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Review

Assessing the effect of biodegradable and degradable plastics on the composting of green wastes and compost quality

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Abstract

An assessment of the effect of the composting potential of Mater-Bi biodegradable plastic with green wastes, noted by GBIO, and degradable plastic (PDQ-H additive) with green wastes, noted by GDEG, was carried out in a lagged two-compartment compost reactor. The composting time was determined until constant mass of the composting substrates was reached. The green wastes composting process was used as control (G). After one week of composting, the biodegradable plastics disappeared completely, while 2% of the original degradable plastic still remained after about 8 weeks of composting. A net reduction in volatile solids contents of 61.8%, 56.5% and 53.2% were obtained for G, GBIO and GDEG, respectively. Compost quality was assessed in terms of nitrogen, potassium and phosphorus contents, which were found to be highest for GBIO compost. From the phytotoxicity test, it has been observed that a diluted extract of GBIO compost has produced the longest length of radicle. From the respiration test, no significant difference in the amount of carbon dioxide released by the composting of GDEG and G was observed. This study showed that the quality of the compost is not affected by the presence of the biodegradable and degradable plastics in the raw materials.

Keywords: Biodegradable; Degradable; Composting; Compost quality; Phytotoxicity

1. Introduction

Solid waste management is one of the main concerns of many governmental organizations worldwide. Mauritius is an island, which forms part of the Mascarene Islands. It is situated in the southwest of the Indian Ocean between longitudes 57°17′ and 57°48′ east and latitudes 19°50′ and 20°32′ south and lies about 900 km east of Madagascar.

Mauritius generates around 1200 tons of wastes daily, out of which around 70% is biodegradable. It has also been reported that green wastes constitute about 45% of municipal solid waste generation (Mohee, 1998). Solid wastes are deposited at the sole sanitary landfill of the island, which is expected to be saturated by next year as Mauritius is a small island of 2030 km^2 and there is huge competition for land. Lack of suitable spaces, potential NIMBY (Not in My Back Yard) syndrome is a few of the reasons to search alternatives to landfills as the major solution to MSW disposal (Robinzon et al., 2000).

The composting of green wastes can be considered as the best option to treat these wastes in the Mauritian context. Fitchner (2000) recommended the setting up of one pilot plant for composting about 10,000 tonne per annum of green waste. Composting can decrease the amount of space that green wastes take up in landfill and at the same time produce a beneficial product as compost.

Around 1000 tonnes of plastic carry bags are deposited annually at the landfill, which lead to a severe disposal problem due to lack of landfill space as well as contamination issues (Ministry of Environment). As such, the Government of Mauritius, in particular the Ministry of

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Environment, has passed a regulation on plastic bags whereby only degradable plastic bags made from non-toxic, non-tinting additive, having a minimum thickness of 20 μm, with a tolerance of 20% before degradation, will be authorized for utilisation. The standard for plastic carry bags in the Government Notices 2004, Schedule (regulations 2–4) stipulates that, the vest type plastic carrier bag is expected to totally degrade within a period of 12 months when exposed to aerobic or anaerobic conditions including exposure in a landfill or regulated dumping area.

During a composting process, a genuine biodegradable plastic will be converted to carbon dioxide, water and compost, without leaving any persistent or toxic residue.

Mohee and Unmar (2007) have shown that the cumulative carbon dioxide evolution for PDQ-H degradable plastic was much higher than that of TDPA degradable plastic. A study carried out by Davis et al. (2005) on the compostability of degradable polyethylene under open windrow composting conditions, has demonstrated that although polyethylene sacks are suitable for the collection of organic wastes, they are not compostable under open windrow conditions. Also, it has been found that the polyethylene sacks did not degrade at a rate consistent with the organic matter and left a visually distinguishable residue in the final compost.

In this study, a comparative assessment was conducted on the effect of biodegradable and degradable plastics on the composting of green wastes, with special emphasis on compost quality.

2. Methods

The site of Curepipe situated in the upper plateau of Mauritius was chosen as previous records (Personal communication)[2] indicated that it generates the largest amount of green wastes. Samples were taken at the Botanical Garden for the determinations of the following parameters using Methods book (1994): moisture content, 100 g of sample was dried in the oven at 105 °C for 24 h; volatile solids content, 2 g of dried and ground sample was burnt at 550 °C for 2 h in a muffle furnace; carbon content, the dry sample was analysed using a spectrophotometer (600 nm) after treatment with potassium dichromate, concentrated sulphuric acid and barium chloride and nitrogen content according to Kjeldahl, the digested sample was distilled with sodium hydroxide and boric acid and titration with hydrochloric acid.

The optimum mix was thus calculated for the composting of green wastes with and without degradable/biodegradable plastic bags. The green wastes were classified as green leaves, green branches, grass, brown branches and brown leaves.

During the course of the composting experiments, various physical parameters of major importance were monitored, such as daily temperature recording and respiration test (absorption of carbon dioxide by sodium hydroxide followed by titration with 1 M hydrochloric acid, using phenolphthalein indicator). On a weekly basis, the following tests were also performed: moisture %, volatile solids %; pH, 200 ml of 0.01 M calcium chloride solution was added to 20 g of fresh sample in a beaker and was measured using a calibrated pH meter (Methods book, 1994); chemical oxygen demand (COD) of compost extract, digestion of sample followed by titration with ferrous ammonium sulphate, (Methods book, 1994) and mass loss was determined by weighing.

The initial and final electrical conductivity (using calibrated electrical conductivity meter) of each mix was measured (Methods book, 1994). The quality of compost produced was determined in terms of nutrients contents such as potassium (using flame photometer), total nitrogen (according to Kjeldahl) and phosphorus (absorbance was read at 660 nm from the spectrophotometer), and germination test (mustard seeds were made to germinate in fresh composts extracts at two different concentrations). All these parameters were determined as per the standards outlined in the Methods book (1994).

2.1. Experimental set-up

The hexagonal rotary composter was used to carry out the experiments. It consists of a dual chamber having a total volume of 0.3 m^3. Each individual chamber has its own opening at the top part of the vessel. Each chamber has a volume of about 150 l. At the bottom corner of the vessel, there were two PVC pipes of 50 mm internal diameters. Along the length of the pipes, small holes were drilled to allow uniform distribution of air throughout the vessel. The tumbler was made from fiberglass materials and was insulated with 10 mm polystyrene sheets throughout the whole exposed surface areas. At the side of the vessel (i.e., the top part), as well as, on the two covers, holes of 60 mm diameters were also drilled to ensure proper exit of hot air from the composter.

Each compartment of the hexagonal rotary composter was filled with 32 kg of green wastes. It should be noted that in the right compartment of the hexagonal rotary composter, the 32 kg of green wastes were mixed with 112.10 ± 0.15 g of plastic material under study (2 cm × 2 cm), taking into consideration that around 1427.20 ± 0.20 g of green wastes can be contained in 5 g of this type of plastic material. In the left compartment only green wastes was composted.

The plastic materials under study were: Plastic A contains 2.5–3% of PDQ-H additive. This additive has been made with proprietary ingredients to disintegrate plastic by oxidation and photodegradation. The PDQ-H additive is a Masterbatch additive to be used with either polyethylene or polypropylene (Personal communication)[3]. This

[2] Personal communication with senior officer from Municipality of Curepipe.

[3] Personal communication with distributor of Willow Ridge Plastic in Mauritius.

plastic was chosen based on a study carried out by Mohee and Unmar (2007).

Mater-Bi plastic is made from starch (corn) and manufactured by Ecosac Ltd. This is patented vegetable Novamont plastic that can be used for refuse collection bags and sheeting for agriculture. On coming into contact with air and water, it can dissolve within 45 days (Novamont, 2002).

3. Results and discussion

3.1. Temperature monitoring

Temperature is an important parameter in composting both as a consequence and as a determinant of activity (Agnew and Leonard, 2003). The monitoring of temperature was carried out daily from the beginning of the experiment until the temperature stabilized at ambient conditions. The temperature was taken at three different positions, T1, T2 and T3 within the compost pile. The variation of temperature over time is shown in Fig. 1. The temperature remained above 60 °C for GDEG and GBIO and above 50 °C for G for about five days. The highest temperature recorded was 63.3 °C, 62.8 °C and 60.4 °C for GBIO, GDEG and G, respectively. Agnew and Leonard (2003) pointed out that thermophilic organisms are generally accepted to be more productive, and the thermophilic temperatures kill pathogens and weed seeds that have been present in the initial mixture. Finally, a decrease in temperature was recorded after 8 days, probably due to excessive loss in volume and quantity of material available for degradation.

3.2. Moisture content

Fig. 2 shows the variation of moisture content over time. At the beginning of the experiment, the moisture contents for GBIO, GDEG and G were 63.1%, 73.7% and 72.6%, respectively. Agnew and Leonard (2003) stated that in a number of cases, the optimum moisture contents were in the range 60–80% and that optimum conditions will depend on the nature of the original materials in the compost mixture. After 3 days of monitoring, it has been found that the moisture contents of the composting processes have increased and eventually decreased after day nine. The moisture content for these processes showed atypical behaviour as it was observed to increase during the first 2–3 days, due to the presence of a large amount of water in the green wastes. This water vapour condensed on the top walls of the compost reactor (closed system) before falling back into the mixture. Also, as decomposition

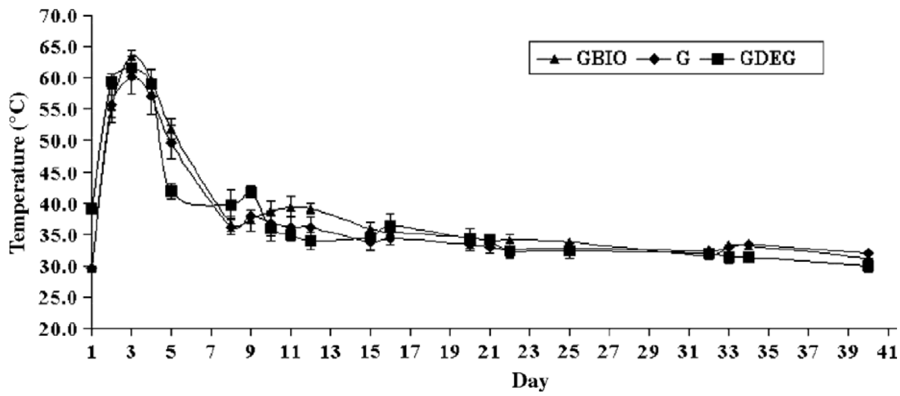

Fig. 1. Temperature profile (Each data point is a mean of three values. Standard deviation is shown.) of different types of composting processes.

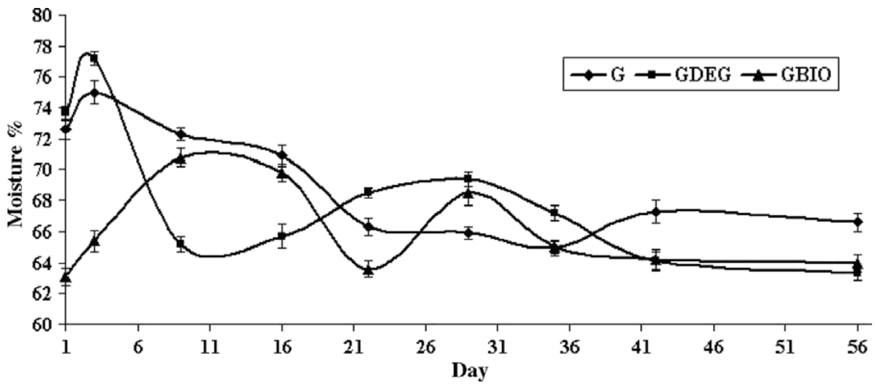

Fig. 2. Moisture (Each data point is a mean of three values. Standard deviation is shown.) pattern.

proceeded, water locked in the cells of the green matter was released within the pile.

Moreover, moisture content can exceed 60% as long as there is sufficient air content in the compost pile to satisfy the oxygen needs of the microbes. It has also been observed that the moisture content of the final compost was higher, particularly at higher grass concentrations due to release of excess water.

3.3. Volatile solids

Volatile solids are a good indicator of how biological degradation occurred over time. The initial volatile solids contents were 84.6%, 86.5% and 83.1% for G, GDEG and GBIO, respectively. The composting of green wastes had higher degradation, as the net change in volatile solids content was around 61.8% as compared to 56.5% and 53.2% for the composting of green wastes with biodegradable plastic and with degradable plastic, respectively, after 7 weeks of monitoring. This may be due to higher amounts of biodegradable matter as compared to plastics.

3.4. pH

At the start of the experiment, a pH of 6.3, 6.9 and 6.3 were obtained for GBIO, GDEG and G, respectively. The mineralization of the organic matter was responsible for the decrease then the increase of pH. Mineralization means the microbial conversion of organic matter to an inorganic state, with production of carbon dioxide and water. However, a gradual increase in pH was observed as the composting process progressed, indicating that the pH was favourable for microbial activity and this corresponded to the release of ammonia and other basic components in the liquid film, and the elimination of organic acids. At the end of the process, a pH of 7.6, 7.7 and 7.4 were recorded for GDEG, GBIO and G, respectively.

3.5. Phytotoxicity bioassay

The seed germination test was carried out to check whether the compost was free of ammonia or organic acids, which can be toxic to plants. The seeds used were mustard seeds. The test was carried out in the dark and at room temperature. The radicle lengths of these different treatments were measured after 24, 48 and 72 h. It has been observed that there was no significant difference in length of radicle, which was around 3.00 cm, for G (full strength), G 10 (dilution × 10), GBIO (full strength), GDEG (full strength) and the blank. However, the longest length recorded was that of GBIO 10 (dilution × 10), with a length of 4.49 cm. The germination maturity test with the three different types of composts (diluted and undiluted) showed a positive response after 72 h, with a germination rate above 90%.

It can thus be deduced that the strips of plastic did not have an inhibitory effect on the growth of the mustard seeds. Davis et al. (2005) also showed that the presence of the shredded degradable PE and its degradation products within the final compost product did not inhibit plant growth or seed germination.

3.6. Respiration test

Table 1 gives an idea of how the readily degradable organic matter has been depleted during the composting process for a period of six weeks. This test was also carried out in order to find out whether the presence of plastic within the composting matrix affects the decomposition rate of the organic matter.

From the results obtained, it can be observed that there was no significant difference in the amount of carbon dioxide released by the composting of green wastes with strips of degradable plastic and the composting of green wastes only. However, it should be pointed out that the composting of green wastes with biodegradable plastic was moderately stable on the second week of the composting process due to the rapid rise in temperature, which was observed at the start of the experiment. The composting of green wastes with biodegradable plastic was stabilized on the third week. Shaw et al. (1999) has also found that respiratory rates decrease as the leaves content increases from 0% to 30%. High leaves content in the basic feed material is detrimental to the composting process, despite the acknowledged

Table 1
Rating of organic matter decomposition

Week	Green wastes		Green wastes + strips of degradable plastic		Green wastes + strips of biodegradable plastic	
	Experimental mg $CO_2 \cdot C$/g organic carb on/day	Rating	Experimental mg $CO_2 \cdot C$/g organic carbon/day	Rating	Experimental mg $CO_2 \cdot C$/g organic carbon/day	Rating
1	33.3	Extremely unstable	39.8	Extremely unstable	25.6	Extremely unstable
2	19.1	Unstable	20.9	Extremely unstable	5.6	Moderately stable
3	11.4	Unstable	12.5	Unstable	4.8	Stable
4	6.1	Moderately stable	6.5	Moderately stable	4.3	Stable
5	4.7	Stable	3.6	Stable	4.2	Stable
6	1.4	Very stable	1.2	Very stable	1.9	Very stable

benefit of leaf mulch for agricultural applications. At the start of the composting experiment, the raw materials were extremely unstable as decomposition of organic matter was initiated by the action of microorganisms. After six weeks of monitoring, the composting process was very much stable and this indicated that almost all the degradable organic matter has been depleted and the compost has reached maturity.

3.7. Particle size distribution

It has been observed that 41%, 49% and 54% of fine compost (through a sieve size of 2.362 mm) were obtained for G, GBIO and GDEG, respectively. This indicated that the raw materials have well degraded in the three composting processes. Moreover, 99.3% of each type of compost has particle size less than 18.85 mm. Also, the strips of degradable plastics consisted 2% (through a sieve size of 9.432 mm) of the total compost mass.

3.8. Chemical oxygen demand (COD)

Fig. 3 shows the variation of COD with time. Soluble COD was measured in this experiment.

The evolution of pH is intimately tied to the release and removed of organic matter in the biofilm surrounding the solid phase. A sensitive parameter of that organic matter evolution may be the COD concentration in the biofilm (De Guardia et al., 1998). The COD concentrations for G and GDEG strips first increased then decreased quickly until day 22. This decrease in COD may be due to the mineralization of the organic matter leading to the production of carbon dioxide and water. A slight increase in COD was observed after 25 days for GDEG and this may be due to the presence of non-biodegradable dissolved organic matter, which may cause a fall in microbiological metabolism. The gradual increase in COD value until day 22 for GBIO may be due to the availability of much organic matter during this period as compared to G and GDEG. After day 22, the COD concentration decreased, indicating stabilization of organic matter to biological activity.

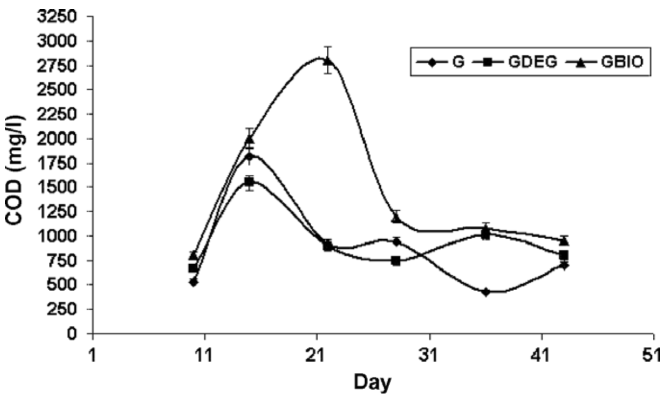

Fig. 3. COD (Each data point is a mean of three values. Standard deviation is shown.) evolution.

3.9. Reduction in material mass

The loss of mass of the composting material was determined every week by emptying the compost reactors and weighing their contents. This reduction in mass can be explained by the mineralization of the organic matter into carbon dioxide and water. The green waste compost gave a mass reduction of 51.6%, while the GDEG and the GBIO composts gave a lower reduction in masses of 48.6% and 45%, respectively. The values obtained for mass reduction (experimental) in the three cases were compared to a calculated mass reduction (using total nonvolatile solids). The equations for reduction in mass (R_m) and volume loss (R_v) were obtained from Breitenbeck and Schellinger (2004), and these are: $R_m = 1 - (A_i/A_f)$ and $R_v = 1 - [(A_i/A_f)^* (D_i/D_f)]$, where A_t and A_i are the initial and final nonvolatile solids concentrations, and D_i and D_f are the initial and final bulk densities. A reduction in mass of 60%, 46% and 56% were obtained for G, GDEG and GBIO, respectively. Also, a volume loss of 79.9%, 82% and 71.4% were obtained for G, GDEG and GBIO, respectively. This showed that the presence of strips of plastics in the green wastes did not affect the oxidation of the organic matter, as there was a slight difference in volume loss for G, GDEG and GBIO.

3.10. Compost quality

Quality parameters such as nitrogen, potassium, phosphorus and trace elements, which make up the nutrient content of compost, are essential as they are indicative of future use of the compost (Mohee and Gaju, 2002). Required and predictable compost quality is essential to secure recycling of the resources and to avoid that the compost again becomes a waste problem (Asdal and Breland, 2003). Table 2 shows the final characteristics of composts for G, GBIO and GDEG.

The final bulk densities for G, GBIO and GDEG were found to be 267 kg/m^3, 326 kg/m^3 and 259 kg/m^3, respectively, as shown in Table 2. Typical dry bulk densities are in the range 100–400 kg/m^3, whereas wet bulk densities are typically 500–900 kg/m^3 (Agnew and Leonard, 2003). Bulk density is dependent on the location within a pile, and, samples from the bottom of the pile had higher bulk densities, and higher values of bulk density imply an increase in mass and a decrease of porosity and air volume. The ability of compost to hold and retain water is also important to the user. Water holding capacity is obviously related to the structure of the compost matrix. The compost matrix depends on certain factors that influence the amount of air that can be held in the compost, which, in turn, have a direct bearing on the ability to sustain aerobic decomposition. These factors are the sizes and distribution of both particles and pores. The water holding capacity of G, GDEG and GBIO composts were over 90% higher than that for soil.

Table 2
Final characteristic of composts

Parameters	Green wastes compost	Green wastes + strips of degradable plastic compost	Green wastes + strips of biodegradable plastic compost	Standard
Visual appearance	Soil-like	Soil-like and presence of plastic strips	Soil-like and no presence of plastic strips	ND
Colour	Dark brown	Dark brown	Dark brown	ND
Smell	Earthy aroma	Earthy aroma	Earthy aroma	ND
Physical characteristics				
Final mass (kg)	15.5	16.5	17.6	ND
Moisture %	66.6	63.3	64.0	ND
Dry solids %	33.4	36.7	36.0	ND
Volatile solids %	60.8	75.0	60.8	ND
Ash %	39.2	25.0	39.2	ND
pH	7.4	7.6	7.7	6.8–7.3[a]
Electrical conductivity (mS/cm)	2.80	3.34	2.53	2.5–3.5[a]
Bulk density (kg/m^3)	266.85	326.15	259.4	ND
Water holding capacity	5.52	4.94	6.46	ND
% Pore space	73.6	68.8	72.2	ND
Chemical characteristics				
Carbon %	38.7	45.3	33.8	ND
Nitrogen %	1.08	1.24	3.01	>0.6[a]
Potassium %	0.10	0.21	1.62	>0.2[a]
Phosphorus %	0.11	0.10	1.03	>0.25[a]

[a] Ministry of Local Government, Rodrigues, Rural and Urban Development (2002).

Porosity is governed by particle size and size degradation. The percentages of pore space for G, GDEG and GBIO were 73.6, 68.8, and 72.2, respectively, as shown in Table 2. From Table 2, it can be observed that there has been an increase in electrical conductivity. Also, a drop in conductivity early in the composting process may be attributed to the fixing of ammonia, and other nutrient ions during the rapid increase in aerobic microbial population. Results from field experiment in Norway have shown that the nitrogen fertilizer value of composts is normally low (Asdal and Breland, 2003). The nitrogen, potassium and phosphorus values for GBIO compost were found to be highest than G and GDEG composts. The Mater-Bi product is a biological and biodegradable material, which on composting produces good quality compost. From the phytotoxicity test, it has been observed that a diluted extract of GBIO compost has produced the longest length of radicle.

4. Conclusions

Based on the findings, it can be concluded that the different types of plastics would degrade but at different rates and would produce composts which varied in quality. The highest thermophilic temperature (63.3 °C) was recorded for GBIO after three days from the start of the composting process. The moisture contents for the three composting processes remained above 60% throughout the experiment. A net reduction in volatile solids contents of 61.8%, 56.5% and 53.2% were obtained for G, GBIO and GDEG, respectively. An increase in bulk densities, in the range of 250–350 kg/m^3, was noted for G, GBIO and GDEG at the end of the composting process. Rapid stabilisation of the organic matter was observed for GBIO on the third week as compared to G and GDEG, which reached stability on the fifth week. A decrease in COD concentrations until day 22 was recorded for G and GDEG and this may be due to the mineralization of the organic matter. However, an increase in COD concentration was observed for GBIO until day 22 due to the availability of much organic matter. Reduction in material masses for G, GDEG and GBIO were 60%, 46% and 56%, respectively. Yields of 40.8%, 49% and 54% of fine composts (through a sieve size of 2.362 mm) were obtained for G, GBIO and GDEG, respectively. High nutrients contents (NPK) were also obtained for GBIO. Good compost quality was also obtained for GBIO as from the phytoxicity test it has been observed that a diluted extract of GBIO compost has produced the longest length of radicle. The most striking feature about the composting of green wastes with biodegradable plastic (Mater-Bi product) was that after one week of monitoring, all the strips of plastic have completely disappeared, while 2% of the original degradable plastic still remained at the end of the composting process. The presence of strips of plastic for the GDEG compost may have a detrimental effect on the physical appearance of the compost when applied to land, as well as on soil quality. Davis et al. (2005) concluded that the rate of degradation of PE (polyethylene) did not match the rate of degradation observed within the organic wastes. In addition, these strips of plastic can also be easily carried away by wind and be deposited on plants and the surrounding environment.

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