The Canadian society for engineering in agricultural, food, and biological systems

CSAE SCGR

La société canadienne de génie agroalimentaire et biologique

Paper No. 05 - 091

Managing tools for the composting of urban food waste

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Written for presentation at the
CSAE/SCGR 2005 Meeting
Winnipeg, Manitoba
June 26 – 29, 2005

Abstract

Quantification and characterization of urban food waste (UFW) and bulking agents is essential to obtain the best compost recipe for an accelerated process, minimal odor emissions and limited leachate production. For downtown Montreal and from May to August 2004, the study examined monthly variation in carbon (C), nitrogen (TKN), C/N ratios and dry matter (DM) of food waste (FW). The FW was collected from residences, a restaurant and a community kitchen. Locally available bulking agents were also analyzed to compare characteristics for the best composting process. Furthermore, trials were conducted using an urban composting unit prototype to compare the performance of various recipes. In each trial, temperature and pH were recorded every day and other day, respectively.

The C, TKN, C/N ratio and DM of the UFW were found to vary from 49.3% to 47.9%, 1.7% to 2.7%, 29.1 to 17.9 and 13.7% to 10.3%, from May to August respectively. These variations resulted from more fresh vegetables and fruits being consumed by the end of the summer. The C/N ratios of chopped wheat straw (CWS) and chopped hay (CH) were found 100 and 58 with DM of 89% and 91%, respectively. From trial experiments, the best ratios (weight basis) of UFW to CWS and CH were found to be 8.9:1 and 8.6:1, respectively. Thus, the composing recipe must be adjusted regularly to correct for variations in UFW characteristics.

1 Introduction

Enormous quantities of municipal solid waste (MSW) are produced and these pose a serious threat to the environmental quality of life and the health of urban populations. The required landfill sites add pressure to land resources and increase risks of water resource contamination (Chakrabarti & Sarkhel 2003). Because the movement of people from rural to urban areas is a global trend, more pressure will be placed on city MSW management.

The food waste (FW) fraction of the MSW adds further problems, by producing greenhouse gases and contaminating leachate once disposed in landfill sites. In rural areas, it is often easier to dispose of the FW. Therefore, proper management of urban food waste (UFW) is a serious challenge of modern world. Determination of various waste characteristics is essential to implement the appropriate waste management practices (Green & Kramer 1979, Metin et al 2003, Abu Qdais et al 1997). The applicable characteristics include physical, chemical and thermal properties as well as quantity and composition (Diaz et al 1993).

FW occupies major portion of MSW stream in urban areas of low and middle-income countries, ranging from 50 to 80%. For high-income countries, it is rather in the range of 25 to 30% of the MSW (Achankeng 2003). In Montreal, Canada, UFW from domestic and commercial sources represent 24 and 27%, respectively of the MSW mass (Ville de Montreal 1991). The residential UFW production in Montreal varies between 0.5 to 0.7 kg/person/day (Morin et al 2003). Composting of source separated UFW at urban composting centers is envisaged as an option to recycle and reuse this organic matter on site while relieving the pressure required to manage MSW.

Several factors affect the process of composting, and when properly controlled, accelerate the process with minimal odor emission and limited leachate production. The main factors are moisture content of the mixture, oxygen level, pH and initial recipe C/N ratio (Pace et al 1995, Zucconi et al 1986). The C/N ratio is important (Bilitewski et al 1994) and should range between 15 and 30 (Haug 1993). A C/N ratio below 20 produces excess ammonia and unpleasant odors while, a C/N ratio above 40 does not provide enough N for microbial growth and a fast composting process. The initial compost mixture of organic waste, bulking agent and additive should offer the required C/N ratio to ensure the quality of finished product (Diaz et al 1993).

A project was initiated with a borough of the City of Montréal, Éco-quartier Jeanne Mance/W End to provide some composting opportunities to residents of the city centre. These residents do not have the space required to compost their FW. For example, leachate is an issue when composting UFW on a balcony. This project consisted in building a small composting centre in park, easily accessible to most residents. Nevertheless, the composting of the UFW required some planning and the knowledge of the production rate of UFW and its characteristics. It also required the formulation of proper composting mixtures to minimize odor and leachate problems.

Therefore, the main objectives of this paper were to:

(1) help cities plan the management of UFW, estimate its growth in a developed country (Canada) and compare it to that in a developing country (Nepal);

(2) in Montreal, characterize UFW and locally available bulking agents, and;

(3) test compost recipes for the composting of UFW in Montreal.

2 Materials and methods

2.1 Estimated growth of UFW production

The production of UFW is known to increase with the wealth of a population. Although the fraction of UFW found in MSW decreases with wealth, the total amount of MSW production increase which in turns result in a net increase in UFW production with wealth.

Accordingly, regression models (Equation 1, 2) were constructed from the data obtained from 26 countries around the world representing more than 90% of the world population: UN Statistics Division, IEA 2002, UNCHS (Habitat), World Resources (1998 – 99), OECD (1995), Diaz et al. (1986 and 1993), Beed and Bloom (1995), Ward (1993), USEPA (1999) and CEPII (2002). The 26 countries also represented low, lower middle, middle and high-income countries in 1995.

$$(FWP)_{y-c} = 3.65 * 10^{-9} * (UP)_{y-c} * (FWPR)_{y-c} * (TP)_{y-c} \quad (1)$$

$$(FWPR)_{y-c} = [1*10^{-5} * (GDP/capita)_{y-c}] + 0.3128 \quad (2)$$

Where:

$(FWPR)_{y-c}$ = Food Waste Production Rate of country “c” in year “y”, kg/capita/day;

$(GDP/capita)_{y-c}$ = Gross Domestic Product per capita of country “c” in year “y”, US$;

$(FWP)_{y-c}$ = Food Waste Production of country “c” in year “y”, million tons;

$(UP)_{y-c}$ = Urban Population of country “c” in year “y”, % and

$(TP)_{y-c}$ = Total Population of country “c” in year “y”.

Equations 1 and 2 were used to estimate quantities of UFW produced in Montréal, Canada, and in Katmandu, Nepal, for 1995, 2000, 2005, 2010, 2015, 2020 and 2025.

2.2 The experimental materials

FW was collected weekly (May to August 2004) from a Montréal downtown restaurant and a community kitchen. These establishments collected FW and, three times per week, brought it to the Éco-quartier/W End composting centre where it was measured and sampled. This waste was mixed manually in trays 1m in diameter and 0.5m in depth. After mixing, samples were taken for laboratory analyses. The samples were ground using an electrical grinder before being analyzed. Samples of locally available bulking agents chopped wheat straw (CWS) and chopped hay (CH) were collected also to establish their characteristics.

2.3 Analytical procedures

Carbon was determined by burning samples at 550^0C (in muffle furnace) for 4 hours. The percentage of C was calculated by dividing the volatile fraction by a conversion factor of 1.8 (Hang 1980). The Total Kjeldahl Nitrogen (TKN) was determined by digesting (HACH Digesdahl Digestion Apparatus) the samples with sulfuric acid at 500^0C and measuring the NH_3-N content at a sample pH of 12.8, using a NH_3 sensitive electrode (Barrington et al 2002). The DM was determined by drying samples of a know weight in an oven (Scientific JHON’s oven) at 105^0C for 24 hours and DM fraction was computed as (oven dry sample weight/wet sample weight). The pH was determined with a probe (attached with pH/Ion meter 450) using 5g of material soaked in 50 ml of distilled water for 24h (Barrington et al 2002).

2.4 The equipment

The compost recipes were tested using six identical in-vessel horizontal composters made from corrugated plastic tubes measuring 1m in length and 0.3m in inside diameter. A passive aeration system with leachate collection provision was provided (Figure 1). An air exit pipe was provided from the top end of the composting unit filled to two thirds of their capacity with a mixture of UFW and bulking agent.

2.5 Compost recipes

After characterization of UFW and the bulking agents, compost recipes were computed to produce different levels of final moisture contents (Table 1 and 2). Table 1 presents three different recipes for UFW mixed with chopped wheat straw (CWS). The UFW and CWS were weighted separately using an electronic scale and mixed manually to produce recipes 1, 2 and 3. Ammonium nitrate (NH_4NO_3) was added to the mixtures as required for a C/N ratio ranging between 20 and 25. The initial DM of the compost mixtures was computed to be 40, 30 and 20 %, for recipes 1, 2 and 3, respectively. Each recipe was tested using duplicates.

Table 2 presents test recipes for UFW and chopped hay (CH). The initial C/N ratios of the mixtures were adjusted between 20 and 25 using NH_4NO_3 as required. The UFW and CH were weighted separately and mixed thoroughly before being loaded into the composting units. The initial DM of the duplicate compost mixtures was 40, 30 and 20%.

2.6 Compost performance indicators

Measuring the mixtures' temperature and pH monitored the composting performance. Temperature is a good indicator of the biological activity. The composting process essentially takes place within two temperature ranges known as mesophilic (25 to 40°C) and thermophilic (over 40°C) (Pace et al 1995). For optimum microbial activity during composting, a neutral to slightly alkaline pH range is required (Bidlingmaier et al

1985) for optimal microbial growth. Organic substrates offer a wide range of pH levels ranging from 3 to 11 (Zucconi et al 1986). At the beginning of composting process, acid-forming microbes initialize the process by breaking down complex carbonaceous materials dropping the pH. Later, the microbes will break down of proteins and liberating ammonia leading to a subsequent rise in pH (Zucconi et al 1986, Bilitewski et al 1994). A pH of 6.5 to 8.0 is recommended for optimum composting (Pace et al 1995).

For all recipes tested (Tables 1 and 2), temperature and pH were measured every day and other day, respectively. The temperature was measured by using a PTC-Thermometer (model 8500D-II). Every alternate day, compost samples were collected and analyzed for pH. The collected samples were soaked in distilled water for 24h before measuring their pH using a pH probe. When the temperature started to drop, the compost was removed from each unit and visually examined.

3 Results and discussions

3.1 Estimated quantification of UFW growth

Figure 2 shows the estimated quantity of UFW production growth and its percentage of MSW stream, for 1995, 2000, 2005, 2010, 2015, 2020 and 2025. These values were computed for Canada and Nepal. For Canada, UFW production is expected to increase by 50%, from 4.23 million tons in 1995 to 6.91 million ton in 2025 whereas in Nepal, it is expected to increase by more than 400%, from 0.25 in 1995 to 1.10 million ton in 2025. The drastic change in UFW production in Nepal will result from a tremendous improvement in the standard of living of the urban population and the migration of a fair number of people from the rural to the urban areas.

The percentage of UFW in MSW is expected to decrease from 24% to 21% in Canada and from 58% to 56% in Nepal, between 1995 and 2025. The lower fraction of UFW in MSW for Canada indicates the use of more processed food, package materials, cans and bottles, whereas the higher % of UFW in Nepal shows a lower consumption of such goods.

Figure 2 indicates that the recycle and reuse of source separated UFW of MSW stream will be needed to reduce the pressure in MSW management systems by 20 to 25% (wet weight basis) in developed countries such as Canada and by 50 to 60% (wet weight basis) in developing countries such as Nepal. Therefore, composting of UFW and its use for agriculture purposes could save land by reducing the need for landfill sites, save on the high collection and transportation cost of MSW and also reduces the environmental ramifications arising from the UFW fraction of MSW.

3.2 Characterization of UFW and bulking agents

3.2.1 UFW

The C (dwb), TKN (dwb), C/N ratio (dwb) and DM of Montreal UFW were found to vary from May to August 2004 (Table 3). The mean monthly C was found to range from 49% (±0.77%) in May, to 47% (±3.05%), 48%(±0.93%) and 48%(±0.32%) in June, July and August, respectively. The TKN of 1.7% (±0.11%) in May, increased to 2.0% (±0.30%), 2.6% (±0.46%) and 2.7% (±0.79%) in June, July and August, respectively. The C/N ratio of 29 in May, was found to decrease to 23, 18 and 18 in June, July and August, respectively. The DM of 13.4% (±2.47%) in May decreased to 12.2% (±2.05%), 10.0% (±1.01%) and 10.3% (±0.83%) in June, July and August respectively.

The increase of TKN and decrease of DM, C/N ratio and C from May to August were found to result from the increased presence of fresh vegetables and fruits in the UFW, because of more of these produce being available in the summer. At the beginning of summer, the UFW was mostly dominated by potato tops and carrot peels. As of the middle of summer, fresh vegetables and fruits began to appear. Therefore, fresh vegetables and fruits like cabbage, onion, pineapple, watermelon and citrus fruits increased the TKN and decreased C/N ratio as well as the DM.

This investigation reveals that from the middle of the summer, composting UFW in Montréal required more bulking agent and a high level of nitrogen amendment. This adjustment is necessary to maintain the adequate rate of composting, minimize odor emissions and limit leachate production. Hence, the compost mix should be adjusted by mixing balanced amount of bulking agents from one month to another.

3.2.2 Bulking agents

The C, TKN, C/N ratio and DM of CWS and CH are presented in Table 4. The C of CWS and CH was found 50.4% (±0.95%) and 51.7% (±0.56%), respectively. The TKN of CWS and CH was found to be 0.50% (±0.08%) and 0.89% (±0.12%), while the C/N ratios was found to be 101 and 58, respectively. The DM of CWS and CH investigated was 89% (±1.26%) and 91% (±1.44%) respectively.

The high C, C/N ratios and structural stability of CWS and CH indicate their suitability as bulking agents for the successful composting of UFW.

3.3 Testing optimal compost recipes

The daily variation in temperature for each compost recipe of UFW and CWS are presented in Figure 3a & b. The temperature regime for the mixture ratios 2:1 and 3.4:1 were found to remain below the thermophilic range. The temperature of mixture 8.9:1 reached the thermophilic range within a week of loading the composting units. For the FW and CH mixture of 8.6:1, the recorded temperature reached the thermophilic range within a week, whereas the mixtures of 1.8:1 and 3.3:1 were found to remain below the thermophilic range (Figure 4).

The pH of the UFW and CWS mixtures were found to be slightly acidic at the beginning of the composting process, which is normal (Zucconi et al. 1986; Bilitewski et al., 1994). After three days of composting, the pH increased above 7 (Table 5). The 8.9:1 mixture was found to offer the least pH variation. For the UFW and CH mixtures, the pH was slightly acidic at the beginning of the composting process and, after three days, also climbed above 7 (Table 6).

The best recipe for the UFW and CWS mixture, the ratio 8.9:1, on a wet weight basis, gave the highest temperatures and the least pH fluctuations. The other ratios did not reach the thermophilic range. Moreover, all mixtures produced leachate and its collection needs to be planned. At least once in 24h, the compost should be mixed for about 30 minutes for a more uniform product and to provide additional aeration.

4 Conclusions

UFW represents 50 to 80% of the MSW stream in developing countries such as Nepal, while in countries like Canada, it may only represent 25 to 30% of the MSW stream. The composting of UFW reduces the financial burden of managing MSW and minimizes environmental ramifications. In Montreal, UFW was collected and monitored over four summer months. This waste was found to vary as more fresh fruits and vegetables came into season. Therefore, the compost recipe must be adjusted during the summer to compensate for such variations. Bulking agents such as CWS and CH are effective in correcting the UFW moisture content as long as used in a ratio of 8:9:1 (UFW:CWS) and 8.6:1 (UFW:CH), on a wet weight basis. Sufficient fresh air supply needs to provide to the composting material and a leachate collection system is inevitable.

5 Acknowledgements

The authors would like to thank the Natural Sciences and Engineering Research Council of Canada (NSERC) and Éco-quartier of Montreal Canada for their support to conduct this research.

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Table 1. Trial recipes of FW & chopped wheat straw (CWS).

Recipe Number	FW:CWS wet weight	FW:CWS dry weight	Additive % (NH_4NO_3 wet weight)	Additive % (NH_4NO_3 dry weight)	C/N dry weight
1	2:1	-	1.8	-	20.24
2	3.4:1	1:2.4	1.15	3.8	20.89
3	8.9:1	1.16:1	0.592	3.0	20.89

Table 2. Trial recipes of FW & chopped hay (CH).

Recipe Number	FW:CH wet weight	FW:CH dry weight	Additive % (NH_4NO_3 wet weight)	Additive % (NH_4NO_3 dry weight)	C/N dry weight
1	1.8:1	1:4.31	0.70	1.7	21.14
2	3.3:1	1:2.23	0.49	1.6	21.21
3	8.6:1	1.12:1	0.29	1.4	21.18

Table 3. Monthly Characteristics of Montreal FW (2004).

Months		Characteristic parameters*		
	%C	%TKN	C/N	%DM
May	49.25	1.69	29.142	13.73
June	47.35	1.98	23.914	12.22
July	47.77	2.67	17.94	10.25

*All the characteristic parameters are presented in dry weight basis (dwb)

Table 4. Characteristics of locally available bulking agents.

Materials	Characteristic parameters*			
	%C	%TKN	C/N	%DM
CWS	50.38	0.5	100.76	88.86
CH	51.65	0.89	58.03	90.78

*All the characteristic parameters are presented in dry weight basis (dwb)

Table 5. pH record of mixtures of FW & CWS during composting process.

FW:CWS	Test no.	Day after loading of test composter			
		2	3	5	7
2:1	1	-	8.1	8.6	8.7
3.4:1	1	6.5	8.3	8.0	8.5
8.9:1	1	6.9	7.0	7.2	8.0

Table 6. pH record of mixtures of FW and CH during composting process.

FW:CH	Test no.	Day after loading of test composter			
		2	3	5	7
1.8:1	1	6.1	6.4	7.3	7.2
3.3:1	1	6.2	6.6	7.0	7.3
8.6:1	1	6.0	7.0	7.0	7.2

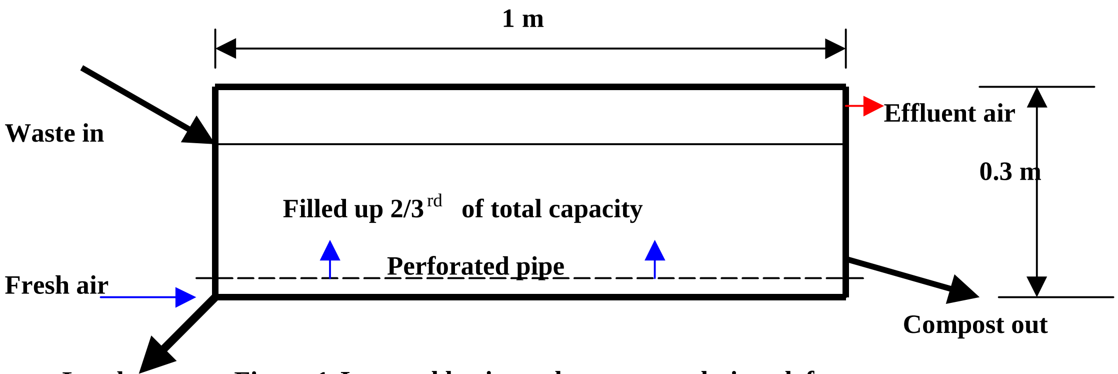

Figure 1 In-vessel horizontal composter designed for trial compost recipe

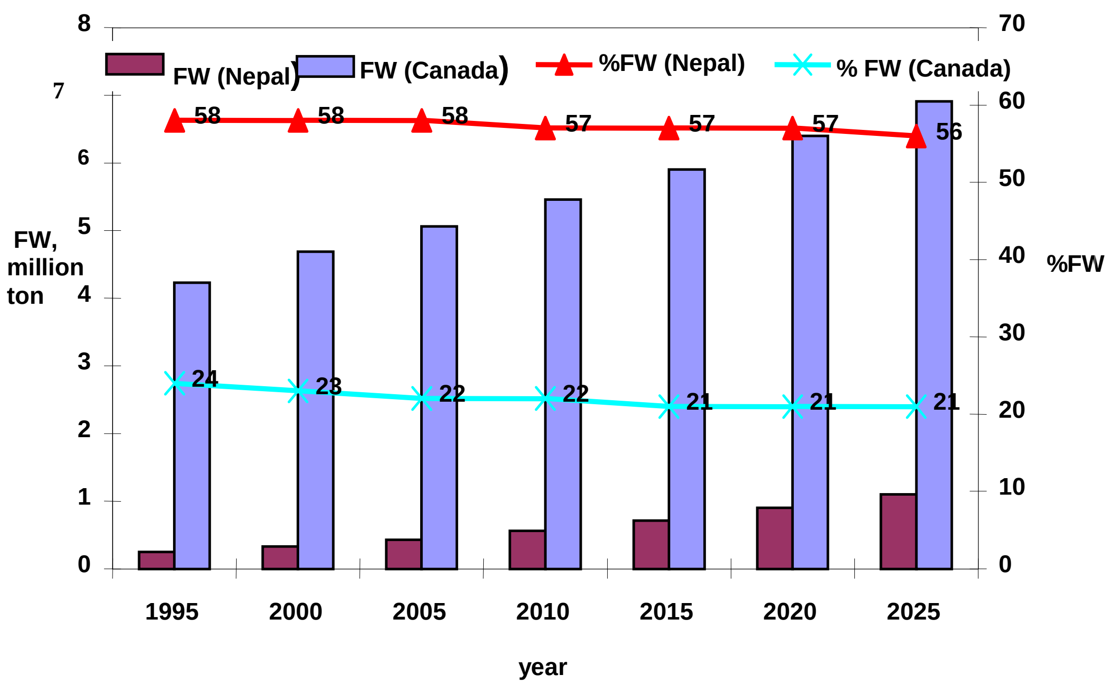

Fig 2 Estimated FW production & %FW in MSW stream

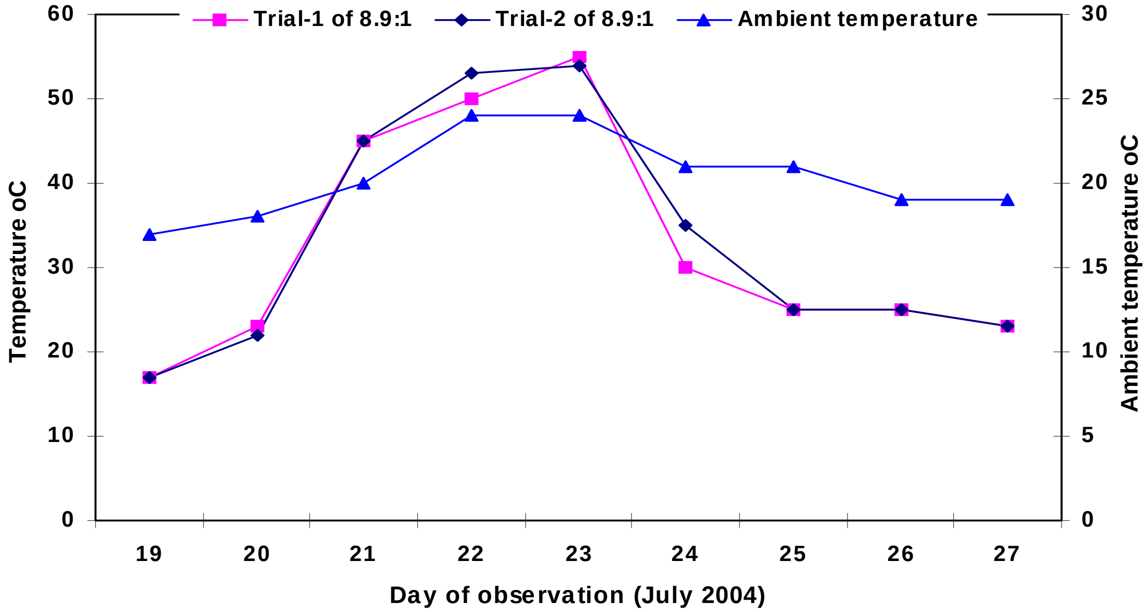

Figure 3a Comparison of temp of trial-1 &2 of mixtures 8.9:1 of FW & CWS

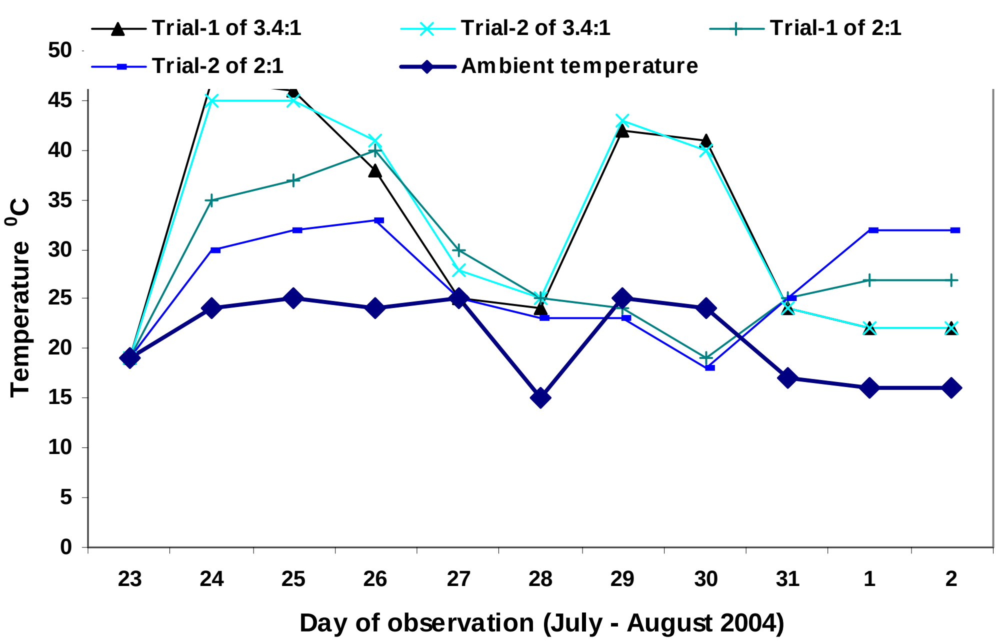

Figure 3b Comparison of temp of different mixtures of FW & CWS

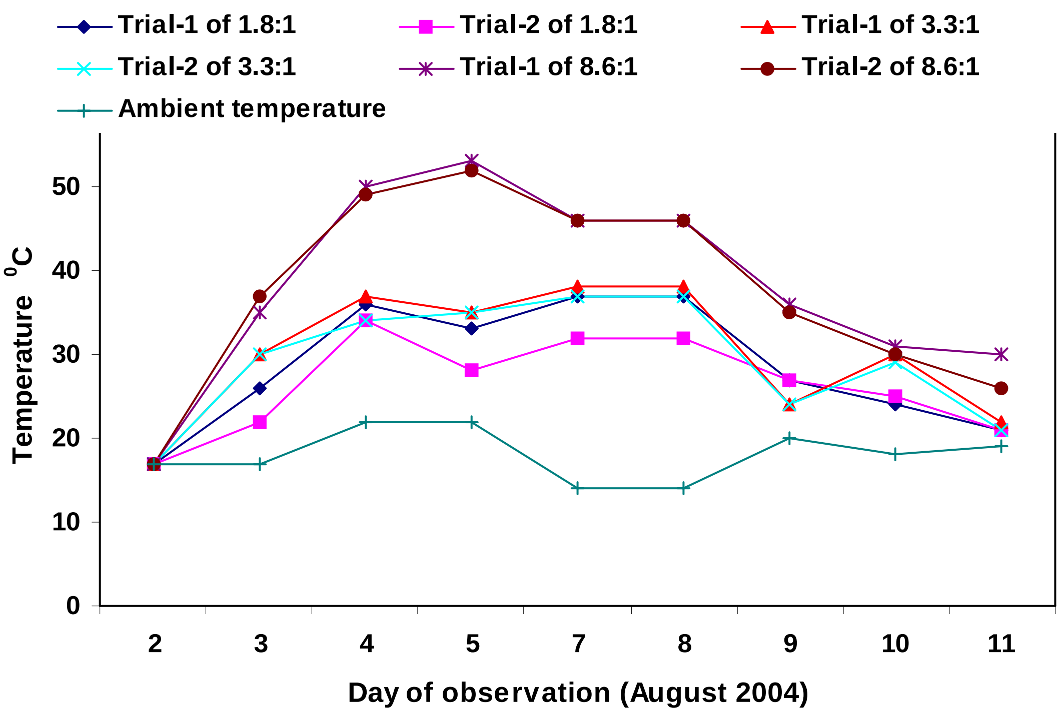

Figure 4 Comparison of temp of different mixtures of FW & CH