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COMPOSITING CHARACTERISTICS OF MIXED DAIRY MANURE WITH BULKING AGENT

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Abstract

The dairy manure can be composted in a batch composter for one week. 0.87 – 1.07 L/min. kg-VM. of air was suitable aeration condition. Favorable initial moisture content was ranged from 55 to 65% (w. b.). Moisture content in uniform distribution of fine particle size must be maintained lower level as around 50% (w. b.). The thermophilic region 55 to 70°C have been found to be most efficient range, visible microbe activity occured to within 1st day after placing. Stabilization time for plateau temperature should be related to aeration and moisture content in compost mass. The maximum decomposition could be obtained in the range of 65 to 70°C and initial pH value as 7.8–8.3, air space as 32–40%, bulk weight as 0.25–0.33 g/cm^3, uniform distribution of fine and coarse particle size of bulking agent.

Carbon dioxide content in effluent gas was around 4.7 to 7.5% per volume at 68°C.

Introduction

Today we see an interest in composting, which reflects the concern for creation energy from livestock wastes and pollution problems that are facing us. The increases in costs of fertilizers and the need for soil conditioners with some unproductive infertile soils may also stimulate additional interest in composting.

It is true that the bioenginerring methods for recycling agricultural wastes is in an embryonic stage. Information is becoming available for composting process that permit a reasonable evaluation as applied to livestock wastes.

Composting process will result in a low level of application until such time as social or economic constraints make their use more appropriate.

The most effective animal wastes recycling with biological method for the vast quantity of livestock wastes continues to be land utilization in a crop production cycle.

There are many utilization processes and their real or potential application with livestock wastes are composting, drying and dehydration, by-product development, methane generation, and waste reclamation.

Composting is a method for the biochemical degradation of organic material.

One of the important factors affecting cost is the lack of demand for the end product. The end product obtained from composting may have some fertilizer value but it should be strongly emphasized that compost is an excellent soil conditioning agent. Incorporating compost into the soil increases the organic content and improves the texture, the permeability, the water holding capacity of that soil.

Studies by a number of researches including TERMAN[39], BONSE[3] and TRINEL[42] have shown an improvement in humus content, hygroscopic moisture, water retention capacity and absorption capacity when organic matter is added to the soil.

Consequently, compost can be used for improving the fertility of marginal and arable land and also for restoration of land that has been severely eroded or strip mined. Compost can also be used as a mulch for nurserymen and vegetable farmers. Compost used as a mulch has advantages over peatmoss or bark in that the compost releases absorbed water more readily than does bark. Many farmers have found compost to make an excellent material for litter or bedding. It is moisture absorbent, odorless and eliminates the need to purchase bedding from an outside source.

Rising cost of fossil fuels and development of biotechnology, the managing problems associated with agricultural wastes especially recycling of the large quantities of livestock wastes is becoming more attractive as an organic fertilizer or soil conditioner.

Solid waste is defined as useless, unused, unwanted or discarded solid materials that has pollution and without managing wastes is of no value.

Many studies are being conducted to determine the potential of livestock manure as a source of soil nutrients, a soil conditioner, a protein supplement for livestock feedstuff or as a source of energy.

The increasing number of animals and modern methods of raising them contribute to the continuing pollution of our ground and surface waters by animal wastes. According to PIMENTAL *et al.*,[25)] it is possible to reduce the energy required for agriculture and the food system.

We should make more use of natural manures more than 10^6 kcal per acre (4046.8 m^2) could be saved by substituting manure for manufactured fertilizer and as a side benefit the soil condition would be improved. Work by STEINHART[35)], if manure were substituted for chemical fertilizer, the saving in energy would be a substantial 1.1 millon kcal per acre.

Energy inputs to farming have increased enormously during the past years, presently much of the wastes from agriculture, such as animal manures and crop residues, are recycled to the land surface as a soild conditioner or used as food products for other animals.

The recycling of livestock wastes has become an important problem in the improvement of environmental quality and for the future of organic agriculture.

The feasible systems are desired for managing livestock wastes.

The purpose of the present study were to identify valuable resource that may be used as organic fertilizer to determine suitable conditions for composting process, to better understand the physical parameters.

The biotechnology in this area is relatively new but as the cost of energy increases. We can expect exciting discoveries and new application in the years ahead.

Although pollution has been occurring for many centuries, it did not arouse the attention of the public until the early 1960's.

Concern about pollution was caused by a combination of developments.

From the standpoint of public health, esthetics, economics, farm manure should be given a management which will stabilize the manure, remove its nuisance characteristics, sustains its fertilizer value and reduce the pollutional properties of the manures to a safe level before final disposal. There are a number of managements but none of them can be applied generally.

This study discussed the composting process a method of bio-cycle of livestock wastes as renewable resource.

The importance of bio-recycling arises from following main purpose.

The need to dispose of the wastes. The need for humus to replace that lost from the soil and prevention of environmental pollution using chemical fertilizer.

In broad scope the research of livestock wastes recycling with biological management is designed to investigate the biotechnical procedures, economic possibilities and public health in accordance with aerobic composting of livestock wastes in combination with other agricultural wastes.

At first, the objective of this study was to measure the physical and chemical analyses required to define the nature and properties of agricultural wastes from farmstead sources for pollution control, wastes recycling, engineering design and determine suitable conditions for the high rate composting, evaluate the effect of organic waste on the compost process and develop a bench scale forced aeration batchcomposter without regular turning based on data obtained from laboratory scale composting system.

Composting of livestock wastes is becoming more attractive for the future of organic agriculture system and pollution control.

Many studies on composting municipal, industrial refuse have been conducted to determine the optimum conditions for composting process. But the suitable conditions for the solid composting of dairy manure have not been studied. The intended purpose of the batch composting for dairy manure with bulking agents was to determine the environmental factors. Most important among these are the particle size and bulk weight of the compost mass, the moisture content and extent of aeration throughout the mass, the hydrogen ion concentration of the waste and its carbon to nitrogen ratio, and the temperature of the compost mass.

Literature Review

Long before microbes were known to exist, prehistoric farmers piled up manure, straw and other plant material and observed the characteristic of physical changes associated with the process. Composting may be anaerobic or aerobic. The anaerobic process is very slow, takes place at low temperature and produces foul odors.

The aerobic process is relatively rapid. High temperature are produced by the aerobic oxidation of organic matter.

Until the 1920's, composting was practiced by individual farmers as a means of disposing of agriculture wastes and restoring valuable humus and plant nutrients to the soil. Despite its wide usage, no advances were made in the treatment process until 1925 when Howard developed a systemized process for composting.

The improved process was labeled the INDORE method. This method described by Howard involves the formation of a layered pile about 1.5 m high, using garbage, animal wastes, sewage sludge, straw and leaves.

Initially the process was anaerobic and required 6 months for completion to occur. The process was later modified by turning the pile over twice, which reduced the composting time to 3 months.

The INDORE process in India and BECCARI process in Italy, unfortunately, both were largely anaerobic process, carried out in soil pits or concrete tanks. The anaerobic process has several disadvantages by comparison to the aerobic process ; generated heat is much less, process is slower and has objectionable odour. The limitations of anaerobic process were soon recognized and from the 1930's to the present efforts have been concentrated primarily on aerobic composting. This process has long been familiar to farmers of stables as a means of converting manure into a much smaller bulk of monodoriferous humus with value as a fertilizer. However, there appeared to be little or no understanding of the biochemical, microbiological, the bio-engineering properties. Much of the necessary basic microbiological information was supplied by the research of WAKSMAN(44).

The organic farming enthusiasts did a great deal to stimulate interest in composting.

RODALE(28) recommends turning the windrow after 3 weeks and again after 5 weeks. This is not too different from the practice at Johnson city Tenn. worked by STUTZENBERGER *et al.*,(3) GABY *et al.*,(7) where the composted wastes are turned over every 5 to 7 days and finished in 49 days.

Enterpriser in several countries saw the opportunity to develop mechanized composting systems capable of being scaled up to handle wastes from entire cities, The VAM, DANO, FRAZER process were aerobic composting system providing for aeration and mixing of the material.

The necessary research was begun at the Univ. of California in 1950, and later by the U. S. public health service, until 1971.

GOLUEKE *et al.*,[10] found that the oxygen requirement was moderate and could be met quite well by diffusion in ordinary windrow composting. SPOHN[34] reported on a process of composting ground municipal solid wastes by artificial aeration in which the compost is intermittently aerated by means of a suction blower below the grating bottom of the composting bin. At the same time, moisture is occasionally sprinkled on top to maintain the compost at optimum moisture concentration.

The system is highly automated with probes near the top center and bottom for measuring oxygen temperature and moisture. With this system control is excellent and temperatures of 80°C are obtained within 24 hrs. regardless of weather conditions. The process yields ripe compost in 4 weeks in which all of the ammonia has been converted to nitrate.

DROBNY *et al.*,[6] reported that most are mechanical digestion systems employing forced aeration and some form of mechanical mixing, with only a 5 days digestion time. This uncured compost then requires an additional 2 to 3 weeks in windrows for curing. The time required for the composting of organic matter has been reported to range from 4 days to several months depending upon environmental conditions, method of composting and the physical characteristics and composting of the material.

BELL[2] found that poultry manure could be composted in a bench composter within 2 weeks. BADDELEY[1] reported that municipal waste could be composted in a DANO biostabilizer, a large scale, horizontal, continuously rotating drum, in 4-5 days.

Work by McGAUHEY and GOLUEKE[20], KOCHTITZKY *et al.*,[18] indicates that the windrow should be turned once every 3 to 4 days to maintain aerobic condition.

Oxygen is added to enclosed digester through continuous tumbling, stirring action, or forced aeration. SCHULZE[32] working with mixed garbage, sewage sludge found that a continuous air supply of 0.22 to 0.52 L/min. kg-VM. (liter per minute per kg of volatile matter) contained in the unit is needed.

Insufficient air or lack of air supply causes the temperature to decrease sharply and continuous mixing and overaeration also decrease temperature and tend to reduce moisture by increased evaporation. Other studies by WILEY and PIERCE[47] indicated that 0.52-1.33 L/min. kg-VM. of air was needed. Determing the true oxygen requirement is a difficult task because it is influenced by temperature, moisture content and the bacterial population.

REGAN and JERIS[27] pointed out that if the oxygen requirement is to be determined it should be done by using the chemical oxygen demand as a means of measurement. The rate of aeration can be controlled by measuring the residual oxygen concentration in the exhaust gas such as a minimum of 5 percent residual oxygen by volume should be maintained[32)].

WILSON and HIMMEL[50)] working with high rate digestion developed of generalized curve showing the effects of aeration on temperature and rate of oxygen consumption. At very low aeration rates the oxygen supply is limiting and decomposition is anaerobic digestion. Under this condition is relatively slow with little heat being produced. With increased aeration the process becomes anaerobic with a corresponding rise in temperature to a level which restricts microbial activity. As the compost begins to cool, water is removed faster than it is produced. In this range, decomposition is limited by the availability of nutrients. If aeration rates are too high, heat will be removed faster than its produced.

This will lower the temperature below the thermophilic range, thus making the process under these conditions temperature limiting. The rate of aeration and quantity of air per unit of composting materials must be controlled. Aeration rate depends not only on the nature of the composting material, environmental factors and moisture content but also on the stage of the composting process. According to WILSON[49)], mechanical aeration reduced the time required for composting to 2–3 weeks.

Oxygen consumption for dairy manure during first few days of operation may be in the range of 9.7 to 35 liter per min. per ton of manure compost. KIMURA and SHIMIZU[17)] reported that condition for certain generation of high temperature was considered to be a range of aeration ratio from 0.3–1.0 L/min. kg of dry matter of mixed material, while the fermentation hardly occured in aeration rate more than 5 L/min. kg of dry matter.

According to WAKSMAN[45)], STUTZENBERGER *et al.*,[36,37)] the organism has an optimum growth temperature of 55°C and a maximum between 60 and 65°C.

Compost sometimes attain temperatures as high as 80°C which stops the growth of the thermoactinomyces until the temperature drops to 65°C or below. Work by MERKEL[23)] indicates that the temperature within a compost pile is affected by moisture content, oxygen availability and microbial activity. A drop in the temperature may indicate the material needs to be moistened or aerated or that the decomposition is in a late stage of activity. Temperature also affects that the type of organisms present in the compost and the degree of microbial activity that is taking place. Between ambient and 40°C, mesophilic microorganisms are predominant the activity of these organisms creates heat which cause the temperature to rise. As the temperature rises above 40°C the mesophilic microbes migrate to the peripheral edge of the pile, while the thermophilic microbes take over the center of the mass. According to OLDS24), it generally requires 2 to 3 days to reach the thermophilic stage.

Thermophilic microbes operate between 40 and 60 or 70°C.

The optimal temperature based on oxidation of organic matter into carbon dioxide and water, was reported by WILEY48) and SCHULZE32) to be 60°C.

Studies by the United States public health service43) indicated that 71°C was optimal. In either case the temperatures stabilize between 60 and 70°C, followed by a gradual cooling to ambient. According to GOLUEKE11), the efficiency or level of activity that the speed of the process increases with increasing temperature from ambient to 35°C.

The process is at its peak efficiency between 35 and 55°C, as the process exceeds 55°C, efficiency begins to drop abruptly and becomes negligible at temperatures in excess of 70°C. At temperatures above 65°C, sporeformers begin to lose their vegetable ability and formspores, resulting in very little activity. As the process cools from 65 or 70°C back to 40°C and lower. Mesophilic organisms reappear in large numbers, establishing a high level of activity. According to LOEHR19) the temperature can be 54–71°C range depending upon the method of operation. At these temperature, the pathogenic organisms are reduced or destroyed. The ultimate rise in temperature is influenced by oxygen availability. When the energy source is depleted, the temperature decrease gradually and the fungi such as actinomycetes become active.

At this stage the organic matter has been stabilized but can be further matured. During maturation slow organic matter degradation occurs until equilibrium conditions occur and the volatile matter content about 50 percent. The final product is a mixture of stable particles useful as a soil conditioner. The completion of the composting process can be noted by a marked drop in temperature. No significant increase in temperature when aerated and a decrease in the rate of volatile solids reduction.

As composting begins the microorganisms requires carbon as a source of energy for growth and nitrogen for protein synthesis. As composting proceeds, the C/N ratio continuously decrease with time, since the nitrogen remains relatively constant and the carbon is released as carbon dioxide gas. Work by GOTAAS12), McGAUHEY and GOLUEKE20), TOTH41) indicates that the optimum C to N ratio was respectively 30, 26, to 35, 30.

TAIGANIDES[38)] pointed out that mixture with low C/N ratio have higher aeration requirements in aeration rate. If C/N ratio exceeds 50, the initiation of the composting process may be delayed. According to WILSON and HUMMEL[50)], reduction which may range 47 to 80% results from carbon loss as carbon dioxide and from moisture loss due to evaporation. According to HAYS[13)], moisture reduction may be 35%, final C to N ratio may be in the range of 12 : 1 to 27 : 1. The nitrogen content of the final compost should be in the range of 1.2–1.5% so as to avoid unfavourable effects on crop. MERKEL[23)] indicated that well matured compost value of the C to N ratio is in the range of 12 to 20. Studied by GALLER *et al.*,[8)] while carbon is lost from compost mass, nitrogen is concentrated.

As the C to N ratio decreases with the evolution of carbon dioxide and nitrogen is no longer needed for cellular growth excess nitrogen may be liberated as ammonia, resulting in nitrogen loss. If the compost is not finished, continuing microbial activity may rob the soil of nitrogen.

A high temperature of 65–70°C may be maintained for a few hour to two days depending upon the C/N ratio and the decomposition rate of carbon.

WAKSMAN[45)] reported that optimal growth of most actinomycetes occurs in the pH range of 7 to 8. This slightly alkaline pH together with the elevated temperature would favor the growth of actinomycetes over that of the fungi. The pH of the decomposing mass decrease to about 6, but this does not impair the activity of the thermophilic flora[32)].

The sawdust was found to have a low pH 4.5 and high buffering capacity[29)]. From the results of batch composting, SATRIANA[30)], JERIS and REGAN[16)] reported that pH values near 8 are optimum for composting. GALLER *et al.*,[8)] SINGLEY *et al.*,[33)] indicated that during the first stage of composting temperature begins to rise slowly while pH decreases to acidic level in the range of 5 to 6. Temperature climbs rapidly from the mesophilic to the thermophilic soon after the pH exceeds 7 and reaches a level of 8 to 9.

While pH remains in the alkaline range of 7 to 9, temperature begins to decrease, reaching ambient temperature levels after several days or weeks depending on the composting method used.

Quite often it is difficult to maintain the porper moisture content mainly because of the size, shape and nature of the particles in the compost mixture.

According to McGAUHEY and GOLUEKE[20)], GOTAAS[12)], WILEY[48)] and SCHULZE[31)] reported that the optimum moisture content for greatest decompostition should be maintained between 50 and 60 percent (w. b.).

However successful composting at higher level of 60-65 percent (w. b.) moisture also has been reported[17,21,22,40].

The moisture content of the initial raw material and produced compost was nearly equal in the thermophilic continuous composting[32].

WELLS *et al.*,[46] GALLER *et al.*,[8] reported that at moisture content above 75 percent, thermophilic temperature may never be reached.

Work by TOTH[41] and TAIGANIDES[38], excessive or low moisture content tend to slow decomposition rate and create anaerobic changes which could result in the release of offensive maladorous and composting process is prolong and incompleted.

According to JERIS and REGAN[15] reported that 30 to 36 percent free air space is required to obtain optimum composting for a wide variety of materials. The beneficial effect of the admixture of the conditioning materials, the free air space ranged from 35 to 40% and a minimum of 30% should be maintained[32].

Materials and Methods

Raw manure and Bulking agents

The slurry of manure picked out holstein dairy cattles which were approximately 650 kg of live weight, six years old and housed in stanchions barn from accessory farmstead of Hokkaido University.

Bulking agent (absorbent material), such as rice straw and hulls, lauan bark and sawdust from field was used for composting.

Physical characteristics of raw materials and analysis for individual ingredients of it are shown in Table 1 and 2.

TABLE 1. Analysis for physical characteristics of raw material

Determinations	Manure		Rice		Laun		Recycled compost with straw, bark
	Raw	Dried	Straw	Hulls	Bark	Sawdust	
Moisture content % (wb)	86.4	11.0	9.3	11.0	7.7	8.2	11.3
Bulk weight (g/cm³)	0.94	0.16	0.06	0.13	0.06	0.16	0.05
Bulk density (g/cm³)	0.13	0.14	0.05	0.12	0.05	0.14	0.05
Specific gravity (g/cm³)	2.21	2.21	2.02	1.72	1.78	2.77	1.72
Porocity (%)	94.3	93.5	97.3	93.2	97.3	95.0	97.4
Air space (%)	12.7	83.5	87.2	83.6	78.9	83.2	88.5
Particle size (mm)	0.2	10-20	30-50	6.0	30-50	2.0	30-50

TABLE 2. Analysis for individul ingredients of raw material

Determinations	Manure		Rice		Laun		Recycled compost with straw, bark
	Raw	Dried	Straw	Hulls	Bark	Sawdust	
pH (−)	7.2	8.5	6.8	7.4	6.5	4.5	8.5
Ash (%) TS	14.9		15.4	13.6	5.1	1.7	9.4
Volatile solids (%) TS	85.1		84.6	86.4	94.9	98.3	90.6
Carbon (%) db	40.9		39.2	41.4	48.3	48.4	39.6
Nitrogen (%) db	2.18		1.18	0.67	0.49	0.19	1.33
C/N (−)	18.8		33.2	61.3	98.6	254.7	29.8

Equipment

Batch composter (Fig. 1) was a cylinder type (24 cm H, 26.5 cm OD, 23.5 cm ID) with 0.3 cm thickness metalic material. 0.3 cm (ID) hole perforated screen plate was installed above the bottom of the composter to aid in aeration and support the compost mass. Air was supplied to the compost mass from the bottom of the composter. The height of air plenum chamber was 5 cm.

Batch composting unit had a loading capacity of around 2.7 kg (7.5 Liter) and the apparatus proved very useful in establishing quantitative data for the relationship between aeration rate, temperature for the effect of decomposition. This laboratory scale composter was built from metalic cylinder which submerged into water bath. Water temperature was controlled by

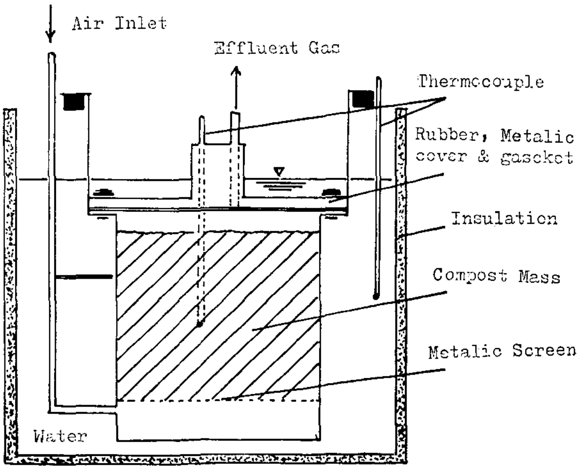


Fig. 1. Schematic diagram of batch composter.

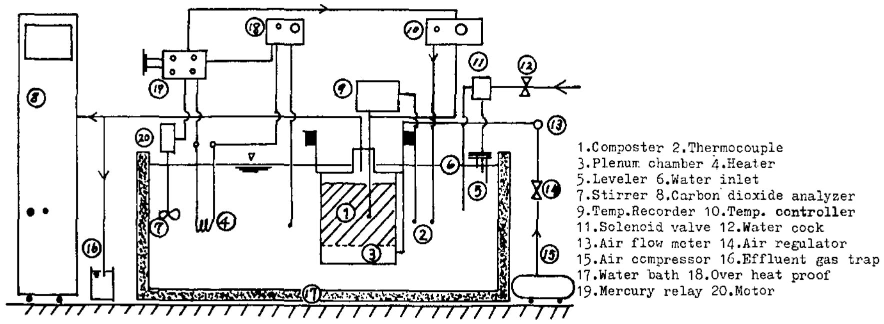
heating equipment, such as temperature controller, over heat proof, stirrer, heater in accordance with the temperature of the admixture in the composter.

Temperature and carbon dioxide on the composting process were measured by the continuous self recording thermometer and infrared spectrophotometer.

The brief specifications of composting unit and measurement equipments are shown in Table 3.

TABLE 3. The brief specification of composting unit and equipments

Items	Specifications
Composter	Forced aeration batch type.
Compressor	Hitachi, SP-5S3, Normal 5 kg/cm^2. Air Capacity 27 L/min.
Air Flowmeter	Ueshima, Tube Size R. 2. 15. A Max. Capacity 2.5 L/min.
Temperature Recorder	Chino EM-100, Thermoelectric type, 20 mm/hr.
Temperature Controller	Chino, NB 161, AC 100-2A, Accuracy ±1.5%
Infrared gas Spectrophometer	Fuji Electric ZAP-1, Discharge 1 L/min.
C/N Auto Analyzer	Yanaco, MT-500, 100 mg sample, Measured time; 15 min.
Air Comparison piconometer	Beckman, M-930, 50 cc sample Hand Operating.
pH Meter	Horiba, M-7, ±0·03 pH meter Reading.
Cross Beater Mill	MRK-Retsch, SK-1, AC 200 (3P), Particle Size after Grinding 0.07-6.0 mm.
Electric Furance	Yamato, FMK-300, Working Temperature 1150°C, 100 V-3.6 kW.



1.Composter 2.Thermocouple
3.Plenum chamber 4.Heater
5.Leveler 6.Water inlet
7.Stirrer 8.Carbon dioxide analyzer
9.Temp.Recorder 10.Temp. controller
11.Solenoid valve 12.Water cock
13.Air flow meter 14.Air regulator
15.Air compressor 16.Effluent gas trap
17.Water bath 18.Over heat proof
19.Mercury relay 20.Motor

Fig. 2. Flow sheet of laboratory scale composting unit.

Fig. 2 is a sectional diagram of the experimental scale apparatus and a photograph of the operating unit is shown in Fig. 3.

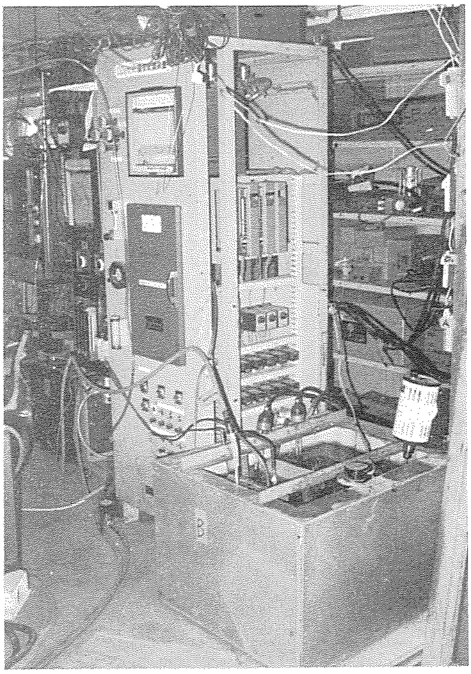


Fig. 3. Photo of experiment apparatus.

Operation and Control

This study was conducted using small scale batch composter operated in such a manner as closely approximate field scale units. Addition and removal of raw material or produced compost was opened the cover and filled approximately 21 cm height, closed by cover finally fitted with rubber, metalic gasket, bolt nut, washer and ring for prevention water from infiltration. The surroundings of composter was provided with the insulated wall water bath (50 cmL × 50 cm W × 40 cm H) for prevention of heat loss. Air was supplied by air compressor. The effluent gas was led into infrared spectrophotometer through a T-piece.

All of compost samples were composted in seven days and after curing for one month. Storage of produced compost was ambient temperature in a vinyl chloride envelope without cover (20 cm H × 20 cm ID).

Sample of raw manure was taken every week from farmstead and it was manually mixed with bulking agent by wet weight ratio of manure (2) to bulking agent (1). The moisture content of admixture at the beginning of the cycle was maintained between 55 and 65 percent (w. b.).

The study running group of first and second were planned to find out suitable aeration rate level ranging from 0.04 to 3.0 L/min. kg-VM. of air. The third group was compared to the degree of composting for a variety of bulking agents.

Sampling and Analysis

Analyzed data for physical and chemical characteristics of admixtures are shown in Table 4 and 9. The weekly samples were analyzed for bulk weight, moisture content, weight, pH, air space, ash and volatile matter, carbon to nitrogen ratio. Samples were taken from raw manure, bulking agent, admixture, produced and cured compost.

The composting rate was estimated by carbon dioxide production.

Each value was the average of three samples.

Approximately 10 grams sample was placed into sampling can weighed and dried overnight at 105°C in electric drying oven after determination of the dryweight and moisture content. The bulk weight is expressed in the wet weight of material per unit volume.

The bulk density and specific gravity values have frequent application in engineering for calculating compaction and volumes.

The bulk density represents the dryweight of the material per unit volume of solids and voids occupied by the original material. This was found from the equation :

$$\text{Bulk density (g/cm}^3) = \text{bulk weight (g/cm}^3) \times \text{dry matter} (\%)/100 \qquad (1)$$

Specific gravity of the solids is defined as the dry weight of solid particles per unit volume of water displaced by them[9]. The specific gravity for each raw materials and mixtures were computed from the air comparison pycnometer (Beckman model 930).

Porocity is an expression for the air space occupied by the both water and air. The porocity in the table was calculated by use of the formula by SCHULZE[32].

$$\text{Porocity} (\%) = 100 \times (1 - \text{bulk density/specific gravity}) \qquad (2)$$

Air space of porocity was obtained by the following formula :

$$\text{Air space} (\%) = \text{porocity} \ (1 - \text{moisture content}/100) \qquad (3)$$

Approximately 5 grams sample was placed in a glass beaker (5 cc) and 30 ML distilled water added after stirring the pH was determined by the pH meter (Horiba M-7).

Approximately 10 grams sample was placed into porcelain dish, weighed and dried 24 hr. at 105°C in electric drying oven after determination of the dry weight. Inorganic matter was determined by weighing the ash remaining after ignition of approximately 2 gr. dried grinding sample at 700°C for 2 hr. in the electric furnace.

Volatile matter content for each raw material and admixtures were computed from the method of soil organic content test (J. S. F., T8-1968).

$$\text{Volatile matter content } (\%) = (\mathrm{Ma}-\mathrm{Mb}/\mathrm{Ma}-\mathrm{Mc})\times 100 \qquad (4)$$

Where; Ma : sample and crucible mass (gr).
Mb : ash and crucible mass after intensive heating at 700°C for 2 hr (gr).
Mc : crucible mass (gr).

Results and Discussion

Physical Characteristics in Compost

Changes in moisture content was remained nearly the same as its initial condition. In the case of aeration was more than 1.88 L/Min. kg-VM. of

TABLE 4-a. Physical characteristics for initial and produced compost

No. of tests	Bulking agents	Aeration rate (L/min. kg-VM.)	Moisture conten % (wb)		Wet weight (kg)		Dry weight (kg)	
			Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1A	Bark	0.14	60.3	60.7	1.95	1.90	0.78	0.77
1B	»	0.30	64.6	66.4	1.75	1.65	0.62	0.55
1C	»	0.45	64.6	62.3	2.00	1.95	0.71	0.61
1D	»	1.36	60.4	67.3	2.85	2.70	1.13	0.88
2A	Straw	0.62	61.2	61.7	1.80	1.75	0.70	0.67
2B	»	0.87	59.1	61.8	2.05	2.00	0.83	0.76
2C	»	0.04	60.7	61.9	2.00	2.00	0.69	0.57
2D	»	1.88	55.6	52.0	2.20	1.40	0.98	0.67
2E	»	3.00	60.3	51.9	2.00	1.45	0.79	0.70
3A	Sawdust	0.76	58.2	61.3	2.00	1.90	0.84	0.74
3B	Dried manure	1.07	62.5	63.7	2.10	1.70	0.79	0.61
3C	Recycled compost	1.06	61.2	66.8	2.50	2.35	0.97	0.78
3D	Hulls	1.04	62.1	65.2	2.35	2.35	0.89	0.82

air, the moisture content of compost was slightly lower than the initial moisture content.

The moisture content of the compost mass remained fairly constant at average of 61 percent (w. b.) as shown in Table 4-a.

The suitable mixing weight ratio of dairy manure (slurry) to bulking agent (moisture absorbent) successfully composted was 2 parts of manure to 1 part bulking agent. The favorable moisture content in the batch type composter may be in the range of 55.6 to 64.6 percent (Table 5).

SCHULZE[32)] reported that moisture content of the initial admixture and compost was nearly equal based on continuous thermophilic composting.

Optimal moisture condition for composting depends upon composition of the mixture. Organic matter will not compost rapidly if the moisture content is below 40 percent[15,48)].

Organic waste should have a moisture content between 50 and 60% (w. b.) for optimum results[31)]. However successful composting at higher levels of moisture content less than 65 percent has been reported[17,40,22,21)].

These reports are about the same as the results of this study.

The moisture content of bottom position was lower than that of top position in the composter and also was increased to the lower aeration level (Table 5.).

TABLE 5. Moisture content changes in compost

No. of tests	M.C. %(wb)				
	Raw material	Top*	Bottom*	Mixed*	Cured compost
1A	60.28	61.81	57.09	60.74	62.96
1B	64.56	66.47	61.71	66.44	61.15
1C	64.61	68.68	30.12	62.31	62.00
1D	60.38	77.28	20.14	67.28	65.74
2A	61.19	78.04	13.23	61.70	58.99
2B	59.14	83.04	10.34	61.83	57.09
2C	60.72	63.13	59.52	61.89	59.90
2D	55.56	75.43	7.33	52.04	55.67
2E	60.31	71.89	8.23	51.89	56.18
3A	58.15	64.30	22.26	61.28	59.06
3B	62.48	66.34	22.51	63.67	56.76
3C	61.15	74.36	20.20	66.84	62.46
3D	62.06	67.85	36.38	65.22	59.06

* Moisture content of Produced compost.

As shown in Fig. 6 fine particle size and uniform distribution, bulking agent such as hulls was more difficult to aerate than coarse ones as straw and others. Suitable moisture content in fine particle size bulking agent may be maintained lower moisture level as around 50 percent (w. b.).

The bulk weight of the compost was always a slight decrease than that of the initial admixture. The average bulk weight of the raw material and compost were respectively 0.31 and 0.29 g/cm^3. Bulk weight of 0.49 g/cm^3 (run No. 1D) could not be composted satisfactory due to its high bulk weight value.

The bulk weight of the initial admixture was higher than that of the produced compost with the exception of run No. 2 C. The optimum bulk weight should be maintained approximately 0.25–0.33 g/cm^3. The effluent bulk weight of run No. 2 D, 2 E were lower than that ranged from 0.09 to 0.13 g/cm^3 due to excess aeration. In sufficient air supply causes the bulk weight increase. Over aeration was decreased sharply it (Table 4-b).

TABLE 4-b. Physical characteristics for initial and produced compost

No. of tests	Bulk weight (g/cm^3)		Bulk density (g/cm^3)		Specific gravity (g/cm^3)		Porocity (%)		Air space (%)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1A	0.34	0.33	0.14	0.13	1.61	1.86	91.3	93.0	36.3	36.5
1B	0.30	0.29	0.11	0.10	1.61	2.33	93.2	95.7	33.0	32.1
1C	0.35	0.29	0.12	0.11	1.61	2.27	92.5	95.2	32.7	35.9
1D	0.49	0.47	0.19	0.15	1.61	2.79	88.2	94.6	34.9	31.0
2A	0.31	0.30	0.12	0.11	1.84	2.31	93.5	95.2	36.3	36.5
2B	0.36	0.35	0.14	0.13	1.84	1.96	92.4	93.4	37.8	35.7
2C	0.29	0.33	0.11	0.09	1.84	1.99	94.0	95.5	36.9	26.8
2D	0.36	0.23	0.16	0.12	1.84	2.13	91.3	94.4	40.6	45.3
2E	0.33	0.24	0.13	0.09	1.84	1.97	92.9	95.4	36.9	45.9
3A	0.23	0.21	0.10	0.08	2.02	3.92	97.5	98.0	40.8	37.9
3B	0.24	0.20	0.09	0.07	2.40	1.82	95.1	96.2	35.7	35.2
3C	0.27	0.26	0.10	0.09	1.74	2.40	95.8	96.3	37.2	31.9
3D	0.26	0.26	9.10	0.09	1.54	1.74	94.3	94.8	35.8	33.0

The results show that the air space was from 32.7 to 40.8 percent that was optimal air space range for composting as moisture content 55.6–64.6 percent. (Table 4-b.). The air space of compost mass should be in the range of 32 to 40 percent[15,32] (Table 4-b). In general, it appears from initial of air space for admixture was low on high moisture content and the final air space was increased to the higher aeration level. As shown in Table 6, the reduction in weight result of evaporation at the elevated temperature during composting and microbial activity on carbohydrates to give carbon dioxide and water. Weight losses during composting were around 10 percent. Weight losses during composting were ranged from 27.5 to 36.4 percent for 1.88 and 3.0 L/min. kg-VM. of air. If aeration rates too high, loss in weight would be higher than the other. CHANG *et al.*,[5] reported that weight losses during continuous aerobic composting of grain dust were 25 to 45 percent at the 0.4 L/min. kg-VM. of air with periodic mixing. The loss in weight should be related to level of quantity of aeration rate.

TABLE 6. Reduction in weight of composting material

No. of tests	Initial Weight (kg)	Produced Weight (kg)	Percent Redution (%)
1A	1.95	1.90	12.5
1B	1.75	1.65	5.7
1C	2.00	1.95	2.5
1D	2.85	2.70	5.2
2A	1.80	1.75	2.7
2B	2.05	2.00	2.4
2C	2.00	2.00	0.0
2D	2.20	1.40	36.4
2E	2.00	1.45	27.5
3A	2.00	1.90	5.0
3B	2.10	1.70	19.0
3C	2.50	2.35	6.0
3D	2.35	2.35	0.0

Changes in pH value

The initial pH of the admixture varied between pH 6.0 and 8.3 during the composting process. The pH of the produced compost remained consistently close to 7 or 8 independent of the variations in pH for the initial mxitures.

Run No. 3 A could not be composted satisfactory due to initial low pH value as 6.0. The sawdust was found to have a low pH 4.5 and high buffering capacity. The initial low pH 4.5 of the sawdust depressed changes in the pH and prolonged acidic conditions (Table 7, Fig. 6). The shortest possible composting time was an important condition to pH for the bulking agent. The pH is one determination employed to characterize compost and to follow the decomposition process[29]. The addition of sawdust must not use for high rapid solid composting. From the results of batch composting, SATRIANA[30], JERIS and REGAN[16] reported that pH values near 8 are optimum for composting. These report are about the same as the results of this study as shown Table 7, Fig. 6 and Fig. 9.

The pH of the bark curing compost was around 7.5 and the straw curing compost was about 9.3. The cured straw compost was alkaline and the mixed manure with straw should be valuable as acid soil conditioner.

TABLE. 7 pH of composting material

No. of tests	pH (−)		
	Initial	Produced	Final
1A	7.2	7.3	7.3
1B	7.2	7.5	7.4
1C	7.6	7.8	7.5
1D	7.1	7.8	7.7
2A	7.4	7.2	9.4
2B	7.8	8.1	9.1
2C	7.7	7.5	9.5
2D	6.8	8.0	9.1
2E	6.9	8.7	9.5
3A	6.0	6.8	6.7
3B	8.0	7.7	7.8
3C	8.3	8.4	8.6
3D	7.7	8.0	8.5

Effect of Oxygen Availability

As shown in Fig. 4, 5 and 6, the curve pattern of the increased temperature was different from the aeration rate and pH value.

Variation in air flow rate conditions through the composter had a significant effect in the temperature. This large range results from varying aeration levels from test to test unfavorable condition encountered for run No. 1 D, 2 C, 3 A, 3 D from the Fig. 4, 5, 6. The inhibited parameter of each experiment were that the run No. 1 D was found to have a high bulk

TABLE 8. Maximum temperature and carbon dioxide for composting

No. of tests	Temperature (°C)	Carbon dioxide (%/volume)	Limiting factor
1A	65.0	2.7	
1B	64.5	1.4	
1C	68.0	1.0	
1D	51.5	1.0	Bulk weight; 0.49 g/cm^3
2A	73.2	2.9	
2B	75.0	4.8	
2C	27.5	0.9	Aeration rate; 0.04 L/min. kg-VM.
2D	69.0	3.0	
2E	70.0	2.2	
3A	46.5	0.9	pH value as 6.0 Uniform distribution of particle size.
3B	74.0	7.8	
3C	73.0	7.0	
3D	63.0	2.5	Uniform distribution of particle size.

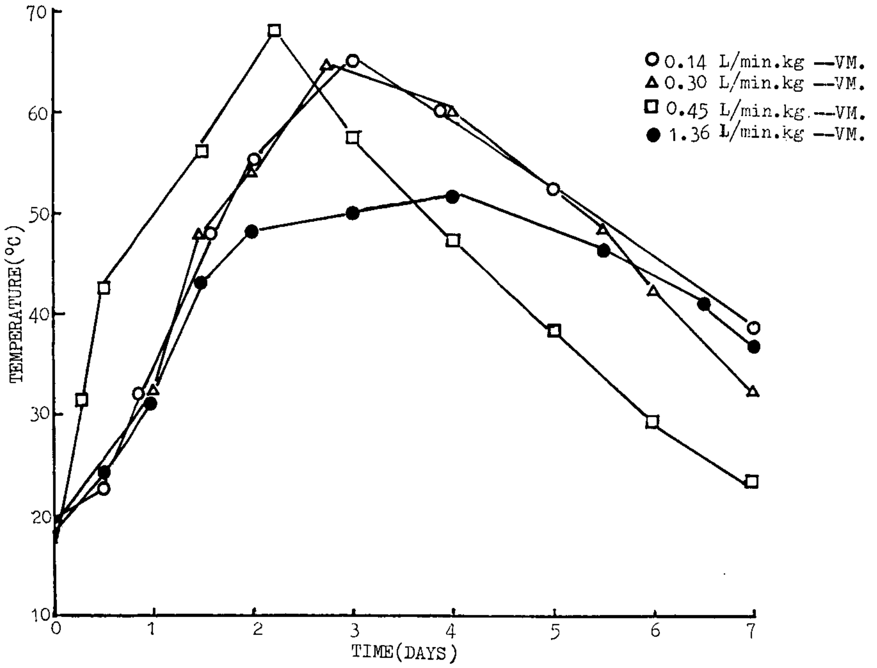


Fig. 4. Recorded temperatures for the mixed manure and bark.

weight as 0.49 g/cm^3, the run No. 2 C had 0.04 L/min. kg-VM. of air, run No. 3 A had initial pH value as 6.0, run No. 3 D was fine and uniform particle size.

Recorded temperature for the mixed manure and bulking agents are shown that the rate of air supply rate amounted to 0.87 and 1.07 L/min. kg-VM. had a pronounced microbial activity and high temperature as 74 or 75°C. (Table 8). Noticed stabilization of the compost within first day of the composting process. The air flow rate amounted to 1.88 and 3.00 L/min. kg-VM. was reached at 70°C and had stability occured during the first 2nd day, had a remarkable cooling effect. Stabilization of the microbial activity was required for 3 days in the range of 0.14-0.45 L/min. kg-VM. and low temperature as 65-68°C. The curve pattern of run No. 2 B, 3 B, 3 C was neary same and the maximum carbon dioxide production was ranged from 4.8 to 7.8%/VoL.. It could be composted in the ranged of 0.87-1.07 L/min. kg-VM. of air for high rapid composting. (Table 8.).

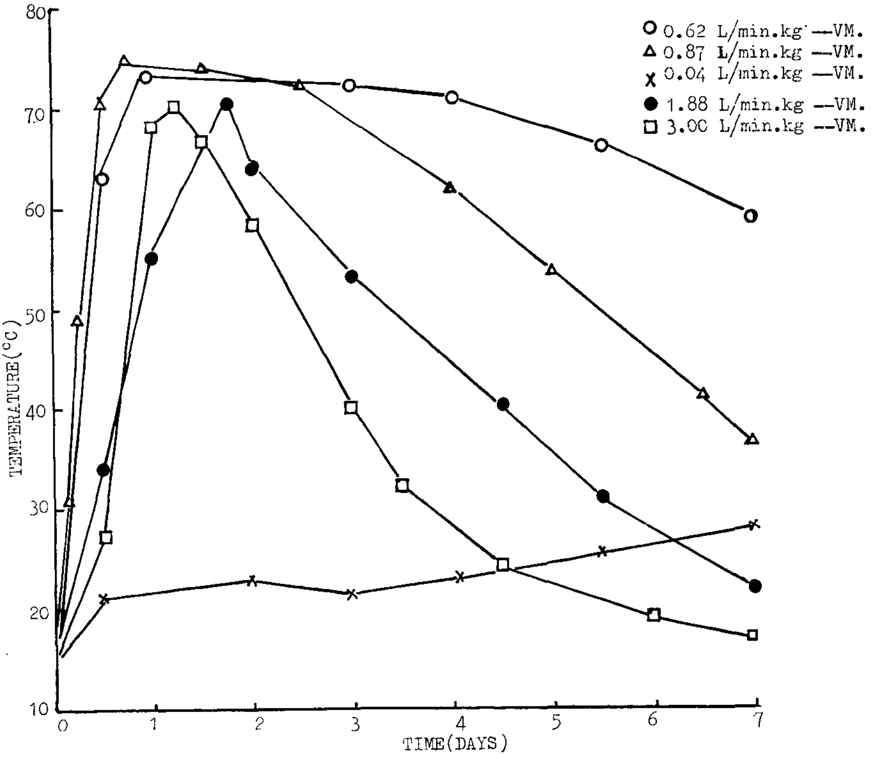


Fig. 5. Recorded temperatures for the mixed manure and straw.

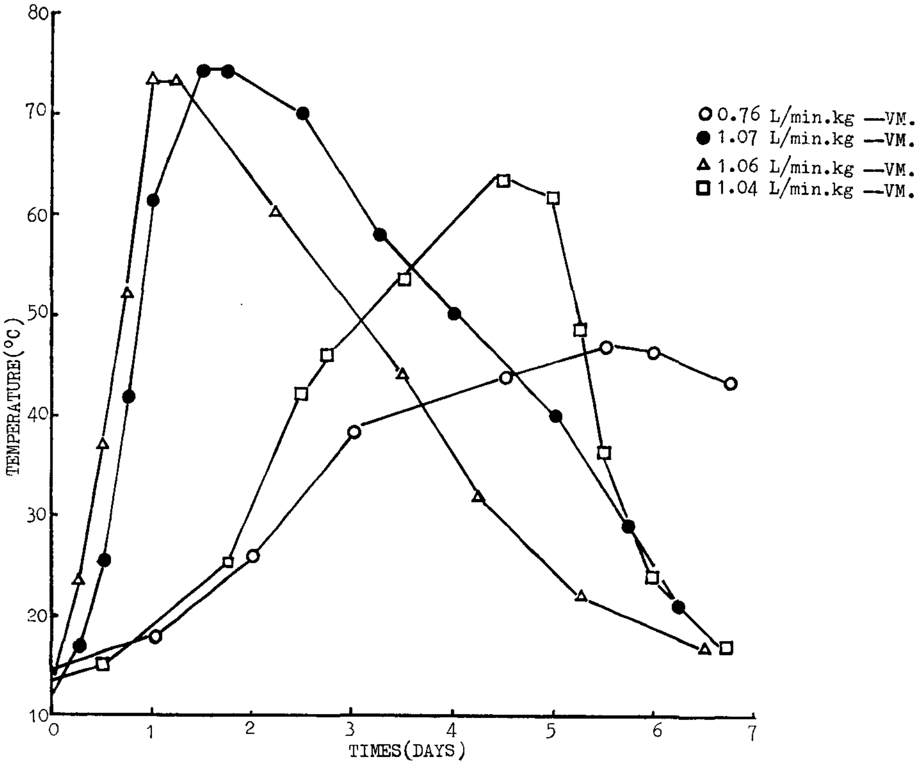


Fig. 6. Recorded temperatures for the mixed dairy manure and bulking agents.

The control of the optimal aeration, pH value, bulk weight and moisture content in batch type composter should be necessarily for composting.

The temperature record showed that excessive aeration had a pronounced cooling effect. At very low aeration rate for the oxygen supply was limit and also decomposition was anaerobic change (run No. 2 C).

For composting under aerobic condition, the suitable aeration rate has been reported 0.22 and 1.33 L/min. kg-VM. of air in various operation methods[32,47]. This value was similar to above results.

Temperature in Compost

Typical temperature curves for the various aeration level and bulking agents during composting are shown in Fig. 4, 5 and 6. The temperature of the compost rose rapidly within 12 hrs. after mixture was placed in the composter and reached at a peak 27.5 to 75°C within 18 hrs. to 7 days on the aeration rate range from 0.04 to 3.00 L/min. kg-VM.

The stabilization time during plateau temperature was affected by the quantity of aeration rate and moisture content in compost mass.

It was found that higher aeration rate as 1.06 L/min. kg-VM., moisture content of produced compost as high as 66.84 percent (w. b.) was early decreased to temperature than that of lower level as 0.87 L/min. kg-VM. of air, 61.83 percent (w. b.). A rapid temperature drop indicated that the compost had stabilized and temperature gradually decreased to about ambient temperature. Run No. 2 B had the high temperature of all the aeration rate. This fact is indicative of greatest biological activity.

The maximum carbon dioxide production in effluent gas was 4.8 percent per volume within first 6 hr.

The required time to reach the thermophilic stage was different from the aeration rate. The level of air supply amount to 0.14-0.30, 1.07-3.00, 0.45 and 0.62-0.87 L/min. kg-VM. was respectively required 30, 18, 12 and 6 hrs. to reach the thermophilic stage. Insufficient and excessive aeration had a pronounced effect to required time.

The rise in temperature after placing must have been due to an increase in microbial activity resulting from aeration. Run No. 2 C did not exhibit any marked increase or difference in temperature during the process and also disagreeable odor was noticed in the produced compost.

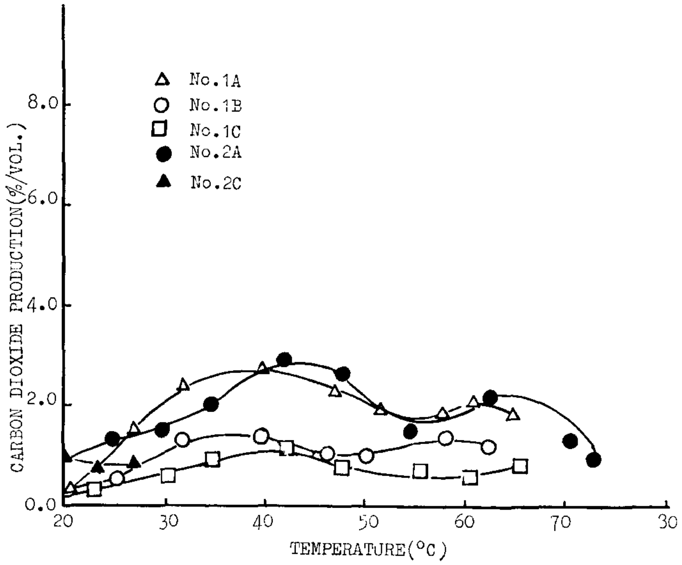


Fig. 7. Relationship between carbon dioxide production and temperature for lower aeration level.

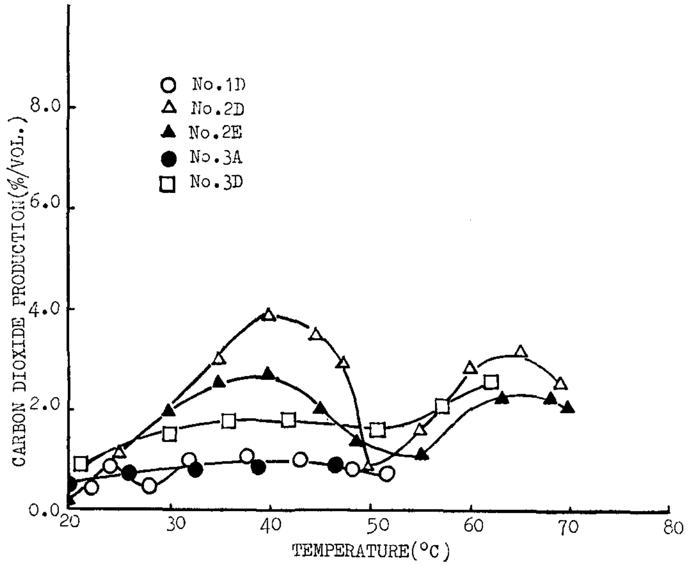


Fig. 8. Relationship between carbon dioxide production and temperature for higher aeration level.

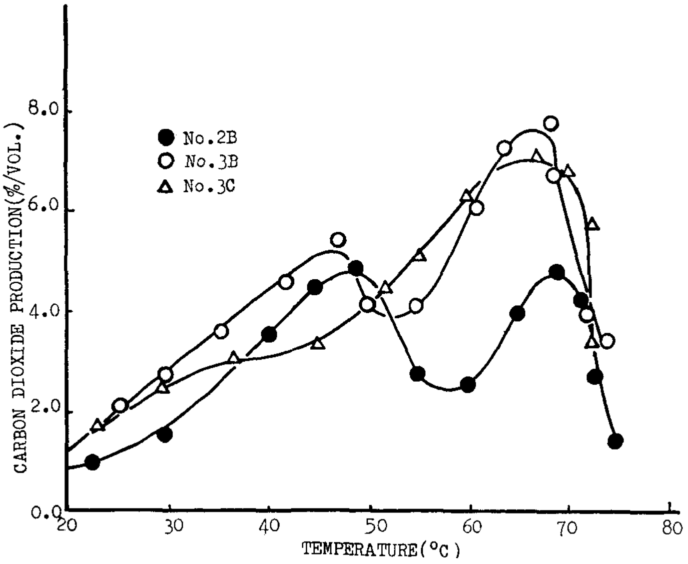


Fig. 9. Relationship between carbon dioxide production and temperature under suitable conditions.

Temperature and carbon dioxide production was greatly affected by the aeration rate, pH value, bulk weight, distribution of fine and coarse particle size[23]. (Table 8). Temperature frequently has been used to judge efficiency and degree of stabilization of a composting mass. The suitabile temperature based on oxidation for organic matter into carbon dioxide and water was between 40 and 70°C.

The thermophilic range 55 to 70°C was more active for decomposition. (Fig. 7, 8, 9). The optimum temperature for composting was ranged from 45 to 70°C[4,11,43,32]. These report was similar to the result.

Degree of Composting and Components

Shortening of the time required for satisfactory composting was considered to be important factor in determination of the feasibility.

Majority of the decomposition in the composting process took place in the 40-70°C region. The thermophilic range 55 to 70°C have been found to be the most efficient range between carbon dioxide production and temperature.

The required time for composting, based on a few days in the high temperature of 40-70°C, was amount to 4 or 7 days under the suitable conditions. A high temperature of 55-70°C was generally aflected by the aeration rate, bulk weight, pH value, distribution of fine and coarse particle size and moisture content. (Fig. 7, 8, 9).

Visiable microbial activity, decomposition and carbon dioxide production varied with the aeration rate. Maximum oxidation for the raw material into carbon dioxide and water was occured to around 24 hrs. after placing raw material (Fig. 5 and 6). Carbon dioxide production rate was ranged from 0.9 to 7.8 percent per volume during active period 40 −70°C.

A decrease in the composting rate was observed at 70−75°C. (high plateau temperature). The maximum composting rate was obtained in the range of 65 −70°C at initial pH value as 7.8 to 8.3 and aeration was between 0.87 and 1.07 L/min. kg-VM. Composting rate was ranged from 4.7 to 7.5 percent per effluent volume at 68°C. The maximum temperature at 73 −75°C was virtually insignificance after peak activity in the range 65 −70°C under 0.87-1.07 L/min. kg-VM. of air. (Fig. 9).

The carbon dioxide concentration in effluent gas provided sensitive indicator of the activity of the composting process. Degradation rate was high within first day during composting and should be related to physical properties such as moisture content, aeration rate, pH value, bulk weight, distribution of fine and coarse particle. (Fig. 6 and 9).

Changes in volatile solids of the admixture and produced compost was different from the C/N ratio. The produced compost was slightly decreased to volatile solids than that of initial value. The loss in volatile solids of the mixed straw and bark compost amounted to around 1.5 to 3.0% exception of run No. 2 E. The mixed bark compost had a higher carbon than the mixed straw compost and hence the required time for the decomposition was longer than the mixed straw compost. (Table 9).

Volatile solids in the initial run No. 2 B decreased from 84.1% at the start to 81.8% at the end of the run. The ash content of the mixed straw compost increased less than 3.00 L/min. kg-VM. of air.

The volatile solids of admixture and produced compost was over 80 percent in nature.

The total solids in run No. 2 C (lower aeration level) was decreased to around 1.2 percent and high aeration of it was increased to 8.4 percent (run No. 2 E). (Table 9).

TABLE 9. Chemical characteristics for initial and produced compost

No. of tests	Total Solids (%) (db)		Ash % (TS)		Volatile Solids % (TS)		Carbon % (bd)		Nitrogen % (db)		C/N (—)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1A	39.7	38.3	7.5	10.4	92.5	89.6	44.5	44.1	1.06	1.30	42.0	33.9
1B	35.4	33.6	7.5	8.7	92.5	91.3	44.5	47.2	1.06	1.22	42.0	38.7
1C	35.4	37.7	7.5	9.9	92.5	90.1	44.5	47.3	1.06	1.32	42.0	35.8
1D	39.6	32.7	7.5	13.1	92.5	86.9	44.5	46.1	1.06	1.38	42.0	33.4
2A	38.8	38.3	15.9	18.8	84.1	81.2	38.5	39.4	1.56	1.82	24.7	21.6
2B	40.9	38.2	15.9	18.2	84.1	81.8	38.5	40.9	1.56	1.76	24.7	23.2
2C	39.3	38.1	15.9	18.2	84.1	81.8	38.5	39.2	1.56	1.69	24.7	23.2
2D	44.4	48.0	15.9	17.3	84.1	82.7	38.5	38.7	1.56	1.51	24.7	25.6
2E	39.7	48.1	15.9	14.7	84.1	85.3	38.5	37.4	1.56	1.39	24.7	27.0
3A	41.8	38.7	5.2	3.7	94.8	96.3	45.4	45.4	0.62	0.67	73.2	67.8
3B	37.5	36.3	13.4	16.5	86.6	83.5	38.6	40.0	2.19	2.23	17.6	17.9
3C	38.8	33.2	15.2	15.1	84.8	84.9	40.2	39.2	1.47	1.49	27.3	26.3
3D	37.9	34.8	11.9	15.2	88.1	84.8	37.7	38.2	0.78	0.88	48.3	43.4

Changes of the total solids results from evaporation of water in the compost mass and decomposition of volatile solids depending on the aeration levels.

C/N analyses of compost

The mixed straw compost contained 1.4 to 1.8 percent nitrogen. Nitrogen loss in the mixed straw compost was occured to the higher aeration levels (run No. 2 D, 2 E) and the loss of it was ranged from 0.05 to 0.17 percent.

The initial C/N ratio of straw and bark admixture was in the range of 24.7 to 42 and also produced compost of it was ranged 21.6–38.7 (Table 9).

For composting under aerobic condition the optimum initial carbon to nitrogen ratio has been theoretically about 30[26,12,20]. This value was about same as results.

At the initial C/N ratio was too high, composting was delayed, inhibited.

When the initial C/N ratio was too low, carbon becomes the limiting factor and needs higher aeration rate[26]. (Table 9).

The final C/N ratio of the mixed bark compost was in the range of 33.4 to 38.7. The nitrogen content of the mixed bark compost was between 1.22 and 1.38 percent. Long before, corrosiveness was expressed by pH, COD, C/N ratio, reduction in volatile solids, odour, colour and others.

By the way, reduction in volatile solids and the C/N ratio of the compost was different from the material and aeration rate. Therefore, the carbon dioxide production of the compost mass may be a good index of corrosiveness.

With regard to the rate of decomposition in composting, the time for completion may be much longer if the C/N ratio as excess of 30.

The C/N ratio and the loss of nitrogen showed a significant increase, while the aeration rate was increased.

The influence of the nitrogen fertilizer component on the decomposition was very important. A higher decomposition rate was found at 2.19% (d. b.) of influent nitrogen than at 0.62% (d. b.) of it. (Table 9).

Summary and Conculusions

This study was initiated to investigated the effect of initial condition about aeration rate, moisture content, pH value, C/N ratio, bulk weight, air space and conducted to measure changes in the temperature, carbon dioxide production during the composting process in accordance with various aeration rates and the mixed dairy manure with bulking agents. Degree of composting should be affected by physical factors.

Dairy manure can be composted in a batch composter in around 7 days.

The result of the study indicate the following conclusions;

1. The most suitable mixing weight ratio was of dairy manure to

bulking agent successfully composted was 2 parts of manure to 1 part bulking agent.

2. Favorable moisture content of initial condition was ranged from 55–65% (w. b.), uniform distribution particle size such as rice hulls may be maintained lower level as around 50% (w. b.).

3. Anaerobic decomposition was occured at 0.04 L/min. kg-VM. of air.

Optimum aeration rate was in the range of 0.87–1.07 L/min. kg-VM. of air without periodic turning.

4. It could not be composted satisfactory due to the initial low pH value as 6.0. Cured compost in the mixed manure with straw was alkaline pH value as above 9.0. The mixed straw compost must be valuable as acid soil conditioner. With regard to successfull composting process depends on pH value as 7.8–8.3.

5. It was confirmed that bulk weight as around 0.49 g/cm^3 was inhibited admixture from high rapid composting.

6. When the initial moisture content from 55.5 to 64.6 percent, the air space of it decreased from 40.6 to 32.7 percent. Effluent airspace of anaerobic change (0.04 L/min. kg-VM.) was lower as around 10%.

7. Carbon dioxide production rate was ranged from 1.0 to 7.8 percent per effluent gas volume during active period 40–70°C. The thermophilic range 55 to 70°C have been found to be the most efficient range for composting.

8. The maximum decomposition should be obtained in the range of 65 to 70°C according to the initial pH value as 7.8–8.3, aeration rate as between 0.87 and 1.07 L/min. kg-VM. Degree of composting ranged from 4.7 to 7.5 percent per exhaust gas volume at 68°C.

9. Stabilization time for plateau temperature (70–75°C) lasted for a few hours to 2 or 3 days. It was found that higher moisture content on produced compost and higher aeration rate (Run No. 3 C) was early decreased to drop the temperature than that of lower level as run No. 2 B. (Fig. 5 and 6).

10. The loss in volatile solids of the produced compost was around 2.2% for composting in one week. The volatile solids of admixture and compost was over 80 percent.

11. With regard to the rate of decomposition in composting, the carbon dioxide production from the compost mass may be a good index of corrosiveness.

Reduction in volatile solids and the C/N ratio of the compost was different from the material and aeration rate. The influence of the nitrogen component on the decomposition was very important. A higher degree of composting was found at 2.19% (d. b.) of influent nitrogen.

Literature Cited

1. BADDELEY, D. C. G.: Engineering equipment used infully mechanized composting, *Compost Sci.*, **7-3**: 22-25. 1967
2. BELL, R. G.: Biological treatment of poultry manure collected from caged laying hens, *Compost Sci.* **10-3**: 18-21. 1969
3. BONSE, H. J.: Influencing physical fertility of soil by application of compost, Int. Res. group refuse disposal, Int. Bull. **13**: 20-23. 1961
4. CHANG, C. S., LAI, F. S., ROUSSER, R. and MILLER, B. S.: Composting grain dust in a continuous composter and evaluation of the compost, *Transactions of the ASAE.*, **24**: 1329-1332. 1981
5. CHANG, C. S., LAI, F. S. and MILLER, B. S.: Composting of grain dust, *Transactions of the ASAE.*, **23**: 709-711. 1981
6. DROBNY, N. L., HULL, H. E. and TESTIN, R. F.: Recovery and Utilization of municipal solid wastes, U. S. Environmental protection agency, Solid wastes manage. office p. 118, 1971
7. GABY,N. S., CREEK, L. L and GABY, W. L.: A study of the bacterial ecology of composting and the use of proteus as an indicator organism of solid waste, *Develop. Ind. Microbiol.*, **13**: 24-29. 1972
8. GALLER, W. S. and DABEY, C. B.: High rate poultry manure composting with sawdust, In; Livestock waste management and pollution abatement, ASAE, St. Joseph. Mich. p. 159-162. 1971
9. GILBERTSON, C. B., MCCALLA, T. M. and SOBEL, A. T.: Analyzing physical and chemical properties of solid wastes, In: Standardizing properties and analytical methods related to animal wastes research ASAE, St. Joseph. Mich. p. 183-196. 1974
10. GOLUEKE, C. G., CARD, B. J. and MCGAUHEY, P. H.: A critical evaluation of inoculums in composting, *Appl. Microbiol.* **2**: 45-53. 1954
11. GOLUEKE, C. G.: A study of the process and its principles, Composting, Rodale Press, Emmaus, Pa., p. 54. 1972
12. GOTAAS, H. B.: Sanitary disposal and reclamation of organic wastes, Composting, W. H. O. *Monogr. Ser.* **31**: 24. 1956
13. HAYS, S. T.: Composting of municipal refuse, In; Symposium on processing agricultural and municipal wastes, Composting of municipal refuse, p. 205-215. 1973
14. HOWARD, A.: On site composting of poultry manure, In; Proc. Natl. Symp. Anim. wastes manage., Mich. State Univ., East Lancing, 1966
15. JERIS, J. S. and REGAN, R. W.: Controlling environmental parameters for optimum composting II.: moisture, free air space and recycle, *Compost Sci.*, **14-2**: 8-15. 1973
16. JERIS, J. S. and REGAN, R. W.: Controlling environmental parameters for optimum composting III.: The effect of pH, nutrients, storage and paper content relative to composting., *Compost Sci.* **14-3**: 16-22. 1973
17. KIMURA, T. and SHIMIZU, H.: Basic studies on composting of animal wastes II.

Limited air flow for fermentation during ventilating at room, *J. Soc. of Agr. Mach., Japan*, **43**: 475-480. 1981

18. KOCHTITZKY, O. W., SEAMAN, W. K. and WILEY, J. S.: Municipal composting research at johnson city, TN. *Compost Sci.*, **9-4**: 5-16. 1969
19. LOEHR, R. C.: Utilization of agricultural wastes, Agricultural wastes managements, p. 335-351, Academic Press Co., N. Y. 1974
20. MCGAUHEY, P. H. and GOLUEKE, C. G.: Reclamation of municipal refuse by composting, Univ. of Calif. Berkeley, Sanit. Eng. Res. Proj. Tech. Bull., 9, p. 30. 1953
21. MERCER, W. A., ROSE, W. W., CHAMPAN, J. E. and KATSUYAMA, A.: Aerobic composting of vegetable and fruit wastes, *Compost Sci.*, **3-3**: 9-19. 1962
22. MERCER, W. A. and ROSE, W. W.: Windrow composting of fruit waste solid, *Compost Sci.*, **9-3**: 19-22. 1968
23. MERKEL, J. A.: Composting, Managing livestock wastes, p. 306-324. AVI Publishing Co., Westport, Connecticut. 1981
24. OLDS, J.: Houston compost plant—2nd year report. *Compost Sci.*, **9-1**: 18-19. 1968
25. PIMENTAL, D., HURD, L. E., BELLOTTI, A. C., FOSTER, M. J., OKA, I.N., SCHOLES, O. D. and WHITMAN, R. J.: Food production and the energy crisis, *Science*, **182**: 443-449. 1973
26. POINCELOT, R. P.: A scientific examination of the principles and practice of composting, *Compost Sci.*, **15-3**: 24. 1974
27. REGAN, R. W. and JERIS, J. S.: A review of the decomposition of cellulose and refuse, *Compost Sci.*, **11-1**: 17-20. 1970
28. RODALE, J. I.: Compost and how to make it, p. 63. Rodale Press, Emmaus, Pa. 1945
29. ROSE, W. W., KATSUYAMA, A., CHAMPMAN, J. E., PORTER, V., ROSEID, S. and MERCER, W. A.: Composting fruit and vegetable refuse, *Compost Sci.*, **6-2**: 13-25. 1965
30. SATRIANA, M. A.: Large scale composting, No yes data Corporation, Park ridge, NJ. p. 21. 1974
31. SCHULZE, K. L.: Relationship between moisture content and activity of finished compost, *Compost Sci.*, **2-2**: 32-34. 1961
32. SCHULZE, K. L.: Continuous thermophilic composting, *Compost Sci.*, **3-1**: 22-33. 1962
33. SINGLEY, M. E. DECKER, M. and TOTH, S. J.: Composting of swine wastes, In Managing livestock wastes, p. 492-496. ASAE, St. Joseph. Mich. 1975
34. SPHON, E.: 100 percent wastes recycling with the RENOVA method. *Compost Sci.*, **13-2**: 8-11. 1972
35. STEINHART, J. S. and STEINHART, C. E.: Energy use in the U. S. food system, *Science*, **184**: 307-315. 1974
36. STUTZENBERGER, F. J.: Cellulolytic activity in municipal refuse composting, Bacteriol. Proc. p. 16. 1969
37. STUTZENBERGER, F. J., KAUFMAN, A. J. and LOSSIN, R. D.: Cellulolytic activity

in municipal solid waste composting, Can. *J. Microbiol.*, **16**: 553-560. 1970

38. TAIGANIDES, E. P.: Composting of feedlot wastes, In Animal wastes, p. 241–251. Applied Science Publishers Ltd., London. 1977
39. TERMAN, G. L.: Utilization and disposal of urban waste compost on agricultural land. Tenn. Val. Auth. Fert. Dev. Center, Muscle. Shoals. Ala. Bull. Y. p. 11 1970
40. TORISU, R., KIMURA, S. and TASHIRO, K.: Effect of moisture content and air flow rate on high rapid composting of cattle manure. *J. Soc. of Agr. Mach. Japan*, **42**: 135–140. 1980
41. TOTH, S. J.: Composting agricultural and municipal wastes, p. 172–182. In Symposium on processing agricultural and municipal wastes, 1973
42. TRINEL, M.: Ten years of soil improvement with peat refuse and sluge, Int. Res. Group refuse disposal. Int. Bull. 12, p. 20. 1961
43. U. S. public health serv.,: Tennessee valley authority composting project U. S. public health serv. cooperative project agreement. Johnson city, Tenn. TV–27246 A, 1966
44. WAKSMAN, S. A. and CORDON, T. C.: Thermophilic decomposition of plant residues in compost by pure and mixed cultures of microoganisms, *Soil Sci.*, **47**: 217-225. 1939
45. WAKSMAN, S. A.: The actinomycestes, In a summary of current knowledge, p. 17–18. Ronald Press Co. N. Y. 1967
46. WELLS, D. M., ALBIN, R. C., GRUB, W. and WHEATON, R. Z.: Aerobic decomposition of solid wastes from cattle feedlots, In Animal wastes manage. proc., Cornell. Agricultural wastes Conf., p. 58-62. 1969
47. WILEY, J. S. and PIERCE, G.: A preliminary study of high rate composting Proc. Am. Soc. civil Eng., J. Sanit. Eng. Div. **81**: 846–850. 1955
48. WILEY, J. S.: High rate composting, *Trans. Am. Soc. civil Eng.*, **122**: 1009–1034. 1957
49. WILSON, G. B.: Composting dairy cow wastes, In livestock wasses management and pollution abatement, p. 163–165. ASAE. St. Joseph, Mich., 1971
50. WILSON, G. B. and HUMMEL, J. W.: Aeration rates for rapid composting dairy manure, In Proc. Agric. Wastes Manage. Conf. Cornell. Univ. Ithaca, N. Y., p. 145–158. 1972