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# Selecting Community Composting Centre Bulking Agent for Sanitization and Minimal N Losses

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## ABSTRACT

As opposed to landfilling which is affordable but not without environmental issues, community composting to recycle food waste (FW) can reduce collection and transportation costs. Nevertheless, community composting centres (CCC) require proper planning to be affordable and good management for a sanitary product and minimal greenhouse gas and ammonia emissions. The objective of the project was therefore to determine the best CCC composting recipe optimizing BA usage and operating costs, and limiting N losses. This objective was met with: laboratory composters testing six duplicate combinations of BA (cereal residue pellets (CRP) alone, CRP with wood chips (WC), and CRP with WC and shredded paper (P)) and two C:N ratios (16-17 and 32-38), and then; using the two best laboratory recipes (CRP alone and CRP with WC) at a C:N of 35-38, test their performance for three years at a CCC in downtown Montreal, Canada. Composting efficiency was evaluated by measuring: the temperature regime during the active phase, and; the loss of mass, carbon and nitrogen (N) during both the active and maturation phases. The laboratory experiment demonstrated that: high C:N ratios minimise N volatilisation while still providing sanitizing thermophilic temperatures; as BA, CRP alone produced a longer thermophilic period and the highest loss of dry mass, organic carbon and N while P shortened the thermophilic period for the high C:N ratio. The CCC tests demonstrated that despite the variation in FW and BA properties over three years, both BA combinations provided sufficient free air space (FAS) for proper compost aeration; thermophilic temperatures were reached when the CCC attendant received the proper training and took the proper precautions to sufficiently aerate the reactor; the best compost recipe of 71% FW, 21% CRP and 8% WC (wet mass) generated sanitizing thermophilic temperatures during five days while minimising N losses.

**Keywords:** compost, cereal residue pellets, wood chips, paper, carbon and nitrogen losses

**Abbreviations**: **BA**, bulking agent; **BD**, bulk density; **C**, organic carbon; **CCC**, community composting centre; **C:N**, carbon to nitrogen ratio; **CRP**, cereal residue pellets; **DM**, dry matter; **ECN**, European Composting Network; **FAS**, free air space; **FW**, food waste; **MSW**, municipal solid waste; **P**, paper; **PD**, particle density; **TK**, total potassium; **TN**, total nitrogen; **TP**, total phosphorous; **WC**, wood chips

## INTRODUCTION

### Objective

The objective of this project was to recommend an effectiveness compost recipe for urban community composting centre (CCC) treating food waste (FW). The recipe optimized the use of bulking agent (BA) reflective of operating costs, and minimized nitrogen (N) volatilization contributing to atmospheric pollution. To achieve this objective, two experiments were conducted: a first using laboratory reactors to test six duplicate bulking agent (BA) combinations and C:N ratios, and; a second test conducted at the Tournesol CCC of downtown Montréal, Canada, where the two best laboratory recipes were tested during three consecutive years. For both the laboratory and CCC experiments, the effectiveness of the compost recipe was evaluated by measuring: the temperature regime during the active composting phase to maximize compost sanitization, and; the resulting N losses to minimise atmospheric pollution. The BA tested consisted of materials readily available in downtown urban centres: cereal residue pellets (CRP) produced from milling operations, wood chips (WC) collected from tree trimmings, and office shredded paper (P).

Although the laboratory experiment used FW composed uniquely of vegetable and fruit residues from a grocery store, the CCC experiment used FW with a limited amount of yard trimmings such as grass and tree leaves. No measurements were conducted on pathogen levels because general research findings including that of the present authors indicate no issue when the waste is clean. Furthermore, no maturity test was conducted on the final CCC compost which is left to mature over one year before being redistributed.

### Justifying community composting centres

Composting is a treatment process now widely accepted for the recycling of the organic fraction of municipal solid wastes (MSW) such as food waste (FW) and yard trimmings, namely grass, horticultural and tree clippings (Diaz *et al*. 1993; Adhikari *et al*. 2008). In 2005, France, Spain, The Netherlands and the United States of America composted 14.3, 32.7, 23.5 and 20.6% of all MSW generated, respectively while in Canada, 12% of total MSW were composted (EPA 2007; Antler 2009; ECN 2009). In the past, centralized mixed MSW composting facilities were built and operated (Antler 2009; ECN 2009) while at present, source separation is preferred for composting to assure the quality of the finished product (Tognetti *et al*. 2006). For example, in Germany, source separation and composting of the organic fraction of MSW is mandatory in many municipalities accounting for the operation of some 800 such composting facilities (ECN 2009). In France, among 119 composting facilities treating MSW, 54 use source separated organic waste as feedstock. In Canada, source separation is mandatory in the maritime province of Nova Scotia, and throughout the country, 54 out of 344 facilities compost source separated food waste generated from residences, industries, businesses and institutions (Antler 2009).

If FW is to be source separated before being composted in a centralized facility, then it must be collected and trans-

**Received: 7 February, 2011. Accepted: 6 July, 2011.**

**Original Research Paper**

ported separately at frequent interval to reduce urban odour nuisances (Mato *et al*. 1994; Iyengar and Bhave 2006). This increases the handling cost of MSW as a whole, even if municipalities can in parallel, less frequently collect the other MSW fractions because of their reduced volume and less putrefactive nature (Lundi and Peters 2004). As an alternative solution to eliminate collection and transportation costs, home composters were introduced for adept recyclers whereas community composting centres (CCC) were instituted for residents not interested or without the space to conduct composting. Nevertheless and despite volunteer time, CCC are not without issues: they must be properly managed or else can become an urban garbage dumping site; unless operated at full capacity with the optimal use of BA, they can be very expensive because of their relatively high investment and labour costs as compared to the volume of compost produced, and; as compared to landfilling, they can release an important amount of ammonia into the atmosphere, leading to N deposition on sensitive ecosystems.

It is possible to compost meat residues along with FW in CCC. Animal carcasses including their bones are successfully decomposed in open composting bin on livestock farms as a sanitary method of disposing of dead animals (Ahn *et al*. 2008). The successful composting of animal carcasses requires their complete covering with a dry BA, lowering risks of flies attracted by material with a moisture content exceeding 50%, and reducing odours attracting rodents. Accordingly, CCC are able to compost meat residues as long as: the composting material is contained in a close vessel preventing the intrusion of rats and other rodents, and; the BA should bring the compost dry matter up to 40% for a good aeration capable of decomposing such waste rich in fats and nitrogen.

## The successful operation of a community composting centre

Community composting centres are not that obvious to run successfully. The present research team of McGill University collaborated with Eco-quartier Jeanne Mance/Mile Ends since 2000 in designing and running its CCC. Eco-quartiers were instituted in the early 1980s by the city of Montreal, Canada, to financially support the hiring of professional at the service of a volunteer organisation representing a city sector (quartier). Their main objectives were to improve their environment by promoting greener practices such as recycling and gardening. The Tournesol CCC created from this collaboration became one of Canada's most successful downtown operations: it won the Phoenix Environmental Prize from the Quebec Ministry of Environment (Canada) in 2006 and the Gold prize in Sustainable Development from the Canadian Geographic Society in 2008.

To achieve such success, the Tournesol CCC was not created over night. The first step was to create awareness towards composting among its citizens. Accordingly and from 2000 to 2002, the Eco-quartier Jeanne Mance/Miles End held workshops and published information on source separation. The second step was to design and build a CCC at a reasonable cost to produce compost at a competitive value. From 2002 to 2003, the McGill University team designed an in-vessel composter adapted to urban areas with limited space. To prevent composter corrosion and minimize weight, the body was built of double walled corrugated polyethylene tubing (Morin *et al*. 2003). This body was rotated at a speed of 5 rpm to mix and aerate the compost. The very first prototype built for $8 000 Can. In 2003 was a batch composter measuring 0.9 m in inside diameter by 3m in length with a total and useful capacity of 1.9 and 1.4 $m^3$ (**Fig. 1A**). The tubing's corrugated exterior wall, glued to a smooth inner wall, produced an insulation value of 1.0 $m^2$ °C/W.

The third step in successfully implementing the Tournesol CCC was to find a location easily accessible to the general urban population. The Tournesol CCC was located along a stone wall in the Jeanne Mance Park, next to a popular path linking a residential area to downtown Montreal (**Fig. 1A**). The floor of the Tournesol CCC was build of concrete patio slabs placed over a bed of crushed stone; the floor could thus be easily drained when washed and even removed if the CCC was ever closed. A fence only 1.2 m high surrounded the CCC to allow passersby to see the composting operation. Although at the outskirt of the park, the Tournesol CCC was quite visible and attracted the attention of a large citizenship including every spring, being a popular outing for school children. Accordingly, the Tournesol CCC became not only a composting centre for limited population but also and education centre.

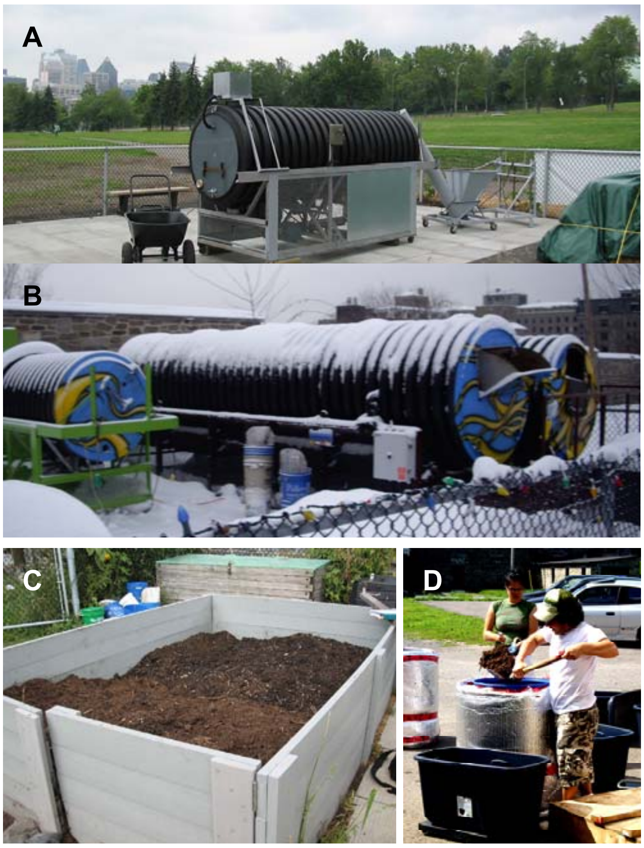

**Fig. 1** The experimental 1.4 $m^3$ composter built of double polyethylene tubing with a corrugated exterior wall (**A**) aerated by turning at 5 rpm and by leaving the top door open otherwise; the 2 larger reactors added in 2005 and 2009 besides the smaller prototype on the left (**B**). The compost maturation box for the Tournesol Community Composting Centre build of wood slates (**C**). Barrels used as experimental laboratory composters for the active phase (covered with an aluminum water-proof liner insulated blanket) and containers used for the maturation phase (rectangular container) (**D**).

The fourth step was to organize the operation of the Tournesol CCC. To control the FW coming into the centre, a specific number of families were required to register, and agree on four opening periods on a weekly basis. During these periods, the attendant was present to receive the FW, prepare and feed the compost mixture, and rotate the reactor for aeration. With a free air space (FAS) exceeding 30%, compost mixtures store enough oxygen to supply the microbial activity for one h. Therefore, composter should preferably be rotated frequently for a short time. Heat loss during aeration is less of an issue with in-vessel reactors enclosing the material as opposed to a windrow.

Once in operation, the Tournesol CCC quickly needed more composting capacity to service a larger population and lower its operating costs. The experience gained with the 2003 prototype allowed the McGill team to improve its design and build in 2005 a new continuously fed reactor measuring 1.2 m in inside diameter and 6.0 m in length for a total and useful capacity of 6.8 and 5.1 $m^3$. This larger composter was built at a cost of $20 000. Finally, a further improved version was added in 2009 at a cost of $30 000; it measured 1.8 m in diameter by 6 m in length (**Fig. 1B**), with a total and useful capacity of 15.3 and 11.4 $m^3$. To mature the compost, the Tournesol CCC used a box built wood slats (**Fig. 1C**). Eight years of experience now suggest optimizing the capacity of a CCC based on the local population density and an access within 500 m. For the Montreal downtown area, this corresponds to a CCC with a useful reactor capacity of 30 $m^3$ for 0.3 kg of FW/person/day and a population density of 3600/$km^2$ where 80% of the population participates.

To further improve the compost production cost, the Tournesol CCC focused its attention on recipe formulation, considering that the BA represents 30 to 40% of the total expenditure. Minimizing the BA cost must still, nevertheless, provide good aeration to minimize greenhouse gas emissions and achieve sanitization thermophilic temperatures. As BA for the composting of FW in CCC, cereal residue pellets (CRP) were an interesting solution because of: their high moisture absorption capacity of 6 kg water/kg of dry mass (Adhikari *et al.* 2008); their faster decomposition as opposed to wood chips, and; their small size requiring no chopping equipment subject to vandalism in an urban park such as Jeanne Mance. Made from flour milling waste representing 25% of the total mass of cereal processed, CRP offers a readily biodegradable carbon source capable of immobilising N and minimizing ammonia volatilization.

As opposed to landfilling, the active phase of composting can release into the atmosphere a substantial amount of nitrogen (N) through ammonia volatilization. Considering the world production of FW of 330 million tons/yr (Adhikari *et al.* 2006), and that 50% of N can be lost during composting (Barrington *et al.* 2002), CCC can load the atmosphere with 3 million tons N/yr. Atmospheric N loading leads to several well acknowledged environmental issues especially resulting from nitrogen deposition at significant rates on sensitive ecosystems: increased risks of eutrophication (Seedorf and Hartung 1999; Sutton *et al.* 2009); water acidification (Ulrich 1991); accumulation of nitrogen introducing changes in plant species, for soils (Ellenberg 1988; Aaby 1994) and in benthonic and pelagic organisms, in water such as corals and algae (Doney *et al.* 2007); increased organic soil subsidence (Sutton *et al.* 1993); increased sensitivity to secondary stresses such as pathogens, frost and drought (Brown 1995), and; increased $CO_2$ emissions from forest soils (Fleischer 2003). Besides sensitive ecosystems, van der Eerden *et al.* (1998) report that major ammonia volatilization sources have damaged tomatoes, cucumbers, conifers and fruit crops. Furthermore, agricultural soils with a low buffering capacity can become acidic when exposed to the ammonia deposition.

Accordingly, a priority for the Tournesol CCC was to optimize its compost recipe to minimize the use of BA and the loss of N while still providing sufficient aeration to produce sanitizing thermophilic temperatures. The following sections describe the research methodology which, in the laboratory evaluated six recipes to select the best two for their validation at the Tournesol CCC, during three consecutive years.

## MATERIALS AND METHODS

### Laboratory recipe optimization

#### *1. Experimental set-up and substrates*

The active composting phase was conducted outside in duplicate batches using vertical 150 L polyethylene composting barrel measuring 1.0 m in height and 0.45 m in inside diameter. The mineral wool layer installed around the barrels offered an insulation value of 2.0 $m^2$ °C/W (**Fig. 1D**). A plenum was created at the bottom of each barrel using a wire mesh to passively aerate the compost material using bottom perforations. These perforations also served as drains for the leachate. The maturation phase was conducted outside using 100 L rectangular polyethylene containers measuring 0.6 m in height by 0.6 m in width and 0.3 m in length. The containers were not insulated but their content was protected from rainfall using a partially opened cover.

Provided by local grocery stores and consisting mainly of fruit and vegetable residues, the food waste (FW) was further checked for foreign material upon reception and stored at -4°C until used. The bulking agents (BA) used in this trial were: cereal residue pellets (CRP); wood chips (WC) consisting of chopped tree and shrub residues, and; shredded writing paper (P). To adjust the C:N of the first series of compost mixtures, commercial grade ammonium-nitrate (30% N) was purchased from a fertilizer plant. All experimental materials except for the N amendment were characterized from five composite samples before balancing the compost recipes and starting the experiment (**Table 1**). The free air space (FAS) of all compost mixtures was calculated from the wet bulk and particle density of the compost and its materials, respectively (Barrington *et al.* 2002):

$$\text{FAS}\ (\%) = 100 \times (1 - (BD / PD) \qquad (1)$$

where $BD$ is bulk density in (kg/$m^3$) and $PD$ is the wet particle density determined using kerosene (kg/$m^3$).

#### *2. Methodology*

Six FW and BA compost formulas (3 BA combinations × 2 C:N ratios) were tested in duplicate to measure the effect of BA type and C:N ratio on temperature regime, and dry mass, carbon and nitrogen losses during both the active and the maturation phases (**Table 2A, 2B**). The first set of treatments with a C:N ratio of 16-17 was started in early June while the second set with a C:N ratio of 32-38 was started in mid July. For each set, the combination of BA consisted of CRP alone, CRP with WC, and CRP with WC and P. These three BA combinations were designed to test: different levels of available carbon for the immobilization of nitrogen, as WC and P are considered less biodegradable compared to CRP; a different mixture structure where CRP and P lose their structure when wet as opposed to WC, and; shredded paper as BA since it is abundant, can absorb moisture and is relatively cheap. In combination with the three BA recipes, two levels of C:N were tested, where the higher and lower level consisted of using the FW and BA without and with $NH_4NO_3$, respectively. In this experiment and as nitrogen supplement, $NH_4NO_3$ was preferred to urea which after breaking down into $NH_4^+$ drives the pH to high alkaline values in the range of 10 (Barrington *et al.* 2002; Erickson *et al.* 2009). Furthermore, the nitrate counter part of $NH_4NO_3$ can be used by microbes as N source (Alexander 1977).

For both sets of treatments (low and high C:N of 16-17 and 32-38), the compost mixtures were randomly assigned to a composting barrel. The FW and BA mixtures, with or without the N amendment, were mixed manually in a wide open container and then, transferred to individual barrel composters. The initial and final wet densities of the compost materials were measured while in the composters. During the active phase, the barrel content was mixed once using a pitch fork.

After an active phase of 30 days and reaching temperatures close to ambient, the composts were transferred into individual 100-L containers for 50 days of maturation. After 30 and 50 days of maturation, all composts were weighed, mixed and sampled for analysis, while also measuring the wet bulk density in the container. For all sessions, three composite samples were collected randomly throughout the mass for characterization.

### Composting centre recipe application

#### *1. Experimental reactors and materials*

Batch trials were conducted using the Tournesol batch reactor measuring 3.0 m in length by 0.9 m in inside diameter (**Fig. 1A**). This composter was operated from June to September, during the three consecutive summers of 2007, 2008 and 2009. For all batches, the composter was filled with at least 1.0 $m^3$ of compost and the mixtures were aerated by turning the composter for a short while, several times weekly, and in the mean time, by leaving the top door open to create some passive aeration from the bottom perforated drain. The compost centre operator was left in charge of the aeration process.

Provided by 120 local families, the FW consisted of: fruit and vegetable residues, plain starches such as rice and bread, egg shells, ground coffee beans, coffee filters and tea bags, and a limited amount of yard trimmings. The bulking agents (BA) used in this trial consisted of cereal residue pellets (CRP) purchased from a local supplier, and wood chips (WC) consisting of chopped tree branches and shrubs obtained from a municipal collection service. Before being used, all experimental materials were analyzed for dry matter (DM), pH, organic carbon (C), total nitrogen (TN), total phosphorous (TP) and total potassium (TK) (**Table 3**).

### *2. Methodology*

This phase of the project consisted in validating the laboratory recipes using the Tournesol 1.9 $m^3$ reactor. As BA and for the in-vessel composting tests, only CRP was used in 2007, while in 2008 and 2009, the two compost recipes were monitored, one with only CRP and the other with CRP and WC (**Table 4**). Compost formulas were tested one at the time, between June and September of each year. For all trials, the FW was received at a rate of 40 kg/day, which filled the composter over 10 days more or less. Upon reception, the FW was checked for foreign material, weighed and place in a container to be manually chopped and mixed with the required amount of BA. The mixture was then transferred to the composter. The process was repeated until at least 575 kg or 1.0 $m^3$ of compost mixture was added. During every filling day, a composite sample of the FW was brought to the laboratory for analysis. The CRP and WC obtained early in the season were sampled compositely three times for characterization.

Once the in-vessel composter was filled, the mixture was reacted for 25 days while keeping track of its temperature regime every two days using a long stem thermometer. The compost material was mixed and aerated several time weekly by rotating the in-vessel composter. The aeration frequency depended on the operator's availability. After 25 days, the composter was emptied using a wheel barrel of known volumetric capacity. Three times during the emptying process, some compost material was used to fill a 20-L bucket and weighed to obtain its bulk density and to compute the total mass of the compost removed from the composter. Three composite samples were also collected during the emptying operation to characterize the compost.

## Analytical procedure

Using standard laboratory methods (APHA 2005), the FW, BA and matured composts were characterized for: dry matter (DM); organic carbon (C); pH; total Kjeldahl nitrogen (TKN) assumed equal to TN since nitrates and nitrites were found in negligible amounts; TP, and; TK. Dry matter (DM) was determined by drying at 103°C for 24 h (Scientific John by Sheldon Manufacturing Inc., Cornelius, Oregon, USA). Organic carbon was determined from the dried samples by burning at 550°C in a muffle furnace (Blue M Electric Co., Blue Island, USA) for 4 h. Total Kjeldahl nitrogen, TP and TK were determined after digesting the samples with sulphuric acid and 50% hydrogen peroxide at 500°C for 15 min. The TKN of the digested samples was quantified by measuring its $NH_3$-N content at a pH of 13, using a $NH_3$ sensitive electrode (Orion, Boston, USA, model BCN). The TP and TK of the digested samples were quantified colorimetrically, at a pH of 7, using a spectrophotometer (Hach, Model DR 5000, Loveland, Co, USA).

The pH was determined using a pH/Ion meter (Orion, Boston, USA, model 450) and a pH probe. All samples were soaked for 24 h without shaking at 5°C, in just enough distilled water to produce a solution in which to place the probe, which corresponded to 20 and 50 ml for 10 g of FW and BA, respectively.

The free air space (FAS) was computed using Equation (1) from the wet bulk and particle densities of the initial compost and their materials, respectively. The wet particle density was determined by placing 5 to 10 g of material in a graduated cylinder and submerging with kerosene. After initially verifying the density of kerosene (0.78 kg/L) and determining the mass of kerosene added, the particle density was calculated (Barrington *et al*. 2002) using Equation (1).

## Statistical analysis

The effect of treatment or BA combination was analyzed using ANOVA (Steel and Torrie 1986) where blocks were assigned to each C:N ratio and the Least-Square method was used to identify the significant treatments at 95% confidence level. Standard deviation values were computed using Excel (Microsoft Office 2003). The Student's *t*-test at 95% confidence level was used to compare the FW collected for each series of composting trial (Steel and Torrie 1986).

## RESULTS AND DISCUSSION

## Laboratory compost recipe optimization

### *1. Characteristics of experimental materials*

The experimental materials used in the compost recipes are described in **Table 1**. In terms of FW, the chemical characteristics were similar for the two sets of compost experiments, namely for that with a C:N of 16-17 and 32-38, except for the TN content. The FW collected in two batches offered a dry matter (DM) of 11.3 and 12.4% and an organic carbon (C) of 51%, where both parameters among the five samples analyzed were not statistically different ($p < 0.05$). For the total nitrogen (TN) of both FW batches, the values were significantly different at 2.40 and 1.26%, respectively. Accordingly, the two FW batches offered a C:N ratio of 21 and 41. Whereas at 930 and 960 kg/$m^3$ the wet particle density was similar among FW batches, the wet bulk density differed with respective values of 630 and 530 kg/$m^3$.

The bulking agents, namely the cereal residue pellets (CRP), the wood chips (WC) and the shredded paper (P) offered a respective dry matter content of 89, 40 and 92%, with an organic carbon of 47, 52 and 48% (dry matter basis) and a TN of 1.1, 0.4 and 0.07% (dry matter basis). Accordingly, the BA offered a C:N ratio of 43, 140 and 690, respectively. In addition, the CRP offered a high level of minerals, especially potassium (TK), which adds to the compost fertilizer value. To inoculate the experimental mixtures, mature compost produced one year earlier was used as described in **Table 1**.

The experimental mixtures used for the compost tests are described in **Table 2A** and **2B**. The low C:N recipes offered a fairly regular ratio of 16 to 17, as obtained by adding the required amount of $NH_4NO_3$. The C:N ratio of the second series was more variable, ranging from 32 to 38, depending on the BA used. The FW and CRP with WC and P offered the highest C:N ratio, because of the high shredded paper C:N ratio. The initial wet bulk density of the compost mixtures was quite variable ranging from 540 to 680 k/$m^3$. Nevertheless, all initial mixtures offered FAS exceeding 30%, except for the BA including P at the higher C:N ratio with a FAS of 26%.

### *2. Temperature regime*

**Fig. 2A** and **2B** illustrate the compost temperature measured during the active phase for both C:N ranges of 16-17 and 32-38. The compost mixtures with a C:N of 16-17 quickly reached thermophilic temperatures after 2 days for all BA combinations with CRP alone showing the lowest thermophilic temperature at this time. Nevertheless, the temperature of the CRP compost surpasses that of the other compost on day 3 to remain above for the rest of the active phase. This slower temperature rise obtained with CRP alone is explained by its smaller particle size and likely lower pore oxygen storage capacity. Thermophilic temperatures above 50°C were maintained for 9 days with CRP alone and CRP/WC/P, and for 7 days with CRP/WC. Among the duplicate compost mixtures tested, no single recipe produced a temperature regime which was significantly different ($P < 0.05$).

**Table 1** Physico-chemical characteristics for the laboratory experimental materials.

| Material | Physico-chemical characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **pH** | **DM (%)** | **C (% DM)** | **TN (% DM)** | **C:N** | **TP (% DM)** | **TK (% DM)** | **PD $kg/m^3$** | **BD $kg/m^3$** |
| Food waste | | | | | | | | | |
| C:N = 16-17 | 4.57 ± 0.36 | 11.3 ± 2.6 | 50.9 ± 2.4 | 2.40 ± 0.77 | 21 | 4.44 ± 1.32 | 3.2 ± 1.4 | 920 ± 25 | 630 ± 50 |
| C:N = 32-38 | 4.07 ± 0.33 | 12.4 ± 3.3 | 51.0 ± 1.0 | 1.26 ± 0.32 | 41 | 3.01 ± 0.73 | 22.4 ±3.7 | 960 ± 30 | 530 ± 35 |
| Cereal residue pellets (CRP) | 5.57 ± 0.15 | 88.8 ± 0.2 | 47.2 ± 0.5 | 1.09 ± 0.35 | 43 | 1.14 ± 0.6 | 12.4 ± 2.4 | 1220 ± 30 | 550 ± 25 |
| Wood chips (WC) | 5.99 ± 0.12 | 39.8 ± 2.0 | 52.9 ± 1.1 | 0.38 ± 0.08 | 140 | 0.24 ± 0.05 | 3.5 ± 0.86 | 550 ± 30 | 180 ± 10 |
| Shredded paper (P) | 8.75 ± 0.20 | 92.4 ± 2.7 | 48.2 ± 0.2 | 0.07 ± 0.04 | 690 | 0.17 ± 0.09 | 2.6 ± 1.7 | 520 ± 50 | 30 ± 5 |
| Compost | - | 28.2 ± 0.8 | 45.2 ± 0.2 | 4.0 ± 0.20 | 8 | 0.20 ± 0.08 | 2.5 ± 0.96 | 1150 ± 45 | 600 ± 45 |

Note: DM – dry matter; C – organic carbon; TN total nitrogen equated to total Kjeldahl nitrogen; TP – total phosphorous; TK – total potassium; PD – particle density; BD – wet bulk density. ± presents the standard deviation for *n*=5

**Table 2A** Laboratory duplicated experimental compost recipes.

| Compost recipe | Composition | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Food waste (kg)** | **CRP (kg)** | **WC (kg)** | **P (kg)** | **N amendment (kg)** | **Compost inoculum (kg)** | **Total mass (kg)** |
| **C:N of 16-17** | | | | | | | |
| FW with CRP | 49 | 16 | 0 | 0 | 0.8 | 10 | 75.8 |
| FW with CRP and WC | 40 | 11 | 5 | 0 | 0.8 | 10 | 66.8 |
| FW with CRP, WC and P | 39 | 7 | 5 | 4 | 0.85 | 10 | 65.9 |
| **C:N of 32-38** | | | | | | | |
| FW with CRP | 49 | 16 | 0 | 0 | 0 | 10 | 75.0 |
| FW with CRP and WC | 40 | 11 | 5 | 0 | 0 | 10 | 66.0 |
| FW with CRP, WC and P | 39 | 7 | 5 | 4 | 0 | 10 | 65.0 |

Note: FW – food waste; CRP – cereal residue pellets; WC – wood chips; P – shredded paper; the N concentration was amended using $NH_4NO_3$.

**Table 2B** Initial physico-chemical characteristics of the laboratory experimental composts.

| Treatment | Physico-chemical characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **FAS (%)** | **DM (%)** | **C (% DM)** | **TN (% DM)** | **TP (% DM)** | **TK (% DM)** | **PD $kg/m^3$** | **BD $kg/m^3$** | **CN** |
| **C:N of 16-17** | | | | | | | | | |
| FW with CRP | 33 | 30.8 | 46.2 | 2.74 | 0.82 | 8.6 | 1025 | 683 ± 30 | 17 |
| FW with CRP and WC | 30 | 29.8 | 46.4 | 2.89 | 0.72 | 7.52 | 989 | 659 ± 9 | 16 |
| FW with CRP, WC and P | 39 | 30.3 | 46.5 | 2.76 | 0.54 | 5.75 | 948 | 542 ± 12 | 17 |
| **C:N of 32-38** | | | | | | | | | |
| FW with CPR | 40 | 30.8 | 48.0 | 1.49 | 0.88 | 8.56 | 1041 | 625 ± 14 | 32 |
| FW with CRP and WC | 42 | 29.6 | 48.5 | 1.48 | 0.78 | 17.5 | 1001 | 561 ± 17 | 33 |
| FW with CRP, WC and P | 26 | 30.1 | 48.6 | 1.29 | 0.60 | 5.74 | 959 | 671 ± 29 | 38 |

Note: FW – food waste; CRP – cereal residue pellets; WC – wood chips; P – shredded paper; DM – dry matter; C – organic carbon; TN total nitrogen equated to total Kjeldahl nitrogen; TP – total phosphorous; TK – total potassium; PD – particle density; ± is the standard deviation for BD on *n* = 5 samples.

**Table 3** Physico-chemical characteristics of the laboratory experimental composts after 30 days of active phase and 50 days of maturation.

| Treatment | Characteristics after the active phase | | | | | Characteristics after the maturation phase | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **pH** | **DM (%)** | **C (% dm)** | **TN (% dm)** | **BD ($g/m^3$)** | **pH** | **DM (%)** | **C (% dm)** | **TN (% dm)** | **BD ($g/m^3$)** |
| **C:N of 16-17** | | | | | | | | | | |
| FW with WC | 8.0 ± 0.1 | 34.8 ± 3.54 | 42.6 ± 0.20 | 2.87 ± 0.37 | 485 ± 30 | 8.3 ± 0.2 | 43.8 ± 14.1 | 39.3 ± 2.34 | 3.20 ± 0.55 | 295 ± 20 |
| FW with CRP and WC | 7.8 ± 0.1 | 38.1 ± 3.98 | 42.9 ± 0.01 | 2.73 ± 0.58 | 380 ± 10 | 8.4 ± 0.1 | 55.4 ± 5.81 | 39.8 ± 1.04 | 3.33 ± 0.07 | 280 ± 30 |
| FW with CRP, WC and P | 7.7 ± 0.1 | 39.7 ± 0.21 | 40.5 ± 0.08 | 3.44 ± 1.02 | 360 ± 5 | 8.3 ± 0.3 | 49.8 ± 12.1 | 40.4 ± 0.08 | 3.19 ± 0.62 | 400 ± 30 |
| **C:N of 32-38** | | | | | | | | | | |
| FW with CRP | 7.8 ± 0.1 | 36.6 ± 2.41 | 41.9 ± 0.16 | 2.26 ± 0.24 | 535 ± 15 | 8.1 ± 0.3 | 45.2 ± 1.39 | 41.8 ± 0.50 | 2.16 ± 0.27 | 505 ± 20 |
| FW with CRP and WC | 8.1 ± 0.1 | 48.0 ± 1.99 | 44.0 ± 0.53 | 1.96 ± 0.15 | 550 ± 05 | 7.9 ± 0.3 | 52.6 ± 1.09 | 43.0 ± 0.41 | 1.98 ± 0.13 | 425 ± 10 |
| FW with CRP, WC and P | 7.6 ± 0.2 | 46.0 ± 0.63 | 42.5 ± 0.60 | 1.46 ± 0.07 | 540 ± 10 | 7.5 ±.01 | 69.53 ± 7.35 | 42.4 ± 1.74 | 1.41 ± 0.04 | 475 ± 15 |

Note: FW – food waste; CRP – cereal residue pellets; WC – wood chips; P – shredded paper. DM – dry matter; C – organic carbon; TN total nitrogen equated to total Kjeldahl nitrogen; TP – total phosphorous; TK – total potassium; BD – wet bulk density; ± is the standard deviation for *n*=2.

As for the compost with a high C:N ratio of 32-38 (**Fig. 2B**), thermophilic temperatures were also reached after 2 days for all BA combinations with once more, CRP alone showing the lowest thermophilic temperature at this time, but the highest after the third day. For both C:N ratio, CRP thus demonstrated a slightly softer structure providing less aeration at the start. Thermophilic temperatures above 50°C were maintained for 6 days with CRP alone and CRP/WC, and for 5 days with CRP/WC/P. For the high C:N ratio, CRP alone produced a significantly higher temperature regime followed by CRP/WC and then CRP/WC/P ($P < 0.05$). Therefore, under conditions of limited N availability or a high C:N ratio, the biodegradability of the BA combination plays an important role in maintaining thermophilic temperatures. Furthermore, a low C:N ratio extends the thermophilic period as compared to a high C:N ratio ($P < 0.05$).

Nevertheless, a high C:N ratio in the range of 35 may be sufficient to produce sanitizing thermophilic conditions above 50°C. Conditions for compost sanitization were established by previous researchers. Erickson *et al.* (2010) monitored chicken manure and peanut hull compost piles for *Escherichia coli*, *Escherichia coli* 0157:H7, *Listeria innocua*, and avirulent *Salmonella* Typhimurium. Despite temperatures exceeding 45°C for over 5 days early in the composting process, only *Escherichia coli* was inactivated after 3 days while *Escherichia coli* 0157:H7, *Listeria in-*

**Table 4** Characteristics of the CCC experimental compost materials.

| Year | Food waste | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **PD (wet kg/m$^3$)** | **pH** | **TS (%)** | **TN (% TS)** | **TP (% TS)** | **TK (% TS)** | **C (% TS)** | **C:N** | **Bulk density wet (kg/m$^3$)** |
| Food waste (FW) | | | | | | | | | |
| 2007 | 1029 ± 27 | 5.0 ± 0.5 | 15.5 ± 3.3 | 1.90 ± 0.60 | - | - | 47.8 ± 2.3 | 25 | 535 ± 32 |
| 2008-1 | - | 5.1 ± 0.4 | 16.0 ± 0.3 | 1.60 ± 0.37 | 0.11 ± 0.03 | 1.83 ± 0.82 | 47.4 ± 2.6 | 30 | 537 ± 26 |
| 2008-2 | 919 ± 9 | 4.8 ± 0.6 | 10.6 ± 0.1 | 2.40 ± 0.60 | 0.20 ± 0.04 | 3.70 ± 1.10 | 44.8 ± 3.3 | 19 | 625 ± 60 |
| 2009 | 1041 ± 16 | 4.4 (0.4) | 17.3 (9.3) | 1.66 (0.66) | 0.29 (0.05) | 2.32 (0.55) | 43.9 (1.0) | 26 | 668 ± 55 |
| Cereal residue pellets | | | | | | | | | |
| (CRP) | 1474 ± 10 | 5.8 ± 0.2 | 94.0 ± 0.1 | 0.64 ± 0.05 | - | - | 50.1 ± 0.6 | 84 | 588 ± 30 |
| 2007 | 1216 ± 33 | 6.3 ± 0.2 | 91.8 ± 0.2 | 0.89 ± 0.03 | 0.11 ± 0.07 | 2.35 ± 0.49 | 49.3 ± 0.4 | 55 | 589 ± 10 |
| 2008 | 1203 ± 33 | 6.0 ± 0.3 | 88.8 ± 0.2 | 1.10 ± 0.04 | 0.11 ± 0.06 | 1.24 ± 0.24 | 54.4 ± 1.5 | 50 | 555 ± 22 |
| 2009 | | | | | | | | | |
| Wood chips (WC) | | | | | | | | | |
| 2007 | 973 ± 61 | 5.2 ± 0.3 | 61.9 ± 7.7 | 0.28 ± 0.23 | - | - | 52.2 ± 1.1 | 186 | 250 ± 12 |
| 2008 | 553 ± 30 | 6.3 ± 0.2 | 62.0 ± 4.8 | 1.03 ± 0.05 | 0.66 ± 0.06 | 0.51 ± 0.1 | 54.4 ± 1.5 | 56 | 164 ± 20 |
| 2009 | 963 ± 23 | 6.2 ± 0.3 | 60.2 ± 2.0 | 0.62 ± 0.27 | 0.10 ± 0.05 | 0.14 ± 0.2 | 52.9 ± 1.1 | 171 | 300 ± 37 |

Note: FW- food waste; CRP – cereal residue pellets; WC – wood chips; PD - particle density; TN – total nitrogen; TP – total phosphorous; TK – total potassium; C – organic carbon; ± presents the standard deviation for $n = 5$.

*nocua* and *Salmonella* Typhimurium were still present after 56 days at a depth of 0.3 m below the pile surface. In another study, Erickson *et al.* (2009) used ammonium sulphate to modify the C:N ratio of a compost mixture of dairy cow manure and straw. In a controlled reactor and for temperatures above 45°C, a lower C:N ratio of 20 inactivated the inoculated *Salmonella* spp within 4 days while a higher C:N ratio of 30 and 40 required 5 days for inactivation. By applying a heat treatment, Gong (2007) inactivated *Escherichia coli* and *Salmonella* for cow manure inoculated with $10^6$ CFU/g DM and kept at 50°C for 24 h. Galvis *et al.* (2010) also found that a population of *Salmnella* spp., regularly found in cattle manure in Peru, can grow within compost piles at temperatures of 65°C. According to this research, a closed reactor maintains uniform sanitizing temperatures within the compost, as opposed to piles and windrows. Thus, closed reactors are better designed to sanitize compost materials. Furthermore, temperatures exceeding 50°C for at least 5 days can offer a safe sanitization criterion. Therefore and in this experiment, all BA combinations even at the higher C:N ratio of 32-38, did achieve sanitizing temperature, with CRP/WC/P being on the limit. If shredded paper is to be used in the BA combination, it may be advisable to correct the C:N ratio to 25 to ensure the proper duration of thermophilic temperatures.

### *3. Impact on carbon and nitrogen losses*

For all compost mixtures, **Fig. 2C, 2D** and **2F** illustrate the remaining dry mass, organic carbon and N over time, respectively. The compost with CRP lost significantly more dry matter and carbon, followed by CRP/WC, and then CRP/WC/P ($P < 0.05$). Thus, CRP was more biodegradable than WC and P, also explaining the longer thermophilic regime. For all BA combinations, the C:N ratio of 16-17 produced a significantly higher loss in DM and C as compared to the C:N ratio of 32-38 ($P < 0.05$) (**Table 3**), indicating that higher N levels foster a more active microbial degradation as also observed from the longer thermophilic regime.

The BA significantly affected N losses. For the high and low C:N ratio respectively, CRP alone lost the most nitrogen at 38 and 58%. In comparison, CRP/WC and CRP/WC/P lost 20 and 40% nitrogen irrespective of C:N ratio. Furthermore, the N supplemented to obtain the lower C:N ratio was mostly lost for all BA combinations. Accordingly, N versus C losses produced the following regression equation for the low and high C:N ratio respectively:

$$\text{N (kg)} = -0.91 + 0.077\ \text{C (kg)} \quad R^2 = 1.00 \qquad (2)$$

$$\text{N (kg)} = 0.20 + 0.003\ \text{C (kg)} \quad R^2 = 0.30 \qquad (3)$$

Equations (2) and (3) indicate that N loss was highly correlated with C loss for the low C:N ratio, but not for the high C:N ratio where N losses were similar irrespective of C losses. High levels of N losses are generally associated with composts offering initially a low C:N ratio (Kithome *et al.* 1999), but available N must still be high enough to sufficiently activate microbial communities and produce sanitizing temperatures (Tuomela *et al.* 2000). When BA offers a low biodegradability, Ogunwande *et al.* (2008) found C:N to have minimal impact on N losses with chicken manure and saw dust compost at C:N ratios of 20, 25 and 30. Eghball *et al.* (1997) observed that ammonia was the most important form of N losses during the composting of beef cattle manure.

## CONCLUSION FROM LABORATORY TESTING

All bulking agent (BA) combinations at both C:N ratio offered sufficient microbial nutrients for the production of sanitizing temperatures of over 50°C for at least 5 days, with the CRP/WC/P combination barely meeting these conditions at the high C:N ratio. This resulted from the lower biodegradability of the BA and the FAS at a low value of 26%. The low C:N ratio lost most of the supplemented N indicating that the high C:N ratio is preferred in terms of limiting atmospheric N emissions. Furthermore, CRP/WC was more efficient than CRP alone in limiting N losses, at both the high and low C:N ratios. The CRP/WC/P combination without amendment was not selected for the CCC tests considering that it barely produced sufficiently long thermophilic conditions for sanitization. Accordingly, the two best recipes selected for further validation at the Tournesol CCC were CRP alone and CRP/WC both at a high C:N ratio in the range of 35.

## Verifying the compost recipe performance at the community composting centre

### *1. Food waste and bulking agent characteristics*

The characteristics of the FW and BA for all three years, 2007, 2008 and 2009, are presented in **Table 4** while the resulting compost mixture characteristics are presented in **Table 5**. The FW characteristics varied among years, with the TS ranging from 10 to 17%, C ranging from 44 to 48% TS, TN ranging from 1.7 to 2.7% TS, TP generally under 0.3% TS and TK ranging from 1.8 to 3.7% TS. The wet particle density of the FW ranged from 920 to 1030 kg/m$^3$, with the 2008 density being slightly lower because of more yard trimmings, also reflected by higher TN and TK values. The bulk density ranged from 535 to 670 kg/m$^3$.

The CRP offered a relatively high dry matter ranging from 89 to 94%, C ranging from 49 to 54% TS, TN ranging from 0.64 to 1.1% TS, TP of 0.1% TS and TK ranging from 1.24 to 2.35% TS. The wet particle and bulk densities of CRP ranged from 1200 to 1470 kg/m$^3$, and 555 to 590 kg/m$^3$. The WC offered a dry matter in the range of 62%, C in the range of 53% TS, TN ranging from 0.3 to 1.0% TS, TP ranging from 0.1 to 0.6% TS and TK ranging from 0.14 to 0.51% TS. The WC offered a wet particle and bulk densities of 553 to 960 kg/m$^3$ and 164 and 300 kg/m$^3$, where the lower 2008 value resulted from the presence of leaves and yard trimmings.

Despite the annual variation in FW and BA characteristics for the tested recipes using a FW: CRP: WC ratio of more or less 71: 21: 8 and a FW: CRP ratio of 80: 20, the C:N ratio remained within the narrow range of 38 to 43 and the dry matter within 31 and 35%.

### *2. Temperature regime and mass balance for the compost batches*

The temperature regime obtained for the 2008 and 2009 batches are illustrated in **Fig. 2F**. Although compost temperatures were not recorded in 2007, a McGill University representative was on site during the entire composting process to ensure that the aeration regime did produce thermophilic temperatures.

In 2008, the first test (batch 2 with FW/CRP) was started at the end of June 2008, shortly before two long holiday weekends, a period during which the operator was not regularly available to turn the composter. Accordingly, thermophilic temperatures of 50°C were not reached within a few days, but were established after 10 days by increasing the frequency of aeration through composter rotation. The second test of July/August 2008 (batch 3 with FW/CRP/WC) was supervised more closely and sanitizing temperatures exceeding 55°C were achieved. In 2009, both compost batches (4 with FW/CRP and 5 with FW/CRP/WC) were poorly aerated as temperatures seldom exceeded 50°C. Despite the variable temperature regimes, all fresh and composted mixtures offered FAS values over 36%, which were sufficient to ensure proper aeration. Furthermore, laboratory tests had demonstrated that CRP with and without WC could easily produce sanitizing thermophilic temperatures at C/N ratios in the range of 35. Therefore, the attention which the centre operator gives to aeration plays a major role in obtaining the proper sanitizing thermophilic temperatures. Using a timer to regularly rotate the in-vessel composter could resolve this aeration issue at minimal cost.

The properties of the compost removed from the in-vessel composter after 25 days are presented in **Table 6**. The temperature regime achieved during composting had a direct impact on the final DM of the compost. During batches 1 and 3, thermophilic temperatures produced final dry matter contents of 32 and 34%, respectively, while for batches 2, 4 and 5, the mostly mesophilic temperatures produced a final dry matter levels under 30%.

**Table 5** Recipe and characteristics of the initial CCC compost mixtures.

| **Batch** | **Compost recipe** | | | **Compost characteristics** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **FW (kg)** | **CRP (kg)** | **WC (kg)** | **DM (%)** | **C (% TS)** | **TN (% TS)** | **TP (% TS)** | **TK (% TS)** | **C:N** | **Bulk density wet (kg/m$^3$)** | **FAS (%)** |
| 1 – CRP 2007 | 462 | 113 | 0 | 31.0 | 49.2 | 1.15 | - | - | 43 | 550 | 50 |
| 2- CRP 2008 | 478 | 111 | 0 | 30.7 | 48.5 | 1.18 | 0.11 | 1.8 | 41 | 599 | 48 |
| 3 - CRP & WC 2008 | 457 | 130 | 47 | 35.5 | 49.0 | 1.29 | 0.10 | 2.3 | 38 | 599 | 51 |
| 4 – CRP 2009 | 496 | 115 | 0 | 30.8 | 44.5 | 1.55 | 0.18 | 2.1 | 38 | 531 | 54 |
| 5- CRP & WC 2009 | 442 | 132 | 47 | 31.6 | 48.1 | 1.21 | 0.24 | 1.8 | 40 | 621 | 46 |

Note: FW- food waste; CRP – cereal residue pellets; WC – wood chips; TN – total nitrogen; TP – total phosphorous; TK – total potassium; C – organic carbon.

**Table 6** Characteristics of the CCC compost after the active phase.

| **Year** | **Food waste** | | | | | |
|---|---|---|---|---|---|---|
| | **FAS (%)** | **TS (%)** | **TN (% TS)** | **C (% TS)** | **C:N** | **Bulk density*** |
| 1 – CRP 2007 | 50 | 34.2 ± 3.05 | 0.9 ± 0.06 | 38.4 ± 1.23 | 42.7 | 617 |
| 2 – CRP 2008 | 36 | 28.8 ± 2.14 | 1.6 ± 0.08 | 43.3 ± 1.16 | 26.3 | 732 |
| 3 – CRP & WC 2008 | 53 | 31.9 ± 0.91 | 2.12 ± 0.30 | 39.9 ± 2.41 | 18.8 | 541 |
| 4 – CRP 2009 | 48 | 29.7 ± 0.95 | 2.31 ± 0.24 | 35.7 ± 1.10 | 15.5 | 600 |
| 5 – CRP & WC 2009 | 49 | 29.3 ± 1.30 | 1.73 ± 0.21 | 43.3 ± 1.20 | 25.0 | 590 |

Note: FW- food waste; CRP – cereal residue pellets; WC – wood chips; TN – total nitrogen; TP – total phosphorous; TK – total potassium; C – organic carbon. ± is the standard deviation for *n* = 5 samples per compost mixture.

**Table 7** Mass balance for the CCC compost.

| **Batch** | **Wet mass** | | **Dry mass** | | **Water mass** | | **Total nitrogen** | | **Organic carbon** | | **Volume** | | **Bulk density (wet)** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **In (kg)** | **Out (kg)** | **In (kg)** | **Out (kg)** | **In (kg)** | **Out (kg)** | **In (kg)** | **Out (kg)** | **In (kg)** | **Out (kg)** | **In (L)** | **Out (L)** | **In (kg/m$^3$)** | **Out (kg/m$^3$)** |
| 1 – CRP 2007 | 575 | 290 | 178 | 99 | 397 | 191 | 2.0 | 0.9 | 87 | 38.0 | 1046 | 470 | 550 | 617 |
| 2- CRP 2008 | 589 | 349 | 181 | 101 | 411 | 249 | 2.1 | 1.7 | 87 | 44 | 948 | 477 | 599 | 732 |
| 3 - CRP & WC 2008 | 633 | 355 | 197 | 113 | 436 | 242 | 2.5 | 2.4 | 96 | 45 | 1310 | 528 | 568 | 541 |
| 4 – CRP 2009 | 611 | 282 | 188 | 84 | 423 | 198 | 2.5 | 1.9 | 86 | 30 | 1150 | 481 | 531 | 600 |
| 5 – CRP & WC 2009 | 621 | 389 | 196 | 114 | 425 | 275 | 2.4 | 2.0 | 94 | 49 | 1300 | 660 | 621 | 590 |

Note: FW- food waste; CRP – cereal residue pellets; WC – wood chips; TN – total nitrogen; TP – total phosphorous; TK – total potassium; TC – total carbon; there is no standard deviation is presented since *n* = 1.

**Table 8** Active phase CCC compost changes in total and dry mass, water, nitrogen and carbon.

| **Batch** | **Total mass (%)** | **Dry mass (%)** | **Water (%)** | **Total nitrogen (%)** | **Organic carbon (%)** | **Wet bulk density (%)** | **Temperature profile** |
|---|---|---|---|---|---|---|---|
| 1 – CRP 2007 | -49.6 | - 44.4 | - 51.9 | - 55.5 | - 56.5 | + 12 | Reached 50 °C |
| 2- CRP 2008 | -40.7 | - 44.5 | - 39.5 | - 20.9 | - 49.9 | + 22 | 2 d at + 50 °C |
| 3 - CRP & WC 2008 | -43.9 | - 42.5 | - 44.6 | - 4.4 | - 53.1 | - 5 | 8 d at + 50 °C |
| 4 – CRP 2009 | -53.8 | -55.4 | -53.1 | -24.0 | -65.2 | -13 | 0 d at + 50 °C |
| 5 – CRP & WC 2009 | -35.9 | -41.9 | -35.3 | -16.9 | -47.7 | - 5 | 2 d at + 50 °C |

Note: FW- food waste; CRP – cereal residue pellets; WC – wood chips; a negative sign means a loss while a positive sign means an increase; no standard deviation is presented since *n* = 1.

The changes in physical and chemical properties during composting are presented in **Tables 7** and **8**, with **Table 7** reporting the masses in and out and **Table 8** reporting the fraction lost. If the CRP batch of 2009 is excluded, all other batches demonstrated similar losses in DM and C ranging between 42 and 44%, and 48 and 57%, respectively. Batch 4 in 2009 with only CRP as BA suffered a higher DM and C loss of 55 and 65% respectively, under temperatures in the vicinity of 40°C. In parallel, only this batch did not exhibit thermophilic temperatures above 50°C. Thus, the higher DM and C losses are associated with the more favourable temperatures in terms of organic matter biodegradation (Tremier *et al*. 2005). This is explained by the larger population of mesophilic bacterial communities as opposed to those in the thermophilic range. In the absence of thermophilic temperatures stabilizing the mesophilic microorganisms, organic matter is more extensively degraded. The N losses were variable but the highest values of 21 to 55% were obtained with CRP as compared to 4 to 17% obtained with CRP/WC. Similar results were observed with the laboratory scale experiment, where CRP alone produced higher nitrogen losses irrespective of the C:N ratio. The wet bulk den-

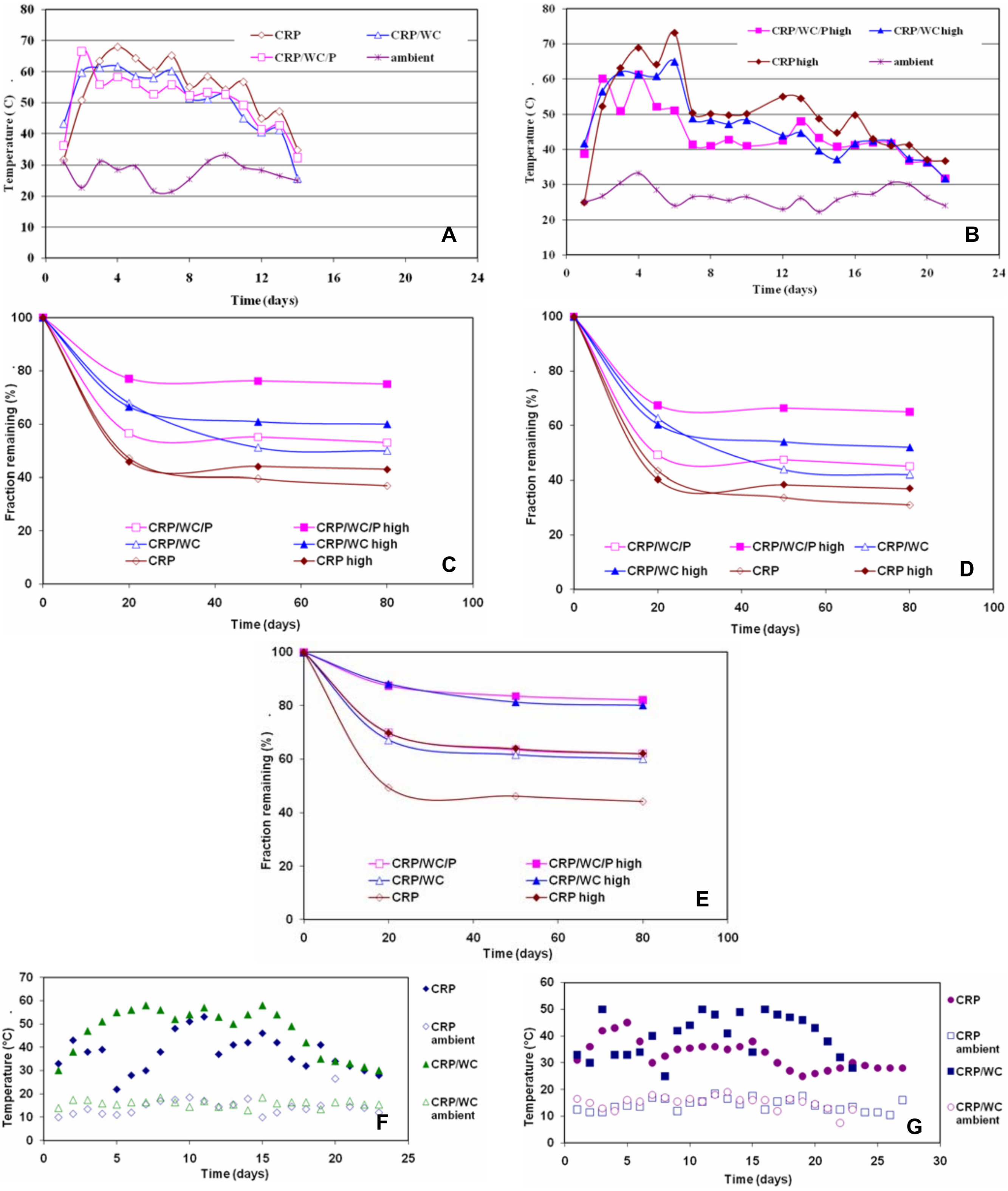

**Fig. 2** Temperature profiles of the compost recipes during the first experiments using (**A**) a low C:N of 16-17, and (**B**) a high C:N of 32-38. Mass balance results for all six BA combinations and C:N ratios for dry matter (**C**), organic carbon (**D**) and total nitrogen (**E**). Temperature regimes for compost with and without WC in 2008 (**F**; batches 2 and 3) and with and without WC in 2009 (**G**; batches 4 and 5) using the 1.9 $m^3$ composter.

**Table 9** Comparing costs between community composting and centralized composting facility.

| Item | Community centre | Centralized facility |
|---|---|---|
| 1. Capital investment | | |
| - site | $100 000 | $300 000 |
| - facility* | $90 000 | $50 000 000 |
| - annual ** | $19 000 | $5 030 000 |
| - annual per ton | $95/ton | $84/ton |
| 2. Labour | $15 000 | $1 700 000 |
| | $75 - 150 | $28 |
| 3. Bulking agent | $100/ton | $100/ton |
| 4. Operating cost | $200 | $3 330 000 |
| | $1/ton | $55/ton |
| 5. Collection and transport | $10/ton | $100/ton |
| 6. Separation cost | $0/ton | $150/ton |
| 7. Capacity | | |
| - operation | 7 months | 12 months |
| - FW treated | 200 tons | 60 000 tons |
| 8. Total cost | $281- $356/ton | $367 - $517/ton |

Note: the facility cost also includes a maturation section; the annual capital investment includes interest and depreciation. For the labour cost, the community centre hires one person at $30 000 to operate 4 centres (each centre is open 2 to 3 days per week, either in the morning or in the evening); this person is given another job during the remaining months of the year (5 months); social benefits (20%) and marginal costs (40% for an office and work space) are added to the salary cost; volunteers assist during centre reception hours otherwise, the labour cost is doubled. Separation costs: at the centralized composting facility, a separation unit can be added if the collected green waste is not properly sorted. References: centralized composting facility costs: Hamilton, Ontario, and Edmonton, Alberta, Canada; community composting centre costs: Tournesol centre, Montréal, Canada.

sity was the parameter which suffered the least change during the 3 week period. Nevertheless, CRP alone produced higher losses of 12 to 22% as compared to CRP/WC with losses of 5% for both years 2008 and 2009, despite temperatures reaching 50°C.

Although variable, C and N losses were within the range of those observed in Switzerland, by Obrist (1987) reporting that composting 0.7 $m^3$ or 440 kg of garden and kitchen waste in an outdoor wire basket, produced C and N losses of 55 and 15%, respectively, after 7 weeks.

### *3. The cost of operating an optimized community composting centre*

**Table 9** presents a cost comparison for the operation of community compost centre (CCC) versus that of a centralized composting facility (CCF) in Canada. The investment costs are within the same range of $84 to 95/ton, where for the CCC, the site flooring consists of concrete slabs over a bed of crushed stone and it is protected by a fence 1.2 m high. The CCC must also have a 5 kW power outlet to operate each one of the 3 composters in a sequence and running water to wash the containers of the residents. The labour costs are much higher for the CCC, where an operator must be present during the opening hours to receive the waste, mix in the BA and feed the composter. Even with the help of volunteers, labour is the second most important expense for the CCC. In exchange for labour cost, the CCF is highly mechanized and thus has much more important operating costs. This also implies the use of greater amounts of energy and the generation of more greenhouse gases. For home composting similar to but less professionally operated than CCC, Martinez-Blanco *et al.* (2010) report the generation of more composting gases but the use of less energy as compared to a CCF. The result is a much smaller carbon foot print for home composting or their intermediate, the CCC. Finally, the CCF facility may have to install separation equipment if the green waste received still contains undesirable substances. In this case, the cost of the CCF is much higher than that of the community centre.

Overall, the cost of producing compost at a CCC can be similar if not slightly lower than that of a CCF as long as the labour costs are minimized and the operator can manage 4 sites, where each site has an active composting capacity of 30 $m^3$. The CCC operator must be helped by volunteers, because the operation of a 30 $m^3$ centre requires at least 2 if not 3 persons to handle to FW as it is brought in by residents.

## CONCLUSIONS

The objective of the present project was to test composting recipes to optimize the use of bulking agent (BA) representing 30 to 40% of the operating costs, and also to minimize N losses. The three BA combinations using cereal residue pellets (CRP), wood chips (WC) and shredded paper (P), were designed to provide different levels of carbon available for N immobilization.

The results show that:

1) FW compost mixtures with CRP alone or CRP/WC as BA and at a C:N ratio of 32-38 can safely produce sanitizing thermophilic temperatures exceeding 50°C for more than 5 days, which suffices in inactivating pathogens such as *Salmonella* spp. as long as the process is carried out in a well mixed reactor; to meet these sanitizing temperatures with CRP/WC/P as BA, a C:N ratio in the range of 25 is preferable;

2) FW compost mixtures loose less N at a C:N ratio of 32-38, compared to a C:N of 16-17 where the N supplement is wasted, despite its prolongation of the thermophilic conditions during the active phase beyond the necessary levels;

3) As BA, CRP/WC at a wet mass ratio of 65:35 was the best combination leading to the least N losses while still achieving good aeration and producing compost with a limited amount of recognizable wood residues.

## ACKNOWLEDGEMENTS

This project was financed by the Natural Science and Engineering Research Council of Canada. The Metro grocery chain is also acknowledged for their food waste contributions.

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