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# Duration of Composting and Changes in Temperature, pH and C/N Ratio during Composting: A Review

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## ABSTRACT
Composting is the most viable treatment for biodegradable solid waste. Numerous techniques have been developed by different agencies to carry out composting. The most common method is aerobic bin method carried out on small scale. Compost piles and windrow methods needs larger land area and are mainly carried out by industries. The total time for completion of composting depend upon the type of substrate and the methods employed. Moisture content, temperature, pH and C:N ratio are among the most important factors for carrying out composting. The present review emphasised on the estimation of time taken by different types of substrates under different methods of composting and the changes in temperature, pH and C:N ratio occurring therein.

**Key words:** Ammonia, Compost pile, Mesophile, Thermophile, Windrow.

Composting is the process of decomposition of organic matter under controlled conditions, brought about by the growth of microorganisms and invertebrates. Although decomposition occurs naturally it can be accelerated and improved by human interventions. The microorganisms and invertebrates require oxygen and water while producing compost, carbon dioxide, heat and water. Organic wastes provide carbon, nitrogen and nutrients necessary for microorganisms to carry out decomposition efficiently. Composting reduce volume of the substrate by 20 to 60%, weight by 50%, pH near neutral and C:N ratio below 20:1, undesirable odours are also replaced by earthy smell (MAF, 1996). Composting is the most viable treatment that can be given to biodegradable waste, since it is a natural process that requires much less capital investment (Bhave and Joshi, 2017).

Compost is a rich source of organic matter. Besides being a source of plant nutrients, organic matter improves the physicochemical and biological properties of the soil. As a result of these improvements the soil becomes more resistant to stress, such as drought, disease and toxicity, helps crops to improve the absorption of plant nutrients and has an active ability to circulate nutrients due to vigorous microbial activity (Shah *et al*. 2019).

Important factors in the process of composting are, particle size of the substrate, moisture content, temperature, pH, C:N ratio, nutrient content and toxic substances. Many studies have reported on the process of composting and quality of compost formed from different types of organic wastes (Goyal *et al*. 2005; Caceres *et al.* 2006; Huang *et al.* 2017; Chaudhary and Mishra, 2019; Jain *et al.* 2019). The present review was undertaken to evaluate the total time taken by different types of organic wastes to convert into compost and the changes in temperature, pH and C:N ratio during the process of composting.

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### Duration of composting

Among the different methods aerobic composting using different kinds of reactor and bin was the most common method observed. Compost piles, simply dumped, windrow and anaerobic type of composting were less studied. Therefore, the duration of composting was studied based upon these five types of methods.

### Aerobic composting

In a study done by Varma *et al.* (2017) where vegetable waste was amended with different ratios of cattle manure, saw dust and dry leaves, it was observed that formation of compost was efficient after 20 days using aerated rotary drum composter. Bhave and Joshi, (2017) observed raw vegetable waste mixed with cooked food waste were significantly converted into compost after 40 days using aerobic reactor. Manu *et al*. (2016) have done composting of leftover cooked vegetable, rice, noodles, curries, fruits peels and salads mixed with green and dry leaves, grass trimmings and parts of plants. The composting process lasts for 60 days. Food waste composting carried out in a computer controlled reactor complete after 42 days (Wong *et al*. 2009). Sugarcane trash composting *in-situ* soil was observed to complete within 60 days (Kannan, 2020).

Composting of Chinese medicinal herbal residue mixed with food waste and saw dust using aerated reactor was complete within a period of 60 days (Zhou *et al.,* 2014). Rice straw mixed separately with chicken manure and donkey manure using aerated bags complete composting within 62 days (Karanja *et al*., 2019). Composting of municipal sewage sludge in the form of solid cake and partially dried to 80-85% carried out using bioreactor was complete within a period of 45 days (Dzulkurian *et al.,* 2017). Poultry manure mixed with maize straw using aerated bioreactors complete within 110 days (Kopec *et al.,* 2018). Pig manure mixed with corn stalks complete composting within a period of 37 days using aerated cylinder (Guo *et al.* 2012). Fan *et al.* (2016) reported that kitchen waste mixed with dried leaves and rice bran complete composting within 60 days using aerated bin method. NaOH/NaClO contaminated poultry manure mixed with different ratios of vegetable waste, food waste, mature compostand green waste treatment complete composting within 40 days (Liu *et al*., 2018). Wheat straw in aerated pipe with inoculants complete composting after 60 days (Pan and Sen, 2013).

**Compost pile, simply dumped, windrow and anaerobic composting**

Compost piles of sheep manure mixed with plant residues and soil added between layers with turning every 10 days was found to mature after 50 days (Abu-Zahra *et al*., 2014). Compost piles of different ratios of fruit waste, saw dust, swine manure and rice straw with regular turning undergoes composting for a period of 120 days (Tibu *et al.,* 2019). Wheat straw in simply dumped method by addition of inoculants complete composting after 75 days (Pan and Sen, 2013). In cement pit method composting of vegetable waste the activities of enzymes was higher in the initial 30 days (Lakshmi *et al*., 2012). Lopez-Mosquera *et al*. (2011) observed that fish waste mixed with seaweed was found to complete composting after 120 days using windrow method. Chicken manure mixed with saw dust using windrow method complete composting within 110 days (Ksheem and Antille, 2016). Cattle manure treated with wheat straw and sawdust complete composting within a period of 120 days using windrow method (Wang *et al.,* 2004). Shah *et al*. (2019) observed that composting of putrishable municipal solid wastes using anaerobic composting method complete within a period of 120 days.

From the observations made it can be stated that composting process can be completed within a wide range of 20 to 120 days independent of the type of method employed. The most common aerobic bin method was found to carry out by either treatment or no treatment with inoculants and with either turning or no turning. Regular turning reduces the time period of composting. Positive effect of amendment with different types of manures namely, cattle, poultry, donkey, sheep and pig manure was observed in aerobic composting. However, in the study done by Kopec *et al*. (2018) aerobic composting of poultry manure treated with maize straw showed a prolonged composting period of 110 days. The treatment with cattle manure and regular turning showed the lowest time period of composting of 20 days (Varma *et al.* 2017).

In aerobic composting excluding the minimum and maximum period of 20 and 110 days composting of vegetable waste, food waste, rice straw, saw dust and corn stalks was found to complete within 40 to 60 days with amendment of manure, green and dry plant residues. Less work was reported on composting using compost piles, simply dumped, windrow and anaerobic methods. Simply dumped method of composting was found to have similar duration with aerobic composting. Compost piles have wider variation of 50 to 120 days. Windrow and anaerobic composting took more time ranging from 110 to 120 days.

**Moisture**

In most of the studies the moisture level during composting is normally maintained at 45 to 55% through controlled system of watering. Razmjoo *et al*. (2015) found that the moisture content between 45 and 50% is an optimum range for the composting process. When moisture is less than 30%, the bacterial activities will be limited and that above 65% will decrease the porosity of the compost resulting in an anaerobic growth and unpleasant odour emissions. Misra *et al.* (2003) also cited the optimal moisture content should be within the range of 40% to 65%, depending on the openness and water holding capacity of the composting substrate.

**Temperature**

There are two main phases in composting process. The first is characterised by microbial activity leading to decomposition of the biodegradable material and the stability of the organic residue. The second is maturation phase characterised by reorganization of organic matter in stable molecules known as humification. The decomposition phase consists of mesophilic, thermophilic and cooling stages. In the mesophilic stage, the pile temperature slowly increases from ambient temperature to reach the average temperature of this stage which is about 40$^{o}$C. The mesophile microorganisms are gradually replaced by thermophile bacteria, fungi and actinomycetes with a gradual rise in temperature between 50 and 60$^{o}$C to reach the thermophilic phase. Above 60$^{o}$C the degradation of organic matter slow down and after 70$^{o}$C only the enzymes released in the previous stage contributes to degradation. The mesophile microorganisms once again take over in the cooling or curing phase. The maturation phase initiates at ambient temperature with the appearance of micro and macro fauna (Azim *et al.* 2018). The optimum temperature range is 32 to 60$^{o}$C as stabilized finished compost products should have a very low rate of decomposition and will therefore not generate much heat (MAF, 1996).

Change in temperature during composting process depend upon the type of substrates. Variation was mostly observed during attainment of maximum temperature in the thermophilic phase.

**Aerobic composting**

In the aerobic composting of rice straw treated with manure done by Karanja *et al*. (2019) the ambient temperature was 23°C which rises upto 56°C. However in the control the rise in temperature was only upto 33.25°C due to lesser variation of microbial activities. In different ratios of kitchen waste and vegetable waste composting in aerated reactor, the temperature during thermophilic phase reach upto 55°C which gradually declined to 33°C in the cooling phase (Long *et al*., 2017). In the aerated composting done by Guo *et al.* (2012) the rise of temperature was upto 70°C from an initial temperature of 25°C and in the study done by Fan *et al.* (2016) the initial temperature was 25°C which reached upto 52°C in the thermophilic stage. Whereas, in the study done by Liu *et al.* (2018) the initial temperature was12 to 18°C which increased to 68°C.

**Compost pile and windrow composting**

In a compost pile of vegetable waste, fruit waste and tree prunnings the initial temperature was 53°C which gradually rose to 67.3°C and declined to 28.0°C (Pereira *et al.* 2018). Solid fraction of cattle slurry in a compost pile reached maximum temperature in the thermophilic phase upto 75°C where air was blown through a fan. In the piles treated with pine debris it was lower with 72°C whereas, in the piles where no treatment was done maximum temperature lies below 60ºC (Caceres *et al.,* 2006). In the compost piles of olive husk and grape stalks the temperature rose to a maximum of 65ºC in mechanical turning and 40ºC in the forced aeration (Baeta-Hall *et al.,* 2005). Sharma *et al.* (2017) reported maximum temperature ranged from 57.32°C to 58.40°C in the compost pile of flower waste amended with cattle manure and saw dust whereas, in the control the maximum was below 45°C. In a windrow type of composting the initial temperature in the pile was 28°C and after a week it increased to 55°C (Ksheem and Antille, 2016). Frederick *et al*. (2004) have reported that in the windrow composting of wheat straw amended with cattle manure the maximum temperature reached upto 60°C while in sawdust amended with cattle manure, it reached upto 70°C.

Maximum temperature in the thermophilic phase was relatively low with <60°C in the composting where no amendments were made. It was observed that amendment of cattle and pig manure in the different types of wastes leads to a maximum rise of 68°C to 75°C showing more variation and activities of microorganisms. The temperature in thermophilic phase could not be differentiated among different types of methods employed for composting. However, irrespective of the types of composting the maximum temperature varied between 40°C to 75°C.

**pH**

The change in pH during composting varied between the type of substrates and the methods employed. However, change in pH can be distinctly divided into 4 stages according to Poincelot (1972). The four stages are: 1. Acid-genesis phase: The pH decreases as flora produces a lot of $CO_2$ and organic acids early in the thermophilic phase. 2. Alkalinisation phase: Increase in pH due to bacterial hydrolysis of protein and negative nitrogen producing ammonia. 3. pH stabilization phase: The C:N ratio decreases and the reactions becomes slower. Ammonia is lost by volatilization (with apH>8) and nitrogen is used by microbes to synthesize new humic compounds. 4. Stable phase: pH near to neutral as the compost is being in maturation. The stability is due to slow reactions and influence of humus buffer.

The pH variation could be substantially affected by the N and C transformation during composting. Ammonification effect at the early stage of composting may partially lead to increase of compost pH and degradation of lignocellulose carbon at later stagemay partially result in the decrease of compost pH (Onwosi *et al.,* 2017; Xu *et al*., 2011).

**Aerobic composting**

In the study done by Karanja *et al.* (2019) initiation of the composting process led to a slight decline of pH upto 6.56 then, it rose gradually to alkaline conditions as high as 10.46 and then gradually decline to almost neutral at the end of composting period to 7.5 to 8.5. Long *et al*. (2017) observed that the initial pH was low with 4.5 to 5.5 than it increased to 7-8.5. In an aerobic dumping of wheat straw treated with microorganisms the initial pH was 5 and as decomposition progressed pH increased upto 8 and the final value was 7 (Pan and Sen, 2013). Fan *et al.* (2016) observed that initial pH was 4.8 to 5 which increased upto a maximum of 8 and gradually declined to 7 to 8 indicating stability of organic matter. The composting in control which was without treatment of inoculants produced very unpleasant smell in the initial stage. Liu *et al.* (2018) reported an initial pH of 8.5 and gradual increase upto 9.0 than gradually declined to 8 to 8.5. In the aerobic composting of sewage sludge mixed with maize straw the average initial pH was 7.9 which gradually increased to 8.26 and reduced to 7.20 (Wang *et al.* 2013). In an aerobic composting of chicken, pig and cattle manure the average initial pH was 7.46, attained a maximum of 8.36 and reduced to a final value of 7.97 (Huang *et al*. 2017). Chen *et al.* (2015) have reported an average initial pH of 6.8, maximum of 8.68 and final of 7.25 in an aerobic composting of different ratios of sewage sludge, rice straw and *Penicillin mycelial* dreg.

**Compost pile, windrow and anaerobic composting**

Tibu *et al.* (2019) have reported an initial pH of 7.14 to 8.29 and a final of 7.1 to 8.20 in a compost pile of fruit waste, saw dust, food waste and rice straw treated with different ratios of pig manure. In the windrow composting done by Ksheem and Antille (2016), initial pH of saw dust mixed with chicken manure was 8.33, which decreased to 6.83 than increased to a final value of 7.66. Increased sawdust to manure ratio leads to the reduction of pH as addition of saw dust promoted conversion of ammonia-N into organic-N forms through microbial immobilization. Khalib *et al.* (2019) reported an average initial pH of 8.31 which increased to 9.7 and finally reduced to 8.5 in anaerobic composting of garden waste treated with different ratios of chicken manure and inoculants.

The general concept of a slight decline in pH in initial stage and gradual increase attaining maximum and gradual decline at final phase was normally not observed in most of the studies except in the study reported by Karanja *et al*. (2019). In most of the studies initial drop in pH was not observed, it gradually increased in the initial phase till maximum and gradually declined in the final stage. However, in the study done by Ksheem and Antille (2016) the pH dropped as composting progressed and increased in the final due to presence of saw dust. The change in pH among the different methods of composting was difficult to differentiate. However, irrespective of the methods, maximum pH in the thermophilic phase was found to range from 7 to 9. In some cases it reached beyond 9 reaching upto 10.4. When the initial pH was high, relatively the change during the process of composting was high and vice versa, however the final pH irrespective of the type of substrates in all the studies was found to range from 7 to 8.5.

The initial pH in the substrates amended with chicken, donkey, swine and cattle manure was high having a range of 7 to 8.5. The substrates having vegetable waste, kitchen waste, wheat straw and saw dust along with and without treatment of inoculants have lower initial pH ranging between 4.5 to 6.8. The studies showed that C:N ratio of the initial substrates have an important role in the initial state of pH.

**Table 1:** Initial C:N ratio of different types of substrate.

| Substrate | Initial C:N ratio | Author |
|---|---|---|
| Rice straw | 60.33 | Karanja *et al*.(2019) |
| | 87.20 | Chen *et al*. (2015) |
| | 76.38 | Tibu *et al.* (2019) |
| Wheat straw | 128.00 | Pan and Sen (2013) |
| Saw dust | 85.62 | Tibu *et al.* (2019) |
| | 182.30 | Chen *et al.* (2015) |
| | 254.00 | Frederick *et al*. (2004) |
| Vegetable waste | 27.07 | Long *et al.* (2017) |
| | 20.00 | Shilev *et al*.(2007) |
| Cooked food | 50.70 | Long *et al.* (2017) |
| Garden waste | 11.00 to 19.00 | Khalib *et al.* (2018) |
| Sewage sludge | 13.20 | Guo *et al.* (2012) |
| | 7.70 | Chen *et al*. (2015) |
| Chicken manure | 5.10 | Huang *et al.* (2017) |
| | 13.90 | Goyal *et al.* (2005) |
| Swine manure | 13.20 | Guo *et al*. (2012) |
| | 8.00 | Huang *et al.* (2017) |
| | 19.78 | Tibu *et al.* (2019) |
| Cattle manure | 10.70 | Huang *et al.* (2017) |
| | 15.00 | Frederick *et al*. (2004) |

Different types of manure and sewage sludge have lower initial C:N ratio (Table 1) therefore, substrates treated with these types of manure increase the initial pH. Whereas, kitchen waste, vegetable waste, wheat straw and saw dust have higher initial C:N ratio therefore composting of these substrates have lower initial pH.

**C:N ratio**

The most widely used parameter for composting is C:N ratio of the initial substrate. Microorganisms can decompose organic material quickly at a steady C:N ratio of 30:1. When the C:N ratio is too high presence of low level of N slows rate of decomposition. Whereas when C:N ratio is too low there is too much N and it will likely be lost to the atmosphere in the form of ammonia gas. This can lead to odour problems. Most materials available for composting do not fit this ideal 30:1 ratio so different materials must be blended to meet the ratio (MAF, 1996). It has been suggested that the final compost having a C:N ratio below 15 indicates maturity and is acceptable (Morais and Queda, 2003).

**Aerobic composting**

In the study reported by Karanja *et al.* (2019), rice straw was amended separately with chicken and donkey manure. The initial C:N ratio of rice straw was 60.33, chicken manure 58.67 and donkey manure 52.00. The final C:N ratio of the compost with no amendment was 23.75, 10.84 in chicken manure and 11.32 in donkey manure amendment. Composting of rice straw was enhanced as the C:N ratio was least when it was treated with chicken manure compared to donkey manure. The C:N ratio decreased from 27.07 in vegetable waste to 8.7 and 50.7 to 27.88 in kitchen waste composting done by Long *et al*. (2017). High C:N ratio of 128:1 was observed in initial stage which gradually decrease to an overall average of 17.1 with passage of substrate decomposition (Pan and Sen, 2013). Fan *et al.* (2016) reported initial C:N ratio of 25:1 in kitchen waste treated with dried leaves, rice bran and microbial inoculants which gradually declined to 10:1. The initial C:N ratio of biowaste was 16.3 to 20.9 which decreased to a final of value of 12.3 to 13.2 (Brinton and Evans, 2000). The initial C:N ratio of sugarcane trash treated with cattle manure was 31.0 and the final was 20.5 (Goyal *et al.,* 2005). Chen *et al*. (2015) reported an initial average C:N ratio of 26.1 in different ratios of sewage sludge, rice straw, saw dust and *Penicillin mycelial* dreg which gradually declined to an average of 14.40. Jain *et al*. (2019) have reported an initial C:N ratio of 24.0 in the aerobic composting of vegetable waste treated with cattle manure, saw dust, dry leaves and inoculants which declined to a final value of 16. Ghinea and Leahu, (2020) reported an average initial C:N ratio of 41.77 of food waste which reduced to 22.10.

**Compost pile and anaerobic composting**

In the study done by Khalib *et al.* (2018) the initial C:N ratio of garden waste treated with inoculants was 11.0 to 19.0 which reduced to 6.0 to 12.0. Tibu *et al*. (2019) reported an initial C:N ratio of 31.0 to 34.9 and a final of 18.02 to 20.51.

Rice straw, wheat straw and saw dust have very high C:N ratio (Table 1) ranging from 60.33 to 254.00. Vegetable waste, fruit waste and cooked food have moderate range of C:N ratio with 27.07 to 50.70. Garden waste, sewage sludge, chicken manure, swine manure and cattle manure have lower C:N ratio ranging from 5.10 to 19.78. Composting of substrates having very high and moderate C:N ratio needs to be treated with substrates having lower C:N ratio. In the various studies reported the initial C:N ratio ranged from as low as 8.4 to as high as 128.1. However, mixing with different substrates were done so that the final C:N ratio in the compost ranged between 10.0 to 28.0.

An orthogonal analysis done by Jiang *et al*. (2011) found that composting of mixtures of pig manure and cornstalks having C:N ratio of 21.0 emitted the lowest amount of green house gas. The C:N ratio of a compost should not be too high as application of such composts can result in immobilization of available N, causing a N- deficiency in plants. Conversely C:N ratio of composts must not be too low as subsequent N toxification and efflux to groundwater may occur Gajalaksmi and Abassi (2008). Due to variations in the raw materials used in composting, changes in the C: N ratio need to be monitored rather than considering its absolute values. For a mature compost, the ratio of final C:N ratio and initial C:N ratio should be monitored and it should be less than 0.7524 (Kumar, 2010).

## CONCLUSION

From the observations made it can be conclude that aerobic method of composting using vegetable waste, food waste, rice straw, saw dust and corn stalks along with amendment of animal manure, green and dry plant residues can be completed within a period of 40 to 60 days. Windrow and anaerobic method of composting needs 110 to 120 days to complete composting using the same type of substrates. During the process of composting irrespective of the methods employed maximum temperature ranged from 40°C to 75°C. Amendment of cattle and pig manure leads to higher level in the maximum temperature. Sewage sludge and animal manures have low C:N ratio ranging from 7.70 to 19.78 therefore, the amendment of these substrates leads to alkaline condition in the initial stage of composting. Composting of vegetable waste, kitchen waste, wheat straw and saw dust without amendment of the manures have lower initial pH ranging from 4.5 to 6.8 since they have high C:N ratio.

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