10 mL in each mini system. The following applications were of 50 mL and 10 mL respectively for system and mini system in the first week, 25 and 10 in the second week and 10 and 5 in the third week.

To monitor the abiotic conditions (pH, electrical conductivity) in the system, weekly samples were taken, in replica, of the vermicompost and monitored the following variables: temperature, humidity, pH and electrical conductivity (EC). The temperature was obtained by measuring the mercury thermometer. The humidity was obtained by the gravimetric humidity method (Uhland, 1951; Embrapa, 1979), using an oven and precision scale (Bel Engineering brand, model M214Ai). For the pH and EC analyses, an aliquot of vermicompost was separated from the systems to make the aqueous extract (2:8 ratio) with deionized water where the pH and the EC were measured. The pH was obtained by potentiometer (pHmeter DIGIMED model DMPH-2) and the EC was obtained by potentiometer (Conduktivimeter DIGIMED DM3).

Weekly an aliquot (ca. 50 mg) was separated and removed from the vermicompost in generation, to perform the extraction of humic substances with alkaline extract (NaOH 0.5 mol/L). The extractions were performed until the extracting solution was no longer colored (i.e., transparent). After extraction the alkaline solutions were swept in the following wavelengths 250, 254, 365, 450 and 665 nm for the calculations of the concentrations of humic substances and the humification indices E2/E3 and E4/E6. The E2/E3 ratio is an index that can be related to the quality of the compound. The value of this ratio decreases with the increase of light absorption by chromophore dissolved organic matter, of high molecular mass (Helms et al., 2008) and of aromaticity (Peuravuori & Pihlaja, 1997; Helms et al., 2008). According to Stevenson (1994), the E4/E6 ratio decreases with the increase in molecular mass and the

condensation of aromatic constituents and is a humification index. Schnitzer & Khan (1972) consider that the E4/E6 ratio is inversely proportional to the degree of condensation of humic materials and the residence time of humic materials in the soil.

After the end of vermicomposting in all treatments (ca. 60 days), the remaining biomass (i.e. not consumed by the worms) of *E. crassipes* was removed from the system and had its masses dried at controlled temperature (50 °C) and then determined gravimetrically in a precision scale (Bel Engineering brand, model M214Ai; precision 0.0001 g). To determine the global efficiency (Equation 1) of the vermicomposting the quantification was calculated from the initial and final masses of the *E. crassipes*. For the descriptions of biomass consumption, a first order model was used (Equation 2). The model parameters (BC_{max} and k) were obtained from nonlinear regressions; for this purpose, the iterative algorithm of Levenberg-Marquardt (Press et al., 2007) was used.

$$BC = BC_{max} \times (1 - e^{-kt}) \quad (2)$$

in which: BC, accumulated biomass consumption (oxidized biomass + transferred biomass to *E. fetida*); BC_{max} , maximum biomass consumption per condition (%); k , consumption coefficient (week^{-1}); t , time (week).

To verify the fertility of the vermicompost in each treatment tests were performed indicating the quality of the compound in an accredited laboratory (Soil Fertility Laboratory - Soil Science Department of ESALQ/USP; Report nº 0017889.1-N-O.S.10668). The following tests were performed: Total organic matter obtained by ignition loss (Alcarde, 2009). The organic carbon (%) was obtained by extraction with dichromate and determination by titulometry. The determination of total N (%) was done by sulfuric digestion/Kjeldahl. Total P (%) was obtained by vanadium ammonium extraction and determination by colorimetry. Total K (%) was obtained by extraction

with hydrochloric acid and determination by flame photometry. Total S (%) was obtained by extraction by barium chloride and gravimetric method. Total Ca (%) and total Mg (%) were obtained by extraction with hydrochloric acid and determination by atomic absorption. The C/N ratio was determined according to MAPA (2007).

2.2 Statistical analysis

Differences in the mean values of variables pH, EC, E2/E3, E4/E6 and humic substances between treatments and days of colonization were compared using Two-way ANOVA without replications, and significant differences were considered with 95% confidence intervals ($p < 0.05$). Changes of pH, EC, E2/E3, E4/E6 and humic substances values along the days of the experiment were analyzed by the Multiple Linear Regression analysis. These variables were used as dependent variables and compared by analysis of variance (ANOVA), with significant differences considered at 95% confidence intervals ($p < 0.05$). Spearman rank correlation analysis was used to analyze the associations between the significant variables in humic substance production. The significances of the associations between the variables were analyzed using the correlation coefficients, and the 95% confidence intervals were considered ($p < 0.05$).

The initial biomasses and abundances of *E. fetida* in each treatment were compared with the final values of the experiment using the Wilcoxon test. The values of water hyacinth composting efficiencies between treatments with presence and absence of *E. fetida* were compared using Two-way ANOVA without replications. Significant differences considered with 95% confidence intervals ($p < 0.05$). The relationships of the vermicomposting efficiency of the different treatments with the total period of the experiment and with presence and absence of *E. fetida* were analyzed through the

analysis of linear multiple regression. The values of vermicomposting efficiency of the treatments with presence and absence of *E. fetida*, were considered as dependent variable and the values compared by analysis of variance (ANOVA). Significant differences were considered with 95% confidence intervals ($p < 0.05$).

3. Results and Discussion

3.1 Monitoring abiotic variables during vermicomposting

Humidity and temperature are important variables for the maintenance of *E. fetida* individuals. The ideal temperature for the vermicomposting process is ca. 25°C, however, worms can withstand conditions at 30°C (Anjos, 2015). The metabolic activity, i.e. breathing and growth of earthworms are extremely influenced by temperature (Edwards & Lofth, 1972), which was observed during vermicomposting temperatures remained below 30°C and close to ideal ($24 \pm 4^\circ\text{C}$). *E. fetida* requires a substrate with relatively high moisture content, with limits between 60 and 90% (Dominguez & Edwards, 2010). The values obtained are within the ideal range, being the mean and standard deviation obtained for each treatment: (i) $56.65\% \pm 5.23$ (Control); (ii) $69.24\% \pm 8.37$ (NPK 1.75); (iii) $44.41\% \pm 8.62$ (NPK 3.5), (iv) 61.73 ± 3.83 (Glucose 0.25 g/L) and (v) 57.48 ± 6.37 (Glucose 0.5 g/L). Humidity is directly related to temperature; experiments on the life cycle of *E. fetida* considered the ideal conditions for the development of this species, 25°C and 75% humidity (Venter & Reinecke, 1988). The weekly EC variation of the vermicompost shows higher mean values in organic treatments (Table 1).

Table 1: Mean values and variances of the variables measured throughout the process of vermicomposting *E. crassipes* from treatments enriched with different concentrations of inorganic and organic nutrients \pm Standard Deviation

Variables	Control	NPK 1.75 %	NPK 3.5 %	Glucose 0.25 g/L
Electric Conductivity	821.78 ±66777.99	1041.993 ±85572.08	770.58 ±24699.42	1196.49 ±60448.31
pH	8.01 ±0.13	7.87 ±0.02	8.13 ±0.29	7.87 ±0.02
E2/E3	3.66 ±2.68	2.94 ±1.10	3.25 ±0.78	1.99 ±16.48
E4/E6	2.28 ±7.64	9.67 ±242.68	7.11 ±303.71	1.76 ±1.32
Humic substances	3.75 ±9.26	68.90 ±4365.86	13.41 ± 174.34	46.86 ±2210.85

High EC values contribute to the hypothesis of more fertile compost, given the greater availability of ions in the compost and subsequent use as fertilizer. The solubilization of the protoplasmic contents of aquatic macrophytes releases in the soil high amounts of ions such as K (Park & Cho, 2003) and metals such as Fe (He et al., 2018). This increase can also occur from the increased availability of soluble salts resulting from the mineralization activity of earthworms and microorganisms that act in their intestines (Karmegam & Daniel, 2009).

The weekly EC variation shows a significant increase in the treatments NPK 1.75%, Glucose 0.25 g/L and Glucose 0.5 g/L, while in the control and NPK 3.50% it decreased (Table 2). The increase in EC values was due to the release of ions from the macrophyte biomass, which were incorporated into the humus during the vermicomposting process. However, lower EC values are shown to be better for plant nutrition and growth, as there is a slow release of necessary ions (Ansari & Rajpersaud, 2012).

Table 2: Changes in vermicomposting variables of *E. crassipes* over the decomposition period in treatments enriched with different concentrations of inorganic and organic nutrients. Where: coefficient (Coeff.), Standard error (Std. err.) and * (significant differences)

Variable	Treatment	Coeff.	Std. err.	T	P	r ²
Electric conductivity	Control	-4.80	1.29	-3.75	<0.001	0.08*
	NPK 1.75	2.68	1.51	1.78	0.08	0.02
	NPK 3.5	-3.10	0.78	-3.99	<0.001	0.10*
	Glucose 0.25	3.67	1.24	2.94	0.03	0.05*
	Glucose 0.50	9.50	1.44	6.59	<0.001	0.23*
pH	Control	-0.01	0.00	-8.26	<0.001	0.32*
	NPK 1.75	0.001	0.00	2.69	0.01	0.04*
	NPK 3.5	-0.00	0.00	-1.14	0.25	0.00
	Glucose 0.25	0.00	0.00	2.69	0.01	0.04*
	Glucose 0.50	0.00	0.00	5.28	<0.001	0.16*
E2/E3	Control	-0.00	0.02	-0.42	0.067	0.00
	NPK 1.75	0.01	0.01	0.73	0.47	0.02
	NPK 3.5	-0.00	0.01	-0.75	0.46	0.02
	Glucose 0.25	0.04	0.05	0.85	0.40	0.03
	Glucose 0.50	-0.03	0.07	-0.52	0.60	0.01
E4/E6	Control	-0.03	0.03	-1.01	0.32	0.04
	NPK 1.75	-0.15	0.20	-0.76	0.45	0.02
	NPK 3.5	0.25	0.22	1.15	0.26	0.05
	Glucose 0.25	0.00	0.01	0.44	0.65	0.00
	Glucose 0.50	-0.12	0.05	-2.15	0.04	0.17*
Humic substances	Control	-0.05	0.03	-1.30	0.20	0.07
	NPK 1.75	-1.08	0.82	-1.30	0.20	0.07
	NPK 3.5	0.14	0.16	0.87	0.39	0.03
	Glucose 0.25	1.33	0.54	2.46	0.02	0.22*
	Glucose 0.50	1.07	0.36	3.02	0.01	0.29*

The pH temporal analyses of the vermicompost for the different treatments show a variation tending to neutrality (Tables 1 and 2). Pramanik et al. (2007) point out that the decomposition of organic matter implies the formation of ammonium and humic acids, being these two elements responsible for antagonistic effects in the soil. While the presence of humic compounds propitiates the decrease of the pH, the ammonium ions induced its increase; the concomitant presence of the two substances makes the pH tend to neutrality. The formation of humic substances is characterized by the mineralization of organic matter (Valente, 2009). As for the humification indexes, De Haan (1983) points out that values of E2/E3 close to 4 indicate high humification. The

results showed that Control and NPK 3.5% had mean values closer to the indicated value (Table 1). However, these values did not change along vermicomposting experiment days. Low values of the E4/E6 ratio (less than 5) show high quality compounds (Haddad et al., 2015). Other authors (Grayson & Holden, 2012) suggest that values between 2 and 5 indicate higher humification. To the Control, the Glucose 0.25g/L and Glucose 0.50g/L treatments obtained averages within this range while the total humic substance in the compound enriched with NPK 1.75% was much higher than the other treatments (Table 1). The glucose-enriched treatments had a significant increase when compared to the other treatments (Table 2). Humic substances consist in the main component of stabilized organic matter and are essential for plant growth (Zandonadi & Busato, 2012) highlighting the possibility of using the compound for use as fertilizer.

3.2 Biomass consumption efficiency

The efficiency of biomass consumption in vermicomposting was not an important indication of feasibility of using macrophyte biomass, however, showed the effectiveness of its use as a sustainable alternative. The kinetics consumption observed by the experiments in the mini systems showed similar patterns in all treatments: an efficiency of less than 50% in the initial weeks. Until the fourth week of the experiment, the efficiency values remained between 50% and 75%. It was also possible to observe a sharp increase in biomass consumption of all treatments throughout the experiment, especially at the end, reaching values around 80% (Figure 1).

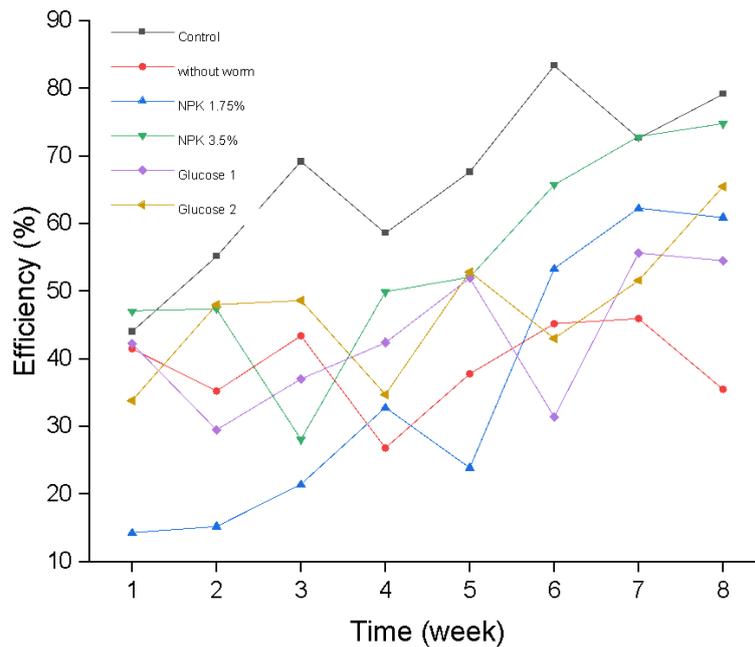


Fig 1: Weekly variation in consumption efficiency of macrophytes in the treatments (Control; NPK 1.75%; NPK 3.5%; Glucose 0.25g/L and Glucose 0.50g/L).

The treatment without earthworms show an efficiency more stable through the experiment, varying between 30% and 50%. Dominguez and Edwards (2010) highlight that the worms used in vermicomposting have well defined limits of these variables, with the waste being processed more efficiently within a restricted range of favorable chemical and environmental conditions. The degradation resulting from the bioconversion by worms accelerates the mineralization of organic matter, favoring the breakage of structural polysaccharides (such as fibers) increasing the rate of humification (Elvira et al., 1996). The increase in humic acid content and increases in mineral nutrients (e.g. S, N, P and K) is related to the degradative processes (decomposition/mineralization) of the organic compound by earthworms (Atiyeh et al., 2001; Cotta et al., 2015).

The comparative analyses of initial and final biomass and abundance of *E. fetida* showed that the Control, NPK 1.75% and 3.50 % treatments concentrations showed significant reduction of biomass at the end of the experiment. The same result was observed for the number of individuals only in the inorganic nutrient treatments (Table 3).

Table 3: Results of Wilcoxon's test analysis between initial and final biomass and number of *E. fetida* individuals in the decomposition process of *E. crassipes* from treatments enriched with different concentrations of inorganic and organic nutrients

	Treatment	Initial	Final	W	z	p
biomass	Without worms	3.11 ±0.01	1.96 ±0.10	300	4.28	<0.0001 *
	Control	2.38 ±0.33	1.43 ±0.45	300	4.28	<0.0001 *
	NPK 1.75%	2.51 ±0.52	0.44 ±0.22	300	4.28	<0.0001 *
	NPK 3.50%	2.74 ±0.83	1.16 ±0.70	295	4.14	<0.0001 *
	Glucose 0.25 g/L	1.21 ±0.12	1.12 ±0.24	164	0.41	0.68
	Glucose 0.50 g/L	2.50 ±18.29	1.51 ±0.27	141	0.47	0.64
number of individuals	Control	2.70 ±0.22	2.20 ±1.65	101	1.78	0.07
	NPK 1.75%	3.00 ±0.00	1.37 ±1.81	168	3.68	<0.0001 *
	NPK 3.50%	3.00 ±0.00	1.70 ±0.91	205	3.85	<0.0001 *
	Glucose 0.25 mg/L	3.00 ±0.00	2.67 ±1.27	40	1.35	0.17
	Glucose 0.50 mg/L	3.00 ±0.00	2.70 ±0.56	10	1.84	0.07

The comparative analysis between the vermicomposting efficiency treatments with presence and absence of the earthworms, showed that the Control treatment followed by NPK 3.50% presented significantly higher average efficiencies than the

other treatments ($F = 16.31$, $p < 0.001$, Figure 2). The treatments with added organic nutrients showed less variation in average efficiency values.

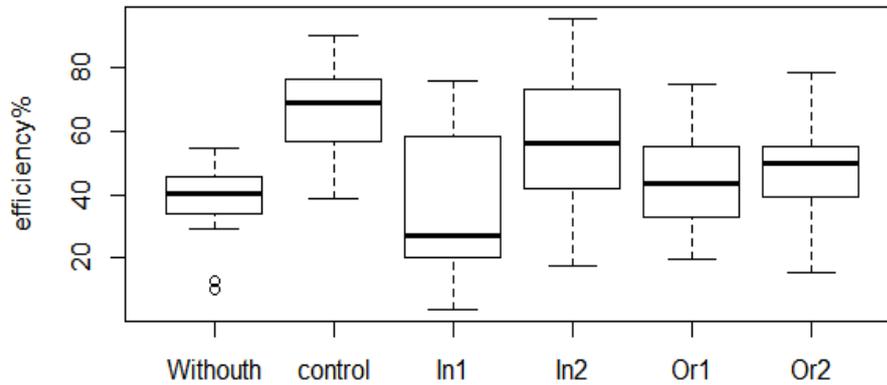


Fig. 2: Average efficiency of vermicomposting of water hyacinth in minisystems with different treatments enriched with different concentrations of inorganic and organic nutrients and absence of earthworms. In1 – NPK 1.75%, In2 – NPK 3.50%, Or1 – Glucose 0.25 g/L, Or2 – Glucose 0.50 g/L.

The treatments also differed significantly over the total vermicomposting period ($F = 3.40$, $p < 0.0001$). The influence analysis of the variables showed that the efficiency of vermicomposting was significantly positive over the long period (Figure 3) contradicting to the final number of *E. fetida* (Figure 4).

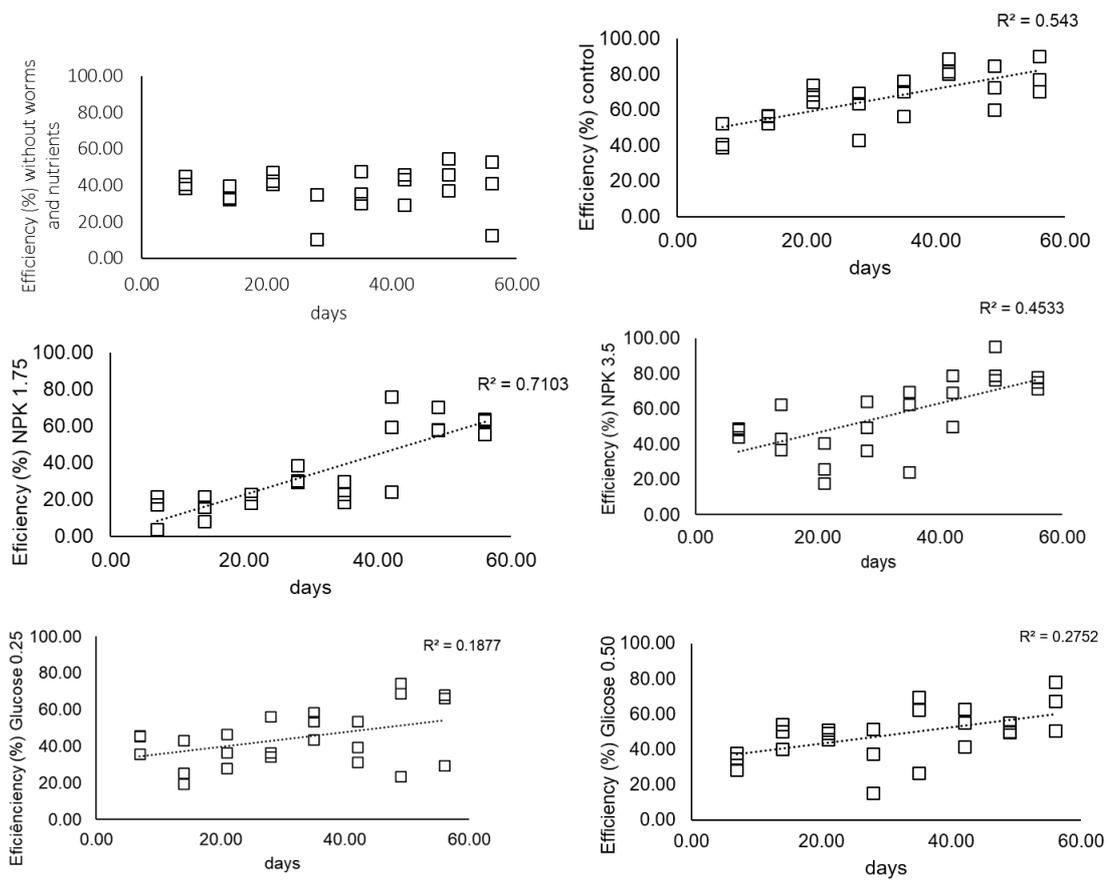


Fig. 3: Influence of the period of days on the formation of humic substances in the vermicomposting process of water hyacinth with different treatments enriched with different concentrations of inorganic and organic nutrients

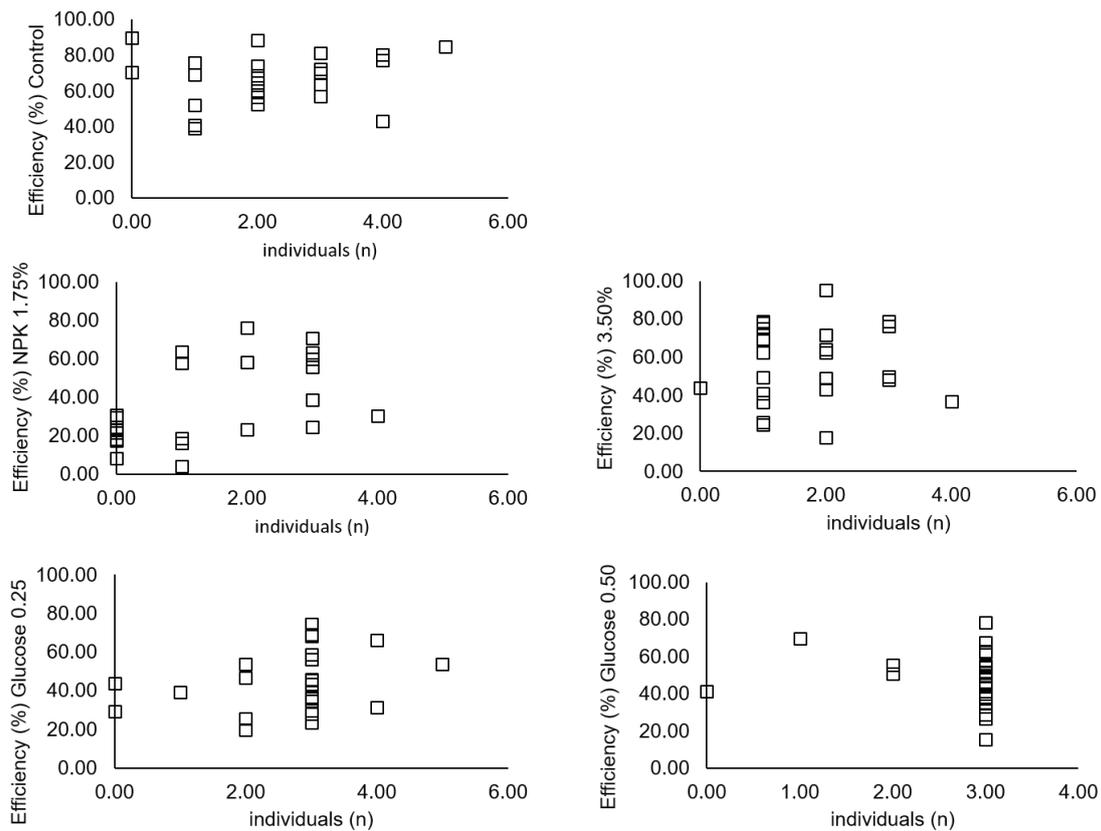


Fig. 4: Influence of the final number of individuals on the formation of humic substances in the vermicomposting process of water hyacinth with different in treatments enriched with different concentrations of inorganic and organic nutrients.

The control and inorganic nutrient treatments showed the highest values of determination coefficients positively influencing the efficiency of water hyacinth composting. We concluded that the influence of *E. fetida* individuals the vermicomposting process of water hyacinth will depend nutrient kind (i.e., organic X inorganic). We observed this; mainly the inorganic treatments decreasing in biomass and number of earthworms, which present strongest efficiency. Najar & Khan (2013) indicated that low biomass consumption at the beginning of the experiment may be related to the acclimatization time of the earthworms to a new supply. Parallel to this,

the change in biomass structure (i.e., decrease in the physical resistance of the biomass) during decomposition may have contributed to increase the consumption, as observed in the final weeks of the experiment, especially to the Glucose 0.50 g/L (Figure 1). Najar & Khan (2013) point out that the chemical composition of the organic resource influences the palatability of worms, which affects biomass consumption. In a review of earthworm food ecology, Curry & Schmidt (2007) indicated that organic matter intake can be very variable, depending on factors such as favorable environmental conditions for earthworm metabolic activity, nutritional quality of food and palatability. The authors indicate that the exclusive use of water hyacinth biomass of the vermicomposting results in increased mortality of *E. fetida* individuals. This may be due to the amount of phenols in these plants, which are unpleasant to earthworms. The authors, however, point out that this type of material degrades in a short period. It is suggested making the pre-composting using cattle manure, which consists of a more favorable environment for earthworms. This would occur once that vegetal biomass appears less nutritive and attractive to the earthworms, where animal product waste results in high biomass and favorable to *E. fetida* life cycle (Vodounnou et al., 2016). Concerning to this, we could infer that probably the efficiency of water hyacinth received the action mainly by development of microbiota along the vermicomposting experiments.

In Table 4 are shown the temporal variations of accumulated consumption and the parameters of the model used (Eq. 2) to describe the kinetics of biomass consumption of *E. crassipes*. It was found that there was a higher biomass consumption in the high enriched with 3.50% NPK, with a maximum consumption of 79.7%. However, this condition presented a consumption coefficient (0.31 wk^{-1}) lower than the control treatment (0.74 wk^{-1}). The intermediate enrichment condition (NPK 1.75%)

showed the lowest consumption yield (65.0%) and the lowest consumption coefficient (0.20 wk⁻¹). The coefficient of determination (r²) obtained for the Control treatment was higher (0.94) when compared to the other treatments. Also, for the Control treatment, the accumulated biomass consumption (BC_{max}) was the second highest (Table 4). Glucose 0.50 g/L presented the highest consumption coefficient (0.99 wk⁻¹) despite having the lowest accumulated consumption among the observed treatments (47.5%). The consumption coefficient for the organic treatments were much higher than the others, reaching maximum values (0.95 and 0.99 wk⁻¹).

Table 4: Parameters of the model of biomass consumption of water hyacinth by *E. fetida* in the tested treatments (Control; NPK 1.75%; NPK 3.5%; Glucose 0.25g/L and Glucose 0.5g/L).

Treatment	BC _{max} (%)	k (wk ⁻¹)	r ²
Control	74.50	0.74	0.94
NPK 1.75%	65.00	0.20	0.83
NPK 3.50%	79.70	0.31	0.72
Glucose 0.25 g/L	52.50	0.95	0.83
Glucose 0.50 g/L	47.50	0.99	0.76

3.3 Fertility

The results of the fertility tests for the composts formed by vermicomposting macrophytes are described in Table 5. The treatments had less than the recommended amount of organic matter. For phosphorus all treatments showed values within the lower limit of this range (0.11% and 0.12%). The values of Mg in the composts produced in vermicomposting were significant, with higher values obtained for the treatments enriched with glucose (1.61% and 1.92%), followed by the Control (1.75%) and the treatments enriched with NPK (1.34% and 1.05%).

Table 5: Results of fertility evaluation (in %) parameters for vermicomposts using *E. crassipes* biomass (Control; NPK 1.75%; NPK 3.50%; Glucose 0.25g/L and Glucose 0.50 g/L). A – recommended values according to Mendes (2007), B – recommended values according to Prezotti & Guarçoni (2012).

	Control	NPK 1.75%	NPK 3.5%	Glucose 0.25g/L	Glucose 0.5g/L	A	B
Total Organic Matter	0.95	1.88	3.11	3.30	5.16	5.00	-
Organic Carbon	0.30	0.31	0.30	0.29	0.60	-	-
Total Nitrogen	0.17	0.14	0.19	0.24	0.24	-	-
Total Phosphorus	0.09	0.11	0.12	0.13	0.13	0.10 - 1.0	1.60
Total Potassium	0.16	0.17	0.19	0.19	0.27	1 - 3.50	1.50
Total Calcium	0.30	0.32	0.36	0.36	0.36	0.60	0.50 - 3.00
Total Magnesium	1.75	1.34	1.05	1.61	1.92	6.00	0.15 - 1.00
Total Sulfur	0.03	0.05	0.07	0.05	0.05	0.10 - 0.40	-

The concentration of macronutrients below the recommended limit showed that the formation of a fertile compost by vermicomposting macrophytes, although feasible, lacks some of the attributes necessary for adequate plant nutrition. Other experiments conducted with the association of macrophytes and animal manure (Ansari & Rajpersaud, 2012; Kannadasan et al., 2013; Sakthika & Sornalaksmi, 2019) showed much higher values than those obtained for the concentration of macronutrients. The addition of manure also has disadvantages due to the possibility of the presence of fecal coliforms and pathogens, making further use as fertilizer impossible. The enrichment

with both inorganic (NPK) and organic (glucose) compost caused a subtle increase in the quality of the compost formed. The compost, however, can work as an aggregator to the soil promoting moisture increase and providing greater soil structuring, as well as in association with another fertilizer. The composts enriched with glucose were superior in terms of biomass consumption efficiency, which were 51.5% and 40.5% higher than the average of the treatments with NPK. The addition of glucose has the benefits of being easy to obtain and low cost, being a viable alternative for improving production through a sustainable alternative for the use of surplus biomass and transformation into a fertilizer applicable in other local productions. We suggest that future studies test the application of this technique on a large scale.

4. Conclusion

Vermicomposting using macrophytes represents a sustainable alternative for the use of this biomass. The addition of both organic and inorganic compounds proved to be adequate for this process, contributing to an increase in efficiency in the consumption of biomass and a subtle improvement in the fertility of the compost formed. The addition of glucose is a low-cost, easily obtained and applicable. Although the addition shows an increase in compost quality, it does not have the necessary requirements for its use as a fertilizer. However, we suggest the use in association with other fertilizers, adding moisture and structuring to the soil.

Declarations

- **Ethics approval and consent to participate**

NOT APPLICABLE

- **Consent for publication**

NOT APPLICABLE

- **Availability of data and materials**

The datasets generated and/or analysed during the current study are available in the “Repositório Institucional UFScar” repository, available in <https://repositorio.ufscar.br/>.

- **Competing interests**

The authors declare that they have no competing interests.

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- **Authors' contributions**

All authors contributed to the study conception and design. KK did the material preparation, investigation, collected data and wrote the manuscript. IB and MBCS provided funding, supervised the project, and wrote the manuscript. HHLS contributed to the statistical analyses. All authors read and approved the final manuscript.

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