International Journal of Environmental Engineering and Management
ISSN 2231-1319 Volume 7, Number 1 (2016), pp. 1-23

http://www.ripublication.com

Optimization for Temperature and Time in Co-Composting Municipal Solid Waste and Brewery Sludge

Hema Nalini. A.V*, Dr. P.R. Sreemahadevan Pillai Dr. Y.V.K.S. Rao*****
** Research Scholar, University of Kerala*
*** Dean-Engineering, University of Calicut*
**** Research Guide, University of Kerala*

Abstract

Temperature and duration of composting are important parameters for quality composting process. The temperature developed due to the self-heating of compost material should be restricted so as to prevent enzyme deactivation. The composting time should be reduced through faster degradation of the composting material. This study deals with the determination of optimal levels of five factors, assigned 2 levels (1 & 2) namely A: the percentage of brewery sludge (20, 30), B: amendment type (cow dung, coconut pith), C: C/N ratio (15, 30): D: starting culture (without, with) and E: aeration rate (0.3 L/min/kg, 0.45 L/min/kg) with interaction of factors A x B and A x C, for the maximum temperature and composting time, in the co-composting of organic fraction of municipal solid waste and brewery sludge. Taguchi's experimental design with an L_8 orthogonal array having 8 trials is adopted. An in-vessel batch type composting reactor was used for conducting the experiment. Temperature and oxygen uptake rate were continuously monitored at regular intervals till the end of composting. A strong correlation is observed between temperature and oxygen uptake rate. Maximum temperature and total composting time for each trial was kept as the responses for signal to noise (SN) analysis. The optimal levels of the factors for a target maximum temperature of 60^0C is A2B1C2D2E1 for nominal the best criteria. For the composting time, for smaller the better criteria, it is A2B1C1D1. Analysis of variance shows that the most significant factor influencing a maximum target temperature of 60^0C is the amendment type - cow dung and for the total composting time it is C/N ratio of 15.

[This study was funded by Kerala State Council for Science, Technology & Environment]

Introduction

Composting is the biological decomposition and stabilization of solid organic substrates, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, low in moisture, free of pathogens and plant seeds, and can be beneficially applied to land. Co-composting is the process of enhancing the composting by increasing the degradation rate and the quality of the compost, by modifications such as addition of biodegradable wastes (industrial and domestic waste, sludge etc.) to reach an optimum Carbon-Nitrogen (C/N) ratio. Under controlled conditions, composting is accomplished in three main phases: mesophilic phase (T ≤ 40 ºC), thermophilic phase (T ≥ 40 ºC), and the cooling and maturation phase as shown in Fig 1. The length of the composting phases depends on the nature of the organic matter being composted and the efficiency of the process, which is determined by the degree of aeration and agitation (Atalia et. al. 2015). At the start of composting the mass is at its ambient temperature and due to degradation of organic matters temperature increases. Testing temperature, moisture content, and oxygen levels can help decisions on composting activities.

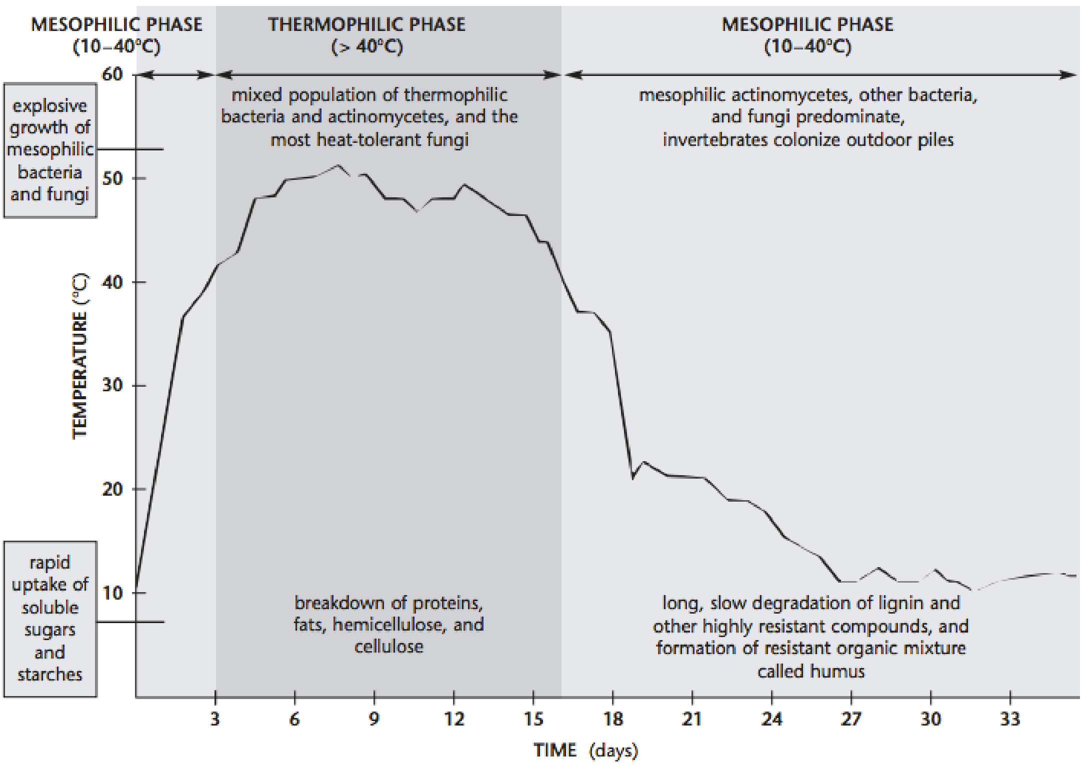

Figure 1: Phases of composting

Table 1: Quality options and S/N ratio equations

Choose...	S/N ratio formulas	Use when the goal is to...	And your data are...
Larger is better	$S/N = -10*\log(\Sigma(1/Y^2)/n)$	Maximize the response	Positive
Nominal is best	$S/N = -10*\log(\sigma^2)$	Target the response and you want to base the S/N ratio on standard deviations only	Positive, zero, or negative
Nominal is best (default)	$S/N = 10*\log((\bar{Y}^2)/\sigma^2)$ The adjusted formula is: $S/N = 10*\log((\bar{Y}^2 - s^2/n)/s^2)$	Target the response and you want to base the S/N ratio on means and standard deviations	Non-negative with an "absolute zero" in which the standard deviation is zero when the mean is zero
Smaller is better	$S/N = -10*\log(\Sigma(Y^2)/n))$	Minimize the response	Non-negative with a target value of zero

Note The Nominal is Best (default) S/N ratio is useful for analyzing or identifying scaling factors, which are factors in which the mean and standard deviation vary proportionally. Scaling factors can be used to adjust the mean on target without affecting S/N ratios.

Where 'Y' is the response and 'n' is the number of tests in a trial.
mean square deviation= $((Y_1-Y_0)^2 + (Y_2-Y_0)^2 + ... + (Y_n-Y_0)^2)/n$, Y_1, Y_2......Y_n are the responses and Y_0 is the target value

Factors affecting composting

C/N ratio, aeration rate, pH, moisture content, temperature, starting culture, bulking agent, amendment, particle size, etc. are the various factors affecting composting. Tang et. al. (2007) found that temperatures ranged from 30 to 45°C and 55 to 66°C in mesophilic and thermophilic composting, respectively, and the change in O_2 content in the exhaust gas corresponded very well to the change in temperature. Y.Q. Wang (2010) conducted a study on the "effect of C/N ratio on the composting of vineyard pruning residues" for C/N of 29, 40, 52 and 60 and showed that the lower the C/N ratio, the higher the maximum temperature attained and the longer the duration of the thermophilic phase. The maximum temperature values reached were 76 °C (C/N 29), 70 °C (C/N 40), 68 °C (C/N 52) and 65 °C (C/N 60), which appeared after three to four days of composting. The length of the thermophilic phase was 20 days (C/N 29 and 40) and 6 days (C/N 52 and 60), respectively. In the co-composting of coir pith and cow-dung for various C/N ratios of 30, 25 and 20, the peak temperature was observed to be 58°C for C/N ratio of 25 and 56°C for 30 and 20 (Sudarut 2012). In studying the effect of amendments the combination of straw and saw dust has attained highest temperature. As straw is more biodegradable than sawdust its presence favours a temperature increase. The maximum temperatures measured in treatments 1 to 4 were 56.4 (saw dust), 65.7 (straw) 60.9 (straw 50%, saw dust 50%) and 66.2 °C (straw 70% and saw dust 30%) respectively. The end of the thermophilic phase, which is indicated by the decrease of biomass temperature, was observed only for straw after approximately 50 days (Higarashi M.M. et. al.). In the composting of Lignocellulosic waste, collected from legume trimming residues used in soil restoration, the temperature profiles of the reactors with the same conditions with different aeration rate 0.2 lit air/min/kg, 0.4 lit air/min/kg and 0.6 lit air/min/kg were 58, 57 and 53 ^{0}C respectively. The temperature decrease due to increase in aeration rate could be due to the significant effect of aeration rate on heat lost. Due to this a cooler effect under a higher aeration level has been found (P. Bueno et. al. 2008). Temperature evolution directly reflects microbial activities and a high temperature maintained during composting serves to promote efficiency and effectiveness of compost by accelerating the process and by destroying pathogenic microorganisms. Low temperatures can retard the composting process and can show the reduced microbial activity and could indicate a lack of oxygen or inadequate moisture conditions. The onset of temperature rise in the first stage of composting was almost independent of the process conditions (Chang et. al., 2006). High temperatures (above 50°C) are essential for the destruction of pathogenic organisms and undesirable weed seeds. The preponderance of information on the effects of temperature on composting suggests that optimum decomposition takes place between 55°C and 60°C in most of the conditions though there is some variation in the optimum temperature range due to variations in waste materials and operational practices. The highest biodiversity of the microbial population, the highest rate of biodegradation, and the highest rate of sanitization of pathogen inactivation have been observed in 25 to 45 °C, 45 to 55 °C and above 55 °C, respectively (Christensen, 2011). Since temperature is generally a good indicator of the biological activity, rise above 60°C should be prevented because the more sensitive microorganisms may be destroyed and the decomposition process may be slowed (Zucconi et. al., 1986).). Excessive temperature (over 70 °C) can increase the ignition risk of composting pile, and enhance the ammonia (NH_3) emission (De Bertoldi et. al., 1983). Miyatake et. al. (2004) demonstrated that enzymatic activity and species diversity of thermophilic bacteria were affected by composting temperatures between 54 and 70 °C. The achievement of minimum temperature levels is essential to an effective composting process and contributes substantially to the high rate of decomposition achieved during processing (Liang et. al., 2003). A high decomposition rate was observed for low-temperature composting at about 35°C (Tang et. al., 2007).

Materials and methods

Percentage of brewery sludge, amendment type, C/N ratio, starting culture presence and aeration rate are the 5 factors with 2 interactions of 3 factors are considered in the present study. Instead of using the conventional one-factor-at-a-time, statistically designed experiments - Taguchi's method - is used. One-factor-at-a-time experiments are always less efficient than other methods based on a statistical approach and fails to consider any possible factor interactions. Taguchi's method is a robust and multi-parameter optimisation statistical technique which employs fewer numbers of experiments to identify and optimize parameters to achieve desired response. Taguchi design is a fractional factorial design using orthogonal array; allows the effects of many factors with two or more levels on a response to be studied in a relatively small number of runs. In addition, the orthogonal array facilitates the analysis of the design. When used properly, Taguchi design may provide a powerful and efficient method to find an optimal combination of factor levels that may achieve optimum. Usually, with the aid of signal-to-noise (S/N) ratio, the key factors that have significant effects on a response can be identified and the best factor levels for a given process can be determined from the pre-determined factor levels.

S/N Ratio Analysis

Taguchi method stresses the importance of studying the response variation using the signal–to-noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. After conducting the experiment for 8 trials, the responses are collected and they are analyzed by means of calculating the S/N ratio. Taguchi uses the S/N ratio analysis to measure the quality characteristic deviating from the desired value. In S/N ratio, the term 'Signal' represents the desirable value (mean) for the output characteristic and the term 'Noise' represents the undesirable value for the output characteristic. In general, a better signal is obtained when the noise is smaller, so that a larger S/N ratio gives better final result. That means, the divergence of the final results becomes smaller. Depending upon the goal to be achieved for the responses, the goal options can be selected and the corresponding equations can be used for S/N analysis. For the quality of processes or products when the responses are to be maximised use larger is better criteria; when it is to achieve a target value use nominal is best option; on the other hand when the responses are to be minimised use smaller is better criteria. The software Minitab 17 is equipped with facilities for doing the analysis for various quality criteria. The quality options and S/N ratio formulae are presented in Table 1. The level of a factor with the highest S/N ratio is the optimum level for responses measured. The higher the signal-to-noise ratio, the more favourable is the effect of input variable on the output. Here the maximum temperature and composting time are considered as the quality characteristics.

Analysis of variance

The relative contribution of the factors on responses is determined by comparing their variances by the process called analysis of variance (ANOVA). ANOVA is applied to Taguchi's statistical method to evaluate the relative significance of the individual factors and interaction effects on responses.

Fixing the factors and levels

Table 2 shows the factor, factor notation and factor levels. The levels of brewery sludge and C/N ratio is fixed based on the micro composting study (Hema Nalini et. al., July 2015) and for the other factors based on previous studies (Xueling Sun, 2006).

Table 2: Factor notation and levels

Sl. No	Factor Notation	Factor	Level 1	Level 2
1	A	Brewery sludge	20% of OFMSW	30% of OFMSW
2	B	Amendment	Cow manure	Coconut pith
3	C	C/N ratio	15	30
4	D	Starting culture	Without	With
5	E	Aeration rate	0.3 L/mt/Kg	0.45 L/mt/Kg

Table 3: Taguchi orthogonal array design

Tr-ial	A Brewery sludge (%)	B Amendment	C C/N	D Starting culture	E Aeration rate (L/min/kg)
1	20	Cow dung	15	Without	0.3
2	20	Cow dung	30	With	0.45
3	20	Coconut pith	15	With	0.45
4	20	Coconut pith	30	Without	0.3
5	30	Cow dung	15	Without	0.45
6	30	Cow dung	30	With	0.3
7	30	Coconut pith	15	With	0.3
8	30	Coconut pith	30	Without	0.45

Experimental set-up

Reactor for in-vessel composting of 10 kg of substrate by wet weight with forced aeration system with accessories for purifying, humidifying, stabilizing and controlling the inlet air was designed with acrylic body. An air pump of variable speed, electric motor with uninterrupted power supply and an aeration rate range of 0-80 L/min was used for aeration. 2 numbers of small ports were provided for inserting digital thermometers at one third and two third heights of the reactor for temperature monitoring. At the top, a large sized port for mixing the sample using hoe fork was also provided. Arrangement is provided at the extreme end of the exhaust for measuring the residual oxygen left after composting using a digital oxygen meter. The experimental setup is shown in Fig 2 (a) and (b).

Preparation of substrate

The substrates used for the composting were synthetic Organic Fraction of Municipal Solid Waste (OFMSW) (Hema Nalini et. al., April 2015, 2) and Dewatered Brewery Sludge (Hema Nalini et. al., April 2015, 1). Use of synthetic waste in composting studies enables repeatability and reproducibility of the experiments. Simulated waste in experiments will give a true picture of the behaviour of the original waste. The sludge from the brew-house of United Breweries Ltd., Kanjikode, Kerala, was collected using the composite sampling technique. Compost recipe can be prepared for a given quantity of synthetic waste by knowing carbon, nitrogen and moisture content of each component in it. Once the carbon, nitrogen and moisture content of the components of substrates are known by choosing the right material and adjusting the weights, the compost recipe can be prepared for a given value of total weight, C/N ratio and moisture content, which can be done with the help of an Excel spread sheet. Table 4 shows the weights of raw materials in kg for the trials 1 to 8. The moisture content and the maximum particle size of the substrate were 70% and 5 mm respectively.

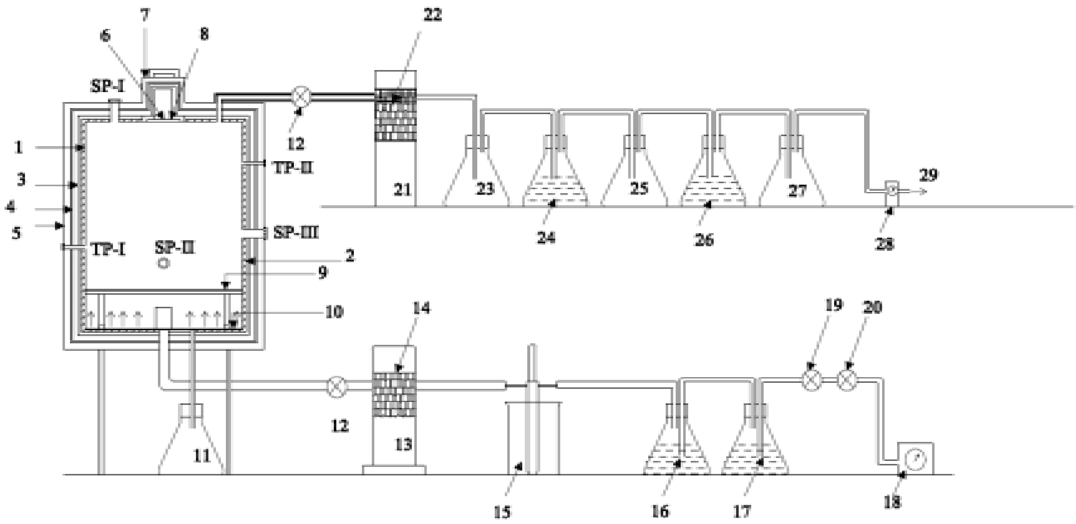

Figure 2(a): Schematic diagram

Figure 2(b): Photograph

1 ACRYLIC GLASS CYLINDER 300 mm DIA, 15 mm THICK
2 ALUMINIUM FOIL 56 micron THICK
3 FELT INSULATION 5 mm
4 ASBESTOSE COATED WINDING ROPE 6.5 mm THICK
5 THERMOCOL INSULATION 60 mm THICK
6 MIXING PORT
7 OUTER CAP 120 mm DIA
8 INNER CAP 100 mm DIA
9 ENAMEL PAINTED STEEL POROUS PLATE 250 mm DIA 2 mm THICK
10 BOTTOM PLATE 15 mm THICK
11 LEACHATE COLLECTOR
12 CONTROL VALVE
13 HUMIDITY STABILIZER
14 ACTIVATED CARBON (GRANULAR)
15 AIR FLOW METER
16 HUMIDIFIER [DISTILLED WATER]
17 CO_2 FILTER [2N, KOH]
18 AIR PUMP
19 TWO WAY VALVE
20 VALVE
21 VOC TRAP
22 ACTIVATED CARBON (GRANULAR)
23 CONDENSER
24 CO_2 TRAP [5M, KOH]
25 STABILIZER
26 NH_3 TRAP [1N, H_2SO_4]
27 STABILIZER
28 OXYGEN ANALYZER
29 OUTLET

TP- TEMPERATURE PORT
SP- SAMPLING PORT

Figure 2: Experimental setup

Table 4: The weights of items in substrate for the experimental trials

Item in kg	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8
Boiled rice	1.5	1.3	1.3	1.4	1.3	1.3	1.2	1.4
Pumpkin	0.8	1.8	0.75	1.8	1	1.7	0.3	1.3
Potato	0.6	0.2	0.75	0.3	0.5	0.15	0.75	0.3
Green Banana	0.8	0.2	0.9	0.2	0.5	0.15	0.75	0.3
Papaya	2.2	0	2.2	0	2	0	2.1	0
Orange	0	2.3	0	2.2	0	1.8	0	2.1
Newspaper	0.4	0.4	0.3	0.4	0.3	0.4	0.3	0.4
Dry leaves	0	0.7	0	0.9	0	0.8	0	0.85
Grass clippings	0.5	0.3	0	0	0	0	0.5	0
Green leaves	0.8	0	1	0.4	1.05	0	0.4	0
Brewery sludge	1.9	1.8	1.8	1.9	2.85	2.7	2.7	2.85
cow dung	0.5	0.5	0	0	0.5	0.5	0	0
Coconut pith	0	0	0.5	0.5	0	0	0.5	0.5
Unmatured compost	0	0.5	0.5	0	0	0.5	0.5	0

Table 5: Duration of time required for composting at various phases and the maximum temperature for the experimental trials

Trial	Time duration in hrs for				Max.
	Meso philic phase	Therm Ophilic phase	Cooling phase	Total compo Sting time	Temperature (°C)
1	4	76	280	360	61.5

2	2	94	384	480	56.9
3	2	78	304	384	54.1
4	4	100	376	480	53.3
5	4	84	224	312	56.8
6	4	112	268	384	59.1
7	4	88	292	384	67.1
8	2	82	300	384	54.5

Running experiments

The random orderings for running the experiments is given in Robert. H. L. and Joseph. E.M, (1990) in 200 different random combinations for 8 run experiment. One among the random combination chosen here is 2, 7, 3, 6, 5, 8, 4 and 1. The experiments were run as per this order. The contents in the reactor were mixed daily using a hoe fork.

Continuous monitoring of temperature and oxygen uptake rate

Temperature (inside the reactor and ambient temperature) and oxygen uptake rate were monitored at 2 hours interval for the first two days and at 4 hours interval for the remaining days. Temperature was measured using digital thermometers. Two temperature ports were provided at one third and two third height of the reactor and thermometers were inserted into the ports for temperature measurement. The average of two temperature values was reported as the reactor temperature. Ambient temperature was measured each time using another digital thermometer. Provision is made in the experimental set up to trap CO_2 and NH_3.

Residual oxygen in the exhaust gas was measured using a digital oxygen analyzer provided at the exit for finding the oxygen uptake rate. The oxygen up-taking rate (OUR) could then be calculated using the following equation:

$$OUR = \left(\frac{O_2air - O_2out}{100} \right) \times \textit{Aeration Rate (L/min/kg)}.$$

The measurements were continued till the reactor temperature becomes equal to or less than the ambient temperature in a period of 24 hours.

Results and discussion

The temperature profile for reactor temperature (average of two readings), ambient temperature and oxygen uptake rate with composting time is plotted for various trials as shown in Fig 3 to Fig 10. Due to the presence of readily biodegradable organic matter in the substrate, the microbial activity quickly started, released heat and the temperature inside the reactor increased rapidly. Table 4 shows the time required in hours for all the three phases of composting, total composting and maximum temperature for the experimental trials. During the initial 2 to 4 hours mesophilic bacteria were highly active and temperature increased above 40^0C and thereafter thermophilic activity started and continued up to 76, 94, 78, 100, 84, 112, 88 and 82 hours for the trials 1 to 8 respectively. Maximum temperature was attained for trial 7 at the end of 10 hours and the temperature was 67.1^{0}C. After the easily degradable substrates were consumed during the active phase, cooling started. At the end of 312 to 480 hours the temperature reached ambient temperature indicating the stability of composting. The maximum temperatures and oxygen uptake rates for various trials vary from 53.3 to 67.1^{0}C and 0.144 to 0.180 lit/min respectively. Maximum uptake rate occurred at peak temperature and decreased with decrease in temperature and is minimum at the end of composting process. In Fig 3 to 10 it can be seen that the oxygen uptake rate is related to temperature with a positive correlation.

Optimal conditions

Maximum temperature and the total composting time are the responses for analysis. The maximum temperature to be maintained during composting is restricted to 60^{0}C for quality composting since higher temperature can cause deactivation of enzymes of microorganisms (Zucconi et. al., 1986). Therefore for the maximum temperature the target value is 60^{0}C and *nominal the best* criterion is selected in quality criteria. For the other response - composting time - the quality criteria is *smaller the better*, since small composting time shows faster degradation of substrates.

Table 6: Response Table for Signal to Noise Ratios *Nominal is best* for maximum target temperature 60^{0}C

Level	Brewery sludge	Amendment	C/N ratio	Starting culture	Aeration rate
1	-8.312	-2.624	-8.506	-8.228	-6.028
2	-7.245	-12.932	-7.050	-7.328	-9.528
Delta	1.067	10.309	1.457	0.900	3.500
Rank	4	1	3	5	2

Table 7: Analysis of Variance for SN ratios for temperature

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% cont ribution
Brew. sludge	1	2.276	2.276	2.276	1.11	0.484	0.76
Amendment	1	212.53	212.53	212.53	103.4	0.062	70.72
C/N ratio	1	4.243	4.243	4.243	2.06	0.387	1.41
Start. culture	1	1.619	1.619	1.619	0.79	0.538	0.54
Aeration rate	1	24.504	24.504	24.504	11.92	0.179	8.15
B.S x C/N	1	53.282	53.282	53.282	25.92	0.123	17.73
Resid. Error	1	2.055	2.055	2.055			0.69
Total	7	300.51					

Table 8: Response Table for signal-to-noise ratios. *Smaller is better* for composting time before pooling factor Aeration Rate

Level	Brewery sludge	Amend ment	C/N ratio	Starting culture	Aeration Rate
1	-52.52	-51.58	-51.10	-51.58	-52.03
2	-51.24	-52.17	-52.66	-52.17	-51.72
Delta	1.28	0.59	1.56	0.59	0.31
Rank	2	3.5	1	3.5	5

Table 9: Response Table for Signal to Noise Ratios. *Smaller is better* for composting time after pooling factor Aeration Rate

Level	Brewery sludge	Amendment	C/N ratio	Starting culture
1	-52.52	-51.58	-51.10	-51.58
2	-51.24	-52.17	-52.66	-52.17
Delta	1.28	0.59	1.56	0.59
Rank	2	3.5	1	3.5

Figure 3-10: Variations in reactor temperature (Tr), ambient temperature (Ta) and oxygen uptake rate (OUR) with composting time for various trials

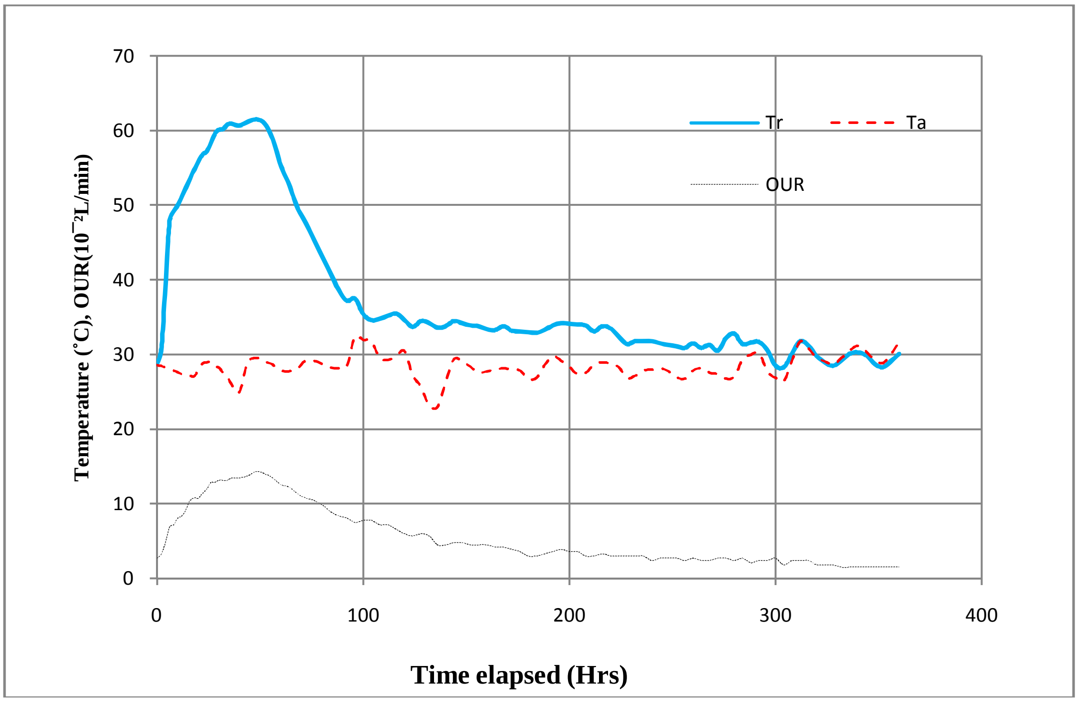

Figure 3: Variations in Tr, Ta & OUR with composting time for trial 1 h

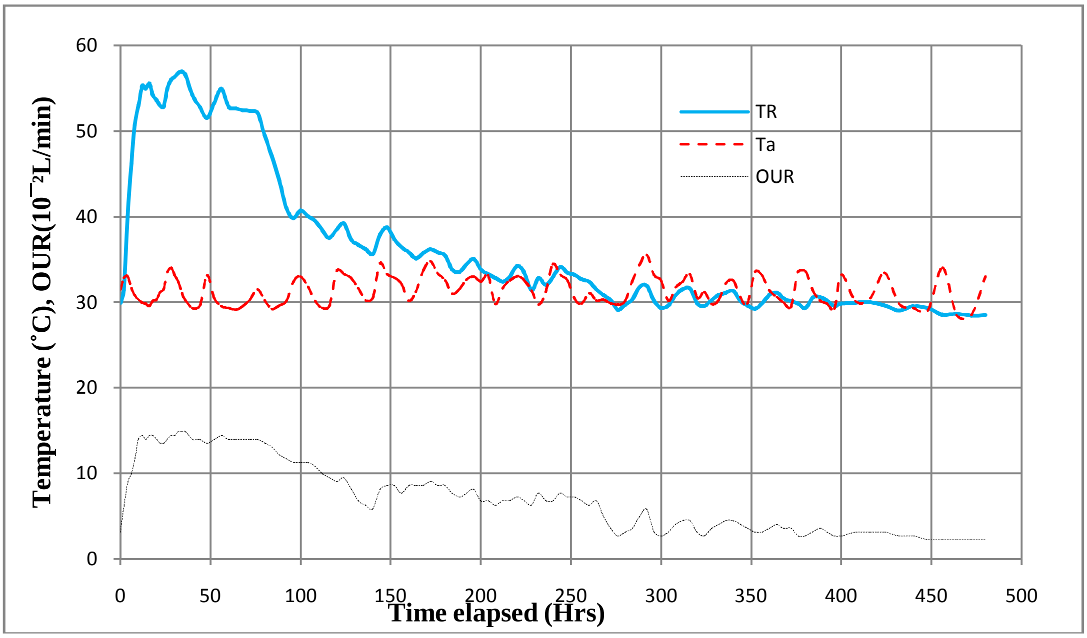

Figure 4: Variations in Tr, Ta & OUR with composting time for trial 2

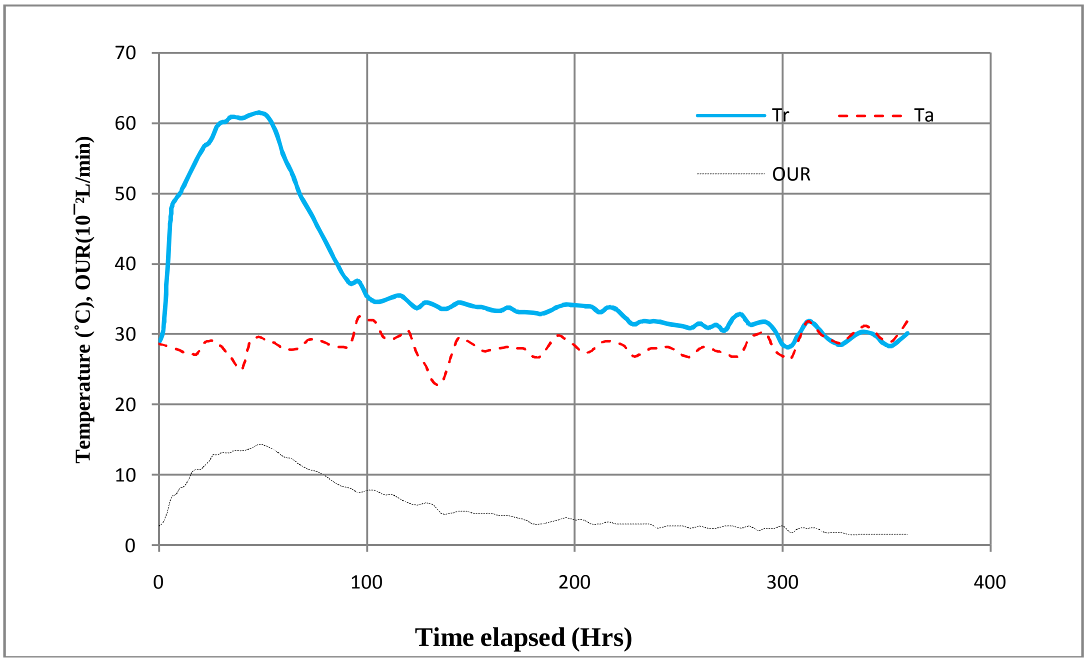

Figure 5: Variations in Tr, Ta & OUR with composting time for trial 3

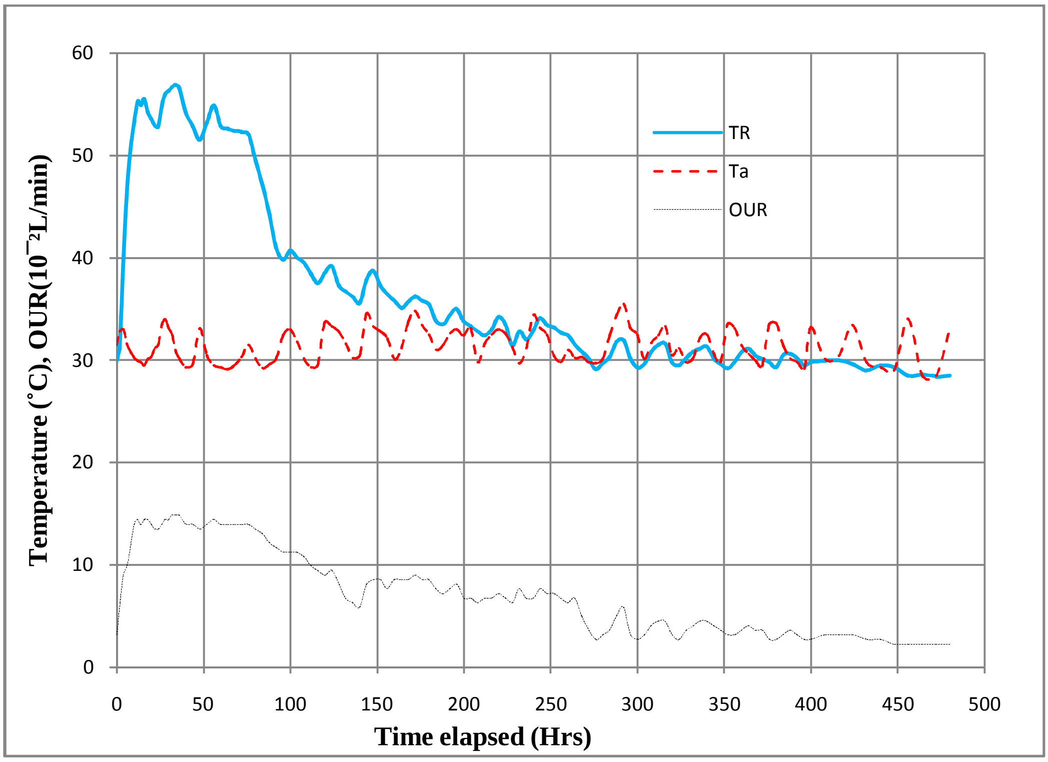

Figure 6: Variations in Tr, Ta & OUR with composting time for trial 4

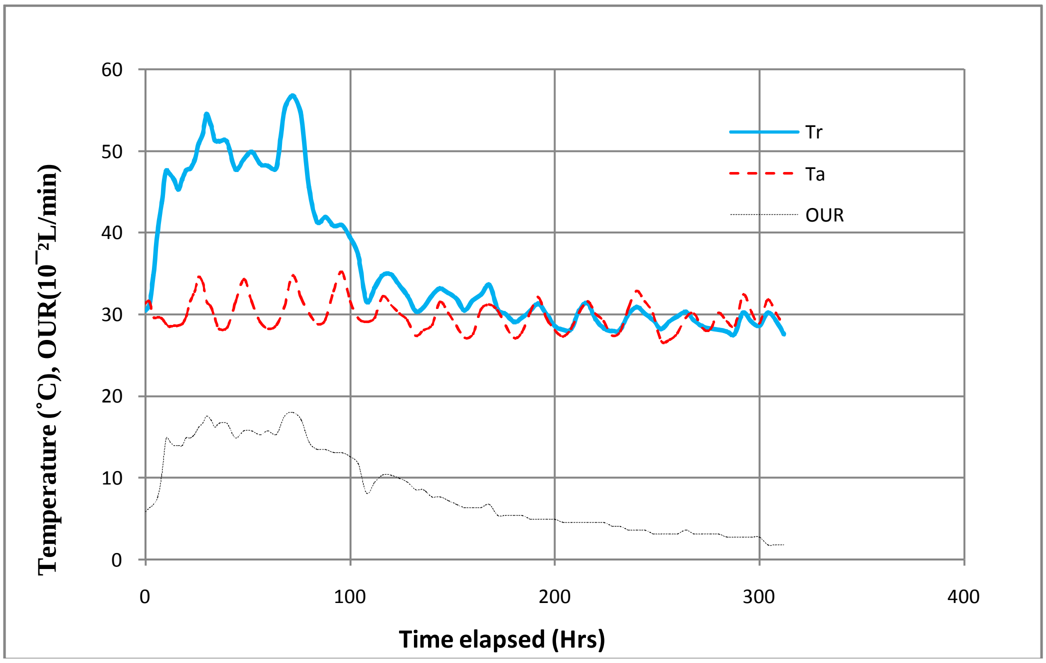

Figure 7: Variations in Tr, Ta & OUR with composting time for trial 5

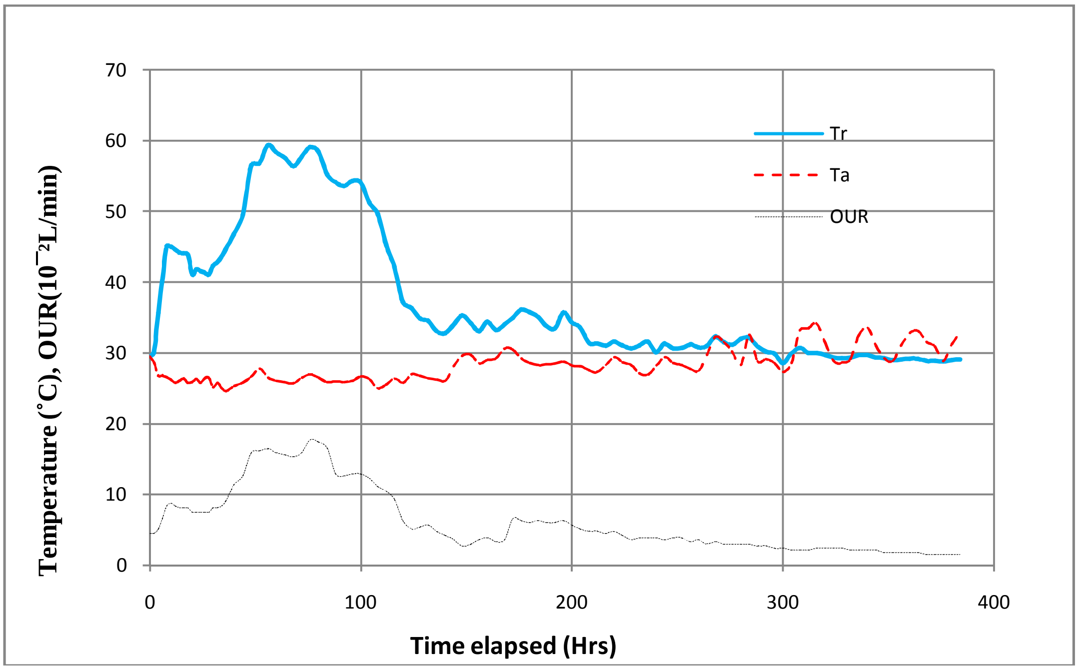

Figure 8: Variations in Tr, Ta & OUR with composting time for trial 6

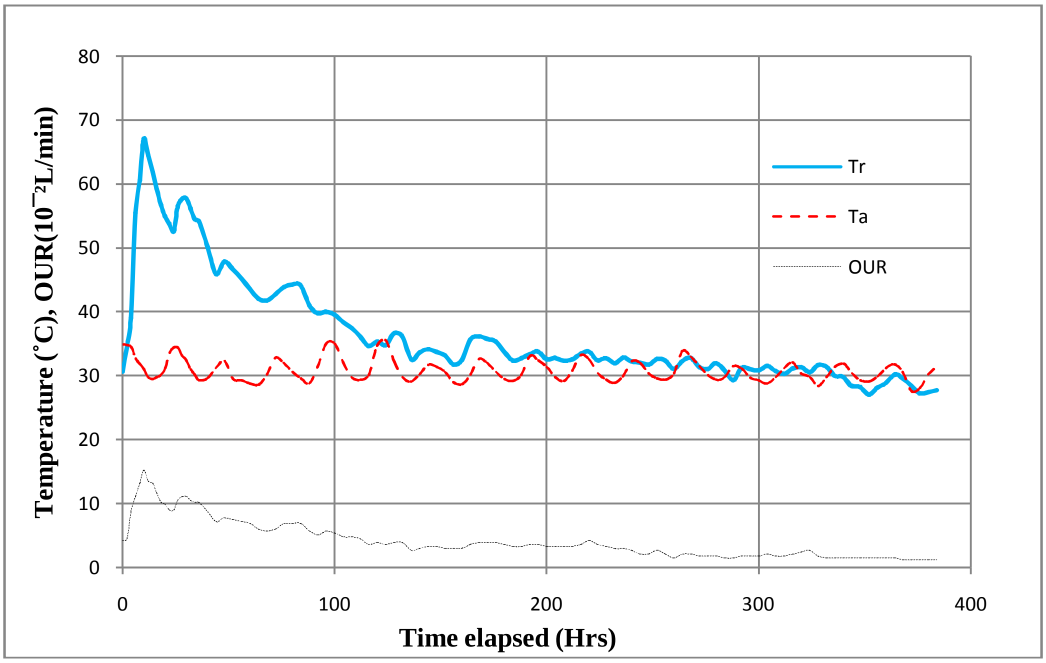

Figure 9: Variations in Tr, Ta & OUR with composting time for trial 7

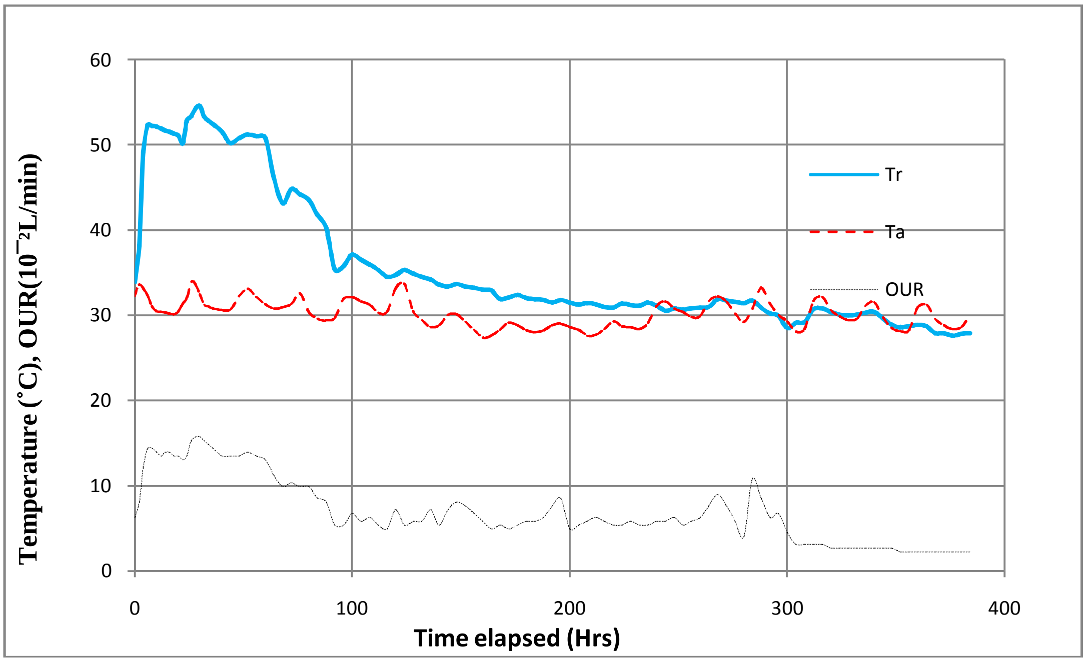

Figure 10: Variations in Tr, Ta & OUR with composting time for trial 8

Optimization for maximum temperature

In order to know the influence of levels of composting factors on maximum temperature, response plots of S/N ratio for main effect and interaction were done for nominal the best in which the target value is 60^0C. The response table for SN ratios is given in Table 6 for all the levels of factors without pooling. The delta value shows the difference between signal-to-noise ratio between the levels of factors, which gives the rank of influencing factors. Fig 11 represents the main effect plot for SN ratios of the maximum temperature and the levels of factors that gives maximum SN ratio is selected, and it is A2B1C2D2E1 for all contributing factors. Fig 12 represents the Interaction plot for SN ratios between brewery sludge and amendment and Fig 13 shows the Interaction plot for SN ratios between brewery sludge and C/N ratio. From Fig 12 it is clear that the interaction between brewery sludge and amendment is absent since the lines are parallel and can be eliminated in the subsequent analysis. But strong interaction exists between brewery sludge and C/N ratio as seen from Fig 13 and the factor levels contributing strong interaction is A2C2. Therefore the optimal condition considering the interaction effect also is A2B1C2D2E1 which is same as that of the optimal condition for main effects. In order to know the most significant factor influencing the maximum target temperature, analysis of variance is done and the results are presented in Table 7. Pooling is required in the process of analysis of variance where error degrees of freedom are zero. Therefore to have a non-zero error degrees of freedom the least contributing factor or interaction effect is pooled and eliminated for further analysis. Since the interaction between brewery sludge and amendment is absent, this term is pooled. From Table 7 it is clear that the most significant factor affecting maximum temperature is amendment and the least significant factor is starting culture. The percentage of contributions of factors and error is shown in the last column of Table 7 and is represented by a pie diagram as shown in Fig 14. It is seen that the maximum contributing factor is amendment.

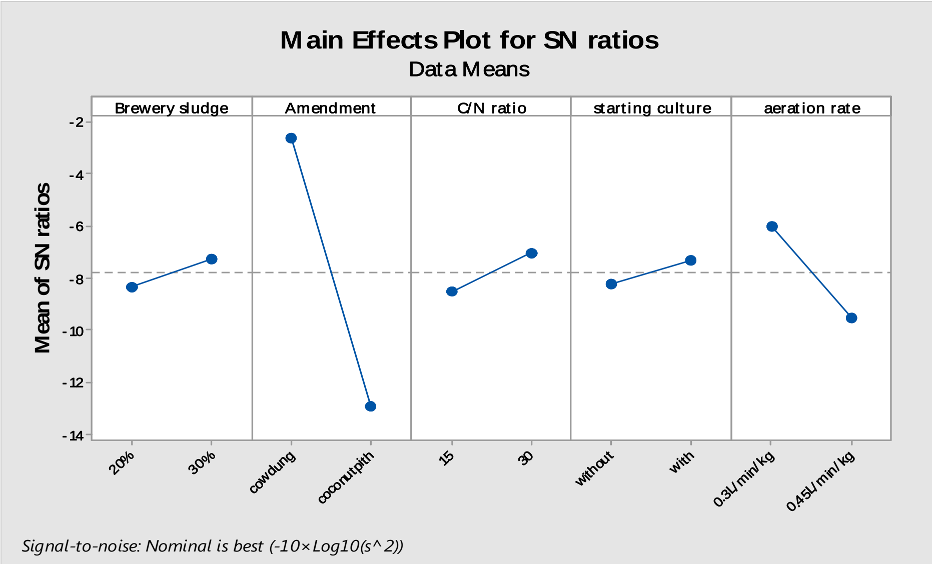

Figure 11: Main effects plot for SN ratios for temperature

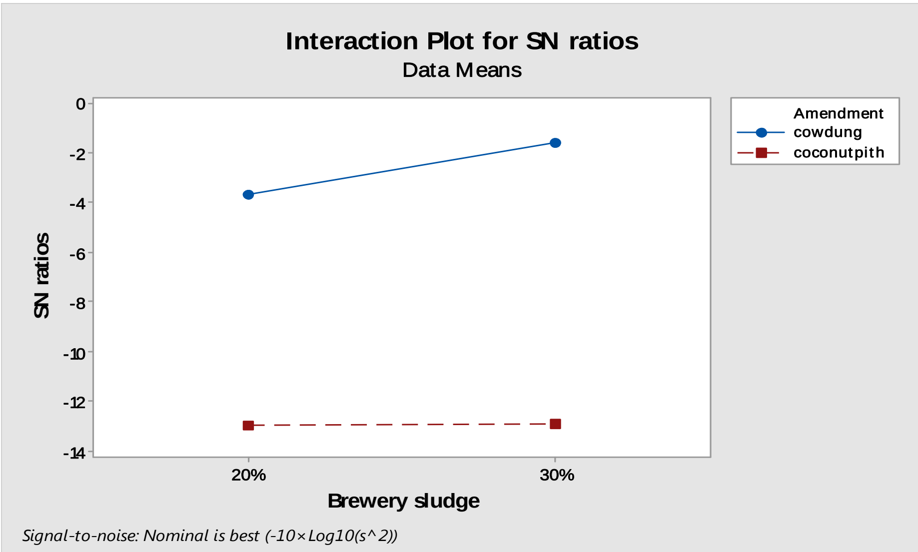

Figure 12: Interaction plot for SN ratios between brewery sludge and amendment for temperature

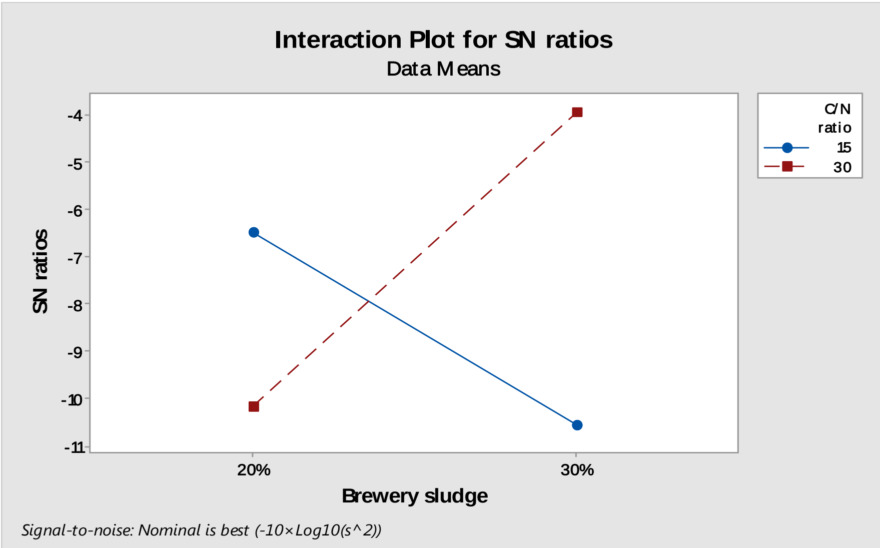

Figure 13: Interaction plot for SN ratios between brewery sludge and C/N ratio for temperature

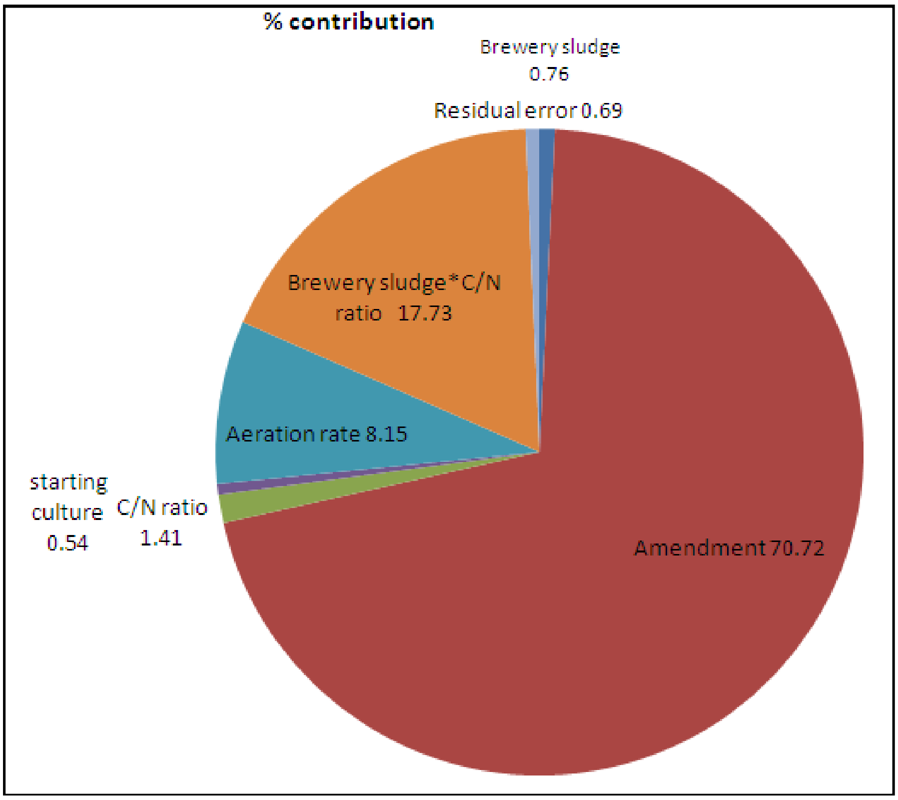

Figure 14. % contribution of factors in the response

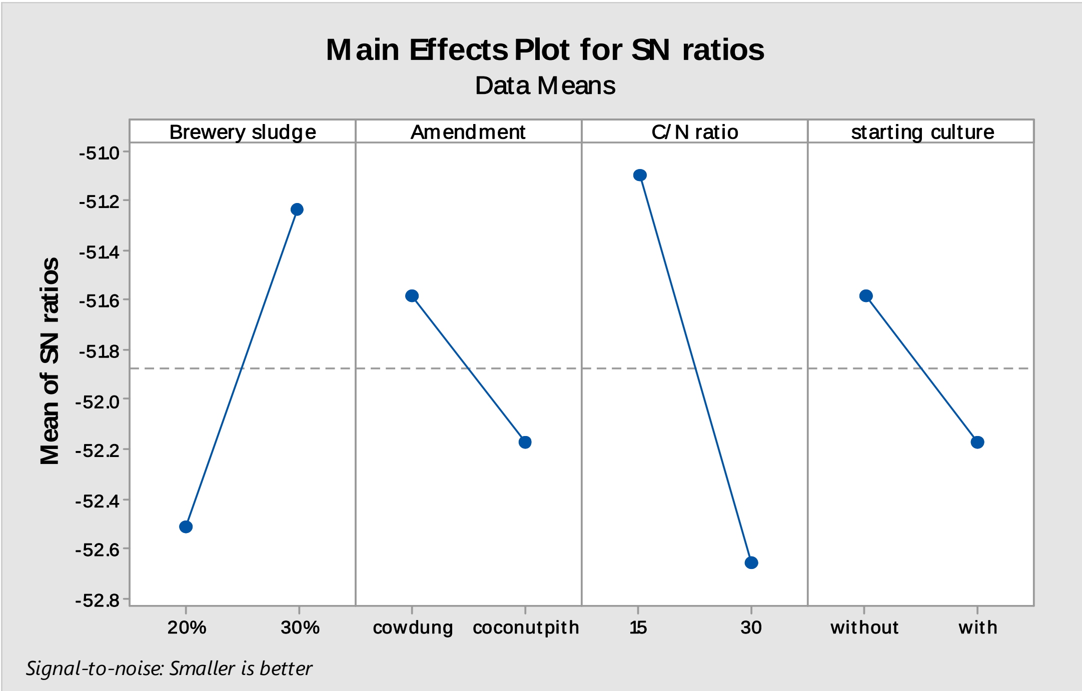

Figure 15: Main effect plot for SN ratios for composting time

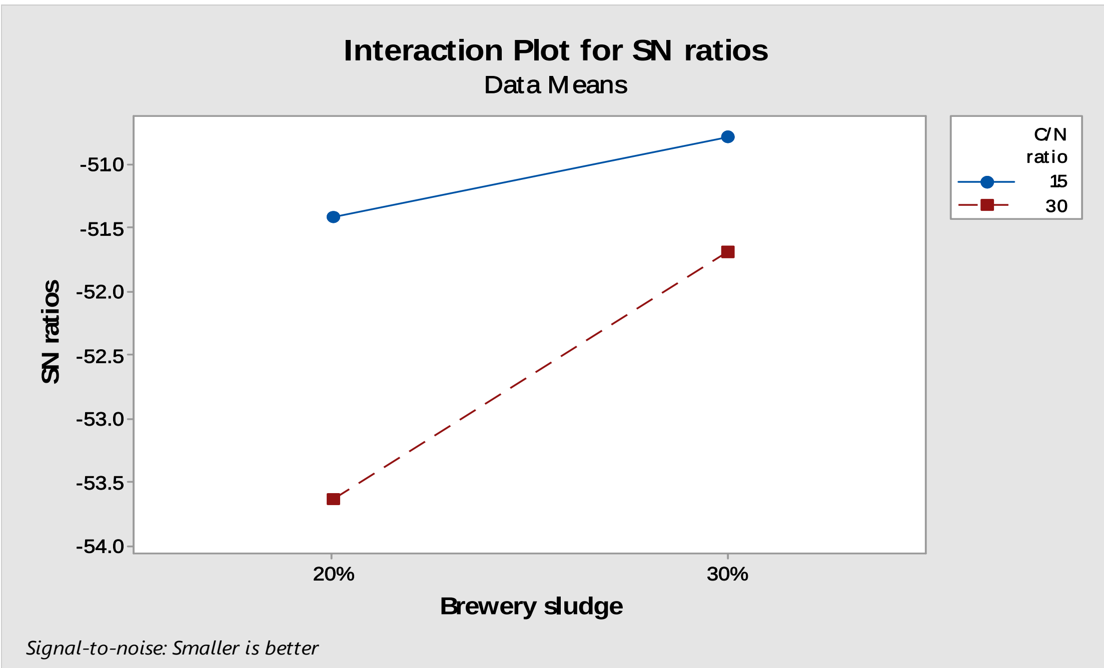

Figure 16: Interaction plot of Brewery Sludge and C/N ratios for SN ratios of composting time

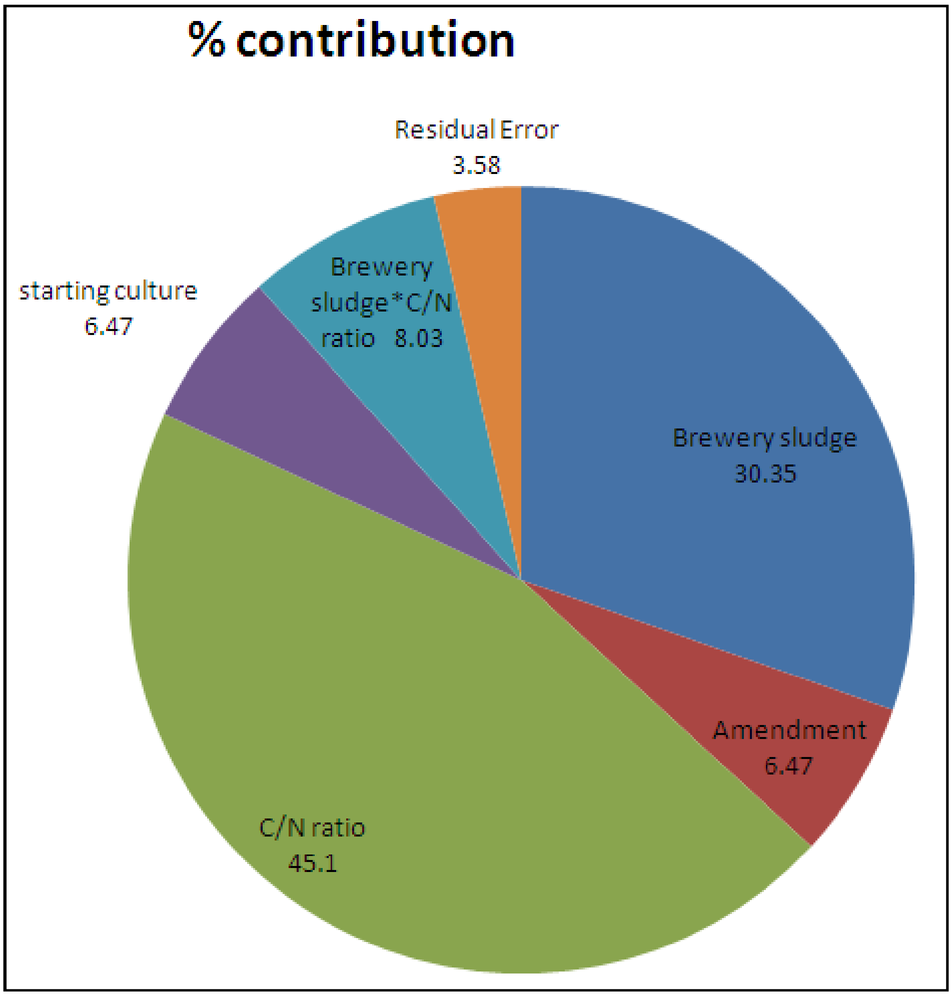

Figure 17: % contribution of factors on composting time

Table 10: Analysis of Variance for SN ratios for composting time

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% cont ribution
B.S	1	3.2760	3.2760	3.2760	16.96	0.054	30.35
Amendment	1	0.6986	0.6986	0.6986	3.62	0.198	6.47
C/N ratio	1	4.8680	4.8680	4.8680	25.21	0.037	45.10
Start culture	1	0.6986	0.6986	0.6986	3.62	0.198	6.47
B. S x C/N	1	0.8669	0.8669	0.8669	4.49	0.168	8.03
Resid. Error	2	0.3862	0.3862	0.1931			3.58
Total	7	10.7943					

Optimization for composting time

To know the influence of levels of composting factors on total composting time, the response plots of S/N ratio for main effect and interactions were done for *smaller the* *better* criteria. The response table for SN ratios is given in Table 8 for all the levels of factors without pooling; delta is the difference between signal to noise ratio between the levels of factors, which gives the rank of influencing factors. The factors aeration rate and the interaction between brewery sludge and amendment were pooled because they are the least contributing factors. This pooling gives an error degrees of freedom 2. Therefore in the subsequent analysis they are eliminated. The response table after pooling is shown in Table 9 which gives the signal-to-noise ratio at various levels of factors. Fig 15 represents the main effect plot for SN ratios of the total composting time and the levels of factors that gives maximum SN ratio is selected and it is A2B1C1D1 for the major contributing factors. Fig 16 represents the interaction plot for SN ratios between brewery sludge and C/N ratio. Contribution of interaction between brewery sludge and amendment is also very less on composting time and therefore it is also pooled. From Fig 16 it is clear that the factor levels for interaction between brewery sludge and amendment is A2C1. The optimal levels of factors that can yield less total composting time is A2B1C1D1 considering the main effects and interaction effect. In order to know the factor contribution and the significance of the factors on total composting time, analysis of variance is done and the results are presented in Table 10. From Table 10 it is clear that the most significant factor influencing total composting time is C/N ratio and the least significant factors are amendment and starting culture. The percentage of contributions of factors and error is shown in the last column of Table 10 and is represented by a pie diagram as shown in Fig 17. It shows that C/N ratio is the most contributing factor in reducing composting time.

Conclusion

Taguchi's experimental design was used for conducting experiments in 8 trials to fix optimal levels of five factors at 2 levels namely A: the percentage of brewery sludge (20, 30), B: amendment type (cow-dung, coconut-pith), C: C/N ratio (15, 30), D: starting culture (without, with) and E: aeration rate (0.3 L/min/kg, 0.45 L/min/kg) and the interaction of factors for the maximum temperature and composting time with an L_8 orthogonal array. Trials were run in random order in a batch-scale in-vessel composting reactor with provision for monitoring temperature and oxygen uptake rate till the end of composting. SN analysis was used for optimisation of the factors for two responses viz. maximum temperature and total composting time. Main effect plots and interaction plots for SN ratio were used for fixing the optimal level of factors. Analysis of variance was done to know the significance of factors and factor contribution on responses.

The optimal levels of the factors for a target maximum temperature of 60^0C is A2B1C2D2E1 for *nominal the best* criteria. For the composting time, *smaller the better criteria* is A2B1C1D1. Analysis of variance shows that the most significant factor influencing a maximum target temperature of 60^0C is the amendment type cow dung and for the total composting time it is C/N ratio of 15. Results indicate that for producing quality compost, since it is necessary to maintain an optimum temperature of 60^0C to reduce microbial enzyme deactivation and to increase degradation rate of compost material, the levels of factors are – brewery sludge - 30%, cow dung as amendment, C/N ratio 30, presence of starting culture and aeration rate of 0.3 L/min/kg are the optimum. But for reducing composting time, brewery sludge - 30%, cow dung as amendment, C/N ratio 15 and aeration rate 0.3 L/min/kg is the optimum. Starting culture is insignificant here. Comparing the two optimal levels of factors for the two responses, it can be seen that the levels of brewery sludge, amendment and aeration rate are same for both. But, levels of C/N ratios are different. C/N ratio of 15 can increase the microbial activity and degradation rate, resulting in shorter composting time, but can cause increase in temperature leading to volatilization of ammonia causing nitrogen loss. C/N ratio 30 can maintain lower temperature compared to 15, thereby reducing volatilization of ammonia and consequent nitrogen loss, but can increase composting time. Since level of starting culture is not an influencing factor in reducing composting time, the prime concern is maintaining the temperature and hence the most desired optimum combination is A2B1C2D2E1.

References

[1] Barrington, S., Choinière, D., Trigui, M. and Knight, W (2002), "Effect of carbon source on compost nitrogen and carbon losses", *Bioresource Technology*, Vol. 83, pp. 189–194.

[2] Bien. J, Neczaj. E, Milezarek. M (2013), "Co-composting of meat packing waste water sludge and organic fraction of municipal solid waste", *Global Nest Journal*, Vol. 15, No.4, pp. 513-521.

[3] Chang J.I., Tsai J.J. and Wu K.H. (2006), "Thermophilic composting of food waste", *Bioresource Technology*, Vol. 97, pp. 116-122.

[4] Christensen, T. H. (Ed.) (2011). "Solid waste technology & management", *Wiley Edition,* Vol. 2, Chichester, West Sussex, UK.

[5] De Bertoldi, M. D., Vallini, G. E., & Pera, A. (1983). "The biology of composting: a review", *Waste Management & Research*, Vol. 1 (2), pp. 157-176.

[6] Delgado. A, Soleradel Rio. R, Sales. D and Garcia-Morales. J.L. (2004), 'Study of the co-composting process of municipal solid waste and sewage sludge: stability and maturity', *Proceedings of the 11th International Conference of the FAO*, Murcia, Spain, 5-9 October, pp. 257-261.

[7] Higarashi M.M., Sardá L.G., Oliveira P.A.V (2010), "The influence of bulking agents on ammonia emission from swine manure co-composting'', *Proceeding of the conference on Technologies/systems for different manure and organic waste treatment options,* Brazil.

[8] Hema Nalini. A.V, P.R. Sreemahadevan Pillai & YVKS Rao, (April 2015), "Shredded Newspaper as a Physical Conditioner for Improving Drainability of Brewery Sludge", *International Journal of Scientific & Engineering Research*, Vol. 6, Issue 4, pp. 64-69.

[9] Hema Nalini. A.V, P.R. Sreemahadevan Pillai & YVKS Rao, (April 2015) "Simulation of Organic Fraction of Municipal Solid Waste in the Preparation

of Synthetic Compost Recipe for Lab-Scale In-Vessel Composting", Proceedings of the *National Conference on Innovative Practices in Construction & Waste Management*, SRIT, Coimbatore, 8 & 9 April 2015 (Also published by the organizers in the *International Journal of Innovative Research in Engineering and Management*).

[10] Hema Nalini. A.V, P.R. Sreemahadevan Pillai & YVKS Rao, (July 2015), "Effect of Carbon Nitrogen ratio on Nitrogen loss in the Co- Composting of Municipal Solid Waste and Brewery Sludge", Proceedings of the *International Conference on Energy and Environment Management*, Department of EEE, NSSCE and IETE, Palakkad.

[11] Hema Nalini. A.V, P.R. Sreemahadevan Pillai & YVKS Rao, (August 2015), "Temporal Variations in Characteristics during Co-composting of Organic Fraction of Municipal Solid Waste and Brewery Sludge with Cow Manure as Amendment", *International Conference on Renewable Energy and Sustainable Development*, Mahalingam College of Engineering and Technology, Pollachi, 10-13 August 2015.

[12] (Also published in *Energy and Environment Science International Journal* by organizers)

[13] Jerzy drozd, Micha£ Licznar, Stanislawa E. Licznar, Karolina Walenczak (2008), "Losses of organic matter and nitrogen during composting of municipal solid wastes", *Polish Lournal of Soil Science*, Vol. 12/2 pp. 127-137.

[14] K.R. Atalia, D.M. Buha, K.A. Bhavsar and N.K. Shah, (2015) "A Review on Composting of Municipal Solid Waste*", IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)* Vol. 9, Issue 5 Ver. I, pp. 20-29.

[15] Liang, C., Das, K. C., & McClendon, R. W. (2003). "The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend", *Bioresource Technology*, Vol. 86(2), pp. 131-137.

[16] Liang, Y., Leonard, J. J., Feddes, J. J. R., & McGill, W. B. (2006), "Influence of carbon and buffer amendment on ammonia volatilization in composting", *Bioresource Technology*, Vol. 97(5), pp. 748-761.

[17] Manjula Gopinathan and Meenambal Thirumurthy (2012), "Feasibility studies on static pile co-composting of organic fraction of municipal solid waste with dairy waste water", *Environmental Research, Engineering and Management*, No.2 (60), pp. 34-39.

[18] Miyatake, F., & Iwabuchi, K. (2005), "Effect of high compost temperature on enzymatic activity and species diversity of culturable bacteria in cattle manure compost. *Bioresource Technology*, Vol. 96(16), pp. 1821-1825.

[19] Miyatake, F., & Iwabuchi, K. (2006), "Effect of compost temperature on oxygen uptake rate, specific growth rate and enzymatic activity of microorganisms in dairy cattle manure, *Bioresource Technology*, Vol. 97(7), pp. 961-965.

[20] P. Bueno, R. Tapias, F. Lo´pez, M.J. Dı´az (2008), "Optimising composting parameters for nitrogen conservation in composting", *Bioresource Technology,* Vol. 99, pp. 5069-5077

[21] Peter Tucker (2005), "Co-composting of paper mill sludges with fruit and vegetable waste", *University of Paisley, National Society for Cleaner and Environmental Protection,* 44 Ground Parada, Brighton, BN2 9QA.

[22] Ranjit Roy (1990), "A primer on the Taguchi Method", *Van Nostrand Reinhold*, New York.

[23] Robert. H. L. and Joseph. E.M (1990), "Design for quality – an introduction to the best of Taguchi and western methods of statistical experimental design", *Chapman & Hall Publishers.*

[24] Ryckeboer, J., Mergaert, J., Coosemans, J., Deprins, K. and Swings, J. (2003), "Microbiological aspects of biowaste during composting in a monitored compost bin", *Journal of Applied microbiology*, Vol. 94, pp. 127-137.

[25] Sarkar et. Al. (2010), "Effectiveness of inoculation with isolated geobacillus strains in the thermophillic stage of vegetable waste composting", *Bioresource Technology*, Vol. 101, pp. 2892-2895

[26] Sreemahadevan Pillai. P.R. & Hema Nalini. A.V, (2001) "A comprehensive study of Solid Waste Management for Palakkad Municipal Area", *Report of the Netherlands Government funded KRPLLD Research Project*, CDS, Govt. of Kerala, Thiruvananthapuram

[27] Stocks. C, Barker. A.J. and Guy. S. (2002), "The composting of brewery sludge", *Journal of Institute of Brewers*, Vol. 108(4), pp. 452-458.

[28] Sudarut Tripetchkul, Kanokwan Pundee, Songpon Koonsrisuk and Saengchai Akeprathumchai (2012), "Co-composting of coir pith and cow manure:initial C/N ratio vs physico-chemical changes" *International Journal of Recycling of Organic Waste in Agriculture*, Vol. 1:15, pp. 1-8.

[29] Sundberg,C. and Jonsson. H. (2005), "Process inhibition due to organic acids in fed batch composting of food waste- influence of starting culture", *Biodegradation*, Vol. 16, pp. 205-213.

[30] Tang, J. C., et. al. (2007), "Effect of temperature on reaction rate and microbial community in composting of cattle manure with rice straw", *Journal of bioscience and bioengineering*, Vol. 104(4), pp. 321-328.

[31] Xueling Sun (2006), "Nitrogen Transformation in Food-Waste Composting", MASc thesis, University of Regina, Canada.

[32] Y. Q. Wang and F. Schuchardt, (2010) "Effect of C/N ratio on the composting of vineyard pruning residues" Landbauforschung - VTI Agriculture and Forestry Research, Vol. 3 (60), pp. 131-138

[33] Zucconi, F., & Bertoldi, M.de. (1986), "Compost specifications for the production and characterization of compost from municipal solid waste in compost: production, quality and use", *Proceedings of a symposium organized by the commission of the European communities*, Directorate General of Science, Research and Development, 17-19 April, Udine, Italy.