中国农业大学资源与环境学院
College of Resource and Environmental Science

有机固体废弃物堆肥及其在土壤培肥中的应用

Organic Solid Waste Composting Treatment and Its Application in Soil Fertilization

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主要内容
Main Contents

- 堆肥基础Composting Foundation
- 堆肥主要工艺Main Composting Processes
- 堆肥反应器研制Manufacture of Composting Reactor
- 堆肥田间应用 Field Composting Application

有机固体废弃物产生量
Generation of Organic Solid Wastes

- 各种农作物秸秆大约有6～7亿t
- About 0.6~0.7 billion tons of stalks from different farm crops are produced.
- 畜禽粪便年产生量已达到24亿t (2005)
- The annual generation of livestock and poultry feces has arrived at 2.4 billion tons (2005).
- 每年城市污水处理产生污泥已达到1360万t (2005)
- The sludge generated annually from urban sewage treatment has reached 13.60 million tons (2005).
- 我国城市的垃圾的产生量达到1.56亿t(2005)
- The generation of municipal refuse has amounted to 0.156 billion tons (2005).

有机固体废弃物处理利用方式
Approaches of Organic Solid Waste Treatment and Utilization

- 农作物秸秆:直接还田和做肥料的各占1.7%和22%，农民当作燃料使用和在田间直接焚烧的分别占45%和17%，剩余的17%作为动物饲料
- Stalks of Farm Crops: The stalks directly returned to field and used as manure have accounted for 1.7% and 22%, respectively, while used by farmers as fuel or directly burned in field have occupied 45% and 17% separately, and the remaining 17% is used as feed for livestock.
- 畜禽粪便:大约80%的畜禽粪便没有经过处理就直接排放到环境中去，有17%的畜禽粪便农民直接做肥料，只有大约3%的畜禽粪便进行了堆肥处理
- Livestock and Poultry Feces: Approximately 80% of the livestock and poultry excreta is directly discharged into environment without treatment, while 17% is directly used by farmers as manure, and only about 3% is treated with composting practice.
- 污泥:大约有44.8%作为肥料农用，在这其中有60%没有经过任何处理直接农用；31%的污泥被填埋掉；13.7%没有做任何处理；其他的处理方式占10%
- Sludge: About 44.8% is used as fertilizers for agricultural purposes, of which 60% is directly applied for farming purposes without any treatment, 31% is landfilled, , 13.7% is not treated at all, while the other approaches of treatment has taken up 10%


FENGSHOU

第一部分: 堆肥基础

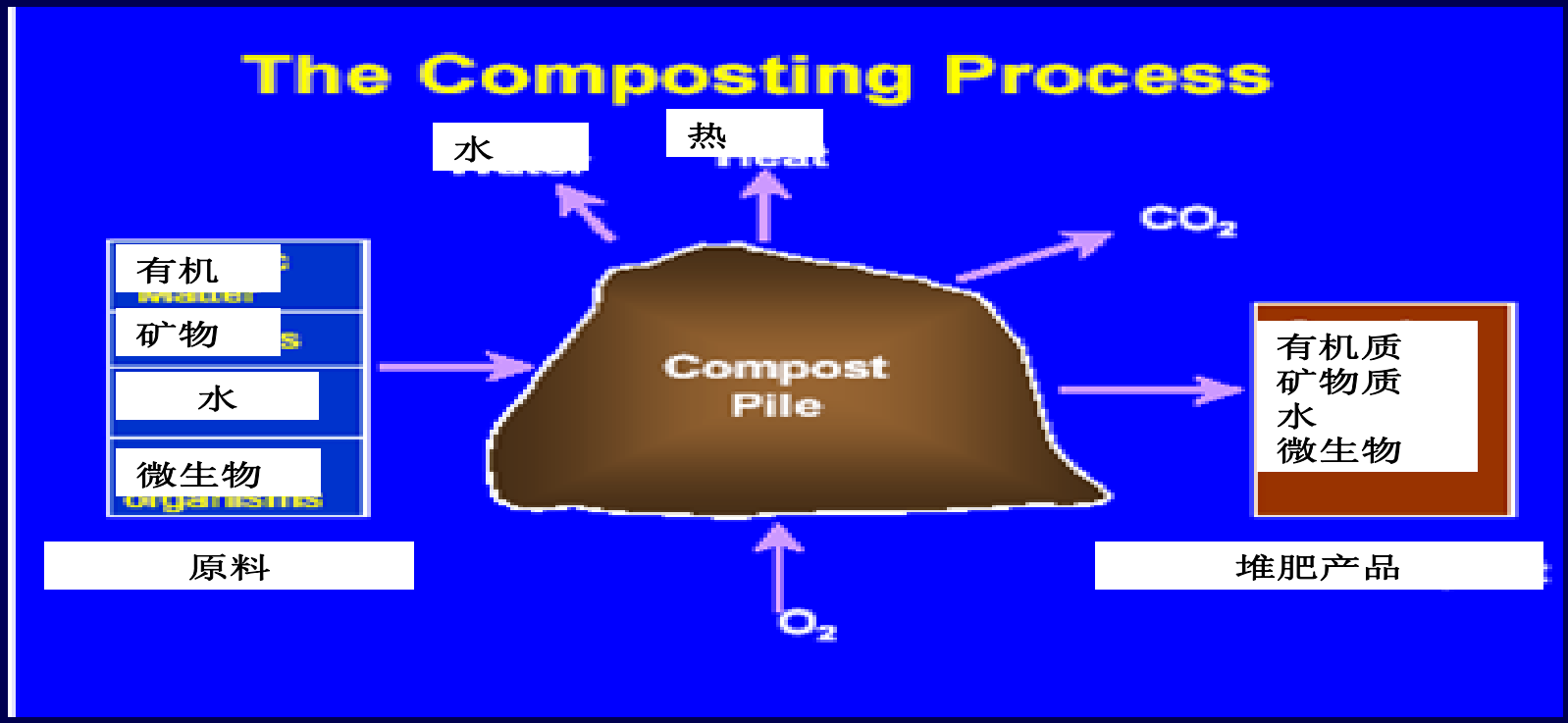
Part I: Composting Foundation

堆肥含义
Meaning of Composting Practice

堆肥，是指在人工控制下，在一定的水分、C/N比和通风条件下通过微生物的发酵作用，将废弃有机物转变为肥料的过程。通过堆肥化过程，有机物由不稳定状态转变为稳定的腐殖质物质，其堆肥产品不含病原菌，不含杂草种子，而且无臭无蝇，可以安全处理和保存，是一种良好的土壤改良剂和有机肥料。

Composting practice indicates a process under manual control to transform waste organic matters into manure through fermentation of microorganisms under certain moisture, C/N ratio, and ventilation conditions. Through composting process, organic matters are turned around from an unstable status into humus substances in stable status, with composted products through the process not containing pathogenic bacteria and weed seeds, as well as being free from odor and flies, able to be safely processed and stored, as a good soil improver and organic fertilizer

堆肥基本原理
Basic Composting Principle



Water Heat Manure Mineral Water Microorganisms Raw Materials

Organic Matters Mineral Matters Water Microorganisms Composted Products

影响堆肥进程的因素
Factors Affecting Composting Progress

- C/N比 C/N Ratio
- 温度和水分Temperature and Moisture
- pH值 pH Value
- 氧气的摄入量 Intake of Oxygen
- 生物菌剂 Biocontrol Bacterial Agent

堆肥腐熟度评价
Evaluation for Maturity of Compost

物理指标：温度、颜色、气味

Physical Indicators: Temperature, Color, and Smell

化学指标：有机物、NH_4^+-N、C/N等等

Chemical Indicators: Organic Matters, NH4+-N, and C/N, etc

生物指标：ＧI

Biological Indicator: Growth Index (GI)

第二部分：堆肥工艺
Part II: Composting Processes

堆肥主要工艺类型

Types of Main Composting Processes

- 传统堆肥Traditional Composting Approach
- 条垛式堆肥Windrow Composting System
- 槽式堆肥Trough Composting System
- 隧道式堆肥Tunnel Composting System

传统堆肥
Traditional Composting Approach

- 农民自制有机肥的一种主要方式，不考虑堆肥物料比和堆肥条件的堆沤的方式，目前该方式在农村还占有一定比例，特别是在蔬菜种植区还用得比较多
- One of the main approaches for farmers to self make organic manure, a waterlogging way for composting pile in which composting material ratio and composting conditions are not considered, and this pattern still takes up certain percentage currently in rural areas, and is yet being used more frequently in vegetable growing areas.

条垛式堆肥
Windrow Composting System

- 中国堆肥企业采用比较多的一种方式
- A more often used way by composting enterprises in China
- 技术差异主要表现在翻堆上，人工翻堆或者机械翻堆
- Technical differences are mainly represented in terms of pile turning by manual pile turning or mechanical pile turning.
- 主要处理的是垃圾或畜禽粪便
- Mainly refuses or feces of livestock and poultry are treated.

条垛式发酵Windrow Fermentation

条垛式堆肥翻堆机

Pile Turning Machine of Windrow Composting System

条垛式堆肥

Windrow Composting System

槽式堆肥
Trough Composting System

- 槽式堆肥系统是中国目前采用的最普遍的一种方式
- Trough composting system is one of the most popular approaches currently adopted in China
- 槽宽一般2m～6m，长度不等。在槽两侧的墙体设置轨道，轨道上放翻堆机。翻堆机可以在轨道上移动、搅拌
- The widths of trough are generally 2m～6m, with varied lengths. Rails are set on the wall on both sides of the trough, with pile turning machine placed on the railway. The pile-turning machine is able for movement and agitation on the railway.
- 翻堆机有齿式、螺旋式、链板式等几种类型，基本上都是国产的
- Pile turning machines are in several types including in teeth form, spiral type, and chain plate form, and all are basically homemade.
- 槽式堆肥系统现在处理的主要是污泥和畜禽粪便
- Mainly sludge and feces of livestock and poultry are treated in trough composting systems

槽式堆肥

Trough Composting System

槽式发酵

Trough Fermentation

槽式堆肥翻堆机

Pile Turning Machine of Trough Composting System

隧道式堆肥
Tunnel Composting System

- 隧道式堆肥系统是反应器堆肥系统中的一种
- Tunnel composting system is one type in the reactor composting system
- 主要在垃圾应用上较多（如：北京南宫堆肥厂）
- It is more often applied to refuses (e.g. Beijing Nangong Composting Plant)

南宫隧道式垃圾堆肥

Nangong Tunnel Waste Composting System

石家庄垃圾处理厂
Shijiazhuang Waste Treatment Plant

四川绵阳垃圾堆肥厂
Sichuan Mianyang Waste Composting Plant

第三部分:堆肥反应器研制
Part III: Manufacture of Composting Reactors

堆肥反应器设计思路

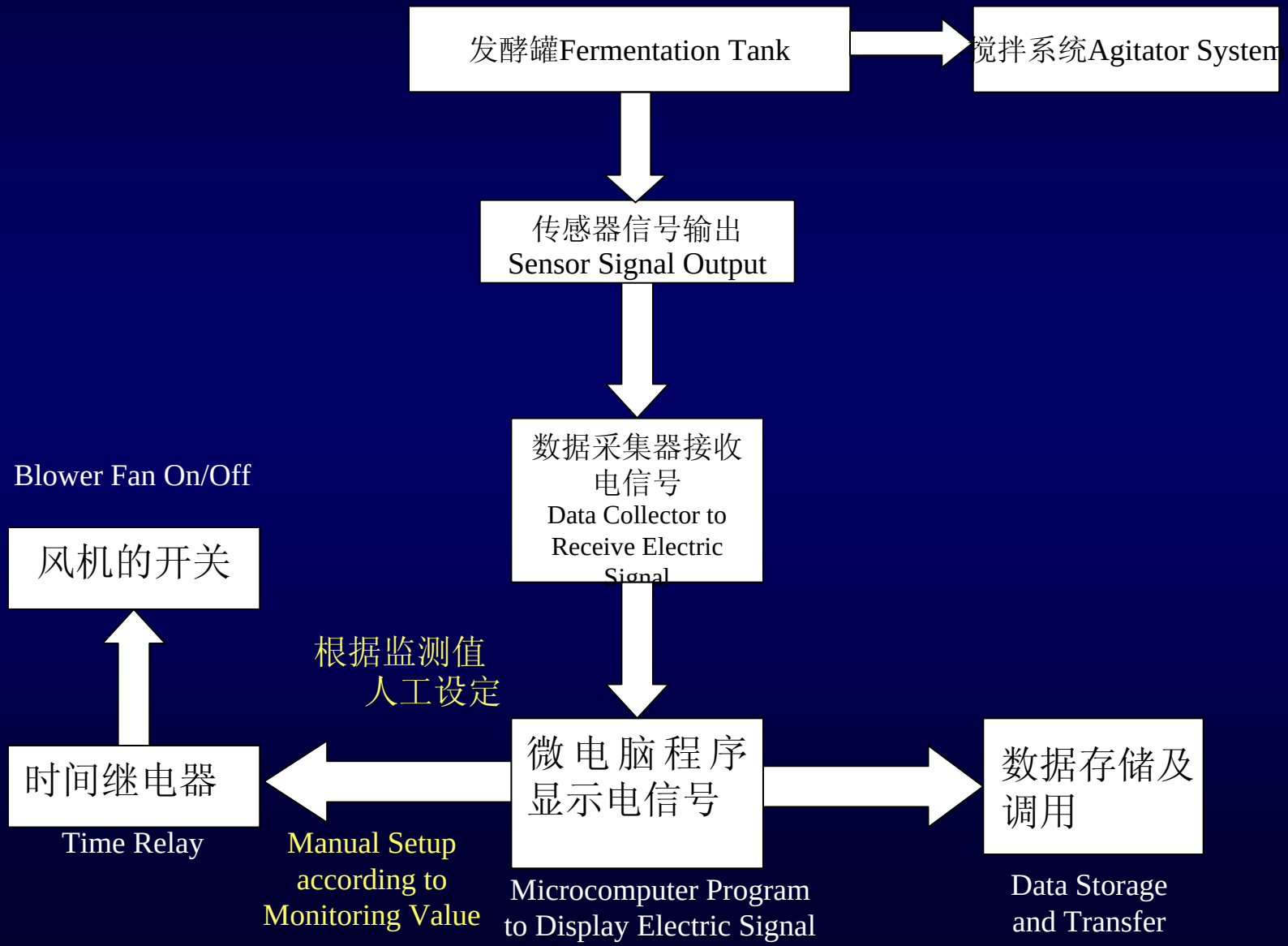
Designing Guidelines for Composting Reactors

堆肥系统由一个发酵罐和四个附属系统构成，发酵罐呈卧式圆柱状，四个附属系统是通风系统、搅拌系统、时间控制系统和数据监测系统。

The composting system is composed of one fermentation tank and four ancillary systems. The fermentation tank is in a horizontal cylindrical shape, and the four ancillary systems are ventilation system, agitation system, time control system, and data monitoring system.

堆肥反应器四个系统的匹配

Matching of the Four Systems for Composting Reactor



通风系统的设计
Design of Ventilation System

- 通风量的确定包括:Determination of ventilation quantity includes:

（1）供氧反应所需通风量Q_1 Ventilation quantity Q_1 required for reaction of oxygen supply

（2）去除水分所需通风量Q_2 Ventilation quantity Q_2 required for dehydration

（3）散热所需通风量Q_3 Ventilation quantity Q_3 required for heat radiation

（4）实际通风量$Q=1.1*（Q_1+Q_2+Q_3）$ Actual ventilation quantity $Q=1.1*（Q_1+Q_2+Q_3）$

- 风压的确定 Determination of Wind Pressure:

堆体的压力损失和风管，穿孔的压力损失之和，计算。

Calculated according to the summation of pressure loss with pile and the pressure loss with aid duct and perforation

搅拌系统的设计
Design of Agitator System

搅拌系统包括电机、减速机、搅拌轴、搅拌桨，搅拌桨共6片，等距离分布在搅拌轴上，每个相邻的搅拌桨，呈夹角60°搅拌转速3rad/min。

Agitator System includes motor, speed reducer, agitator shaft, and agitator paddles (6 in total) distributed at equidistance on the agitator shaft, with respective neighboring agitator paddles in a 60° included angle, and the agitator rotational speed is 3rad/min.

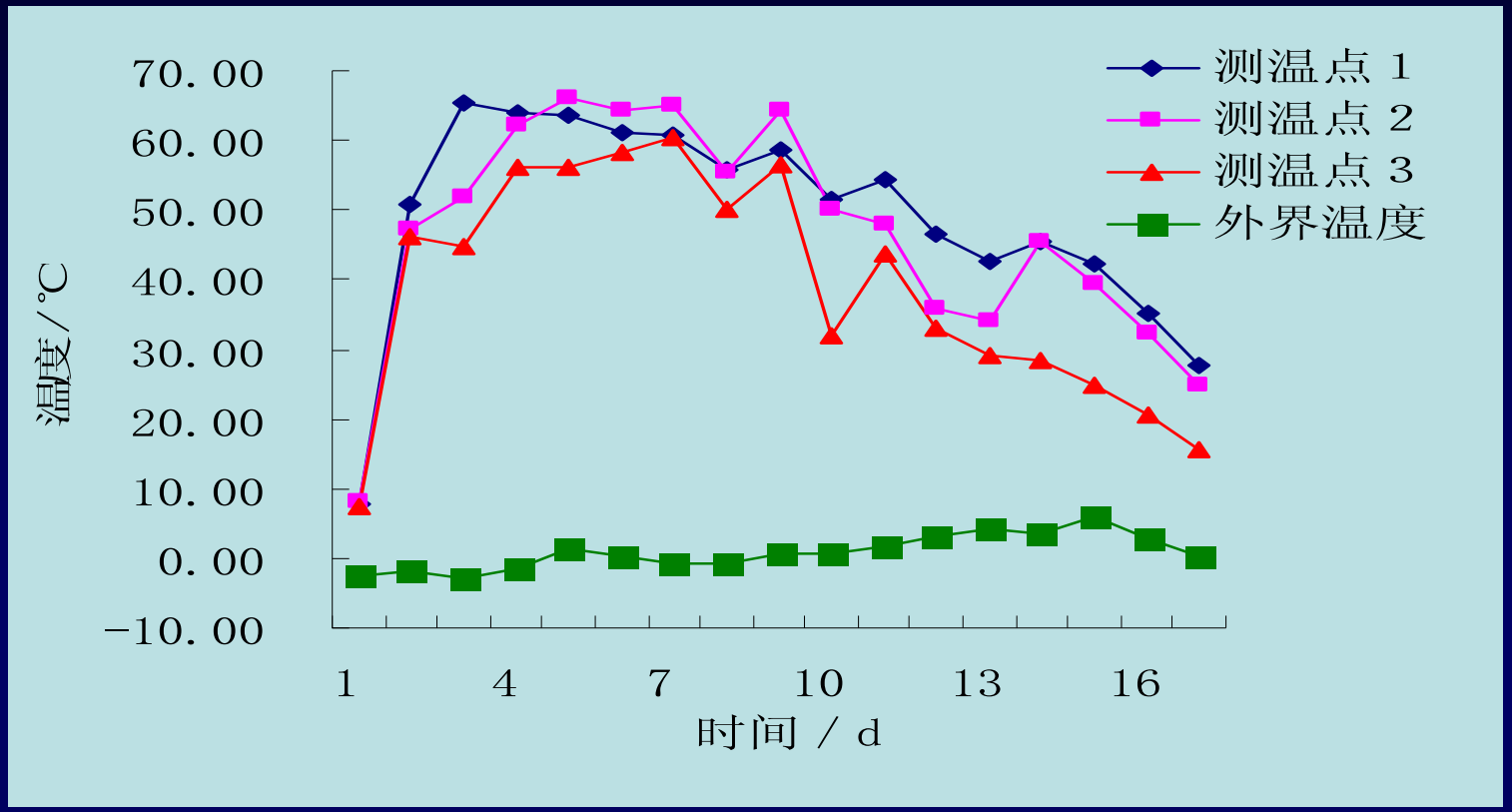
通风方案的确定
Determination of Ventilation Scheme

- 堆肥实验在制作完成的装置中进行，原料是鸡粪和锯末
- Composting experiment was performed in the device whose fabrication had been completed, and the raw materials were excrement of chicken and sawdust.
- 不接种菌剂Bacterial agent not inoculated
- 处理堆制周期17d，从2007年1月4日到1月19日。本实验未进行采样后的生化指标分析。 The pile composting cycle for the treatment was 17d, from Jan. 1 to Jan. 19, 2007. Biochemical indicators were not analyzed after sampling in this experiment.
- 测定指标有：The Indicators for determination included:

（1）温度测定：温度传感器，温度热电阻PT-100，5只 Temperature Determination: Temperature sensor, temperature thermal resistance PT-100, Five Pieces

（2）O_2含量测定：MF010-0-LC 氧气传感器 O_2 Content Determination : MF010-0-LC Oxygen Sensor

（3）水分测定：水分传感器，用于测定土壤水分的FDR-406，三根探针，可以测得插孔处的堆肥材料水分值，若需测量堆体内部水分值，将堆肥样品取出，放入烧杯中，将传感器插入堆肥样中，测得水分值。Moisture Determination: Moisture sensor, used to determine FDR-406 of soil moisture, with three feelers, able to determine the moisture value of the composting material in the areas of pigeonholes. Composting samples were to be taken out and placed into beaker, and the sensor was to be inserted into the compost sample, to get the moisture value if it was required to measure the internal moisture value of piles.



温度的变化过程

Temperature Changing Process

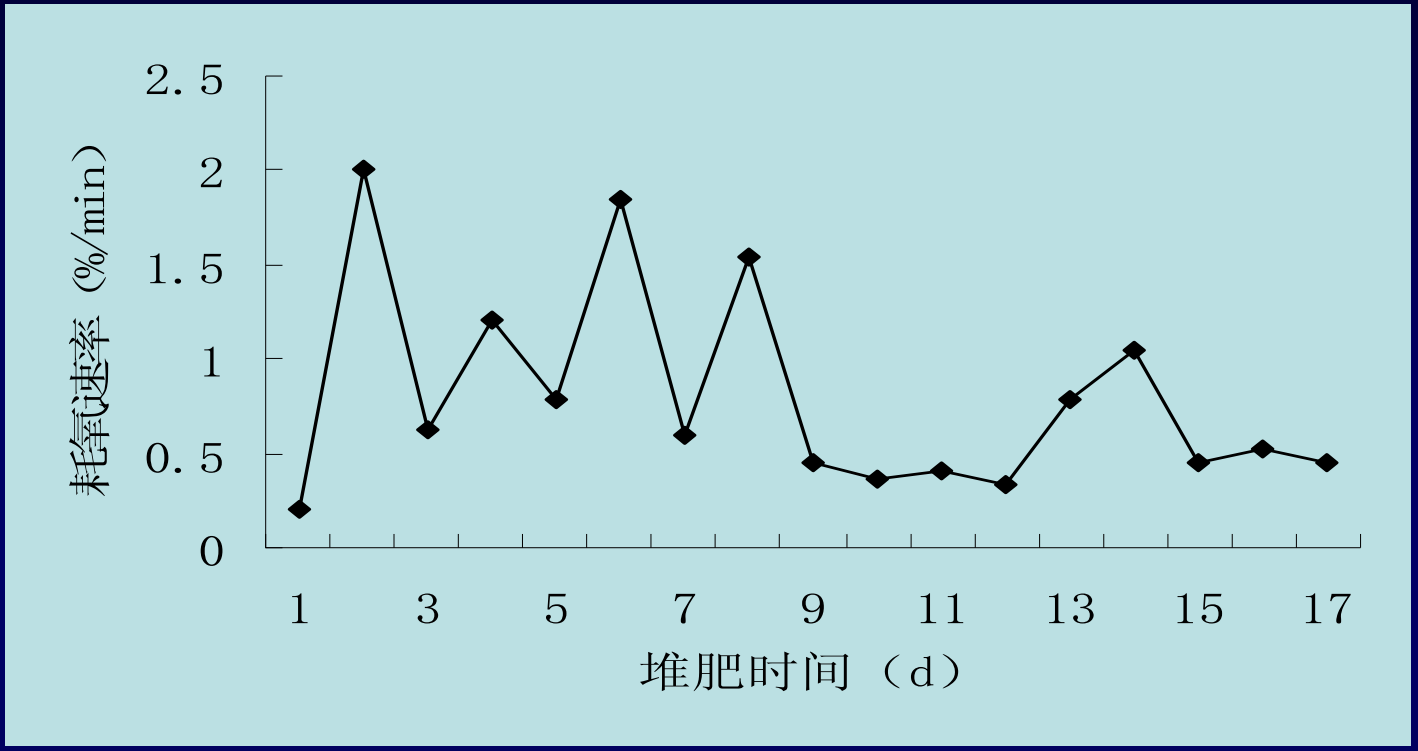
Temperature/℃ Time/d

Temperature Measurement Points 1 2 3

Outside Temperature

耗氧速率的变化

Change in Oxygen Consumption Rate



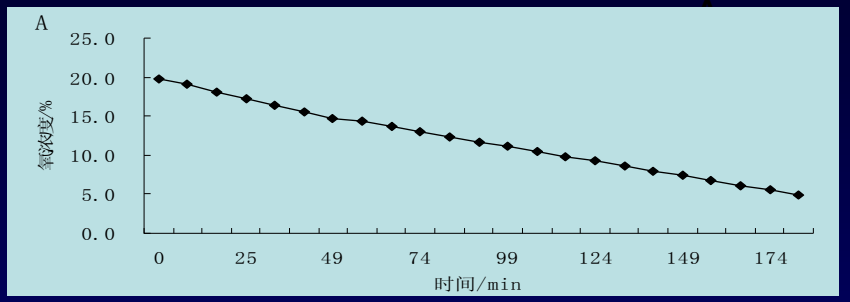
堆肥的第二天耗氧速率达到了最高值，此时温度达到55℃，耗氧量大

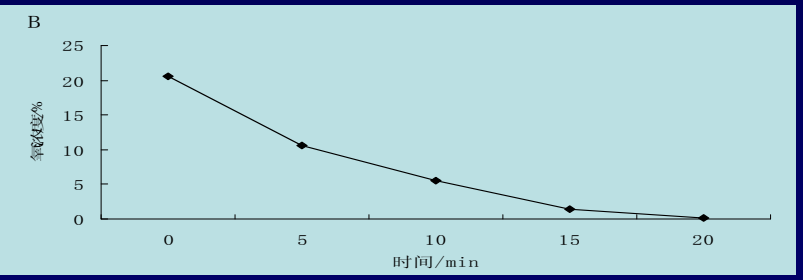
The speed rate of oxygen consumption reached the highest value on the 2nd day of composting experiment, and at this point temperature had arrived at 55℃ and oxygen was largely consumed.

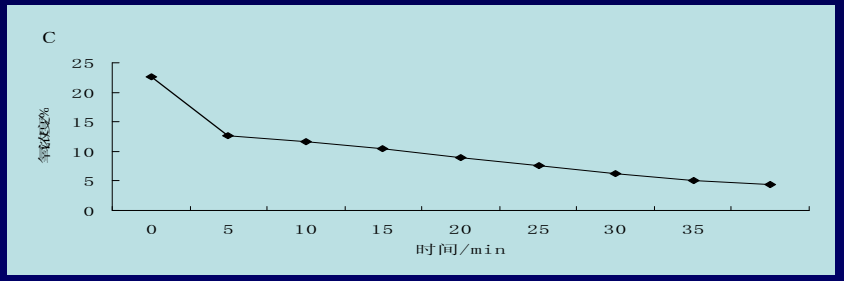
Rate of Oxygen Consumption (%/min)　Composting Time (d)

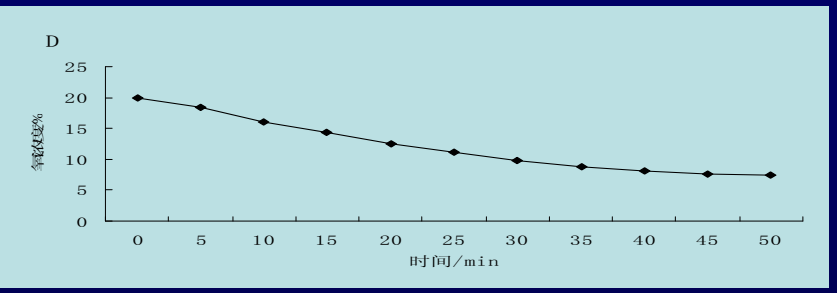
不同堆肥阶段通风停止后氧气浓度的变化

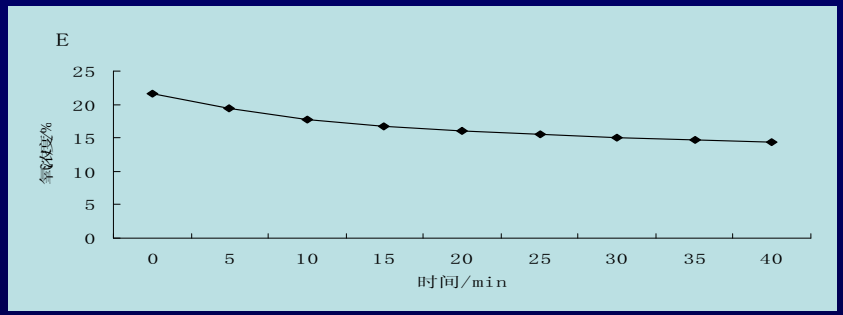
Variations in Oxygen Concentration after Ventilation Stopped at Different Composting Stages







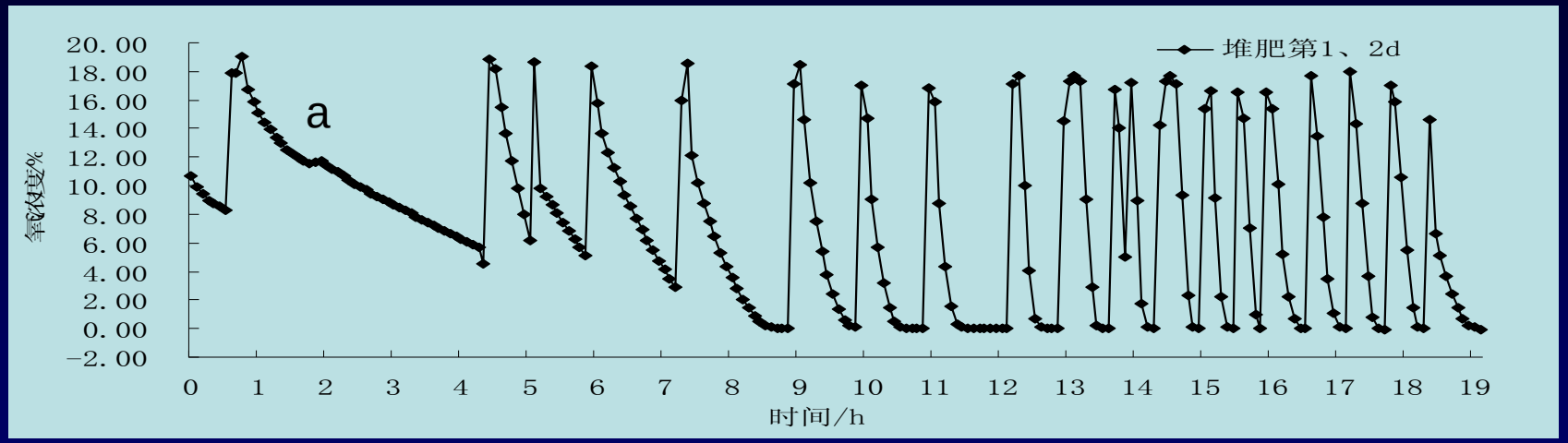




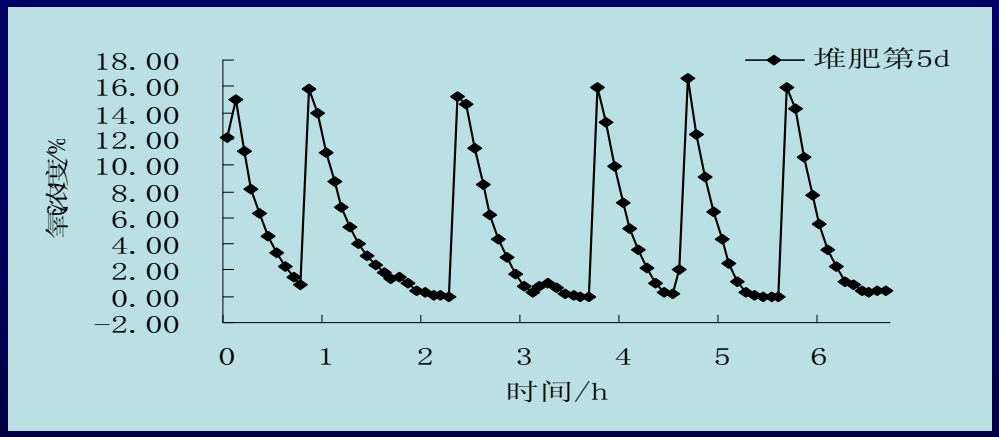
Rate(%/min) Time/min

A：升温阶段，堆肥第1d　B-D：高温阶段，堆肥第2，8，9天
E：降温阶段，堆肥第17d

A: Heating-up Stage, 1st Day of Composting Treatment B-D: High-temperature Stage, 2nd, 8th, and 9th Days of Composting Treatment E: Cooling-down Stage: 17th Day of Composting Treatment

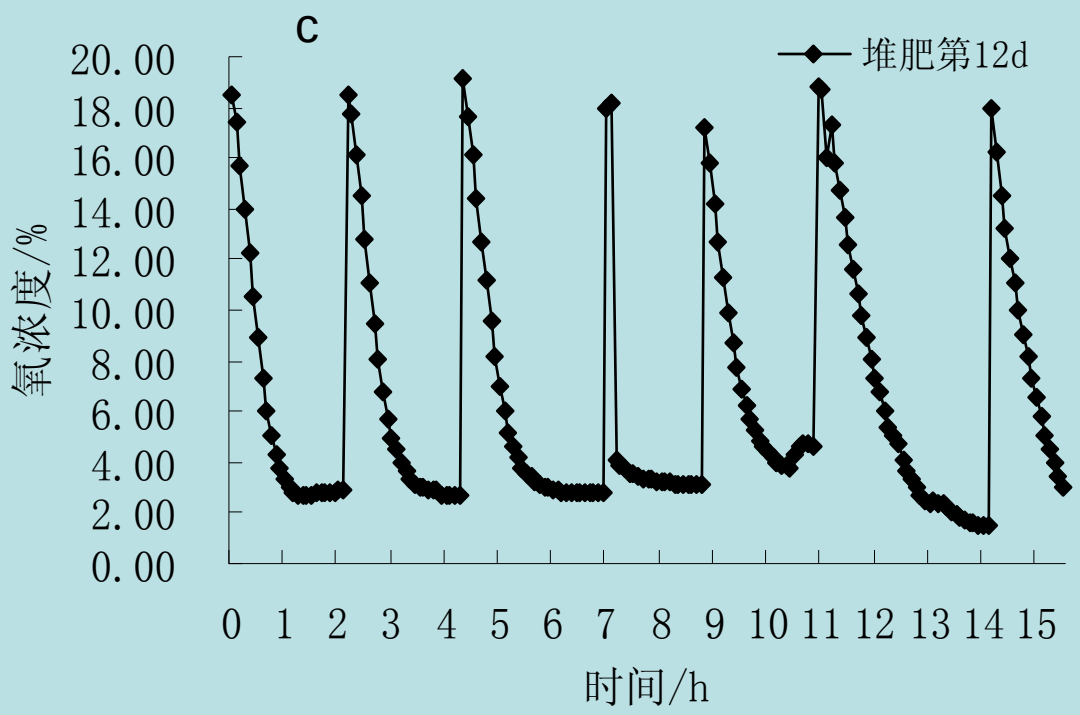


Oxygen Concentration/% Time/h 1st and 2nd Days of Composting Treatment



Oxygen Concentration/% Time/h 5th Day of Composting Treatment

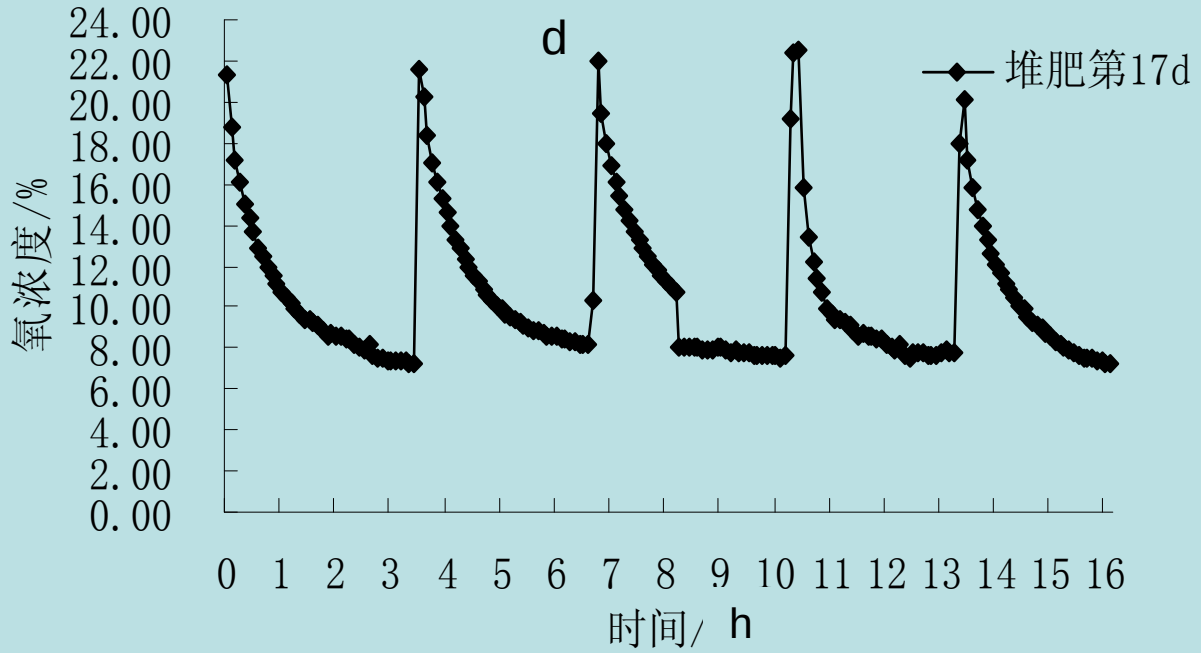
不同堆肥阶段氧浓度的连续变化
Continuous Changes in Oxygen Concentration at Respective Composting States



Oxygen Concentration/%
Time/h 12th Day of Composting Treatment

不同堆肥阶段氧浓度的连续变化
Continuous Changes in Oxygen Concentration at Respective composting Stages

Oxygen Concentration/%
Time/h 17th Day of Composting Treatment



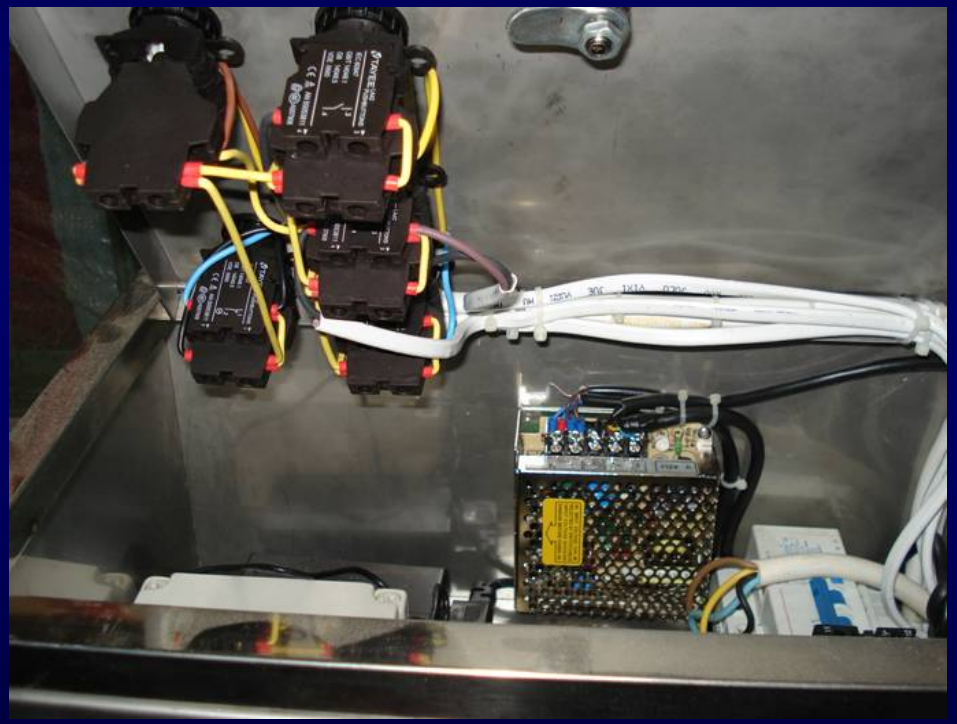
小结

确定通风方案为升温期（温度达到55℃以前）风机开1h，停5min；高温期风机开30min，停5min；降温期风机开1h，停5min。

Ventilation scheme was determined at heating-up stage (before temperature reached 55℃), for blower fan to run for 1h and to stop for 5min, while at the high-temperature, for blower fan to run for 30min and to stop for 5min, and at the cooling-down stage, for blower fan to run for 1h and to stop for 5min.

堆肥反应器罐体实图
As-built Drawing for Composting Reactor Tank

堆肥反应器控制系统
Control System of Composting Reactor



第四部分:堆肥田间应用
Part IV: Field Composting Application

试验地点:中国农业大学曲周试验站(1993--2005)

Experiment Location: Quzhou Experimental Station of China Agricultural University (1993-2005)

供试土壤:改良后的盐化潮土，试验地基础土壤肥力水平基本相同

Test Soil: The fertility levels of the improved salinized fluvo-aquic soil and the foundation soil in the experiment field were basically the same.

种植制度:冬小麦---夏玉米一年两熟制

Cropping system: Winter Wheat – Summer Corn in one-year two-maturity system

试验设计
Design of Experiment

试验共6个处理，历年每季作物施肥量：

Totally 6 treatments were designed for the experiment, and the amounts of applied fertilizer for crops for each quarter in past years were referred to:

- 处理 1：每公顷生物堆肥 15t；
- Treatment 1: 15t bio compost per ha
- 处理 2：每公顷传统堆肥 15t；
- Treatment 2: 15t traditional compost per ha
- 处理 3：每公顷生物堆肥 7.5t；
- Treatment 3: 7.5t bio Compost per ha
- 处理 4：每公顷传统堆肥 7.5t；
- Treatment 4: 7.5t traditional compost per ha
- 处理 5：当地一般施肥；
- Treatment 5: General local fertilization
- CK：不施肥；Check: Not fertilized

田间排列，随机区组，三重复，小区面积 10.5m×3m，均按当地管理水平统一管理。

Field Arrangement: Random blocks in three replications over a plot area 10.5m x 3m, all managed in a unified manner according to local level

注：当地施肥是指每年每公顷 0.75t 碳铵，0.3t 尿素，0.75t 过磷酸钙

Note: Local fertilization means 0.75t carbon-ammonium, 0.3t urea, and 0.75t calcium superphosphate

试验结果
Experiment Results

- 土壤理化性质Soil Physical and Chemical Characters
- 微生物生长环境、种群数量和微生物活性 Microorganism Growth Environment, Population Number, and Microorganism Activity
- 土壤环境Soil Environment
- 作物的产量 Crop Yield
- 作物品质 Crop Quality

土壤理化性质

Soil Physical and Chemical Characters

- 降低盐化潮褐土pH值
- pH value of salinized fluvo-aquic brown soil was reduced.
- 改善土壤容重，提高土壤总孔隙度，降低土壤全盐含量
- Volume weight of soil was improved, total porosity of soil was increased, and total salt content of soil was reduced.
- 明显增高土壤有机质含量、全N、全P，同时土壤速效养分含量也明显提高
- Soil contents of organic matters, total N, and total P were significantly increased, and at the same time the quick-result nutrient contents of soil were evidently enhanced as well.

微生物群落

Microorganism Community

- 土壤细菌数量各处理比对照分别高出108%、96%、76%、55%、6%
- Numbers of soil bacteria in different treatments were respectively higher than the check by 108%, 96%, 76%, 55%, and 6%.
- 土壤放线菌各处理分别比对照（CK）高出93%、60%、80%、46%、20%
- Ray fungi of soil for different treatments were respectively high than the check (CK) by 93%, 60%, 80%, 46%, and 20%.
- 土壤真菌表现为各处理分别比对照高出125%、180%、88%、81%、14%
- The performances of soil fungi in different treatments were high than the check by 125%, 180%, 885, 81%, and 14%, respectively.

土壤环境

Soil Environment

- 土壤生物多样性包括蚯蚓、螨虫的密度均以生物堆肥处理最高；
- The soil biological diversities including the densities of earthworms and acarids with bio composting treatments were the highest.
- 在整个生育期生物堆肥处理土壤线虫的平均数量比传统堆肥低；
- The average number of ray fungi in the whole growth duration in bio composting treatments was lower than that in traditional composting treatment.
- 在等量的有机物料施用条件下，施用生物堆肥处理比传统堆肥的原生动物要丰富。
- Under the condition when same amounts of organic fertilizers were applied, the number of protozoans in bio composting treatments was more abundant than that in the traditional composting treatment.

蚯蚓数量比较

Comparison in Number of Earthworms

作物产量

Crop Yield

- 十年的不同施肥处理的产量结果表明，生物堆肥对产量提高最多，传统堆肥次之，化肥再次。
- The yield results of different fertilizing treatments in 10 years have indicated that the yield increase for bio composting treatments was the highest, that for traditional composting treatment was the second, and that for chemical fertilizers was inferior.
- 每公顷施15000kg生物堆肥（处理 1）的作用效果最好，已连续7年保持亩产吨粮的水平，年均单产 16779.7kg，效果稳定。
- The functional effect with fertilization of 15000kg bio component (Treatment 1) per hectare was the best, and the level of per-mu yield of 1000kg had been maintained successively for 7 years, with an average annual unit production of 16779.7kg, typical of stable effect.
- 每公顷施15000kg生物堆肥的历年年均单产比等量传统堆肥（处理2）、施肥量减半的生物堆肥（处理3）、化肥（处理4）分别增产9.2%、15.5%、34.8%。
- The average annual unit productions in past years with fertilization of 15000kg bio compost per hectare were respectively increased by 9.2%, 15.5%, and 34.8% as compared with the same applied amount of traditional compost (Treatment 2), the halved application of bio compost (Treatment 3), and the application of chemical fertilizer (Treatment 4).

作物品质
Crop Quality

- 两个生物堆肥处理的籽粒粗蛋白含量是各处理中最高的，每公顷施15000kg生物堆肥处理的小麦籽粒粗蛋白含量比等量传统堆肥、施肥量减半的生物堆肥、化肥、对照分别提高 5.5%、4.9%、10.4%、19.9%；
- The grain crude protein contents of two bio compost treatments were the highest among respective treatments, and the wheat grain crude protein content for the bio compost treatment with fertilization of 15000kg per ha was increased by 5.5%, 4.8%, 10.4%, and 19.9%, respectively, comparing those with same applied amount of traditional compost, halved application of bio compost, applied with chemical fertilizer, and the check.
- 每公顷施15000kg生物堆肥处理的夏玉米籽粒粗蛋白含量比等量传统堆肥、施肥量减半的生物堆肥、化肥、对照处理分别提高3.7%、2.1%、10.4%、21.3%。
- The summer corn grain crude protein content for the bio compost treatment with fertilization of 15000kg per ha was increased by 3.7%, 2.1%, 10.4%, and 21.3%, respectively against those with same applied amount of traditional compost, halved application of bio compost, applied with chemical fertilizer, and the check.

总　结
Summary

总体上介绍了我国有机固体废弃物的产生、处理、利用基本情况，以及堆肥处理的原理、工艺和堆肥反应器研制方面的一些研究工作，并进一步对已开展的施用生物堆肥的长期试验进行了介绍。证明采用堆肥方式结合复合微生物处理废弃物生产生物有机肥对于改良土壤、恢复生物多样性和提高农田生态系统生产力的技术路线是可取的。但有关微生物作用机理以及如何提高这种作用效果仍需要深入的大量研究。

A general basic background information about generation, treatment, and utilization of organic solid wastes, as well as some research work on principles and processes for compost treatment, together with manufacture of compost reactors in China has been described, and thereupon a further description about the long-term experiments that have been carried out on application of biochemical compost has been given in this presentation, to prove that the technical approach of compost application combined with production of biological organic fertilizers through compound microorganism treatment of wastes is advisable with regard to improvement of soil, recovery of biochemical diversity, and increase in productivity of farmland eco-systems. However, massive research on functional mechanisms of related microorganisms and on how to improve such functional effects needs to be further intensified.


Thanks and Welcome
to Give Your Valuable Comments!
谢谢！
欢迎各位多提宝贵意见！