Feasibility and Performance Evaluation of Different Low-Tech Composter Prototypes

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***Abstract*-Decentralized composting has become a powerful option for municipal organic waste management. This technology, not only is an effective tool to treat organic waste, producing compost as a valuable by-product, but also represents an innovative way to involve waste generators in treatment operations. Decentralized composting contributes to reducing waste transportation, treatment costs and landfilling volumes thus resulting in a positive impact on municipal waste management programs. In this work, three low-tech composter prototypes were designed and built using discarded metallic oil drums and recycled plastic materials. The composting experience was carried out at an oilfield, using food waste from a catering service for 65 people. Temperature was used as the main indicator of the composting process, and final product quality was characterized through the following variables: total nitrogen, total phosphorous, extractable phosphorous, pH, organic matter and electrical conductivity. Results confirm the effectiveness of this composting technology for organic waste treatment: thermophilic temperatures were reached in all prototypes, and final products obtained from all composters showed high nutrient and organic matter contents, but also high pH and electrical conductivity values, which frequently appear in decentralized composting product; however, obtained values are still adequate for agronomic applications. Nevertheless, some significant differences were found for these variables among the prototypes, possibly related to design characteristics. Finally, composters construction could be optimised by recycling other waste, as shown in this experience (metallic drums, high density polyethylene and accessories), in order to improve the strategies for decentralised composting.**

Keywords- Decentralised Composting; Composter; Organic Waste; Oilfield Solid Waste

I. INTRODUCTION

Composting is a well-known and advantageous strategy to treat the organic fraction of municipal solid waste. This technology has demonstrated to be appropriate to recycle large quantities of organic waste, being technically accessible and reducing environmental impacts of organic waste accumulated without proper control or treatment. Furthermore, waste valorization is accomplished by generating compost, an amendment of high agronomical value [1-3]. Particularly, decentralised composting is also an innovative way to involve waste generators as key actors in treatment operations. This technology also contributes to reducing waste transportation, treatment costs and landfilling volumes, as it was demonstrated in several life cycle assessments reported in literature [4-7].

Decentralised composting process has not been fully described as traditional or centralised composting. Relevant composting process parameters like temperature profile, thermophilic period extension and C/N ratio, are highly variable in decentralised composting literature, and this variability is related to composter loading frequency and feedstock composition [8-12]. Considering these conditions, decentralised composting feasibility must be evaluated for each particular scenario and, in particular, composter design becomes a central issue in this context.

Composter designs should especially take into account geometric shape, volume, homogenization and aeration mechanisms [12-14]. On the one hand, composter geometric shape and volume ought to avoid material compaction and to favour heat retention, when no other temperature control is applied. On the other hand composting material homogenization and adequate oxygen concentration are essential conditions for the process to succeed [14, 15]. Finally, user-friendly characteristics, low construction costs and maintenance requirements are desirable aspects for a waste management solution [16].

Compost agronomic quality parameters, like organic matter, nutrient content, pH and salts or heavy metal concentration, are very important for the valorisation of municipal organic waste, because these parameters define future applications of the final product and consequently, technology acceptability [16, 17]. Compost quality is affected by feedstock composition and separation practices. For example, kitchen organic waste is usually associated with a high nutrient content but also with an elevated salt concentration in the resulting compost [15, 16, 18]. Besides, source separation of organic wastes associated with decentralised facilities treatment, will presumably help to avoid final compost contamination with inorganic waste, unlike post collection separation and centralised municipal plant composting. Thereby, decentralised composting offers some interesting advantages as valuable organic waste recycling opportunity to explore [16, 19, 20].

Patagonia, the southern region of Argentina, is an oil and gas producing area. Organic waste represents approximately 50 % of the total urban-like solid waste generated in an oilfield. This fraction is mainly generated by staff catering services and

DOI: 10.5963/IJEP0501001

source separation along with an adequate treatment is enforced by environmental regulations in petroleum companies. In addition, oilfield long distances and scarce treatment facilities complete a suitable scenario for decentralised composting [21, 22].

The main objective of this work is to assess decentralised composting performance at an oilfield, employing three low-tech composter prototypes made of refused materials, taking into account temperature evolution, resulting waste mass reduction, operational and structural prototype aspects and final compost quality parameters.

II. MATERIALS AND METHODS

Composting trials were conducted at an oilfield facility, near to Neuquén city in NW-Patagonia, Argentina (latitude: 38°44'21.39"S; longitude: 68°11'58.35"O), from November 2008 to April 2009. This region is characterized by a xeric climate with 10 °C, 17 °C and 32 °C as minimum, medium and maximum mean temperatures, respectively, in summer.

Organic wastes generated by a daily catering service for 65 people were composted in three different composter prototypes (treatments) with two replicates each.

The first prototype (Fig. 1) was named Assisted Aeration Composter (AAC). Its main component was a 200 liters metallic drum, with a vertical layout, aerated trough a wind extractor connected to a PVC pipe fixed along the drum's central vertical axis, also eight perforations were located at the sides of the drum. Leachates produced by the composting mixture were collected into a metallic tray located 20 cm above the bottom. Organic waste was introduced through an opening at the top of the composter, and a side door (25 cm x 40 cm) was added to facilitate compost collection. Water-protex paint was employed as coating to preserve these composters from weathering.

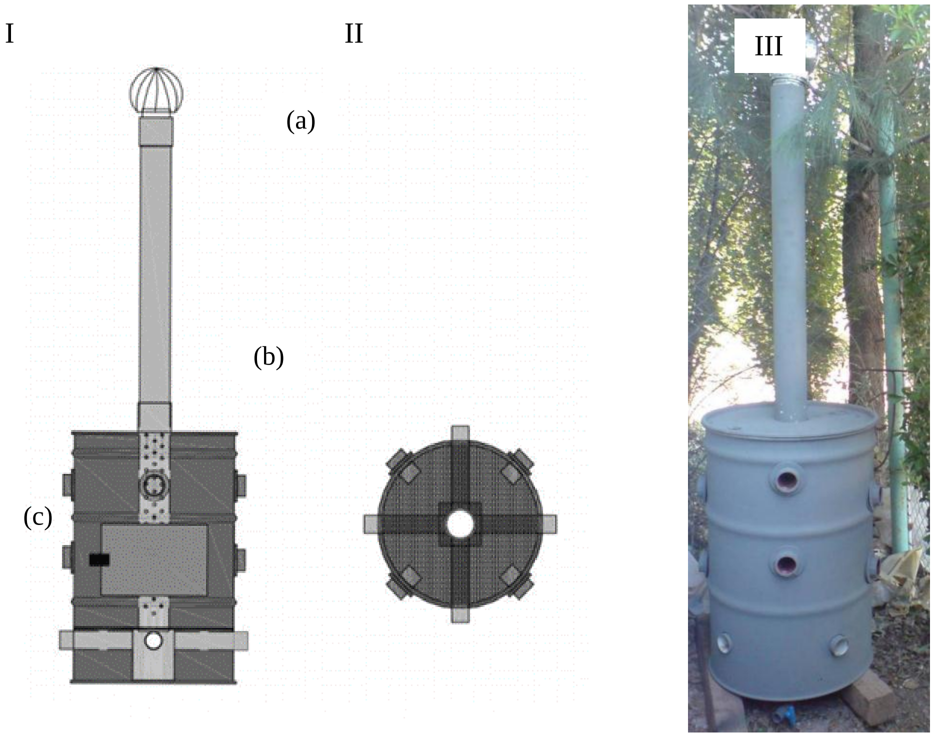

Fig. 1 Assisted Aeration Composter (AAC). Computer Aided Designs: front view (I) and upper view (II). Figure I shows wind extractor (a), central axis PVC pipe (b), lateral perforations (c), and side door for compost collection (d). Figure III is a final prototype image

The second prototype (Fig. 2), also constructed with a 200 liters metal drum as main component laid out horizontally on a rotating mechanism, composed of a central axis connected to bearings installed at the sides of the composter, was named Assisted Turning Composter (ATC). A top door (25 cm x 40 cm) was made for waste additions as well as for final product harvesting. Two metallic screen grids were installed on both sides to allow natural aeration. Also in this case water-protex painting was used to protect these composters.

Fig. 3 shows the third prototype, named Extended Volume Composter (EVC), built with recycled plastic boards (6.35 cm x 65.00 cm x 2.54 cm). This prototype was 1.5 m high, with a volume of approximately 300 liters, and furnished with a lid on the top to allow waste loading. Natural aeration was generated between the boards (1-2 mm), and two doors were installed on both sides of the composter to collect the final product.

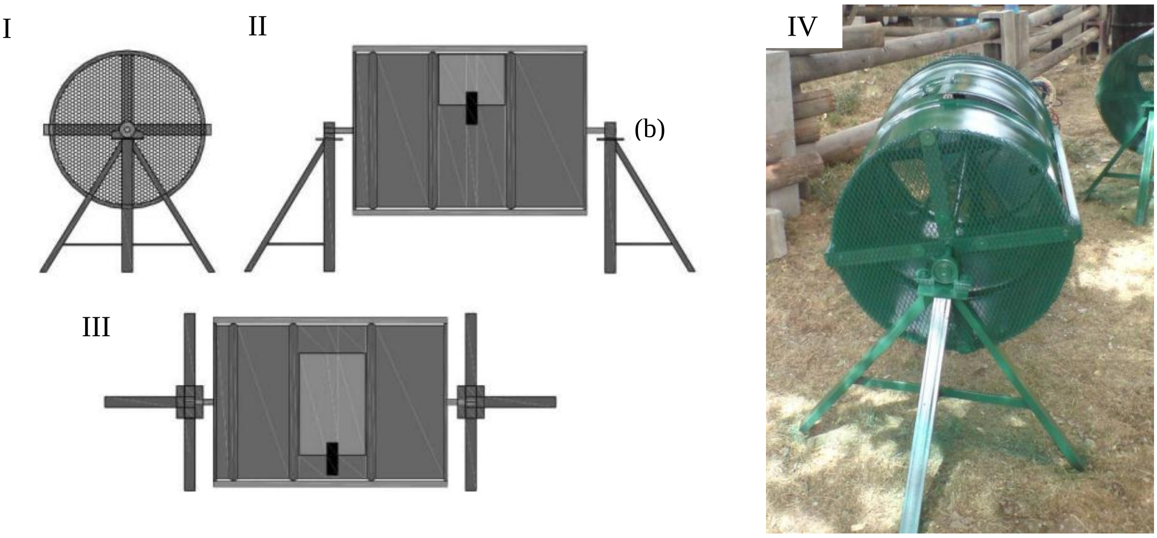

Fig. 2 Assisted Turning Composter (ATC) computer aided design: lateral view (I), front view (II) and upper view (III). Metallic screen grids (a), rotating mechanism (b) and the top door (c) are pointed out. Figure IV shows a final prototype image

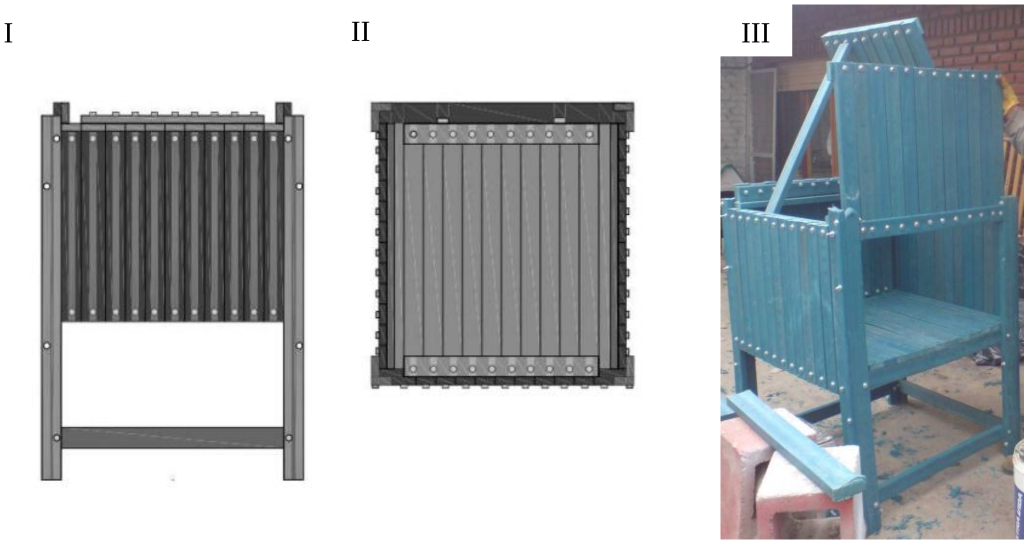

Fig. 3 Extended Volume Composter (EVC). Computer Aided design: front view (I) and upper view (II). Figure III shows final prototype with side door and the top lid opened

In AAC and EVC prototypes, composting materials were mixed manually using a corkscrew-like tool, every time fresh feedstock was loaded.

From November 2008 to February 2009, a total of 1,414 kg of catering service organic waste was equally distributed and fed into each composter two to three times a week, up to complete each composter's full capacity; the volume and mass of each waste batch was then registered. The organic waste was a mixture of raw and cooked vegetables (70 % V/V), meat (10 % V/V), and paper (20 % V/V) from place mats and napkins, these last ones added as water absorbent material. Collected leachates from AAC were not recycled into the composters and were discharged into the existing sewage sludge treatment system.

Temperature was monitored and used as indicator of composting process evolution. Before each feedstock loading, temperature per composter was registered using an analogical compost thermometer placed at different random points into composting substrate and mean values were recorded. Moisture level was also measured empirically trough the "hand squeezing method" described by Rodriguez-Salinas & Córdoba-Vazquez [3] and water was added if needed.

Ten months after the beginning of the trial, 1500 g composite samples (three sub-samples of 500 g each) were taken from the composters. To assess the quality of the final product, samples were air-dried, milled and analyzed twice for pH and electrical conductivity (EC) on water extracts obtained by mechanical shaking the samples with distilled water (1:10 compost:water) as described by García et al. [23]. Total N (NKj) was determined by semi-micro Kjeldahl method (NKj). Extractable P in $NaHCO_3$ 0.5 M extraction solution (relation 1:100) by the molibdate-ascorbic acid method [24]. Total P was determined on ashes (obtained by 550 °C ignition), through HCl and HNO_3 extraction and subsequent molibdate-ascorbic acid

DOI: 10.5963/IJEP0501001

method [25], and Organic matter (OM) was determined by 4 hours sample ignition at 550 ℃ (Total C was obtained dividing measured OM by 2) [26].

Differences among the above mentioned variables in final products obtained from different composter prototypes (treatments), were evaluated using minimum squares method by “lm” function (general linear models), and mixed effects model estimated trough restricted maximum likelihood using “nlme” on R software, 2.12.1 version [27], and significance of treatments effects was evaluated by Student’s contrasts. Independence restrictions were found in both cases. Considering the number of replicates, P-value was established on 0.1 to consider significant differences. The variables were also analyzed by Principal Component Analysis (PCA) [28] in order to determine interdependence on metric variables and to find the optimum graphic representation (biplot) of the variability cases figured on a table including observations and analyzed variables [1, 29].

III. RESULTS

All composter prototypes mixtures achieved thermophilic temperatures (≥ 45°C) (Fig. 4). The thermophilic phase was maintained for 60 days in EVC prototypes, 70 days in ATC and 85 days in AAC. Maximum temperatures registered were: 58 ℃, 53 ℃ and 50 ℃ in ATC, AAC and EVC respectively.

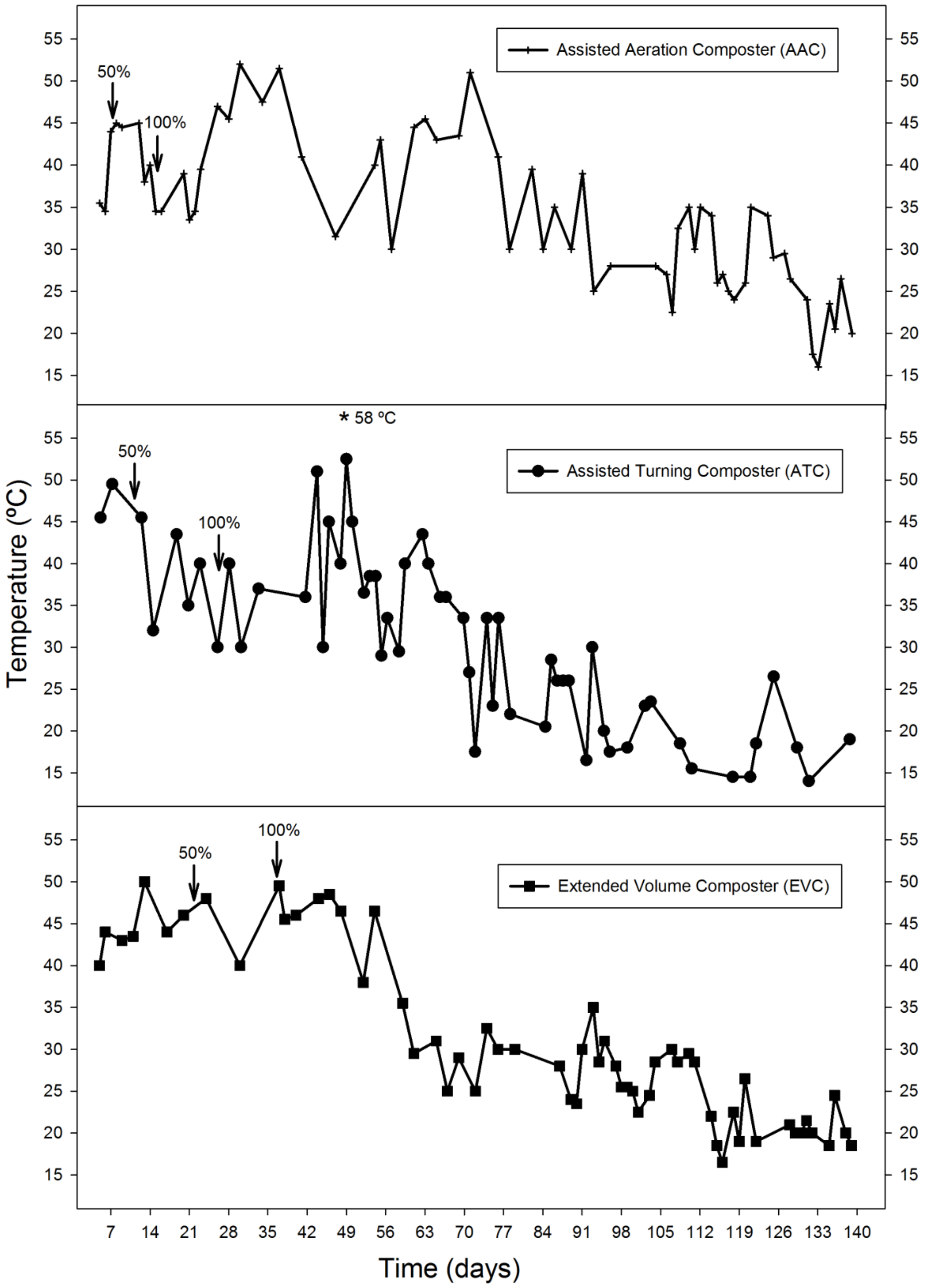

Fig. 4 Temperature changes during composting. Arrows indicate when 50 % and 100 % of composter volume capacity was reached

DOI: 10.5963/IJEP0501001

Table 1 summarizes waste quantities treated and compost produced by each composter prototype, expressing total mass reduction as % of initial mass feedstock employed.

TABLE 1 WASTE QUANTITIES TREATED AND FINAL PRODUCT OBTAINED ON EACH COMPOSTER PROTOTYPE

Composter Prototype	Composter Volume (l)	Waste (l)	Waste (kg)	Mass reduction (% of initial mass)
AAC	160	384	165	5,5
ATC	200	550	252	7,1
EVC	300	714	290	6,0

pH values in the final products were alkaline (Table 2), but EVC prototype compost exhibited a higher pH value than AAC (P = 0.0083) and ATC (P = 0.0293) treatments. Soluble salt concentration, indicated by electrical conductivity (EC), was lower in compost obtained from AAC than concentrations obtained from EVC (P = 0.001667) and from ATC (P = 0.002059). The organic matter (OM) content was lower in the AAC final product than ATC (P = 0.0546), while EVC presented an intermediate OM content. EVC compost showed the lowest NKj content (organic-N + NH_4^+-N) (P = 0.036687, for AAC and P = 0.077515 for ATC). Extractable P in AAC was nearly half of ATC and EVC concentration, and no differences were found in Total P values among compost from different prototypes analyzed.

TABLE 2 QUALITY OF FINAL PRODUCTS OF COMPOSTER PROTOTYPES

Variable	Composter Prototypes					
	AAC		ATC		EVC	
	Mean (*)	SD	Mean (*)	SD	Mean (*)	SD
pH	9.12 (a)	0.06	9.31 (a)	0.08	9.62 (b)	0.08
EC (mS/m)	4.97 (a)	0.24	8.46 (b)	0.34	8.76 (b)	0.34
OM (%)	55.43 (a)	2.25	65.13 (b)	3.18	61.23 (ab)	3.19
Total C (%)	27.72 (a)	1.14	32.57 (b)	1.60	30.62 (ab)	1.61
NKj (%)	3.65 (a)	0.15	3.45 (a)	0.20	2.90 (b)	0.21
Extractable P (mg/kg)	1,239 (a)	221	3,266 (b)	313	3,186 (b)	314
Total P %	1.08 (a)	0.11	0.92 (a)	0.15	0.79 (a)	0.15
C/N ratio	7.6	0.00	9.50	0.36	10.60	0.28

(*) Different letters means significant differences ($P < 0, 1$) between treatments (design prototypes)

Data corresponding to final product quality were subjected to a Principal Component Analysis (PCA) where prototypes and variables were included simultaneously (Fig. 5) [1, 29].The PCA employed allowed us to select axes 1 and 2, with a cumulative variance of 93.07 % over the total variability. On the one hand, first axis represents variability with high correlation (≥ 0.6), and all variables (pH, EC, OM, Total N, Total and Extractable P) presented significant relations. On the other hand, second axis represents unexplained variability by first axis, consisting in a positive and significant correlation between OM and Total N.

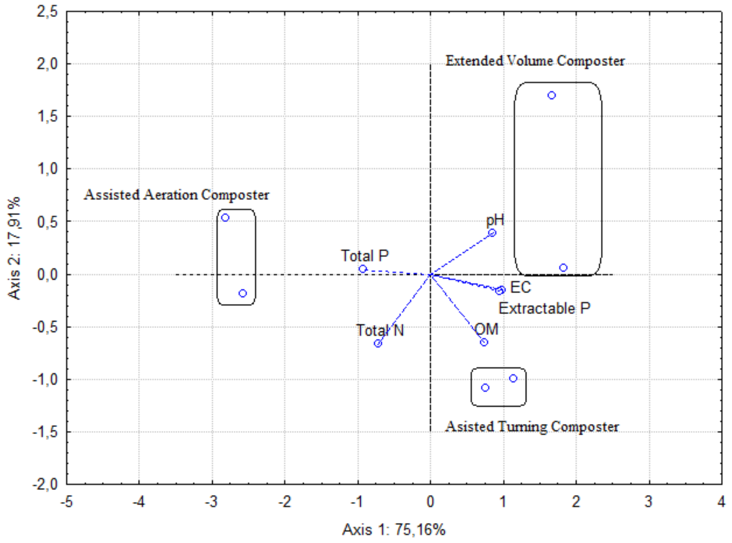

Fig. 5 Principal Component Analysis (axis 1 and 2) of Total P, Total N, OM, pH, extractable P and EC, analyzed on final products

DOI: 10.5963/IJEP0501001

IV. DISCUSSION AND CONCLUSIONS

Based on temperature profile, adequate conditions for composting (i.e. C/N ratio, easily degradable carbon, oxygen and moisture) were achieved for all design prototypes [14, 30-32]. Nevertheless, prototypes proved to be different in their operational aspects, especially in mixing mechanisms, and in final product quality. Thermophilic period length differences between treatments could be related to temperature fluctuations number (peaks) because both, number of peaks and thermophilic period extension, increased in the same order: EVC < ATC < AAC, suggesting that temperature fluctuations extended the thermophilic phase period. These temperature oscillations are probably related to heat exchange with the external environment, so fewer peaks were observed when composter volume capacity increased because of a possible thermal insulation effect. After 14 to 17 days of composting, all prototypes mixtures showed a decrease in temperature, which may be associated with moisture loss, because all cases showed an evident temperature increase watering. Temperature variability could be associated with changes in moisture (excess or deficit) during the composting process or to excess of mixing or leachate accumulation [12, 30]; for example, Kalamdhad & Kazmi [11] did not observe leachate generation during composting on home composters with similar characteristic to the ATC prototype evaluated in this work. Particularly, when small waste batches are composted, moisture loss is expected; furthermore, high summer temperatures characteristic of Argentinean Patagonia xeric climate, made irrigation a critical aspect to the composting process.

Elevated pH values are expected for municipal or kitchen organic waste compost [1, 14, 15]; particularly, alkaline pH is related to elevated quantities of paper, cellulose or ashes incorporated into the composting mix as it was the case in this work [16, 33]. Differences in pH values between EVC compost and the others prototypes final product could not be explained based on available data or design aspects. According to literature, compost produced from catering waste, kitchen waste, or produced using home composters, has a wide variation on electrical conductivity (EC) values (from 1 to 10 dS. m^{-1}) [2, 34, 35], but high soluble salt concentrations are more usually found in compost produced from cooked or preserved food [36]. Although, similar composed feedstock was equally incorporated into each composter, compost from AAC showed half EC values of those obtained from EVC and ATC; this could be attributed to a lower salt loss through lixiviation in these last two treatments prototypes. Beyond that, all EC values obtained were below 10 dS.m^{-1}, reported as a critical level for compost to be applied to a wide range of agricultural and horticultural uses by the USCC [33]. All OM values were within recommended range for most compost uses [33, 37], but it is possible that manual mixing and material tearing applied on AAC and EVC, could have favored a higher particle specific surface, and therefore a higher microbial decomposition and C losing in CO_2 form [10]. This could have resulted in a lower organic matter content than in compost obtained from ATC prototype. Total Nitrogen and extractable P contents were adequate for agronomical applications according to recommended values [1, 10, 33]. Total P values were high, confirming the nutrient quality of kitchen waste [33]. In AAC compost, a significantly lower extractable P concentration was observed, which may be related to a higher potential leachate production for this prototype than for other designs. Bernal et al. [38] and other authors, recommend C/N values < 20 for mature compost, and Iglesias-Jiménez & Perez-García (1989) [39] propose C/N relations < 12 for mature compost. In this work, compost from all prototypes achieved C/N recommended ratio values (AAC: 8; ATC: 10 and EVC: 11).

PCA analysis showed that Total P and Total N are clearly differentiated from other variables, but it will not be appropriate to associate exclusively the AAC treatment to high quality compost, because the variables on the other side of the axis, i.e. pH, CE, OM and extractable P are also associated with compost quality. Furthermore, EVC and ATC also produced compost with high Total N and P values.

Finally, besides composter design aspects that have already been detailed, three main issues should be taken into account as operational and functional recommendations: composter's construction costs and materials, user exposition to composting material and leachate collection and disposal. Composter's construction costs could be reduced by recycling different materials (metallic drums, high density polyethylene and accessories) strengthening decentralized composting strategy by reusing other residual materials. Particularly, in our experiment, recycled plastics were useful to be employed in composter construction and this material did not show weathering after the experiment; this could imply a longer lifetime for plastic composters than for composters made with metallic drums, which showed paint damage and corrosion effects. Furthermore plastic materials could be recycled once again, while metallic drums would be more difficult to dispose in local recycling services, so traditional landfilling or incineration would be the available options for metallic drums disposal. Regarding user exposition, mechanical assistance is a key recommendation for reducing user exposition period to unpleasant odors and flies, so in this study case, ATC design was more comfortable to operate than the others prototypes, because it avoids user-waste direct contact. Leachate generated may be recirculated into the composter to improve the efficiency and quality of compost; however, since adequate leachate management is associated with confidence and social acceptance as home composting practices, complementary analysis to assess potential phytotoxic effects may be recommended.

The three low tech composter prototypes designed, constructed and tested, were effective for catering wastes composting and they could be similarly effective in different climate conditions. Beyond the quality of organic waste compost obtained through this experiment, other outstanding advantages like waste mass reduction, transportation and treatment costs decrease, generator awareness and commitment, and environmental impacts minimization must be pointed out in order to adopt decentralized composting as a sustainable strategy for organic waste treatment.

ACKNOWLEDGEMENTS

We would like to thank P.J.A. SRL Co. for financial support and contribution with prototypes construction; Luis Arceo Co.; Dangen Plásticos Co. and Pablo Fuentes from Petrobras S.A. Co., for providing experimental site and inputs. We also thank L.Garibaldi and L. Halladjian from the National University of Río Negro, and V. Silvert, G. Garrido and E. Pettigiani from the National Institute of Industrial Technology, for their collaboration on statistical analysis and text review.

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