Fundamentals in Compost Preparation and Utilization

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1) What is compost ?

1. Raw material: A) Feces of domestic animals, municipal wastes, and sewage sludges are main raw materials, while B) straws, rice husks, saw dusts, grasses and recycled papers are often used as feedstocks..
2. Mixture of A and B is piled and decomposed by the action of mainly arerobic bacteria through high temperature stage (> 50 ^{0}C).
3. The completed compost is easy to handle and store, ready to be applied to soil without causing any harmful effects to environments.
4. Compost is a solid mature product resulting from composting, which is a managed process of bio-oxidation of a solid heterogeneous organic substrate including a thermophilic phase.

2) Purpose of composting

Usually, feces of domestic animals are composted before applied to soil. The reasons for composting are as follows.

1. To make manure easy for handling and transporting, by reducing dirty feeling, malodor, and stickiness.
2. To prevent soil reduction and emission of harmful gasses and the resulting inhibition in crop growth which is assumed to occur when raw material is applied to soil.
3. To kill pathogens and parasites for human, animals, and plants.
4. To kill the weed seeds which are mixed in feces, hays and feedstocks.
5. To decompose phenolic compounds in feedstocks such as straw and sawdust and low molecular weight organic acids in feces which are assumed to cause growth inhibition of plants.

3) Factors which affect composting

In the initial stage,

1. Moisure : recommended to fall between 65 – 70 %.

2. Aeration: Ratio of volume to weight should be larger than 1.5. Pile of compost should be turned, when its temperature decreases.
3. Initial pH > 6. When pH < 6, composting will be retarded. During composting, pH will be automatically raised to around 8 or higher.
4. Initial C/N should fall between 25 and 30.

Temperature:

The temperature of compost pile depends on the balance of generation and loss of heat. The heat is generated by the activity of microorganisms and lost by moisture evaporation and aeration. Under appropriate moisture condition, the temperature of the pile reaches nearly 80 degree C or higher. Temperature higher than 70 ^{0}C, however, deactivates even most of the thermophilic bacteria.

Moisture:

The most important factor for composting is moisture content. Too high (> 70 %) moisture prevents the activity of aerobic bacteria, and too low moisture stops the process of composting before it reaches maturity (Fig. 1).

To decrease the high moisture content of cow feces (>85 %), large amounts of feedstocks (straw, saw dusts, etc) are required. When feedstock is not available, "feed-back compost" technique may be applied.

Aeration:

Forced aeration is effective to accelerate the composting process. When aeration is not applied, frequency in turning of compost determines the speed of composting. Turning of compost piles is effective for homogeneous fermentation, because aerobic microbes hardly enter the large clods of feces. However, too frequent turning is not recommended, because it lowers the compost temperature.

4) Change in constituents during composting

1. First stage (Saccharide decomposition stage): Mainly easily decomposable organic materials (monosaccharides, starch, amino acids, proteins) are decomposed.
2. Second stage (Cellulose decomposition stage): Mainly cellulose is decomposed by thermophilic bacteria.
3. Third stage (Lignin decomposition stage): Mainly lignin is decomposed by Basidiomycota (mushrooms).

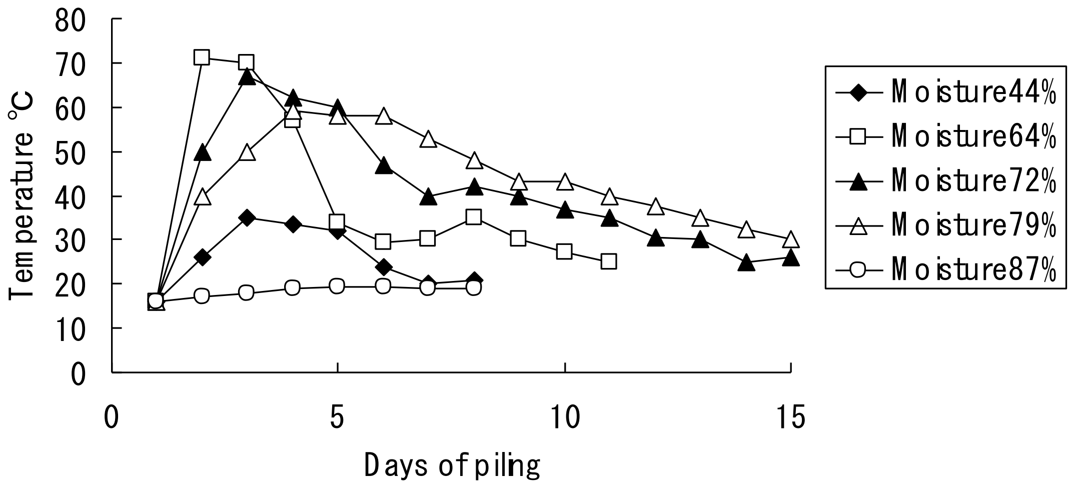

Fig. 1. Fermentation temperature of cow manure depending on different moisture contents

(Shintoku Experiment Station of Animal Husbandry, 1998)

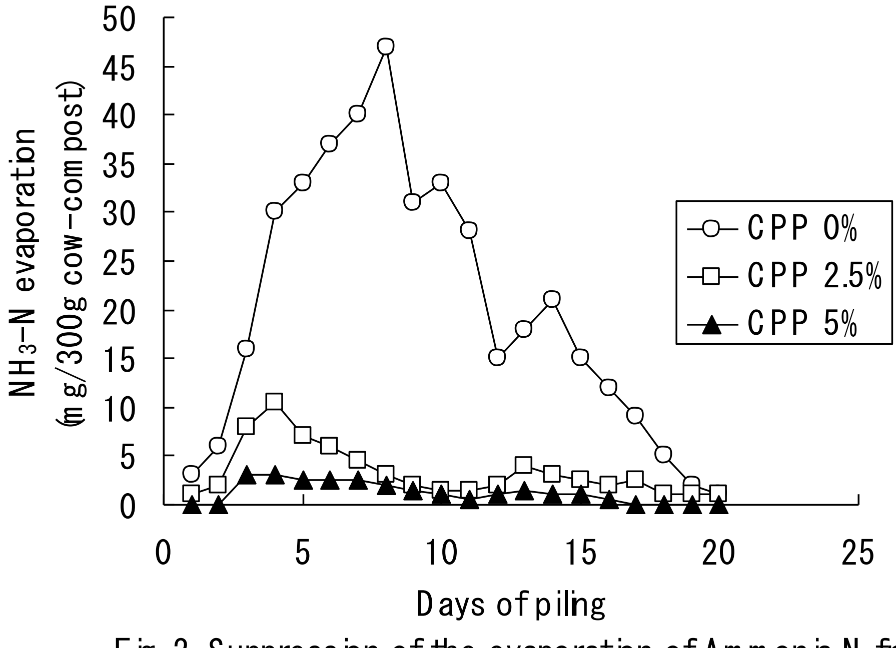

Fig. 2. Suppression of the evaporation of Ammonia N from cow manure by mixing calcium perphosphate (CPP)

(Shintoku Experiment Station of Animal Husbandry, 1998).

First stage (Saccharide decomposition stage):

Mesophilic bacteria and fungi (aerobic fast growers) mainly act in this stage and easily decomposable organic matter is decomposed which accompanies considerable heat generation. With increase in temperature (>40 degree C), microbial fauna will change to thermophillic members of bacteria, actinomycetes, and fungi.

Under a favorable condition for composting, ammonia is formed by the decomposition of protein constituents, which also causes the increase in pH. Due to evaporation of ammonia, pH does not reach too high level. On the other hand, under the deficiency of oxygen, organic acids are formed and the pH is decreased. With decrease in pH, the composting process is delayed.

Second stage (Cellulose decomposition stage):

This is a thermophilic stage and the temperature of compost often reaches 60 – 80 degree C. General bacteria are deactivated(Table 1) and only very limited kinds of thermphilic bacteria work actively. Firstly, aerobic and thermophilic actinomycetes decomposes hemicellulose and exposes cellulose to surface, while creating an anaerobic environment. Followingly, anaerobic cellulolytic bacteria (*Clostridium*) decomposes cellulose. Composting proceeds mostly under aerobic condition, while anaerobic bacteria also take role partially. Therefore, moisture management is important, so that the compost pile should not be too dry or too wet in this stage.

After the decomposition of hemicellulose and celluloce mostly ceases, the temperature of the compost starts to decrease.

Table 1.. Change in numbers of *Escherichia Coli.* during the culture of cow compost at different temperatures. (Shintoku Experiment Station of Animal Husbandry, 1998).

Days cultured	4 ℃	20 ℃	30 ℃	40 ℃	50 ℃	60 ℃
	log CFU g^{-1}					
0	7.9	6.8	7.9	7.9	5.4	6.8
1	5.6	8.6	9	8.4	※	※
3	6.4	7.7	8	6.2	※	※
7	5.9	8.1	7	5.8	※	※
10	6.1	7.9	6.8	6.6	※	※

※ below the detection limit

Third stage (Lignin decompositionstage):

In this stage, hardly decomposing organic matter, such as lignin, are decomposed by Basidiomycota (mushrooms). Intemediate decomposition products of cellulose and hardly decomposing materials will also be decomposed by various kinds of microbes, as the temperature is not high any more. Then, microbes eat each other, and the dead body of microbes will occupy considerable part of the compost. The color of compost turns to brown-black in this stage.

5) Preventing the malodor

1. Feces should be quickly composted.
2. Ammonia volatilization can be reduced by adjusting the pH of compost to around 7 (by adding calcium perphosphate)(Fig. 2).
3. Aerobic condition of compost should be kept by appropriate turning.

6) Characteristics of feedstock material

Feedstock material is used to 1) prevent the soiling of animal body, 2) prevent the elution of liquid material from feces and urine in the animal stable, 3) to adjust the moisture to an appropriate level for composting. High water holding capacity is required for feedstock material.

Table 2. Water absorbing capacity of barleys and pasture crops.

Crop materials	Water absorbing capacity (%)
Oats	354 - 423
Barley	494
Wheat	264
Rye	312
Rye wheat	290
Timothy	254 - 256
Tallfesc	268
Reedcanarygrass	324
Saw-dust	236

Water absorbing capacity = absorbed amount of water after 24 hours / initial weight of the sample x 100. (Shintoku Experiment Station of Animal Husbandry 1996)

Table 3. Water holding capacity of alternative feedstock material

Material	Water holding capacity (%)
Recycled news paper	238
Recycled cartoon paper	167
Rice husk	50
Bagasse (Residue of sugar cane)	110
Saw dust	435

Water holding capacity = water content after 24 hours / initial dry weight of the sample x 100. (Shintoku Experiment Station of Animal Husbandry 1996)

7) Compost maturity

Mature compost is material in which biological activity has slowed. All of the easily degraded molecules have been broken down, leaving the complex organic material behind. It is difficult to identify the original feedstock materials. A fine texture, dark color, and a rich earthy smell often characterize mature composts.

While mature compost is very beneficial to plants, some of the intermediate stages may temporarily produce compounds, such as organic acids, that can be harmful to plant growth.

Immature composts continue to break down once they are incorporated into the soil. This can affect plant health by consuming or tying up two resources that growing roots need. The high level of microbial activity in unfinished compost requires a large intake of oxygen, and the microbes may pull this from the surrounding soil, essentially suffocating the roots. The high C:N ratio of immature compost also means that as the carbon compounds continue to break down, microorganisms will draw on soil nitrogen to assist in the process, leaving the root zone temporarily nitrogen poor.

Immature compost may also become a substrate for plant pathogenic microbes and enhances the activity of soil borne plant diseases. Stunting of seedlings by a Fungi *Pythium* spp is a good example.

It is therefore crucial that responsible compost producers ensure that their compost has time to fully mature before handed to customers or applied to soil, as compost that is still “hot” can do serious damage to both customers plantings and your reputation.

The term stability is often used interchangeably with maturity. They are not really equivalent, however, and you must be sure that you are assessing maturity, rather than simply stability, when monitoring your composting process.

Maturity: biological activity has slowed, as most remaining molecules are difficult to break down any further.

Stability: biological activity has slowed, but this may be due to a variety of factors – the material may be mature, or it may lack adequate nitrogen or water for the process to continue. In this case, if the missing factors are added, biological activity will resume at active levels.

8) Indicators for compost maturity

1. Detection of NH_4^+ or NH_3 (by Nesler reagent). Occurrence of NH_4^+ or NH_3 suggests that the compost is still immature. There are exceptional cases and can not be a single measure.
2. Detection of NO_3^- (by diphenylamine reagent). Occurrence of NO_3^- suggests that the composting process reached final stage. Easily subverted by adding chemical NO_3^- to compost. Detection of nitrate is interfered by several ions in the compost.
3. Temperature change. Applicable to all types of composting materials.
4. pH. First increase due to ammonia, then decrease due to nitrate, carbonate, and humic substances.
5. Electron conductivity (EC): Increase through composting, but should not reach toxic level.
6. Plastic bag method. Compost mixture is put in a plastic bag and tightly closed. If the compost is immature, the plastic bag will inflate due to the emission of carbon dioxide from the compost.
7. Cation exchange capacity: Increase during composting. Applicable to composts using straws, wood and bark, sewage sludge, and municipal wastes as feedstocks.
8. C/N ratio: When C/N was high than 30 at the start and it reached 15 – 20, it shows that the compost has fully matured. It is not applicable when composting mixture had low C/N from the beginning.
9. Optical density of water extract of composts. Samples of compost are suspended in a hot water at 60 degree C in 1:10 wet weight ratios and shaken for 30 min. Supernatant is centrifuged at 10,000 g and filtered through 0.45 micrometer membrane filter. Optical densities at 280, 465, and 665 nm are measured. They increase in the mid-stage of composting, then decrease in the final stage.
10. Earthworm method. Put a compost sample in a cup. Place a few earthworms on it. Cover the cup with a black cloth. If the earthworms creep into the compost, it is mature. If they try to escape, it is immature.
11. Germination test. Seeds of Komatsuna(*Brassica campestris*l), Cress (*Lepidium*

sativum), or radish (*Raphanus sativus*) may be used, because these seed are small, quick to germinate, and sensitive to phytotoxic (plant damaging) substances like the organic acids temporarily present in immature composts. Using the water extract of the compost, germinating rate is compared with the control (distilled water).

12. Seedling growth method. Compost (150 g) and soil (350 g) are mixed and put in Neubauer pots. The control is only the soil (500 g). Each 35mg of N, P_2O_5, and K_2O are applied to each pot in forms of ammonium sulfate, ammonium phosphate, and potassium sulfate. Water is applied to about 60 % of the water holding capacity. Twenty seeds of *Brassica campestris*I are sawn on the surface of mixture, and germination rate and growth rate are observed. This is the most ideal and effective testing method for the compost maturity, though it provides only the information on the effect of compost in the initial growth stage.

9) Compost standards in Canada

In Canada, three organizations are responsible for the development of standards and regulations for compost and composting: Agriculture and Agri-Food Canada (AAFC), the provincial and territorial governments, and the Standards Council of Canada (SCC) (through the *Bureau de normalisation du Québec* (BNQ)). This collective responsibility reflects government regulatory requirements (of both the AAFC and the provinces and territories) as well as voluntary industry initiatives (BNQ).

The scope of their responsibilities is as follows:

• Agriculture and Agri-Food Canada (AAFC) regulates compost under the authority of the *Fertilizers Act and Regulations*. All compost that is sold in Canada must comply with the requirements of the *Fertilizers Act*. This includes provisions for product safety, benefit claims and labeling.

• the provinces and territories regulate the disposal and use of waste, including its production and use. Consequently, compost which is **produced and used** is regulated within this jurisdication. The Canadian Council of Ministers of the Environment (CCME) assists to coordinate provincial and territorial initiatives wherever possible.

• the BNQ, acting on behalf of the Standards Council of Canada, establishes voluntary industry standards and endorses products which meet these standards.

I. Maturity

Compost maturity is fundamental to the classification of the product. Several indicators are necessary to determine compost maturity. The BNQ/CCME/AAFC standards use the same compost maturity indicator tests. The CCME guidelines also have identified additional criteria which may be used instead, and which reflect criteria already in existence in certain provinces.

The compost maturity indicator tests which are recognized by all three organizations (BNQ, CCME, AAFC) are as follows:
Compost is deemed mature if it meets 2 of the following requirements:

* C/N ratio <= 25;
* oxygen uptake rate <= 150 mg O_2/kg volatile solids per hour; and
* germination of cress (*Lepidium sativum*) seeds and of radish (*Raphanus sativus*) seeds in compost must be greater than 90 percent of the germination rate of the control sample, and the growth rate of plants grown in a mixture of compost and soil must not differ more than 50 percent in comparison with the control sample.

The CCME guideline also identifies the following criteria which may be used instead of the above to confirm compost maturity:

* Compost must be cured for at least 21 days; and

* Compost will not reheat upon standing to greater than 20°C above ambient temperature.

OR

* Compost must be cured for at least 21 days; and
* Reduction of organic matter must be > 60 percent by weight.

OR

* If no other determination of maturity is made, the compost must be cured for a six month period. The state of the curing pile must be conducive to aerobic biological activity. The curing stage begins when the pathogenic reduction process is complete and the compost no longer reheats to thermophilic temperatures.

II. Foreign Matter

Foreign matter is defined as:

"Any matter over a 2 mm dimension that results from human intervention and having organic or inorganic constituents such as metal, glass and synthetic polymers (e.g. plastic and rubber) that may be present in the compost but excluding mineral soils, woody material and rocks."

Safety and aesthetics constitute the key considerations in the development of foreign matter content standards in compost.

The safety criteria, relating to sharp foreign matter content, are similar across the BNQ, CCME and AAFC standards.

The BNQ standards establish three different foreign matter mass content limits for Types AA, A and B compost, reflective of product aesthetics. The CCME guidelines also identify a limit for foreign matter content, which is the same as the maximum dimension allowed by BNQ (25 mm) (Table 4).

FOREIGN MATTER -- SAFETY CRITERIA

Compost must not contain any sharp foreign matter measuring over a 3 mm dimension that may cause damage or injury to humans, animals and plants during or resulting from its intended use.

FOREIGN MATTER -- AESTHETICS

Table 4. BNQ Standard

	Type AA	Type A	Type B
Foreign matter content as a percentage of oven-dried mass	<= 0.01	<= 0.5	<= 1.5
Foreign matter, maximum dimensions, in mm	12.5	12.5	25

CCME Guideline

The compost must not contain any foreign matter greater than 25 mm in any dimension.

III. Trace Elements

A "trace element" is defined as "*a chemical element present in compost at a very low concentration.*" The compost standards identify trace elements that are essential to plant growth in addition to identifying heavy metals which, depending on their concentration in the soil, could be harmful to human health and the environment.

The similarities across the BNQ, CCME and AAFC criteria for trace elements are significant.

The BNQ Types AA and A are identical to the CCME Category A. The B classificaiton is similar across all 3 standards with the exception that maximum permissible concentrations for chromium and copper are not identified by AAFC and CCME, having yet to be established by AAFC under the *Fertilizers Act.*

The maximum cumulative additions to the soil are the same across the standards although its not specifically referenced in the BNQ standards. This reflects the fact that the BNQ standards deal with product-specifics only.

It is recognized that additional elements may be added to the list according to the availability of new scientific data.

Table 5. Maximum Trace Element Concentration Limits for Compost

	BNQ CCME Types AA and A Category A	BNQ CCME AAFC Type B** Category B² Maximum Acceptable Concentrations within Product
Trace Elements*	(mg/kg, air-dried mass)	(mg/kg, air-dried mass)
Arsenic (As)	13	75
Cadmium (Cd)	3	20
Cobalt (Co)	34	150
Chromium (Cr)	210	1,060 (BNQ only); not stated in CCME/AAFC
Copper (Cu)	100	757 (BNQ only); not stated in CCME/AAFC
Mercury (Hg)	0.8	5
Molybdenum (Mo)	5	20
Nickel (Ni)	62	180
Lead (Pb)	150	500
Selenium (Se)	2	14
Zinc (Zn)	500	1,850

*Other elements, such as boron, manganese, aluminum and iron, may eventually be regulated in certain provinces to accomodate regional and national concerns.

**Type B limits for maximum trace element concentrations in compost are based on the standards enforced by AAFC under Trade Memorandum T-4-93 since 1979.

Table 6. Maximum Cumulative Metal Additions to Soil

	CCME AAFC Trace Elements* (kg/ha)
Arsenic (As)	15
Cadmium (Cd)	4
Chromium (Cr)	**
Copper (Cu)	**
Mercury (Hg)	1
Molybdenum (Mo)	4
Nickel (Ni)	36
Lead (Pb)	100
Selenium (Se)	2.8
Zinc (Zn)	370

*Other elements, such as boron, manganese, aluminum and iron, may be eventually be regulated in certain provinces to accommodate regional and national concerns.

**Limits for copper and chromium are not established in the Fertilizers Act. Agriculture and Agri-Food Canada will be conducting a consultation process for adopting limits for chromium and copper. The CCME will re-evaluate these parameters when this process is complete.

IV. Pathogens

Pathogenic organisms are sometimes present in the feedstocks used to make compost. As a result, the compost may also contain pathogens. To reduce any potential health concerns, treatment processes as well as biological specifications have been identified.

All 3 standards (BNQ, CCME, AAFC) identify that the pathogenic organism content must not exceed the following limits:

* the quantity of faecal coliforms must be < 1,000 Most Probable Number (MPN)/g of total solids calculated on a dry weight basis; and
* there can be no salmonellae present (< 3 MPN/4g total solids).

Reflective of its ability to regulate and monitor processs, the CCME has also identified additional process guidelines to be followed to meet pathogen limits. The process choice reflects both the feedstock in addition to the composting method being used.

Within the CCME guideline, *if the compost does not originate from feedstock known to be high in human pathogens*, either a test may be conducted to meet the limits identified above (similar to BNQ and AAFC) or the following process may be done:

* Using the **in-vessel composting method**, the solid waste shall be maintained at operating conditions of 55°C or greater for three days.

* Using the **windrow composting method**, the solid waste shall attain a temperature of 55°C or greater for at least 15 days during the composting period. Also, during the high temperature period, the windrow shall be turned at least five times.

* Using the **aerated static pile composting method**, the solid waste will be maintained at operating conditions of 55°C or greater for three days. The preferable practice is to cover the pile with an insulating layer of material, such as cured compost or wood chips, to ensure that all areas of the feed material are exposed to the required temperature.

If the compost contains feedstock known to be high in human pathogens, it must not exceed the identified limits for faecal coliforms or be abset of salmonellae as well as undergo the composting process identified above or other treatment as identifid by the relevant province or territory.

10) Compost Standards in Japan

Common standards for all composts (According to the Ministry of Agriculture, Law of Fertilizer Regulation):

1. As < 50 mg/kg, Cd <5mg/kg, Hg <2mg/kg

2. No irregular growth of plants. Seedling growth test using Komatsuna (Brassica campestris) is recommended.

3. Copper content < 600 ppm, Zinc content <1800ppm (weight/weight oven dry basis).

Analysis should be done according to the Official Method for Fertilizer Analysis.

Table 7. Regulated values (upper limits) for heavy metals in special fertilizers including sewage sludges according to Ministry of Agriculture

	Total contents	Contents in water extracts (1:10)
Arsenic (As)	50 mg/kg	1.5 mg/L
Cadmium (Cd)	5 mg/kg	0.3 mg/L
Mercury (Hg)	2 mg/kg	0.005 mg/L
Lead (Pb)		3 mg/L
Organo-phosphorus compounds		1 mg/L
Cr^{6+}		1.5 mg/L
Cyan (CN^-)		1 mg/L
Alkyl mercury		should not be detected
PCB		0.03 mg/L
Method	Official Fertilizer Analysis Method by Ministry of Agriculture	Official methods for determining harmful materials in industry wastes by the Prime Minister's Office

Quality standards for animal manure compost

A: Following items should be indicated on the package of the compost.

Raw materials should be indicated. (For example: cow manure and saw-dust)

Organic matter (%) > 60 %

Carbon:Nitorgen ratio (C/N ratio): < 30

Total nitrogen content: > 1% dry matter basis

Total phosphate (P_2O_5) content: > 1% dry matter basis

Total potassium (K_2O) content: > 1% dry matter basis

Total copper content < 600 mg/kg

Total zinc content < 1800 mg/kg

Total calcium (CaO) content

Moisture: < 70% of the raw product

B: Following standards should be fulfilled but need not be indicated on the package of the compost.

Electron conductivity: < 5 mS/cm for raw product

C: For production of manure compost, compost should be piled for more than three months with turning several times.

Table 8. Standard and recommended values for composts by the central federation of agricultural cooperative associations in Japan

	Raw material				
	Animal feces	Bark	Sewage sluge	Human feces sludge	Food wastes
Organic matter (dry matter basis)	＞60％	＞70％	＞35％	＞35％	＞40％
C/N	＜30	＜40	＜20	＜20	＜10
Total Nitrogen (dry matter basis)	＞1％	＞1％	＞1.5％	＞2％	＞2.5％
Inorganic nitrogen (dry matter basis)		＞25 mg/100g			
Phosphorus (dry matter basis)	＞1％		＞2％	＞2％	＞2％
Potassium (dry matter basis)	＞1％				
Alkali substances (dry matter basis)			＜25％	＜25％	＜25％
Moisture (fresh weight basis)	＜70％	＜60％	＜50％	＜50％	＜50％
pH (fresh)	＜8.5		＜8.5	＜8.5	＜8.5
EC (fresh weight basis)	＜5 mS	＜3 mS			
CEC (fresh weight basis)		＞70 meq/100g			

Total regulation for heavy metal content in soil:

Zinc content in the plowed soil should not exceed 120 ppm. In soils which exceed this level, composts made from sewage sludges or municipal wastes should not be applied any more. (Guideline by the Ministry of Environment: 1984)

11) Benefits of compost

Plant available nutrients and micro-nutrients

As compost breaks down in soils, it provides the fertilizer nutrients of nitrogen, phosphate, and potassium in forms that are readily available to plants.

Compost functions as slow release store of nutrients, so that nutrients are available to plants as they require them.

Compost also provides a wide range of important micro-nutrients not found in commercial fertilizers.

Organic matter

The organic matter in compost increases the water holding capacity of the soil.

Compost lightens heavy soils.

Organic matter retain moisture and nutrients in the root zone.

Soil structure is improved, allowing effective drainage, extensive root growth, and soil aggregate stabilization.

Biological activity

Earthworm activity is encouraged, so that further enhancing fertility.

Compost supplies a range of microorganisms that enhance the health of both soil and crops.

Compost appears to suppress some types of plant diseases.

Compost will be a food for heterotrophic soil microbes and supports the richness and heterogeneity of soil fauna.

Weed seed and pathogen free

Properly processed compost will not introduce weed seeds or human pathogens when applied.

Improve the quality of crops

Crops grown with compost contain less nitrate and more carbohydrates and vitamins. Thus, it improves the health of people who eat the crops.

12) Conclusion

Production of compost is indispensable for reducing the environmental load of dairy farming, maintaining the fertility of farm soils, and creating healthy soils and crops. The qualities of composts, however, differ considerably from product to product, because different kinds of raw materials are used besides animal feces and various methods of compost preparation are adopted. Some of the composts may be unfavorable for use in agriculture. It is important for us to keep the principles in compost preparation (for example, activating aerobic process, experiencing the thermophilic period, providing enough duration for maturing, minimizing the mixing of heavy metals and foreign / artificial materials), in order to make safe and effective composts. On the other hand, preparation and utilization of compost both require a huge labor. Reward for this labor is not remarkable, because higher yield of crops can be achieved by the use of cheaper chemical fertilizers and cheaper crops may be imported from foreign countries. Community based organic matter recycling project and the understanding from the consumer is, therefore, very important.

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