A Scientific Perspective on Composting

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From a scientific perspective, composting is the partial decomposition and stabilization of heterogeneous organic substances by a mixed microbial population under optimum conditions of moisture, temperature and aeration. Compost is composed of fairly homogeneous, stable organic matter with high molecular weight and is free of pathogens and weeds seeds. In nature, dead organic materials undergo several processes of microbial transformation according to substrate composition and physical environment. Composting requires that the process be mostly aerobic so that the organic matter is partially mineralized and humified. In order to produce suitable compost for agriculture, the composting process must be controlled, particularly through the choices of substrate, moisture content and aeration. Many of the different composting systems that have been developed have utilized this basic principle in their design (Table 1).

Many agricultural wastes contain sufficient organic material for composting. These include solid urban waste, food factory waste and other industrial by-products, sewage sludge, agricultural residues and domestic waste. Some of these wastes require careful separation of organic matter from inert materials such as glass, plastic and metals. The organic fraction of the waste is quite heterogeneous and if introduced directly into the soil, it will not perform in as predictable a manner. Composting radically transforms various organic substances, it mineralizes the readily assimilable materials and humifies them into more complex compounds. Stated more simply, composting is an elegant, but rather complex process that blends different ingredients into a uniform useful product.

Stages of Composting

The composting process is characterized by a period of rapid decomposition and temperature accumulation followed by cooler, slower decay of the remaining organic substrates. The rate of decomposition can be increased by stacking the materials in a pile to a height of 1.0 to 1.5 m, however, taller stacks must be more frequently turned to facilitate rapid decomposition and prevent the formation of unwanted anaerobic by-products.

The temperature in the compost pile will rise due to enhanced microbial (fauna and flora) heat production resulting from heterotrophic oxidation and also because of the relatively slow heat transfer to the environment. Other important aspects of composting include the C/N ratio of the organic substrates, other nutrient concentrations, surface area and acidity. Microorganisms, primarily bacteria, actinomycetes and fungi, use the organic materials as a source of energy and nutrients, producing heat, gases and stabilized organic matter. Microbial populations change with temperature during the mesophilic (20-40 ^{0}C) and the thermophilic stage (>40 ^{0}C) then back to ambient during the curing stage (Figure 1).

Table 1. A summary of composting systems for organic wastes which are also utilized for industrial composting (adapted from Bertoldi *et al.*, 1985).

Open Systems

- Turned pile (commonly used in Kenya)
- Static pile
  - air suction
  - air blowing
  - alternating ventilation (blowing and suction)
  - air blowing in conjunction with temperature control

Closed Systems

- Vertical reactors
  - continuous
  - discontinuous
- Horizontal reactors
  - static

- static
- with movement of material

The mesophilic stage is a preparatory state that initiates the decomposition process and brings the compost into temperature ranges that are suitable for thermophiles. This stage is achieved by the rapidly decomposing and readily-available compost substrate. In the mesophilic stage, temperatures rise rapidly to high levels up to 65^0C.

The thermophilic stage is necessary to ensure stabilization and to pasteurize the compost, eliminating many harmful organisms. This stage may last a number of days depending on how well oxygen is supplied to the pile and the quality and quantity of the substrate.

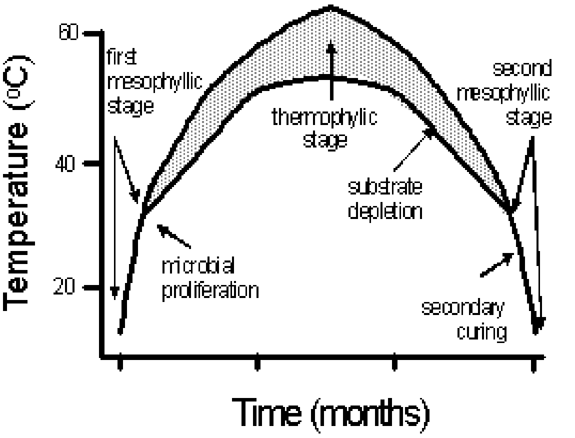

Figure 1. The stages and major events in composting.

Temperatures vary in a compost pile with the outer layer having a lower temperature compared to the inner zone of high temperature (Figure 2). To ensure even decomposition and better aeration, periodic turning is necessary. Enteric pathogens such as *Salmonella* spp., normally survive less than one hour once the compost enters the thermophilic stage. Other noxious organisms such as weed seeds and parasites eggs may be more durable but are often eliminated or greatly reduced during composting. Pasteurization is one reason composting is a popular waste treatment. During the stabilization stage, substrate becomes a limit to microorganisms. The compost pile temperatures fall back to mesophilic stage range and reestablishment of the mesophilic organisms occurs. During slower processing, the compost may become colonized by soil fauna, such as earthworms or beetles, and these organisms assist in curing.

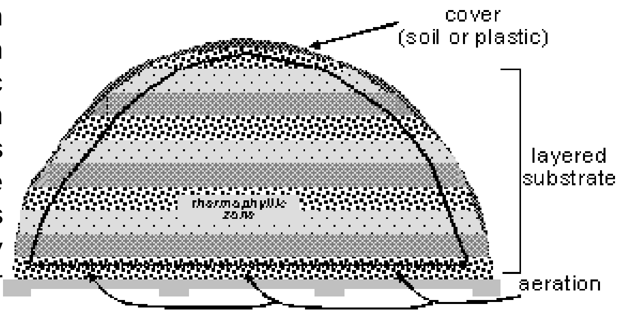

Figure 2. The principle elements of a compost pile, including the interior thermophilic zone.

Properties of compostable materials

The important physical properties of materials intended for composting are particle size and moisture content. Particle size affects oxygen movement into and within the pile, as well as microbial and enzymatic access to the substrate. Proper balance in the particle size should be maintained. If too large, the organic materials should be chopped into smaller pieces. On the other hand if too small, the organic materials should be mixed with a bulking agent (eg. wood chips or tree bark). The optimum moisture content for composting is 40 to 60%. Water interferes with oxygen accessibility, slowing the rate of composting while too little water hinders diffusion of soluble molecules and microbial activity.

The chemical characteristics of the organic residues may be considered in terms of nutrient quality and quantity. The ranges of elemental composition for some residues suitable for composting are shown in Table 1. The relative quantity of the C, N, P S and other nutrients is important, but keep in mind that mineral nutrients are largely concentrated during composting as the carbon compounds are oxidized by microorganisms. Substrate quality is also influenced by secondary compounds, such as lignin and polyphenol, that are more recalcitrant to decomposition and may compounds, such as lignin and polyphenol, that are more recalcitrant to decomposition and may restrict nitrogen availability through proteins-binding.

Table 2. Nutrient concentrations of selected dry compostable materials

Composting material	N	P	Ca	K	Mg	C/N
	-- (%) --					
Chicken manure	4.5	0.8	1.8	0.7	0.4	7
Cattle manure	1.5	0.5	1.0	0.6	0.3	18
Grass cuttings	1.2	1.1	<0.1	2.0	0.1	27
Alfalfa	2.4	0.2	1.4	1.8	3.9	15
Maize stover	0.9	0.1	0.4	1.2	0.1	42
Wheat straw	0.6	0.1	0.6	1.2	0.1	90
Mixed green weeds	2.3	0.3	0.1	1.3	<0.1	21

Although different compostable substrates often begin with widely divergent nutrient contents, the quality and quantity of the nutrient converge as composting proceeds. Metabolic processes also affect the pH of the compost. Deamination of proteins rapidly increases the pH due to ammonia. Conversely, production of organic acids during the decomposition of carbohydrates and lipids decreases the pH. On average, pH of inputs is somewhat acidic while finished compost is near neutral.

The relative quality and quantity of the organic residues affects the rates of composting and the characteristics of the finished products. For example, when the C/N ratio of the organic matter is about 25, metabolism of the organic material may proceed rapidly with a high degree of efficiency of N assimilation into the microbial biomass. A narrower C/N ratio may lead to loss of N from compost through ammonia volatilization. Wider C/N ratios (>40) promote immobilization of available N in the compost slowing the rate of decomposition. Therefore, addition of mineral N and P in the process of fortification can enhance rapid decomposition and enrichment of low quality residues.

Assessing Compost Maturity

Compost most suitable for agriculture should be well cured and mature. The basis for efficient preparation of compost hinges upon recognizing differences in quality and adjusting application rates and timing of application accordingly. At present, as well as the traditional tools for investigating decomposition (C:N ratio, temperature, humidity) other methods are available from the most sophisticated, which may be employed only in well-equipped laboratories, to the most basic which can be adapted to the immediate needs of a smallscale composting operation.

A study was conducted in Maragua District in Kenya to identify simple methods of rapidly assessing the quality of composted cattle manure (Lekasi *et al.*, 2003). Several discernible characteristics could be used to judge maturity and quality of these composts including texture, colour, smell and biological activity.

Table 3. Chemical characteristics of some mature compost entered into the FORMAT Compost Contest in 2002.

Source	N	P	K	Ca	Mg	C	polyphenol	lignin
	---%---							
C. Othiambo	1.6	1.1	1.1	3.5	1.9	41	3.2	8.4
K.W. Kamau	1.2	0.3	2.0	3.8	0.5	35	4.2	10.7

T. Kiroga	0.3	0.2	0.4	0.3	0.2	34	0.3	7.9
C.M Ameka	0.6	0.2	0.5	0.1	0.3	38	0.3	8.3
E. Simiyu	0.4	0.1	0.3	trace	0.2	32	0.1	0.7
M.K Ouma	2.0	0.6	0.2	1.8	0.3	32	0.6	13.1
J Kosgey	1.5	1.0	0.8	3.0	0.7	33	2.0	5.5
F.W. Wafula	0.8	0.3	0.6	0.1	0.3	31	0.4	7.0
E.K. Telewa	1.5	0.5	1.4	0.6	0.6	38	3.2	15.1
J. Chirchir	2.5	0.6	0.7	3.3	0.6	41	2.3	12.2
P.S. Watua.	2.6	0.7	2.4	1.6	0.7	55	3.8	22.2

When compost texture was considered, coarse materials become finer over time until a fine, loamy material is produced. Changes in the colour of the compost can also tell its quality and maturity. The assumption for this parameter is that less decomposed material consists of a more heterogeneous mixture of animal feaces and other organic materials that also differing in color, resulting in a mottled appearance. As decomposition progresses, such material becomes more homogeneous, appearing as uniform dark brown or black at maturity. When composting cattle manure, sewage sludge and some industrial wastes, the smell can indicate the stage of composting. Fresh animal manure and wastes have a strong smell of ammonia and putrefaction during the early stages of decomposition. Mature compost is expected to have only a slight 'earthy' and inoffensive smell.

Biological activity is another useful indicator of compost maturity. The presence of macrofauna in maturing compost, particularly earthworms and grubs, serves as an indication of the stage of compost maturity because time is required for these invertebrates to re-colonize the substrate following the thermophilic stage. The fauna and flora of compost heaps changes with time, both increasing and decreasing with maturity depending on the group of organisms. For example, earthworm activity might increase to a maximum and then decline towards maturity, while other soil fauna and fungi demonstrate peak activity at other times. Grubs (beetle larvae) are often in mature compost heaps. A clear understanding of changes of these different domains in respect to the composting process and stages can, therefore, be used in combination to predict the quality and maturity of compost to a fairly accurate extent.

Maximizing Decomposition during Composting

In composting for waste management purposes, odour control and cost effectiveness are both served by maximizing the rate of decomposition. The composting "ecosystem" tends to become self-limiting by excessive accumulation of metabolically-generated heat, leading to inhibitively high temperature. The threshold to significant inhibition is approximately 60 ^{o}C, and inhibition increases sharply at higher temperatures. Unless controlled through deliberate venting, composting masses may reach as much as 80 ^{o}C, at which point the rate of decomposition becomes extremely low. Prolonged temperature exposure literally pasteurizes the decomposing substrate, destroying many harmful organisms.

A practical means of removing heat from the composting mass is through ventilation. The main ventilation-association mechanism of heat removal is the vaporization of water. Ventilation also supplies O_2 for aerobic decomposition. During composting, the rate of heat generation varies with time. At the small-scale level, occasionally turning the heaps serves this purpose very well. In the most advanced commercial composting, ventilation is achieved by using fans that are mechanically controlled with temperature and moisture sensors. When an initial substrate contains a large proportion of water, as with manure slurries or sewage sludge, composting also serves as a effective means of removing the excess water in addition to producing quality organic fertilizer for use in agricultural production.

Conclusion

Fortunately most of the composting science is intuitively considered by those with experience. Mixing and layering inputs results in a wide range of nutrients and substrates. Covering the compost pile reduces water loss and conserves heat. Placing the pile on a platform and periodic turning facilitates aeration. Composting is one example where the considerations of science are well covered by those who approach it as an art.

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Chapter 9

Producing Fortified Compost from Crop Residues

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Many African countries continue to require increasing amount of food aid (World Bank, 1996) because their agricultural production does not match population growth. This is most evident in countries where population growth is very high and yet soils tend to be highly weathered and have low inherent fertility (Smaling *et al.,* 1997). In Kenya, farmers realize the need for soil amendments by using available resources such as farmyard manure, poultry wastes and piggery effluent (Woomer and Swift, 1994), however, the quantity and quality of these materials limit their use (Delve, 1998). In addition, farmers appreciate the use of mineral fertilizers but their ever-increasing costs often prohibit their application at recommended rates (Heisey and Mwangi 1996). In some areas, crop residues such as wheat straw and maize stovers are left on the land but their decomposition rate is very low because of the high C:N ratio. These materials accumulate in very large amounts and are difficult to dispose. For example, in Uasin Gishu and Trans Nzoia districts of Kenya, yields of maize stover and wheat straw range from 4 to 15 t ha^{-1} (Muasya, 1996). Management of these residues includes incorporation back into the soil, feeding residues to livestock or burning (Lwayo *et al*., 2001). The Faculty of Agriculture at Moi University has developed a technology to recycle plant nutrients from wheat straw and maize stover. This technology involves fortification of these residues with nitrogen (N) and phosphorus (P) fertilizers to reduce losses from the composting process.

Procedure for Fortification of Organic Residues

Low quality organic materials such as maize stover or wheat straw with a wide C/N ratio are suitable for preparing fortified compost. The procedure for fortifying such organic materials is:

1. Chop crop residues into 30-45 cm lengths in order to increase their surface area.
2. Spread the chopped material in five successive layers of 30 cm high by 2.0 m wide into windrows 25 m long (» 500 kg in each layer).
3. At every 30 cm layer, evenly broadcast 3.75 kg DAP (or any other nitrogen-bearing fertilizer) for fortification lowering the C:N ratio from 80 to about 12.
4. Apply 1.0 kg of organic soil uniformly as a "starter inoculant". Farmyard manure, sugarcane mill filter mud or pond sediments are suitable materials for this purpose.
5. Apply 20 litres of water at the same height to enhance dissolution of fertilizers and to moisten the stover for microbial activity.
6. Repeat steps 1 to 5 until the 25 m windrows are 1.5 m in height (Figure1).

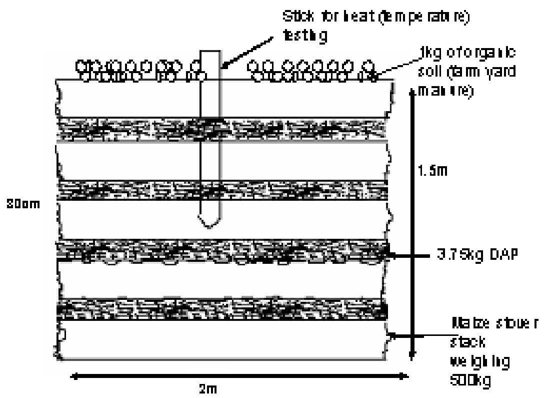

Figure 1. Fortified compost heap set up using the Moi University fortification method

Turning the Compost

Turning compost is important as it ensures proper mixing, wetting, aeration and decomposition. The compost heap is allowed to settle for one month, and then turned using pitch forks. Material on the top of the heap and along the edges is laid on the ground first, followed by the materials in the middle of the heap. Materials at the bottom are then placed at the top of the heap. It is recommended to sprinkle 20 liters of water on the heap during turning particularly when conditions are dry. Compost turning is continued until the heaped materials turn dark gray. Biological activity is monitored by pushing a stick into the middle and sides of the stack. The stick is pulled periodically and felt by hand for any temperature changes. For example, eight days after compost piling, much heat is generated from the center of the heap and the stick driven in the compost should indicate the same. This is an indication of biological activity in the compost (e.g. the thermophilic stage). Composting requires 4 to 6 months and at maturity and about 1900 kg of fortified compost is produced. Mature compost is odourless and has a fine texture. When the stick for testing temperature is driven into the heap, it should be cool (at ambient temperature) indicating that all the potentially harmful organisms and by-products have been eliminated.

Table 1. Sources and characteristics of commonly available crop residues, compost and manure among smallhold farmers in western Kenya

Material	Nutrient content			
	Organic matter	N	P	K
	---------------------%--------------------			
Maize stover	-	0.89	0.08	2.78
Bean trash	-	1.20	0.13	2.06
Banana trash	-	0.83	0.06	4.54
Compost (Ben Mutambo, Kanduyi)	39.6	1.17	0.24	0.53
Slaughter house manure (Bungoma)	44.7	1.65	0.59	0.56
FYM[1] (Protus Opicho, Bungoma)	21.3	0.89	0.19	0.82
FYM (Mary Wangila, Webuye)	42.8	1.61	0.54	2.52
FYM (Boniface Wamalwa)	13.1	0.39	0.11	0.40
Compost (Peter Simiyu, Siritanyi)	19.6	1.22	0.26	0.86
Fortified compost (Moi University)	52.0	2.20	0.42	1.40

[1]FYM = farmyard manure

Chemical Properties and Use

A comparison between fortified compost and a number of crop residues and organic manures appears in Table 1. Fortified compost is consistently among the highest organic resources in terms of nitrogen (2.2%), phosphorus (0.42%), potassium (1.42%) and organic matter (52%).

Significant maize grain yields from fortified compost applied at 2 t ha^{-1} were observed as compared to the control (Figure 2). Fortified compost provided 4 t ha^{-1} of grain yield, which was comparable to DAP at 20 kg P per ha, probably due to the increased N and P release from the compost. Non-fortified compost applied in conjunction with DAP at 20 kg P ha^{-1} resulted in reduced yields, demonstrating better agronomic effectiveness of fortified compost compared to an alternative allocation of the same inputs. In areas with large quantities of maize stover, fortifying these residues is an alternative to burning.

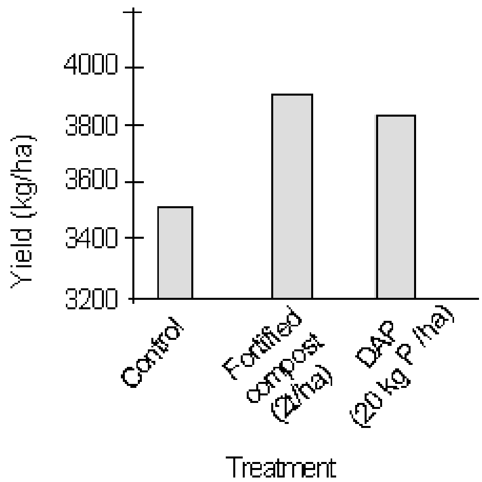

Figure 2. Effect of fortified compost, conventional compost and DAP fertilizer on maize yield in Uasin Gishu, 1998.

Conclusion

There is potentially a large number of farmers in western Kenya who could benefit from the use of fortified compost to improve their overall crop yields and better utilize post harvest residues. The technology offers potential to smallhold sugar outgrowers in western Kenya as well as large-scale and wheat producers in the Rift Valley. The mound and windrow composting technique described in this chapter is appropriate for materials other than maize stover and wheat straw and when higher quality materials such as manure, tree prunings and grass cuttings are being composted, there is little or no need to fortify them with mineral fertilizer. However, lack of technical know-how to make and use compost is lacking. Farmers should be trained on how to prepare fortified compost. On-farm trials should be conducted at multiple locations to enable as many farmers as possible to learn how to make and use fortified compost. Socio-economic factors, such as labor availability or lack of space, that hamper the adoption of this technology should also be identified and solutions to these problems offered.

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