SUSTAINABLE VEGETABLE GREENHOUSE PRODUCTION THROUGH BIO-CONVERSION OF GREENHOUSE SOLID WASTES AND RE-UTILIZATION

by

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE STUDIES

Department of Chemical and Biological Engineering
Faculty of Applied Science

We accept this thesis as conforming
to the required standard

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THE UNIVERSITY OF BRITISH COLUMBIA
November, 2003

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ABSTRACT

Current practices of handling greenhouse wastes are not the sustainable ways to conserve agricultural lands and ground waters. This study developed a sustainable growing practice in the vegetable greenhouse industry. Waste handling (shredding) and the biodegradable plastics were investigated first. Then, different composting control algorithms and substrate recipes were tested in both lab scale and pilot scale composting. With a good control algorithm, composting of greenhouse wastes could reach the requirement for Process to Reduce Further Pathogens, PFRP (55 0C for 3 days). Ammonia emission might be a problem but it could be reduced by using air-recirculation or removed by a biofilter with compost as medium. Recirculation cooling control was found to be a more effective method, to maintain the process temperature below the set point, than any kind of temperature feedback control. Less leachate and condensate were found from the reactors with air recirculation control. Systems with air recirculation for cooling and aeration showed higher degradation rates, and also more consistent moisture content of the final compost.

Alder bark was found out to be a better choice of bulking agent than hemlock bark in terms of better substrate structure, more carbon loss, less nitrogen loss, and higher process temperature. Shredding was proven to be not necessary before composting of prunings and it also helped minimizing the amount of leachate. Bulking agents (alder bark) of about 20-30% (in weight) were found necessary for composting prunings. For

year-end wastes, a ratio of 62% vines, 13% used sawdust and 25% alder bark was recommended for in-vessel composting.

Using conventional management techniques in greenhouse tomatoes, a similar yield using a 2:1 sawdust to amendment mix by could be achieved compared to conventional sawdust medium. Significant reduction of crown and root rot disease caused by Fusarium oxysporum f. sp. radicis- lycopersici in susceptible tomatoes was achieved by addition of the greenhouse compost amendment to seedling plugs or blocks, and by mixing with the sawdust medium. A mixture of 2:1 sawdust to amendment by volume was shown to be effective. The reduction in disease resulted in 74% improved yield over a full growing season under high disease pressure.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BC	Province of British Columbia
BC MAFF	British Columbia Ministry of Agriculture, Food and Fisheries
BC MWLAP	B.C. Ministry of Water, Land and Air Protection
BC Reg	British Columbia Provincial Government Regulation
BTA	Combination of 1,4-butanediol, terephthalic acid and adipic acid
CCP	Combined anaerobic/aerobic Composting Process
CEC	Cation Exchange Capacity
C:N Ratio	Carbon to Nitrogen Ratio
DMS	Dimethyl Sulfide
$Duration_{40°C}$	Duration of the temperature above 40^0C
$Duration_{45°C}$	Duration of the temperature above 45^0C
$Duration_{55°C}$	Duration of the temperature above 55^0C
EC	Electrical Conductivity
FAS	Porosity or Free Air Space
FORL	*Fusarium oxysporum* f. sp. *radicis. lycopersici*
GI	Germination Index
GVRD	Greater Vancouver Regional District
HDPE	High Density Polyethylene
MC	Moisture Content
OAP	Organic Amendment Products
P	Porosity
ρ_b	Bulk Density
ρ_p	Particle density
PBT	Poly-butylene terephthalate
PCL	Poly-e-caprolactone
PET	Ethylene terephthlate
PFRP	Process to further reduce pathogens

PHB	Polyhydroxybutyrate
PLA	Polylactic acids
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl chloride
SAR	Systemic acquired resistance
TC	Thermocouple
TC	Total Carbon
TN	Total Nitrogen
$TEMP_{max}$	Maximum temperature
$TIME_{55°C}$	Time required for temperature to reach 55^0C
UBC	University of British Columbia
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
VARP	Vector Attraction Reduction Process

ACKNOWLEDGEMENTS

I would like to thank the following people and agencies that contributed to the completion of this research project and dissertation.

Dr. Victor Lo and **Dr. Richard Branion** of Chemical and Biological Engineering Department at the University of British Columbia (UBC) as my supervisors for the assistance to identify this important research topic, to share their extensive knowledge and experince on composting process, and to provide many technical resources related to this research project. **Dr. Anthony Lau** of Chemical and Biological Engineering Department (UBC) and **Dr. Peter Jolliffe** of Plant Science Department (UBC) as my committee members for their encouragement, timely guidance and unreserved support throughout my Ph.D. program.

The financial support from the Natural Science and Enginneering Research Council (NSERC) of Canada (Industrial Postgraduate Scholarship), Science Council of British Columbia (G.R.E.A.T. Scholarship), BC Greenhouse Growers Association (the industrial sponsor), National Research Council (T.A.P. funding), Investment Agricultural Foundation (I.A.F. funding), and the University of British Columbia are sincerely acknowledged.

The undertaking of my Ph.D. would not have been possible without the encouragement and patience of my wife, Amy. The confidence and encouragement I received from her are greatly appreciated.

CHAPTER I

OVERVIEW OF THE THESIS PROJECT

I.1 INTRODUCTION

I.1.1 VEGETABLE GREENHOUSE INDUSTRY

Every year, more and more vegetable supply comes from greenhouse vegetable production regardless of seasonal changes. In fact, the greenhouse vegetable industry has repeatedly achieved positive growth in sales in the last ten consecutive years. With the increasing number of greenhouse operations, environmental concerns regarding the industry are also on the rise.

The greenhouse vegetable industry is one of the fastest growing sectors of agriculture in British Columbia. The crops produced by greenhouses include tomatoes, cucumbers, sweet peppers and lettuces. In 1986, there were only about 36 hectares of vegetable greenhouses in B.C. By the end of 2001, there were about 80 commercial greenhouses covering 200 hectares of agricultural land in B.C. According to Statistics Canada, income from the sales of greenhouse vegetables in BC increased from $43 million in 1993 to $200 million in 2001 (Agriculture Statistics, 2002). Tomato was the largest income earner, representing half of the greenhouse vegetable total income, while pepper and cucumber were the second and third in production area. In 2001, the industry directly employs over 1000 workers and spends approximately $20 million on labour costs. Unfortunately, the BC greenhouse industry also produces about 30,000 to 40,000 tonnes of wastes per year according to our survey in 1999. The bulk of the wastes come

from the residues of the plants that are uprooted at the end of the growing season in November. Other organics wastes are generated during the growing season which consist of damaged or rotten crops and prunings.

I.1.2 SOLID WASTES PROBLEM

Most of the solid wastes from greenhouses are either piled up on lands beside the greenhouses or trucked to landfills. Figure I.1 shows an example of how those wastes were being stored at the backyard of the greenhouses. Piles of untreated organic wastes not only led to odour and pest problems, but also created a leachate problem, where high ammonia concentrations could pose a threat to watercourses (Robinson, 1990). Landfilling is also not considered a good waste management practice because it puts to waste two valuable resources, namely, the nutrient-rich plant wastes and the land it occupies. Besides, it costs the greenhouse operators millions in expenses in trucking and tipping fees each year. Incineration or local burning of greenhouse wastes is not suitable due to the high moisture content and generation of dioxin from plastics (Mitsuo, 2001).

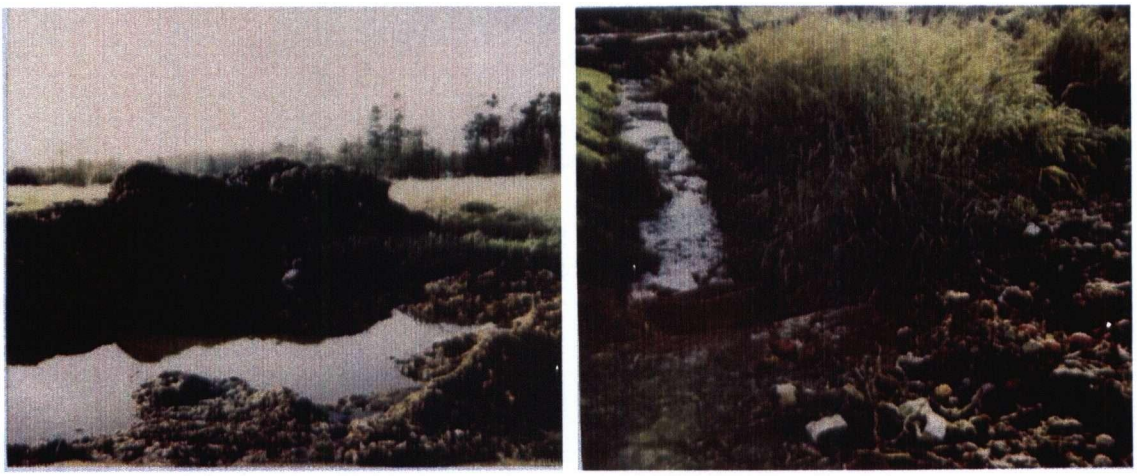


Figure I.1 Dumping of plant debris beside greenhouses

On the other hand, bio-conversion of greenhouse wastes promises to be an environmentally sound practice. Firstly, bio-conversion would convert the biodegradable wastes into a useful product - compost. Secondly, it would make use of abundant local waste products such as sawdust and wood chips as bulking agents. Finally, the finished compost product would be a usable product with agricultural and horticultural value (Eitzer, 1997).

Large commercial composting plants are already in operation in B.C. Unfortunately, the large operations usually accept wastes from greenhouses only if they have already been cleared of materials, such as plastic clips, twines, etc. This requirement has prompted many growers to simply truck their wastes to landfill areas where there is no such restriction. Centralized composting, like landfilling, also entails huge hauling and tipping fees. For a 4 ha greenhouse like Hazelmere greenhouse in our survey, the operator claimed that the expenses could accumulate to about $100,000 per year. For these reasons, greenhouse operators are looking into the possibility of operating their own bio-conversion facilities on site. Such an option would eliminate excessive hauling and tipping fees. Although the environmental impacts of several small composting sites remain to be assessed and compared to those of a single large operation, it is obvious that on-site bio-conversion would be a more environmentally friendly alternative than landfilling (Environmental Guidelines for Greenhouse Growers in B.C., 1994).

The fact remains that, so far, no greenhouse operator has resorted to composting wastes on site. Such reluctance is founded mainly on the fear that the practice could give

rise to problems such as odour pollution, groundwater contamination, infestation of flies and mice, spread of pathogens, and outbreak of plant disease. To a lesser degree, the hesitation may be due to uncertainties over technological issues such as which bio-conversion method is to be used or what bio-conversion techniques are to be adopted.

Moreover, there are strict regulations for organic matter recycling in B.C., especially for on-farm composting. For example, the composting process has to achieve 55 ^{0}C for a minimum of 3 days for pathogen reduction and waste materials derived from other non-agricultural operations are not allowed to be treated on the farm (B.C. Reg. 334/93). Compostable materials and recycling materials continue to be a waste until dealt with in accordance with the regulations; therefore, are not allowed to be sold as retail-grade organic matter or re-used in farm applications.

This study represents the first concerted effort to address all of the above concerns. It hopes to show that bio-conversion on-site, if properly done, can be a cost-effective means of greenhouse waste management without becoming a threat to the safety and well-being of the workers, the crops, and the environment.

I.2 OBJECTIVES

I.2.1 SUSTAINABLE DEVELOPMENT

Sustainable Development, as defined ten years ago by United Nations Commission on Environment and Development, means "meeting the basic needs of all the world's people today without compromising the ability of the future generations to

meet their needs" (Tebo, 1997). With the increased demands created by growing populations and rising incomes, sustainable agricultural development emphasises the need to enhance agricultural productivity in a manner that provides affordable, efficient and healthy diets to all at the lowest environmental cost (UNCED, 1992).

The 2000s have emerged as a decade of the environment. An important dimension of this is a societal focus on reducing the volume of materials that are landfilled (Arent, 1996). The initial focus of the Canadian Federal government was to reduce the volume of solid wastes generated by large firms. The present focus is on local units of governments (e.g. GVRD) developing recycling and other programs to reduce the volume of household wastes. These efforts will be followed by greater governmental focus on wastes generated by small and medium businesses, including the greenhouse industry.

In the last ten years, there has been an awakening of environmental consciousness in the agricultural and horticultural industry, such as the discharge of nutrients, pesticides, and waste materials. In Holland, a recent covenant between horticultural employers and the Dutch government for a sustainable development of greenhouse between 2000 and 2010 enables the growers to achieve the environmental targets in their own way, if they make a specific plan for their greenhouses (Erik, 1999). In Canada, we need a new era of agricultural growth in which the greenhouse industry plays a strong role, reaps the benefits and breaks the traditional industrial paradigm – creating wealth without regard to environmental consequences. The environmental consequences of existing greenhouse production – deterioration of agricultural lands, contamination of groundwater and spread of plant diseases – all contribute to reducing the ability of the environment to provide

resources for crop production; therefore, diminishing the potential well-being of future productions.

The overall objective of the thesis project is to develop a sustainable growing practice in the vegetable greenhouse industry. It can be achieved by two steps (see Figure I.1). First, an appropriate technology will be developed for the bio-conversion biodegradable wastes generated by the vegetable greenhouse. Second, the products from the process will be utilized in the greenhouse as organic growing media and disease suppression agent. By doing so, the greenhouse industry would not only achieve a sustainable growing practice with minimal wastes output, but also could benefit from cost savings in waste trucking, fertilizers and growing medium and increase in crop yield as well.

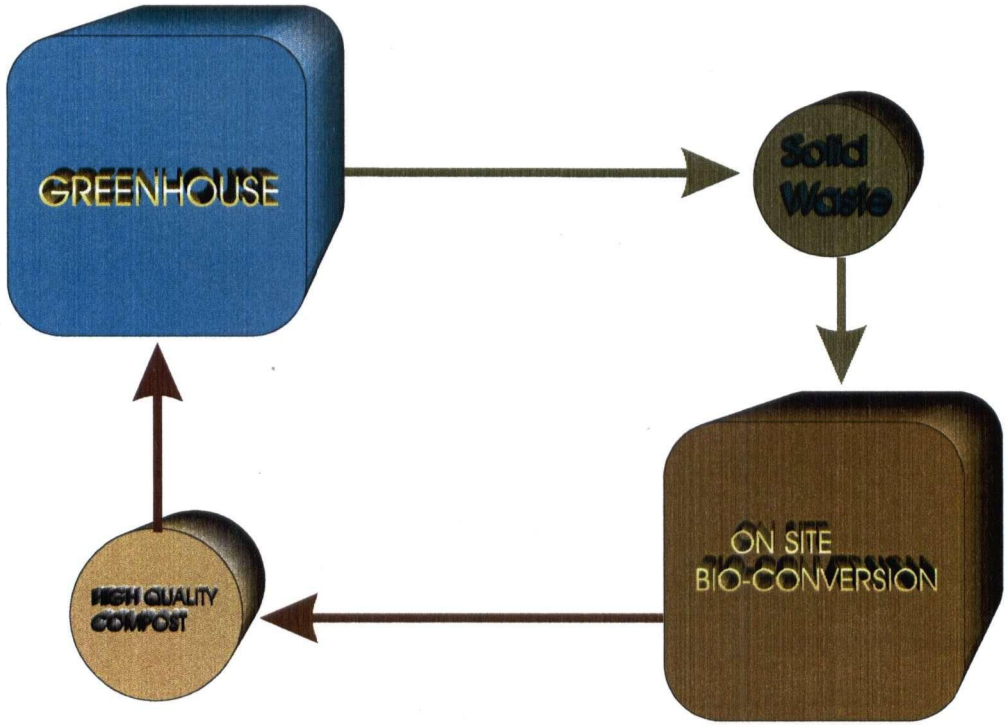


Figure I.2 Sustainable greenhouse production with bio-conversion of solid wastes

I.2.2 HYPOTHESIS

a) With the constituents of the greenhouse wastes and proper process controls, the bio-conversion of the wastes can proceed with minimal addition of bulking agents, and no supplemental heat needed to achieve the pathogen reduction requirement - a minimum of at least 55 °C for three days (B.C. Reg 334/93).

b) The bio-converted greenhouse wastes can be re-utilized in the greenhouse as growing medium or amendments, which will provide nutrients for the plants, including the macro-nutrients (N,P,K) and trace elements.

c) The products can also be used as disease suppressive agents for certain plant diseases, and such disease suppression properties can be correlated to the bio-conversion process.

I.2.3 SPECIFIC OBJECTIVES

I.2.3.1 Bio-Conversion of Vegetable Greenhouse Wastes

This part of the project concerns the development and demonstration of an appropriate technology for the bio-conversion of wastes generated by greenhouses in B.C. The specific objectives are:

- Characterize the various types of wastes generated in greenhouses.
- Test the effects of relevant parameters on bio-conversion efficiency.
- Assess the quality of the finished compost product.
- Assess the quality of some of the by-products from the process and the products, e.g. leachate, condensate and extracts.

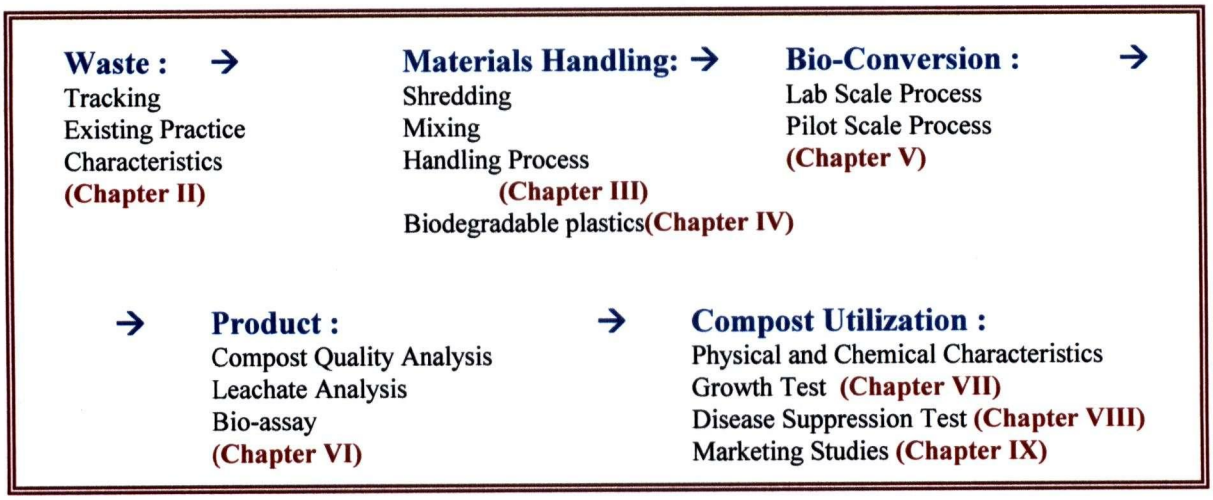
- Investigate the technical possibility of using bio-degradable plastics for greenhouse production.
- Investigate the feasibility of adopting box-type (in-vessel) bio-conversion technology for on-farm operation and to evaluate the economic feasibility of the bio-conversion technology.

I.2.3.2 Re-Utilization of the Bio-converted products

This part of the project aims at evaluating the benefits of utilizing the bio-converted products as high-quality organic medium amendment for growing vegetable crops in greenhouses. The specific objectives are:

- Analyze and compare the physical, chemical, and microbiological characteristics of the organic amendments with conventional sawdust growing medium.
- Demonstrate the feasibility of using the organic amendments in a commercial greenhouse, and measure the effect on crop health and yield.
- Investigate the disease-suppression abilities of the organic amendments on greenhouse vegetable seedlings.
- Investigate the disease suppression ability of the organic amendments on greenhouse crop yield and health.

The following diagram shows the overall framework of the project.



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CHAPTER II

WASTES TRACKING, WASTES CHARACTERISTICS AND GREENHOUSE SURVEYS

II.1 BACKGROUND

This section deals with the wastes tracking throughout the growing season (February to December) and the characteristics of the wastes. The quantity of wastes produced per hectare of greenhouse per year was estimated. The waste materials include:

- Daily prunings (from deleafing and truss breaking)
- Daily fruit rejects
- Year-end plant wastes
- Year-end used sawdust

→ **BIODEGRADABLE**

- Plastic twine → investigating biodegradable twine
- Rock wool → is attached and shredded with the year-end used sawdust
- Plastic films and bags → can be easily separated and trucked to landfill. Some greenhouses have been investigating the use of bio-degradable films and bags.

II.2 SPECIFIC OBJECTIVES

- To understand the characteristics of the solid wastes produced from the vegetable greenhouse industry.
- To understand the common waste management practices in the industry.

II.3 METHODOLOGY

Generation of organic waste was studied in detail for Hazelmere Greenhouse (pepper and tomato), located at 17830-16th Avenue, Surrey, BC. Appendix A shows a waste tracking sheet that was used for monitoring the organic wastes from Hazelmere Greenhouses Ltd. (2 ha peppers and 2.4 ha tomatoes).

As one of the objectives of this project is to come up with a feasible solution for treating the greenhouse wastes in B.C., we might need to know the existing practices of the operators in different greenhouses and their preference in terms of land use and cost. Therefore, different greenhouses were visited and surveyed, done either on site or by phone. The principal aim of the survey was to understand other greenhouses' wastes streams and current practices in wastes handling, so as to understand their concerns about plant disease and the possibility of incorporating "Composting" into their growing practice. Surveys were done for 8 other vegetable greenhouses: 4 tomato, 3 pepper, and 1 cucumber. A sample of the survey is shown in Appendix B.

II.4 RESULTS

II.4.1 PLANT WASTES

The annual amount of organic wastes generated from each hectare of greenhouse was about 150-200 tonnes according to the survey. Organic wastes from the vegetable greenhouses can be grouped into 4 major categories as follows (see Figure II.1).

a. Prunings

- primarily leaves, small stem portions, and a limited amount of fruit
- generated throughout the growing season
- high moisture content, potentially rotting and producing odour if stored too long

b. Rejects

- fruit culls
- generated throughout the production season, peaking during summer months
- very high moisture content

c. Year End

- whole plants left at end of growing season
- lower moisture content, contain more woody material (lignin and cellulose)
- large, tough stems require size reduction
- typically contaminated with plastic twine and clips

d. Sawdust Growing Medium

- usually hemlock or yellow cedar
- used by most but not all vegetable greenhouses
- low moisture content, may be contaminated with plastic bags

The tomato crop was found to have slightly higher volume of wastes than pepper. Table II.1 summarizes this data (note the survey average includes Hazelmere). Table II.2 shows chemical characteristics of the wastes.

Figure II.1 Monthly organic wastes production
(Top Left : Used Sawdust Medium, Top Right : Leaves and Prunings,
Bottom Left : Year-end vines, Bottom Right : Fruit Rejects)

Table II.1 Organic wastes generation

Waste	Annual Generation T/ha(Hazelmere Grn)		Annual Generation T/ha (Average from Survey)	Annual Generation T/ha(Average from Survey)
	Tomato	**Pepper**	**Tomato& Pepper**	**Cucumber**
Pruning	34.6	41.7	31.9	n/a
Rejects[1]	22	4.4	13.2	n/a
Year End	55.2	45	55.3	40
Sawdust medium	81.6	68	74.6	13.3
Total	193.4	159.1	175	n/a

Table II.2 Greenhouse organic waste characteristics

	Moisture Content %	TC % (wb)	TN%(wb)	C : N
Leaves	87.15±2.38	4.28±0.86	0.75±0.08	5.71±0.89
Vines	82.02±2.89	6.56±1.23	0.35±0.06	18.74±2.59
Sawdust	73.13±1.58	15.41±2.34	0.21±0.05	73.38±5.66
Roots	86.64±1.71	4.19±0.57	0.49±0.14	8.57±0.64

Note : 1. Mean values of five determinations ± standard deviations.
2. The leaves, vines and roots were based on greenhouse tomato crop.

II.4.2 NON-PLANT WASTES

Apart from plant wastes, the generation of non-plant wastes from the greenhouses was also investigated in order to get a full picture of the waste stream. The non-plant waste materials generated in a vegetable greenhouse production can be grouped into four major categories as follows.

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[1] Rejects estimation: tomato - 4% * 55kg/m^3 production = 22 T/ha; pepper – 2% * 22kg/m^3 production = 4.4 T/ha; average = 13.2 T/ha

a. Plastic Films and Bags

- constitute about 26% of the total wastes
- low density polyethylene ground cover and sawdust bags
- a number of greenhouse materials, such as fertilizers, are packaged in plastics
- not much in the way of recycling or recovery options is available. Currently, they are either trucked to landfill or an incinerator

b. Polystyrene Plastic (also known as Styrofoam)

- used in greenhouse operations include shipping containers, seedling trays and media components
- most of the growers have been re-using polystyrene shipping containers and seedling flats to the greatest extent possible

c. Rockwool

- an inert, soilless medium manufactured from lava rock which is both non-polluting and non-degradable in the environment
- the material, used primarily in slab form, has to be disposed after each growing season as its water retention characteristics change
- the medium contains the concentrations and mix of plant nutrients found in the irrigation water
- there are currently no recycling or recovery options available to greenhouse growers in BC for the disposal of rockwool

d. Plastic Twines

- plastic twines are used to tie the stems of the plants to the crop wires at 3.5 metres high
- normally, they are removed and wasted after the end of the crop season
- they create nuisance environmental concerns for the growers since they are difficult to separate from the plant debris

II.5 DISCUSSIONS

II.5.1 CONVENTIONAL DISPOSAL

A variety of organic waste disposal methods are currently used by growers, depending on the type of waste, greenhouse location, land availability, and grower preference. Based on the surveys and some site visits, typical disposal methods for the different types of wastes are as follows:

- Prunings - land application (may be dried first), landfill, farm animal feed
- Rejects - landfill, land application, farm animal feed
- Year end - land application, landfill, burning
- Sawdust – land application, pickup by landscapers or composting companies

Land application may be on the grower's property, or a nearby farm or other private property. It may involve pre-drying pruning, spreading, or storing/composting in piles. Generally, growers will choose the least expensive disposal method; convenience is also an issue. In some cases, disposal methods appear to be not in accordance with recommended or legislated environmental practices (BC MAFF, 1994), in that the amount of waste applied or stored on the land is excessive, with no covering, potentially leaching into the surface or ground water.

In many cases, it is likely that in the future, less waste can be applied to on-site land, due to waste build-up and potential leaching to surface or ground water. This would necessitate more expensive off-site disposal. Moreover, among the 8 greenhouses that were surveyed and visited, all of them had disease problems in their greenhouses (most

common ones were fusarium, pythium and boytrytis) and they were concerned about disease transmission from previous years' plant debris which had been stock piled beside the greenhouse.

The collected information about the type of wastes and their daily/weekly volume is very important for designing the bio-conversion treatment system, which includes the sizing of the system, the waste handling, possible bulking agents required, storage, curing area, etc.

Three terms used to describe reprocessing of waste are "re-use", "recycle", and "recover." Re-use means using the product again for its original purpose. Re-use of greenhouse materials wherever possible is always an important strategy to reduce the volume of wastes to be dealt with in greenhouse operations. However, not a lot of wastes can be re-used. Recycle refers to the process by which waste is remanufactured into a new product. Recover refers to any process that diverts wastes from landfills or incinerators. Greenhouse wastes consists of organic and inorganic materials, some of which can be recycled and recovered. The Resource Management division of BC's Ministry of Agricultural, Food and Fisheries (Environmental Guidelines, 1994) has been encouraging greenhouse growers to choose waste treatment options which reduce the volumes of waste generated and materials discarded by :

- Composting organic debris
- Substituting biodegradable materials for those that are not
- Using recyclable materials
- Using recoverable materials

II.6 CONCLUSIONS

From the data and surveys, the following conclusions can be drawn:

1. Greenhouse wastes, when not handled properly, can leach out pollutants like ammonia and nitrate to the land and emit unpleasant rotten odors. Current practices are polluting the agricultural lands and groundwater.

2. The wastes may pose a disease transmission problem to the greenhouse which can account for crop losses as high as 30 to 50%, for example due to *Fusarium* crown rot in tomato.

3. The greenhouse industry has a continuous organic waste stream, and a consistent waste characteristic. Almost 80 % of this waste is generated in a 3-month window near the end of the season. This suggests that plants and media from the remainder of the waste stream may be separated during this time.

4. Growers should be aware that disposal costs money. Waste-hauler tipping fees are increasing rapidly as the number of landfills declines and establishing new sites becomes a more politically difficult process.

II.7 REFERENCES

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CHAPTER III

MATERIALS HANDLING

III.1 BACKGROUND AND LITERATURE RESEARCH

Greenhouse year-end waste, mostly composed of stems, leaves, fruit rejects, prunings and twines, needs to be shredded to proper sizes prior to the bio-conversion process. The initial moisture content of the collected waste is about 75-85%. Such a high moisture content in the waste tends to pose difficulties for the ordinary hammer mill type of shredder. Besides polyethylene twines, which are attached to the plants for support, also create problems for high-speed hammer mill machines as the twines may wrap around the rotating shaft and stop the machine. The twines may also damage the bearings for some smaller machines.

The wetter the organic material, the coarser should be the grind. Since finely ground materials give up moisture quickly, they become a soggy mass and cannot be properly aerated. Thus, it is necessary that the material be ground to the right degree of fineness, uniformity and degree of compression. Besides, it is also essential to know and understand the composting process to be employed so that the grinding operation can be tailored to it.

Studies showed that depending on the type of raw materials to be processed, one or more of the following types of grinders and shredders could be chosen (Savage, 1981; Christopher, 1996; Gray, 1999; Glenn, 1999) :

a. garden chipper/hammermill;

b. granulator;

c. tub grinders;

d. high speed, high process volume shredders;

e. shear shredders;

f. medium-speed grinders.

It has been suggested that material to be composted in a mechanical digester may be ground much more finely than that which would be windrowed. Composting employing forced air and occasional turning can also take advantage of finer grinds (Snell, 1991).

Many garden **chipper/hammermill** have engine power rating ranges from 3.5 hp to 40 hp. Some machines are driven by the Power Take-Off (PTO) of a tractor while some smaller models are generally electric-powered and are best at shredding leafy green matter and small branches. Shredding is done by fixed-arm hammers. Such mechanisms spin at high speeds, pulverizing material that is fed into the machine (Ettlinger, 1994). Chipping, however, is accomplished by one or more fixed blades mounted on a rotary disc. The blades cut off material as it is fed through a chute. For the greenhouse's purpose, shredder machines are more suitable since they are better in handling soft materials such as leaves and twigs. However, the twines attached to the tomato plants may wrap around the shafts of those high-speed hammers of the shredders.

A **granulator** uses sharp knives rather than blunt faced hammers, that produce a chopping and slicing effect resulting in a granular grind containing far less objectionable dust and fines. Although this machine does not utilize the exploding action that a hammer

mill does, it has a very serious disadvantage, which make this machine not suitable for the greenhouse's application. According to the chief operating officer of H.C. Davis Sons Manufacturing Company Inc.- Mr. Thomas McPherson, the maximum tolerance for moisture content of the input material is 12% while the greenhouse waste will easily exceed 80% (McPherson, 1999).

Tub grinders are a high volume organic or wood waste processor. Their dump height can be as high as a house, and the width of the tub can range from 2 to 4 meters. In general, material is fed into a round hopper by either a conveyor system or a machine such as a wheel loader. Large tub grinders have their own knuckle boom grappler/loaders, and the hopper usually rotates to prevent clogging. Material passes through a hammermill and is discharged into a conveyor (Aquino, 1996).

High speed, high process volume shredders can do several jobs simultaneously. Such a shredder can grind and shred different materials, mix them up and blow the material into windrows up to 7.5 meters high. This high speed shredder can process a wide array of materials like biosolids, sawdust, recycled compost, brush, pallets, logs, wet grass or even Christmas trees. This kind of machine can be powered by a 150 to 200 hp engine and can process up to 200 cubic yard of sludge per hour (Anonymous, 1991) . Although such a machine has a very high throughput and can handle both big branches or high moisture content waste (sludge for example), its large volume and high price hinder greenhouse operators from considering it a practical option.

The **shear shredder** - properly described as a high torque, low speed industrial shear shredder is a newcomer to reduction technology. It has some advantages over the

hammermill, grinder and granulator. The industrial shear shredder has two or more counter-rotating shafts equipped with hooked knives capable of reducing a wide variety of materials from municipal solid waste to baled metals.

There are couple of factors to be considered. First, one should not equate horsepower and shredder performance. Factors such as maximum knife tip force and shredder shaft speed are much more reliable indicators of a shredder's capability and capacity than mere horsepower. Usually, the knife tip force determines the type of materials such a shredder can handle while the shaft speed indicates the throughput of the shredder, provided it can shred that particular waste. Besides, the drive type is also an important issue to be considered. Usually, shredders under 200 hp have a single drive motor and shredders over 200 hp have a dual drive motor (Glass, 1997). Besides the knife tip force and shaft speed, one should also consider other design features like knife design, configuration of knives on the shredder shafts and method of feed. In knife design, engineers need to consider parameters such as width of knife, the number of hooks per knife, and the length and angle of the hooks to suit a specific application.

A particular product must easily fit within the shredder feed opening to allow the shredder knives to grasp items to be shredded. Bulk loading using overhead cranes or front end loaders can increase labor savings and decreases the risk of injury caused by heavy lifting.

Although shear shredders are easier and less costly to maintain than hammermills and others, it is also important to examine specific features provided by manufacturers. Features like hexagonal shredder shafts, adequate bearing and seal protection, stack

tightening systems and shredder drive configurations will help to keep maintenance and operating costs to a minimum.

Medium-speed grinders are usually a single-rotor design and operate between 100 rpm and 400 rpm. Unlike the shear shredders which utilize shafts, the grinder consists of a round drum with multiple replaceable cutter inserts which cut against a fixed bed knife. Material exits through a screen on the discharge size and thus product sizes are usually consistent. A typical machine consists of a solid, machined-steel rotor with relatively small cutter tips, a charge hopper, a hydraulic feed ram and an electric motor with speed reducer.

These grinders can operate with or without screens, and are used to shred plastics, electronic scrap, wood waste and non-ferrous metals. A common application of this kind of machine is for shredding plastic bottles and tires. It can also grind scrap wood into a fuel-quality product. The power rating of such macahines may go up to 400 hp and the rotor weights of up to 20,000 lbs (Newell, 1997). They rely on vertical feed, and, much like a hammermill, the rotor inertia is used to produce the work. But unlike a hammermill, a true cutting process occurs within the machine.

III.2 SPECIFIC OBJECTIVES

- To find specific types of shredders or grinders that can handle high moisture content greenhouse waste and are able to shred twines.
- To modify some existing machines to suit our purposes.
- To design the waste feeding mechanism from greenhouse decropping to the bio-conversion reactor, e.g. whether shredding the waste in the greenhouse aisle or outside when the waste is piled up.

III.3 METHODOLOGY

In order to find a suitable shredder and/or grinder for the greenhouse application, a few different suppliers were contacted. Firstly, the greenhouse operators were not in the composting business, and were not prepared to spend a lot for a shredder to process their waste. So, a machine of below $10,000 Cdn was targeted. Secondly, the machine had to be small enough to be brought into the centre pathway (4 m wide) of the greenhouse in case the operator wanted to shred the waste right after removal. Thirdly, the shredder needed to be able to handle all three kinds of greenhouse crop wastes which were unique in their characteristics: leaves and fruit prunings (wet and soft), vines (long and woody), plastics twines (thin and rigid). Based on the above three criteria, two shredders were bought for the project and tested. The machines were tested for their flow rates, shredded product size, the handling by workers and the ability to cut twines. Mechanical modifications could be made, if necessary, to improve particle size distribution, flow rate,

sharpness, etc. The chosen shredder would be tested in a greenhouse at the end of the crop year to monitor the complete shredding process, including move-in, shredding and move-out. Time would be recorded for different wastes as reference.

III.4 RESULTS AND DISCUSSIONS

III.4.1 SHREDDER TEST 1

- Bear Cat Full Size Chipper/hammermill (Model 70080)

Figure III.1 Hammermill Shredder – Bear Cat

Mechanism : Hammermill – staggered pattern of free swinging, reversible, self-sharpening shredding knives.

Horsepower : 8 hp

Hopper Size : 22" x 35" (55 cm x 87.5 cm)

Overall Size : 40" x 22" x 39.5" (100 cm x 55 cm x 99 cm)

Figure III.1 shows the "Bear Cat". This particular shredder would be too small for commercial operation, but would be good enough for testing the mechanism of hammermill shredding for greenhouse wastes application. At the end of a crop season, the Bear Cat was used to shred the year-end plants, mainly vines with the twines attached, for the lab scale and pilot scale composting. This machine could shred on average 10 plants

within 2 ½ minutes, provided that the flow was smooth and the machine did not need to be stopped as a result of plugging.

In the beginning of the project, it was thought that the plant residues would be very easy to shred or chop. It was said that any machine could chop plant debris from a commercial greenhouse and the only factor we would have to consider was the horsepower of the machine. However, after this hammermill shredder was used, two major problems were realized with the greenhouse year-end waste: 1. High moisture content (over 80%); 2. The twines would spin with the shaft eventually forming a big wool-like mass which would plug the machine. The high moisture wastes after being shredded would become a soggy mass and could not be properly aerated in the composting process. The twines attached to the plants could wrap around the rotating shaft and eventually damage the bearings. In addition, the noise level was quite high because of hammering mechanism.

Therefore, this kind of hammermill shredder was considered not suitable for processing greenhouse plant debris.

III.4.2 SHREDDER TEST 2

- Teagle Tomahawk 100 Bale Shredder (shear shredder)

Since twine presents a problem for most size reduction equipment such as hammer mills, other suitable shredders for greenhouse application were investigated. After searching a few manufacturers, the Teagle bale shredder was bought for testing (Figure III.2).

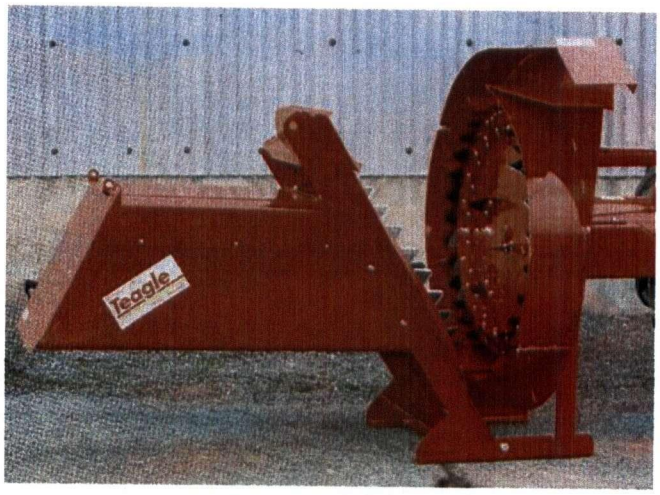

Figure III.2 Teagle Tomahawk 100 Bale Shredder

Mechanism : rotating disk within a drum, mounted with steel cutter sections

Horsepower : PTO-driven / 18 hp (separately built engine)

Hopper Size (WxL): 32" x 20" (80 cm x 50 cm)

Overall Size (WxLxH) : 62" x 72" x 49" (155 cm x 180 cm x 122.5 cm)

A PTO-driven straw bale shredder was purchased (Teagle Tomahawk 100) after the Bear Cat Chipper proved to be unsuitable. In the first trial, the speed was a bit slow as the wastes were wet and accumulated inside the drum. There was not enough of an air blowing effect to throw the shredded wastes out from the drum and the twines were not cut efficiently. Therefore, the following modifications were made at different times after trial and error for our application (see Figure III.3, 4, 5):

a. Extra blades were added to enhance the cutting mechanism;

b. Baffles were added onto the rotating drum to increase the air blowing speed, thus enhancing the throughput rate;

c. As it was found that the wet shredded wastes always stuck on the inside wall of the shredder, a teflon sheet was used to line the inside of the drum to reduce the friction and thus avoid plugging by the chopped materials;

d. As it was found out that the hopper and the shredding blades were to far apart and the opening was too small to push the leaves into the shredder, the hopper was shortened and widened in order to make feeding easier;

e. An 18 hp propane-driven motor was added to the machine so that it would be more mobile for shredding inside the greenhouse, instead of being driven by the PTO of a tractor.

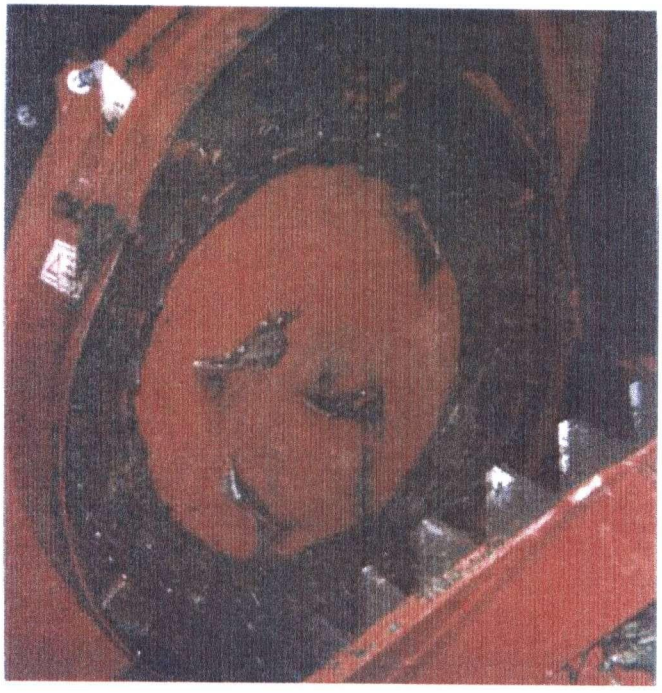

Figure III.3 Modification of the Teagle Shredder – More Blades Added

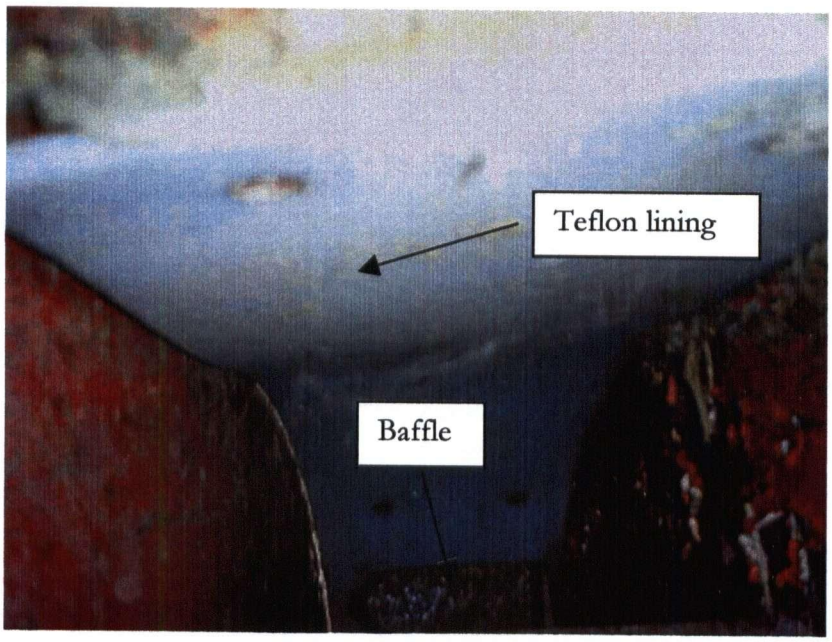

Figure III.4 Modification of the Teagle Shredder – Baffles and Teflon Lining Added

Figure III.5 Modification of the Teagle Shredder – Larger and Shorter Hopper, and Propane Motor

It was found that this type of shredder mechanism (a rotating disk within a drum, mounted with steel cutter sections) successfully shredded the year-end waste (tomato and pepper) including twines. What makes this shredder different than other size reduction machines is that it operates at a low speed with high torque. Opposing rows of cutting rings with hook-like protrusions gradually pull materials in between the knives at constant speed rather than chopping them with high speed rotating knives. This difference accounts for lower noise and heat generation (Knights, 1995).

ON-SITE WASTE HANDLING PROCESS

Once the machine was tested successfully, it was then used in the real clean-up situation in the greenhouse at the end of the year. The machine was used in both tomato and pepper greenhouses. The whole shredding process, which is described in Fig. III.6, was done inside the greenhouse with minimal interference with the original clean-up procedure. The time, labour required and size reduction were recorded for both crops. The distribution of particle sizes was measured by simply sieving the shredded wastes through 3 screens with mesh sizes of 4.8 mm, 2.4 mm, and 1.0 mm. According to Haug (1993), the desired range of particles for composting should be between 0.5 mm to 10 mm. During the test, one phenomenon was observed: pepper wastes had a faster through-put rate than tomato wastes, but less compression (volume reduction) and smaller particle sizes after shredding. See Table III.1. This was due to two reasons. First, the pepper vines were much shorter than tomato vines (3 m compared to 10 m), and thus much easier to handle and put through the hopper of the shredder. Second, the pepper vines were more woody (lower moisture content). For the pepper crop cleanup, approximately 55 m^3 of

waste was shredded resulting in 11 m^3 of shredded waste, in 4 hrs and 15 mins (approx. 10 plants in 30 seconds). For tomato crop cleanup, approximately 80 m^3 of wastes was shredded resulting in 13 m^3 of shredded wastes, in 7 hrs and 20 mins.

The results showed that the year-end plants, including the twines and clips could be shredded into uniform pieces using the modified machine. A shredder like this would be able to handle the wastes for a 1 to 3-ha size greenhouse without delaying the cleanup process. However, there were also maintenance problems with the unit, e.g. broken blades, due to its light construction and small size; a heavier, more reliable unit would be required for commercial operation. A trial was also done to investigate whether separating the twines before shredding was possible. Workers were then asked to unwind the twines along the tomato vines before shredding. This was found to slow down the process by at least 3 to 4 times.

Table III.1 Comparison of shredding pepper and tomato year-end wastes

	Pepper Year-end Wastes	Tomato Year-end Wastes
Volume before shredding	55 m^3	80 m^3
Volume after shredding	11 m^3	13 m^3
Volume reduction	5 times	6.15 times
Time required	4 hr 15 min	7 hr 20 min
Shredding Rate (based on intial volume)	12.9 m^3/hr	10.9 m^3/hr
No. of Labour required	4 (2 cutting crop, 1 putting cut crop into the hopper, 1 operating the shredder)	5 (2 cutting crop, 2 putting cut crop into the hopper since tomato vines are longer, 1 operating the shredder)
Particle size : >4.8 mm 2.4-4.8 mm 1.0-2.4 mm <1.0 mm	 17.5% 35% 40% 7.5%	 23% 46% 25% 6%

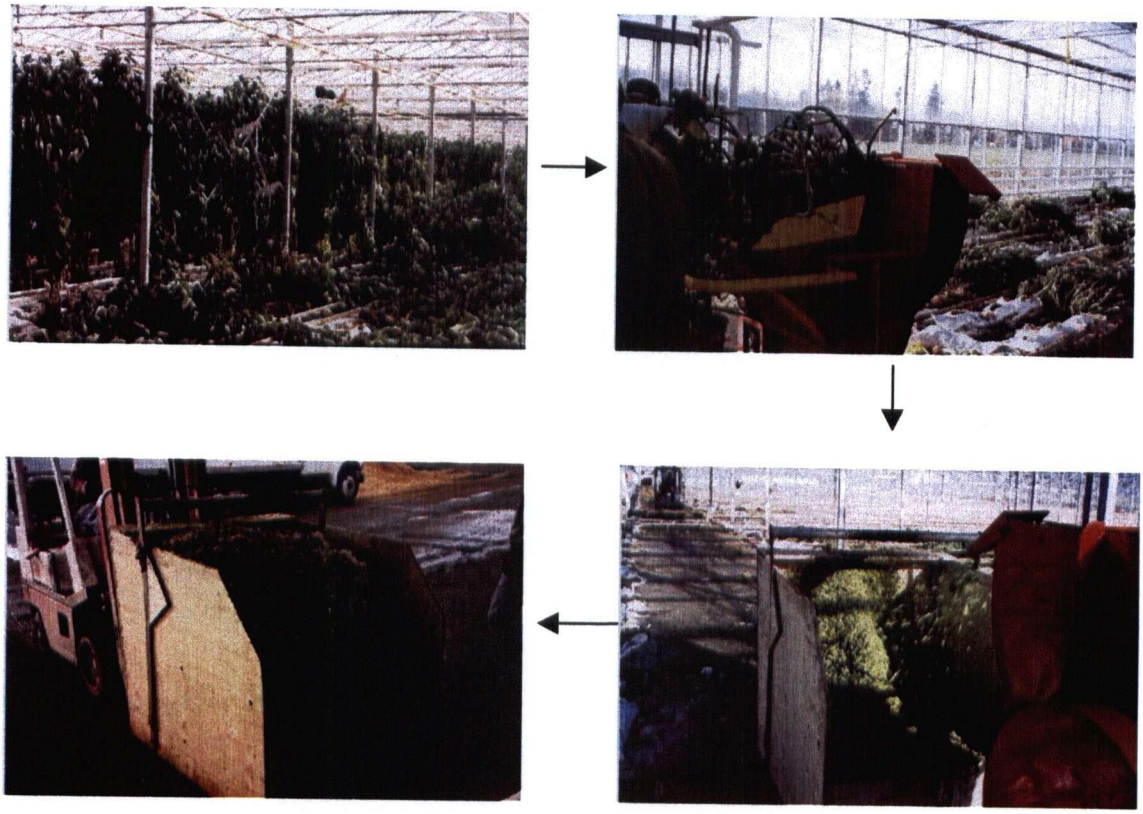

Figure III.6 Greenhouse Wastes Handling Process :

1. Cutting down the plants; 2. Pushing the plants into the hopper; 3. Shredded wastes collected into a bin; 4. Forklift taking full bin out of the greenhouse.

III.5 CONCLUSIONS

Waste processing and handling are mainly about using space and time efficiently to produce good quality substrates for composting. The less space waste occupies; the more one can haul in one load or hold in a composting facility. The less time it takes to process waste; the more efficient the operation (Siegel, 1999). Generally, only the year-end waste requires size reduction, due to the long, tough plant stems. The desired range of particle size of the shredded material should be large enough to provide some physical structure, but small enough to maximize breakdown over the composting and curing period. As the desired range for composting should be between 0.5 mm to 10 mm, from the results, more than 75% of pepper crop and more than 71% of tomato crop shredded by the modified Teagle machine fell into this range.

Contamination of year-end waste, primarily with plastic twines, presents a significant problem for both size reduction of the waste, and compost quality in terms of handling and appearance. There are several methods that can be used to deal with this.

From a composting point of view, the ideal option is to source separate the organic plant waste from non-plant contaminants at the time of waste collection, for example removing twines from pepper and tomato vines during cleanup. However preliminary studies of this method showed a significant increase in cleanup time by 3 to 4 times and thus increased the labour costs.

Shredding the conventional plastic twines along with the organic plant waste is another option which has been investigated. In this case the shredded plastics pass through the composting process unaltered, and should be later screened out (as much as

possible). Note however that although the shredded twine is highly visible after composting, the amount of plastic contamination is typically well below the 1% foreign matter content limit for Class A horticultural compost (B.C. Reg. 334/93).

Utilization of bio-degradable twine products is another alternative and will be investigated in the next chapter.

In this study it was found that a shredder with a rotating bladed drum would be more suitable for greenhouse applications. Not only because it could handle twines, but also it was economical (about $ 10,000 Cdn, including modifications) and mobile inside a greenhouse, whereas most of other commercial composting shredders were too big and too expensive. The ones used in Holland for greenhouse operation cost about $150,000 Cdn and questionnaires showed local B.C. growers could not afford them.

It was also found out that the vines should be shredded as soon as they were taken out from the rows before they are piled up and get tangled with each other. Therefore, it may be more desirable to have the shredding inside the greenhouse when the plants are pulled from the sawdust bags.

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CHAPTER IV

UTILIZATION OF BIO-DEGRADABLE TWINES

IV.1 BACKGROUND AND LITERATURE RESEARCH

IV.1.1 TRENDS IN BIO-DEGRADABLE PLASTICS

Plastics have been used in many applications due to their durability, light weight and processability. However most plastics remain undegraded after discard, which pollutes the environment and disturbs the ecosystem. As plastic recycling is quite limited from an economic view point, biodegradable plastics could be a good substitute for plastics used for many industrial, commercial and agricultural usages (Jang, 2002).

Initiated by increasing problems with plastics wastes during the last decade, new polymers have been developed, which can undergo a controlled biological degradation, i.e. composting (Amass, 1998). In most cases, the primary attack is an enzymatically catalyzed hydrolysis of ester, amide or urethane bonds in the polymers. However, in many cases, the term "biodegradation" is also used if the primary degradation step is caused by a hydrolysis which is not catalyzed by enzymes, but the depolymerization intermediates are finally metabolized by micro-organisms or resorbed by the body, in the case of medical applications (Muller, 2001).

Since 1970s, the production and processing of polyhydroxybutyrate (PHB) as biodegradable plastics materials were developed. PHB is a natural aliphatic polyester and belongs to the group of polyhydroxyalkanoates, which are produced and intracellularly

accumulated by various micro-organisms. It was available on the market under the trade name "Biopol". Beside this natural polyester, a number of synthetic aliphatic polyesters have been shown to be also enzymatically hydrolyzable. The aliphatic polyester currently most important for commercial biodegradable plastics is poly-e-caprolactone (PCL), which is predominantly used as component in starch-blends. However, PCL exhibits a significant disadvantage - its low melting temperature of about 60 ^{0}C - excluding it from many applications (Muller, 2001).

Polymers like PHB and PCL have good biodegradability, but lack structure and durability. Polymers like PET (ethylene terephthlate) and PBT (poly-butylene terephthalate) provide excellent material properties but are considered non-biodegradable. In order to combine both biodegradability and good material properties, copolyesters containing aliphatic and aromatic monomers were tested as biodegradable materials. By investigating the material properties, biodegradability and price, the combination of terephthalic acid, adipic acid and 1,4-butanediol (BTA) turned out to be the most appropriate combination (Witt, 1996). A number of materials, which are probably modifications of this basic BTA-structure are ready at the market (`Ecoflex' from BASF AG/Germany or `Eastar' from Eastman/US). Figure IV.1 shows the chemical structure of PHB, PCL, and BTA-copolyester.

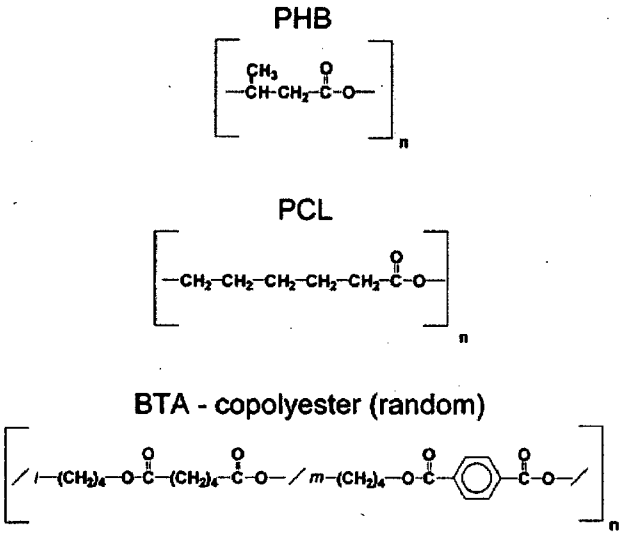

Figure IV.1. Chemical Formula of PHB, PCL and aliphatic-aromatic copolyesters

Bioploymers (e.g. starch, protein and cellulose) from various agricultural sources have also been investigated for manufacturing biodegradable plastics (Jane, 1994). Cross-linking of starch and zein mixtures and of soy proteins have shown that the tensile strength and water resistance of the plastics can be increased. Cereal flours are economically competitive materials for bio-plastics. Soy isolate and soy concentrate, with proper processing, showed positive properties for extrusion and injection molding of bio-plastics. Cellulose fibers can be used as extenders in the plastics to improve tensile strength and water resistance. These polyesters can be degraded by a variety of microorganisms, including some fungal phytopathogens. Many phytopathogens, for example Fusarium (a common pathogen in greenhouse crops) secrete cutinase, a serine hydrolase that degrades cutin, the structural polymer of plant cuticle (Murphy, 1998).

The main constraint on the use of biodegradable polymers is the difference in the price of these polymers compared with that of bulk-produced, oil based plastics. The cost

of Biopol® was approximately £8,000 per tonne, compared with prices of commodity polymers of between £500 per tonne (PVC and PP) and £600 per tonne (HDPE and high impact PS) (Amass, 1998).

The blending of biodegradable polymers is a method of reducing the overall cost of the material and offers a method of modifying both the properties and the degradation rates of the materials. These kind of materials were also tested in this study. The blends can be miscible or immiscible with each others. The advantages of producing miscible blends include single-phase morphology in the melt and reproducible mechanical properties. However, forming a miscible blend, particularly with a non-biodegradable polymer, can reduce or even inhibit the degradation of the biodegradable component. Immiscible blends have the disadvantage of having properties that are dependent on the blend morphology produced by processing and these are often not reproducible. However, some can show higher biodegradation rates than the unblended biodegradable homopolymer(s) (Amass, 1998).

IV.1.2 USE OF BIO-DEGRADABLE PLASTICS IN HORTICULTURE

Plants, in particular, tomatoes, peppers, and cucumbers, have soft stems. They rely heavily on the strength of twines, linking them to a support wire, to support their weight as they grow. For a tomato plant, the vines grow approximately 30 centimeters (12 inches) per week and can reach 12 meters (40 feet) in length by the end of the production season (BC Hothouse, 1999). Twines are also used to help greenhouse workers to move the plants along crop wires before the plants reach the ceiling of the

greenhouse. According to Hazelmere Greenhouses Ltd. (the surveyed greenhouse), for a 4 ha tomato greenhouse, it is estimated that approximately 2,000 kilograms of twines are needed per year.

Twines also impose a burden on both the environment and the greenhouse growers. After the plants have grown around the twines throughout the season, they become entangled. Therefore, they are mixed together with the plants when the plants are taken down at the end of the production season. The large volume of organic plant residues could potentially be regenerated into a soil amendment by a bio-conversion process. However, the presence of the plastic twines in plant residues significantly reduces the value of the organic waste as the twine content interferes with the composting process during mixing making the waste undesirable for alternative solid waste disposals. Commercial composters generally do not accept organic wastes with plastic because producing and marketing compost with plastic – even small amounts – hurts the compost industry as a whole (Purman, 1998 ; Croteau, 1998). This is part of the reason why a large volume of greenhouse solid wastes ends up in the already overflowing landfills, as mentioned in Chapter II.

Significant effort has been made to promote the use of alternative renewable resources to reduce the reliance on petroleum and its chemical derivatives. For example, in the United States, the Plant/Crop-based Renewable Resources 2020 is one such strategic vision supported by the U.S. Department of Energy, USDA and U.S. agricultural, chemical, and forestry communities (Faulkner, 1999). Reducing the use of

plastic twines in the greenhouse vegetable industry would contribute to the recognition of this vision.

The use of biodegradable substitutes to replace the use of plastic twines could offer additional waste management options for the greenhouse industry. It would not only reduce the generation of plastic waste but also greatly increase the commercial value of the organic wastes as the absence of impurities and consistent quality of the organic wastes would make them more attractive to commercial composters (Purman, 1998). This could permanently remove a large fraction of the municipal solid waste stream from landfills (Khan, 1996). A process with lots of waste, as long as it's "wanted waste", may be better than one with a small amount of waste that must be landfilled or burned (Benyus, 1997). Furthermore, it could avoid the complications induced by separating twines from plants. In short, it was believed that the problems associated with the plastic twines could be minimized or even eliminated by using biodegradable twines that would possess similar, desirable physical qualities as traditional plastic twines.

IV.2 SPECIFIC OBJECTIVES

- To identify an environmentally compatible substitute(s) that could replace the current use of petrochemically-derived plastic twines in greenhouse vegetable production;
- To test the substitutes' durability under the greenhouse growing environment;
- To test the substitutes' compostability in an in-vessel composter.

IV.3 METHODOLOGY

The purpose of this study is to investigate the use of alternative bio-degradable twines for the greenhouse vegetable industry in order to replace the current non-biodegradable plastic twines. There were four stages in this study :

First stage : Select twine candidates for the study, which involved literature and industry-based research to understand the properties of twines, their physical conditions as well as the market needs.

Second stage : Utilize the selected twines as support for plants in a commercial greenhouse located in Surrey, BC.

Third stage : Measure the changes in physical properties of the twines collected from the greenhouse in a laboratory during the growing season.

Fourth stage : Conduct a compostability study on the alternative twines in a pilot scale composter.

IV.3.1 SELECTION OF TWINE CANDIDATES

The first stage of the experiment was to select twine candidates for the experiment. They had to meet the following criteria:

1. Availability

   They must be commercially available in large quantities to meet the market demand. Twines are usually demanded in large quantities in the beginning of the year when a new production season begins.

2. Tensile Strength

   It must have sufficient physical strength to support the plants during the production period under typical greenhouse conditions. For greenhouse crops, which generally have a production period of 11 months or less, the twines must not only sustain the weight of the plants throughout this period but also withstand the physical stress imposed when twines are being move along the crop wire.

3. Handling

   Twines that tend to easily absorb and retain moisture would be more likely to host plant pathogens that are prone to causing a disease outbreak. Also, materials that

have a rough texture might potentially injure greenhouse workers as they could cause scratches or cuts.

4. Cost

They must be relatively economical compared to traditional plastic twines. This practical aspect of the product must enable the twines to compete with other similar products available in the market in order to attract the greenhouse growers.

5. Biodegradability

They must be readily biodegradable. "Readily biodegradable", in this case, is defined as the breakdown of the material into inorganic components within a reasonable time frame, between 4 to 8 weeks of active composting and 4 to 8 weeks of curing. This range of time frames was chosen based on the operation schemes commonly observed in commercial composting facilities.

6. Colour

It is desired that the twine be white or transparent in colour to maximize the reflection of sunlight inside the greenhouse. In a greenhouse environment, sunlight plays a crucial role in both energy consumption and crop yield. Therefore, any amount of reduction in sunlight would be undesirable. A lot of materials inside a greenhouse, for example plastic ground cover, bags, lamp covers, glutters, trusses, are specially made in white.

A brief outline of the six criteria is provided in Table IV.1. The twines selected for this study included Vertomil®, Ecolan®, Cargill EcoPLA (EcoPLA® 2000D), cotton,

and jute. Vertomil® and Ecolan® were supplied by Lankhorst Touwhfabrieken bv. based in Holland. EcoPLA®2000D was supplied by Cargill Plastic Company based in the United States. Cotton and jute were made available by Westgro Co. Ltd., a local agricultural product supplier. Table IV.2 summaries the compositions of the selected twines. The following section provides further information on the five types of twines and the reasons why they were chosen in this study.

Table IV.1 Criteria for Twines

Criteria
1. Readily available
2. Sufficient strength throughout a production period
3. Pose no or very little harm to both plants and humans
4. Relatively economical
5. Readily biodegradable
6. Light in colour

Cotton

Cotton is a naturally occurring fiber made of seed-hair fibers obtained from *Gossypium* sp. At present, the chief cotton-growing countries of the world are China (23%), the United States (17%), the former USSR (15%), India (11%), Pakistan (8%), Brazil (4%), Turkey (3%), and Egypt (2%). It is one of the three most important fibers in the textile industry. Chemically, cotton is the purest, containing over 90% of cellulose with little or no lignin. Established techniques have been developed to measure soil microbial activity by cotton strip assay (CSA). The technique involves burying cotton strips and measuring their tensile strength after a certain time. This gives a measure of the rotting rate, R, of the cotton strips. R is then a measure of soil microbial activity (Corella, 1997).

Jute

Jute is a naturally occurring fiber made from two herbaceous annual plants, *Corchorus capsularis* (linden family, Tiliaceae) originating from Asia, and *C. olitorius* originating from Africa. It contains high contents of lignin, a natural phenolic polymer frequently present in cell walls of fibers, which contributes to their stiffness. Compared to cotton, jute has a higher tensile strength and modulus of elasticity but a lower extensibility (elongation). Among all fibers, jute has the highest moisture regain of 14%. The colour ranges from white to reddish brown, but usually has a golden luster. It has traditionally been one of the principal bast fibers (tonnage basis) sold on the world market; however, the precipitous decline in jute exports by India indicates a decreasing market demand for this fiber that is vitally important to the economies of India (West Bengal), Bangladesh, and Pakistan. Nowadays, in addition to India, jute is grown Bangladesh, Thailand, Nepal and Brazil (Young, 1994).

EcoPLA® 2000D

EcoPLA®2000D is a biodegradable plastic made from polyesters, namely, EcoPLA resins. EcoPLA resins are thermoplastic starch with starch/polylactic acid composites. This thermoplastic starch is used as a strengthening agent. It also increases the surface area that can be directly attacked by microorganisms. These products are much more affected by moisture than the starch/polyethylene/catalyst composites. The primary bonds in these biodegradable synthetics are readily broken apart by hydrolysis. Heat and UV light will also cause deterioration, which can be a problem for greenhouse usage. Two

major PLA resin producers are Cargill Plastics Ltd. and Dow Chemicals Ltd., based in the U.S.A. Since polylactic acids (PLA) are made from starches, such as potato wastes, the resources required are renewable and sustainable. Since the raw materials are biologically based, they undergo complete degradation usually within several weeks. Furthermore, the by-products produced during the composting process would likely be benign compared to nonhydrolyzable polymers, such as, polyethylene (Karlsson, 1995).

Cotton/Viscose & Jute/Viscose

These two types of twines are made of both natural fibers and a regenerated cellulosic fiber, more commonly known as rayon. The terms, viscose and rayon, are used somewhat interchangably. The regenerated cellulosic fibers are formed when a natural polymer, or its chemical derivative, is dissolved and extruded as a continuous filament, and the chemical nature of the natural polymer is either retained or regenerated after the fiber formation process. The details of production process can be found in various literature (BeMiller, 1992 and Woodings, 1994). The main raw material required for the production of viscose is cellulose, a natural polymer of D-glucose. An estimated 10 billion tonnes is produced annually by natural processes. In general, regenerated cellulosics are highly hydrophilic with a moisture regain from 11% for the polynosics to 13% for regular rayon at 65% relative humidity. The fiber structure swells as fluid is imbibed, and fiber strength and stiffness fall. The fibers degrade hydrolytically when contacted with hot dilute or cold concentrated mineral acids. Regarding environmental issues, cellulosic fibers are the only mass-produced, man-made fibers made directly from

a natural polymer (cellulose), unlike polyesters, nylons, polyolefins, and acrylics, which come from nonrenewable reserves of fossil fuels. These natural polymers can undergo complete biodegradation or incineration resulting in final breakdown products of carbon dioxide and water (Woodings, 1994).

Table IV.2 Selected Twine Candidates and Their Compositions

Names / Trade names	Composition	Remarks
Jute	Jute	Natural fiber
Vertomil®	Viscose / Jute	Regenerated cellulosic fiber and natural fiber
Ecolan®	Viscose / Cotton	Regenerated cellulosic fiber and natural fiber
EcoPLA® 2000D	Biodegradable plastic	Made from polylactic acids; Underwent biodegradability studies.
Cotton	Cotton	Natural fiber

IV.3.2 UTILIZATION OF SELECTED TWINES

After the five twine candidates were selected, they were tested in a commercial greenhouse located in Surrey, B.C. from January 1998 to November 1998 (one full growing season). A total of 250 sample twines, with 50 replications for each material, were individually tied to pepper plants as supports. Figure IV.2 shows jute being used in the greenhouse. The twines were exposed to the typical greenhouse conditions, such as high humidity, high temperature and sunlight exposure, throughout the production period between January and November. Table IV.3 represents the range of climatic conditions found in the greenhouse.

Table IV.3 Typical Greenhouse Conditions

Daytime Temperature	20-24 ^{0}C
Night Temperature	17-18 ^{0}C
Humidity	60-80%
Plant Density	250 – 280 plants per 100m^2
Crop Season	Approximately 11 months

These environmental conditions are believed to play a crucial role in the physical strength of the twines since the initiation of material degradation generally proceeds via thermal, hydrolytic, photo, oxidative, and/or mechanochemical chemical pathways (Griffin, 1994). Increased exposure to sunlight, high temperatures, and high humidity could trigger the onset of degradation prematurely and result in an accelerated reduction in the physical strength of twines that are in use. On the other hand, these conditions tend to favour biodegradation of the twines since biodegradation is usually the secondary process following one or more of the chemical reactions.

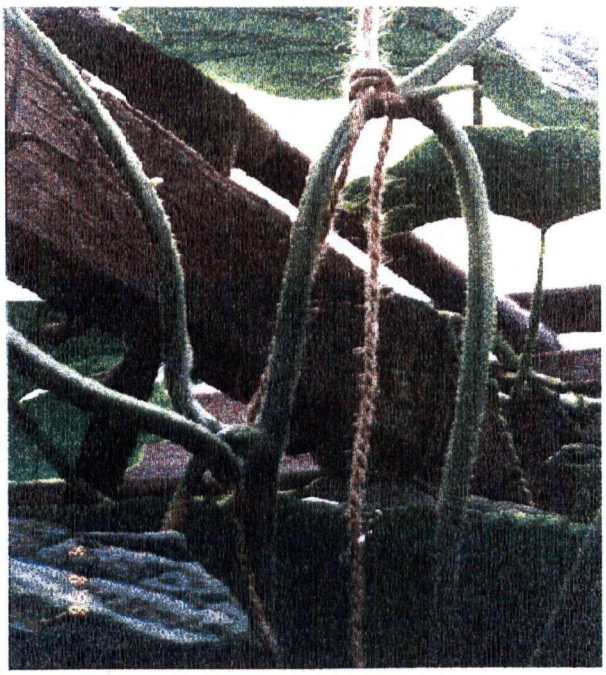

Figure IV.2 Jute Twine for Plant Support

During the field test, the 250 twines were treated as if they were part of the commercial production. The plants were pruned, and mature peppers were harvested. The twines were manually maneuvered along the main lines as the plants grew. Periodically, they were examined, and the number of nearly broken twines was recorded. They were then replaced. In most cases, the twines were replaced before breaking to avoid damaging the plants. In addition, a sample of each type of the twines was collected for laboratory measurement at the end of each month until the pepper production ceased.

IV.3.3 MEASUREMENT OF CHANGES IN PHYSICAL PROPERTIES OF TWINES

Laboratory measurements were conducted in the Pulp and Paper Research Building on the UBC campus. A total of 11 sets of twine samples, each set containing all five types of the twines, were collected from the commercial greenhouse for laboratory testing from January to November. Continuous monitoring of the twines began in January 1998 and observations were recorded. The laboratory measurements were designed to measure two parameters of the twines: **linear density** and **tensile strength**. These properties were believed to provide sufficient evidence in determining the physical properties and durability of the twines. When the twines arrived in the laboratory, they were allowed at least two days to acclimatize to the laboratory conditions - a controlled environment having a relative humidity of 51% and a temperature of 21 ^{0}C - to minimize effects induced by variations in moisture content and temperature of the twines.

Linear Density

The size of the twines was first determined in order to put a quantitative measurement on their thickness. Linear density of the twines was measured for it is a common practice in the fiber industry to designate the thickness of fibers. Linear density has a unit of mass per unit length. This particular method of measurement was chosen because it would be difficult to determine the cross-sectional area by other methods, such as direct microscopic observation and measurement. Direct observation and measurement of a cross section under a microscope is considered the most accurate method. However, it is a destructive test that does not allow subsequent study of other mechanical properties. It is also slow and tedious. In addition, it does not take into account any variations in the cross-sectional area along the fiber length. Measurement of fiber diameters from microscope observation of longitudinal views is slightly easier, but the ellipticity of the cross section in certain fibers could lead to serious errors (Akhtar, 1988). For the determination of linear density, each month five twine samples were sectioned into lengths of 25cm. The five twine samples were weighed, and the mean and standard deviation were recorded. The linear density of the twines was calculated in the unit of grams per centimeter.

Tensile Strength

The tensile strength and elongation of the five candidates were determined using an electronic tensile tester Model QC II from Thwing-Albert Instrument Company shown in Figure IV.3. The tensile strength test was a destructive test where the material was not recoverable after the test. Table IV.4 summarizes the settings of the electronic tensile

tester. The setting "peak" indicated that the twine was subjected to a load until the tensile tester sensed its maximum strength. This load-and-release cycle was repeated until the breakage of the twine sample occurred. Each time the load was exerted on the twine, readings of tensile strength and elongation were recorded. The American Standardization and Material Testing (ASTM D2433-93, 1998) was used as a reference for the procedures of the test.

Samples obtained over a period of eleven months from January to November were tested. Twines with a length of 25 centimeters were used in the measurement. The results were recorded in British units, pounds and one thousand of an inch, respectively. These units were selected because the industry still utilizes the British system. However, the analysis of the data was performed in SI units.

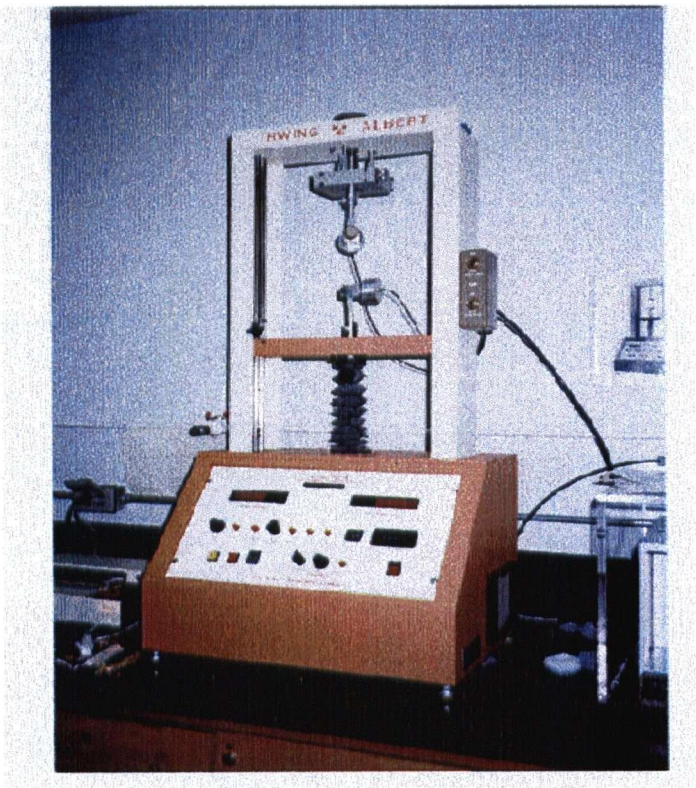

Figure IV.3 Electronic Tensile Tester Used in Laboratory Measurements

Table IV.4 Settings of Tensile Tester

Variables	Setting
Unit of tensile strength	British (pounds)
Sensitivity	Moderate
Speed	B
Testing mode	Peak
Unit of elongation	British (fraction of an inch)

IV.3.4 COMPOSTABILITY

A compostability test was conducted in the middle of November 1998 after the production period was completed and plant residues were collected. Data collection began on December 1, 1998 and carried through till April, 1999. The three materials that believed to be bio-degradable were selected for this test, i.e. cotton, jute and EcoPLA®2000D.

Determination of biodegradability had been a controversial topic until ASTM's Committee D20 issued a new standard – D6400, Standard Specification for Compostable Plastics in May 1999. This marked the culmination of eight years of research and testing by leading producers and users of bio-degradable plastics. Prior to May 1999, no scientifically based standard existed for determining the biodegradability and compostability of plastic products. Before this point, manufacturers were free to use any test method they felt most appropriate (Mojo, 2001). To measure biodegradability, most producers used tests such as those found in ASTM D822, which had historically been used to assess the physical properties of plastics films. The compostability test in this study was designed by the author based on this information since at the time of the study the ASTM D6400 had not been published yet.

Samples of these three candidates were composted in a pilot scale composter described in Chapter V.3.2. The main ingredients of the compost included the plant residues collected from the greenhouse, and alder bark chips. Sections of new twines with a length of approximately 76 cm were individually enclosed in a mesh bag with a mesh size of 1.5 mm x 1.5 mm. They were placed in the composter containing approximately 10 tons of organic waste, an estimated 8 to10 cubic meters in volume.

In order to achieve maximal homogeneity, periodical mixing and turning was done. For ease of recovery, the twines were chained to a fishing line whose end was tied to the side of the composter. Composted twine samples were collected periodically. A total of eight twine samples were recovered for each type of the twines. According to ASTM, a synthetic material is biodegradable when it retains no more than 10% of its original weight after 12 weeks in a highly controlled compost environment at optimal conditions of aerobic/anaerobic activity, nitrogen levels, etc (McDonald, 1998). Therefore, a reduction in weight was used to determine biodegradability. The composted twines were removed from the mesh and then washed in distilled water. They were let dry for at least six days in the laboratory before weighing. To obtain the weight of some of the very fragmented twines, the mesh and the twine were weighed together. The mesh was then weighed again after the content was removed completely. Wherever possible, the tensile strength of the composted twines was measured to reflect the deterioration in strength.

IV.3.5 STATISTICAL ANALYSIS

For the linear density and tensile strength tests, 5 samples from each of the five twine candidates were selected randomly in the test area of the greenhouse each month, and taken out and replaced by conventional plastic twines with a different color to avoid confusion in next month's test. Means and standard deviations were calculated and presented as error bars in the graphs. For the compostability test, 3 samples from each of EcoPLA, Cotton and Jute were dug out from the compost mass each time for linear density and tensile strenght tests. Tests were done more frequently, i.e. about once a week, in the active composting period and were slowed down to once a month during the curing period.

IV.4 RESULTS AND DISCUSSIONS

This section focuses on the presentation and discussion of the findings. The first section accounts for the observations made during the use of the twines in the commercial greenhouse. The second section describes the physical testing of twines in the laboratory. It also contains data analyses and discussion of the laboratory measurements, which are presented both graphically and in tables. The last section embodies the results from the compostability study.

IV.4.1 ON-SITE OBSERVATIONS AND SURVEYS

During the application of the twines in the commercial greenhouse, it was observed that 49 out of all 250 biodegradable twines broke or showed signs of breakage. Among those 49 twines, cotton and cotton/viscose represented the majority of them, 14 and 18 twines, respectively, translated into 29% and 37%, respectively. Twines that were broken or showing sign of breakage twines were replaced to avoid damage of the crop. Table IV.5 listed the time in service of each twine.

Table IV.5 Time in Service of each type of twine (50 samples each)

Type of twine	Breakage by time (non-cumulative)					
	2 months	4 months	6 months	8 months	10 months	Total
Jute	0	1	2	3	2	8 (16 %)
Cotton	1	3	3	6	1	14 (28 %)
Jute/Viscose	0	1	2	3	3	9 (18 %)
Cotton/Viscose	1	3	6	5	3	18 (36 %)
EcoPLA	0	0	0	0	0	0 (0 %)
Plastics (control)	0	0	0	0	0	0 (0 %)

The details of the results and observations are as follows :

Jute – A few loosened jute twines were observed, although none of them were completely broken. Greenhouse workers did not particularly like jute because it was rough and difficult to tie and cut. It was noted that jute became soft and slowly deteriorated when it remained wetted for a long time.

Cotton – A few loosened cotton twines were observed and some of them were partially broken and therefore were replaced before the plants fell down. Softness of cotton appealed to the greenhouse workers. It was also easy to cut during the year-end removal. However, due to its softness, it was difficult to tie. It had a tendency to absorb moisture and could be potential trap of fungi and microorganisms.

Jute/Viscose – For all the broken jute/viscose twines, the broken parts were from the jute portion. Since it is composed of two separate thin twines winding around each other, the jute component was found to be more vulnerable. It appeared that most of the strength was sustained by the viscose component. The workers preferred jute/viscose to cotton and jute because it was thinner and easier to handle in comparison.

Cotton/Viscose – For all the broken cotton/viscose twines, the broken parts were from the cotton portion. Since it is composed of two separate thin twines winding around each other, the cotton component was found to be more vulnerable. It appeared that the strength of the twine lay in the viscose component. The greenhouse workers preferred cotton/viscose because it was thinner and easier to tie and cut compared to cotton and jute alone.

EcoPLA – None of the 50 EcoPLA twines showed signs of breakage. It seemed, in this regard, that it was the only one comparable to the traditional plastic twines. They were strong and did not show any sign of deterioration at the end of the season. However, the workers found that the EcoPLA twines were hard to tie and cut since its texture was rather tough and inflexible, and was quite slippery.

Based on the above results, the biodegradable plastic twine EcoPLA®2000D was found to be most durable among the five biodegradable candidates in the eleven months field trial.

IV.4.2 LINEAR DENSITY

Linear density is one way of representing the thickness (weight/length) of the twines. Figure IV.4 depicts the linear density of the five types of twines over the period of time between January and November. Cotton, jute/viscose and cotton viscose retained their original linear densities throughout the test period. Jute, which had the highest linear density, appeared to experience an increase in linear density over the test period. EcoPLA®2000 showed the greatest decrease in linear density. This occurred in the spring and summer. In those months, the temperature inside the greenhouse in the daytime was usually higher than the desired set point temperature because greenhouses in B.C. usually have heating capability but no cooling capability. Therefore, this phenomenon could be caused by the accelerated degradation in those months, which had higher temperature, humidity and sunlight levels (particularly UV).

The change in linear density was characterized by the negative slopes in Figure IV.4. The linear density of jute, on the other hand, varied over time primarily due to the inconsistency in thickness. The result indicated a gain in linear density for jute, demonstrated by a positive slope in linear density. This might also be due to the absorption of moisture and growth of microorganisms on the jute.

During the laboratory testing, several significant observations were made. It was observed that there was a considerable variation in the linear density of jute from each batch of testing (see the error bars from Figure IV.4). The variation was likely induced

during the manufacturing process. Also, the texture of jute tended to be the roughest among all five candidates.

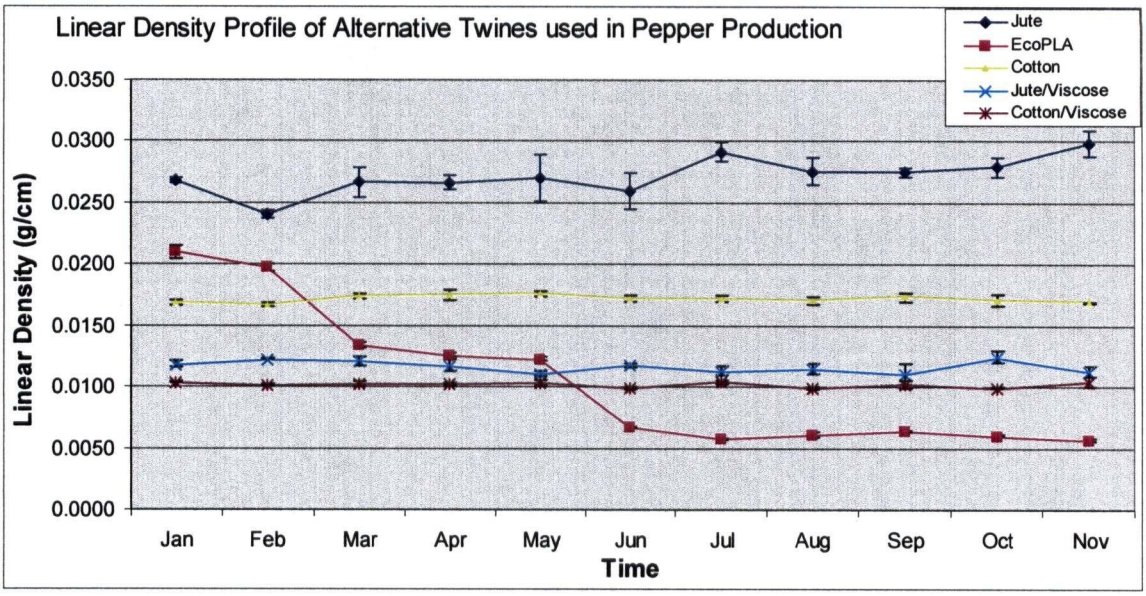

Figure IV.4 Linear Density of Alternative Twines

IV.4.3 TENSILE STRENGTH TEST

Tensile strengths of all five twine candidates over a time period between January and November are graphically presented in Figure IV.5. Jute, cotton and cotton/viscose tended to retain their original tensile strengths throughout the test period. Jute was stronger than cotton which, in turn, was stronger than cotton/viscose. EcoPLA had a high

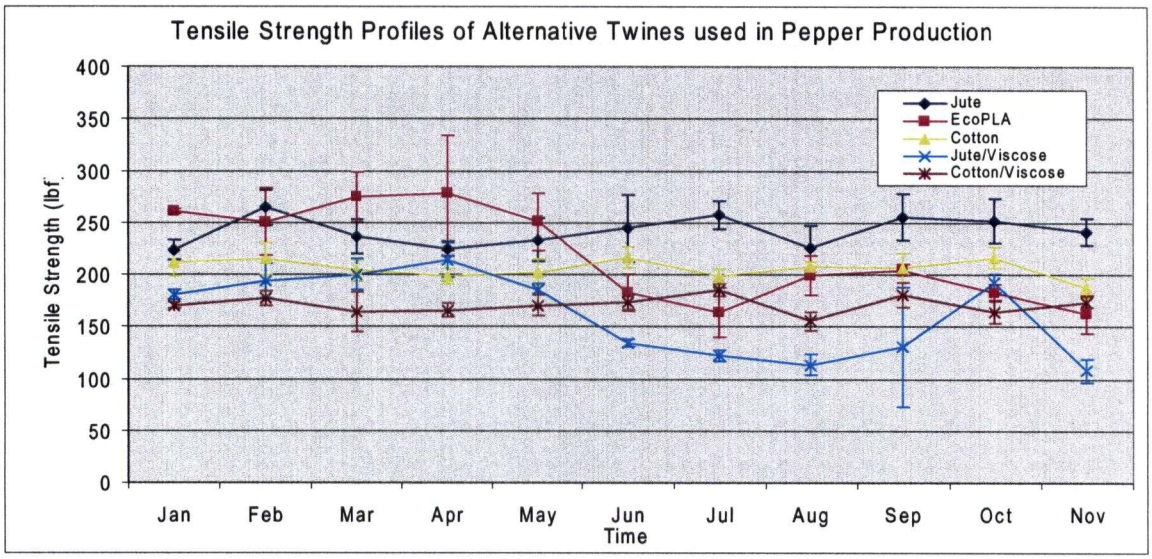

Figure IV.5 Tensile Strength of Alternative Twines

initial tensile strength which was retained for about four months, after that its tensile strength began to decline becoming lower than that of jute and about the same as cotton. This is at least partially attributable to the observed decline in linear density which meant that there was less substance to resist the load in the tensile tester. Jute/viscose retained its original tensile strength for about four months then becoming weaker. At the end of the test period it had the lowest strength.

Change in tensile strength with time was characterized by the slope of a plot of tensile strength vs time. It was anticipated that the strength of the twines would decline over time due to physical degradation and increasing loading as the plants grew. EcoPLA, jute/viscose showed declining tensile strengths. Especially EcoPLA came up with a relatively declining slope. Jute showed fluctuation throughout the study. This might be due to the uneven manufacturing and its moisture absorbing properties. Although some of the twines showed declining tensile strengths, especially the EcoPLA, none of the twines showed breakage under 80 lb, i.e. they would all be good enough to sustain the weight of the plant (20 to 40 lb) for the whole growing season under the greenhouse climatic conditions.

Compared to others, jute was able to withstand the most load-and-release cycles before it broke. With cotton/viscose and jute/viscose, the cotton and the jute components often broke first. The viscose component sustained the load solely after three to four cycles of load-and-release. The texture of EcoPLA®2000D tended to be more rigid compared to its counterparts.

IV.4.4 COMPOSTABILITY STUDY

In this bio-degradability study, only EcoPLA®2000D, cotton and jute were used. Cotton/viscose and jute/viscose were not used, because both had a twisted combination of two twines and viscose was not readily degradable in an ordinary composting environment. The purpose of this study was to find out the biodegradability properties of cotton, jute and EcoPLA. Figure IV.6 shows how the twine samples were placed inside a screen-net which was put inside the composter. The "net" and its contents got mixed and composted together with the other substrates. The "nets" were taken out from time to time to examine the biodegradability.

Figure IV.7 shows an example of a broken-down EcoPLA twine after a few days of composting. It was taken out from the net, all the dirt attached was washed off, and then it was dried before weighing. The composting results showed that, in general, there was a significant decline in the linear densities of the three biodegradable twine materials - EcoPLA®2000D, cotton and jute (see Figure IV.8). EcoPLA, jute and cotton had an 80.5%, 85.6% and 89.4% weight loss after 136 days of composting, respectively. However, since all the twines were very "dirty" when they were taken out, they needed to be washed carefully in order to take out any foreign materials. In this process some weight loss would be expected since there were always some small fragments of the broken twines being washed out as well, especially when the twines were degraded into very small pieces at the end of the curing process. This meant that there were some unavoidable errors in this experiment.

Figure IV.8 shows the loss in linear density over time in the composter. The small linear density gains for jute on day 28 and cotton on day 21 might be explained by the lack of uniformity in the composting environment. These twines were most probably located at the outer edge of the compost where composting was less active. Nevertheless the overall result from the compostability study of the twines suggested that the materials could indeed degrade readily in a composting environment within a reasonable time frame – they all began to break into fragments in the active composting process where the temperature was maintained at around 55-65 ^{0}C. All of the twines experienced most of their loss in linear density in about 100 days. Jute degraded faster than cotton which lost linear density more rapidly than EcoPLA.

Figure IV.9 shows the effects of composting on tensile strength. The arrows indicate the occurrence of fragmentation (breakage) of the any twine sample at that time i.e. they broke apart with tension. Jute first fragmented, then cotton, and finally EcoPLA. Even though they showed breakage at different times, their breakages were all before the end of the active composting period. Tensile strength of all of the twines was virtually destroyed in 30 days of exposure to composting. EcoPLA was more resistant than cotton which in turn was more resistant than jute.

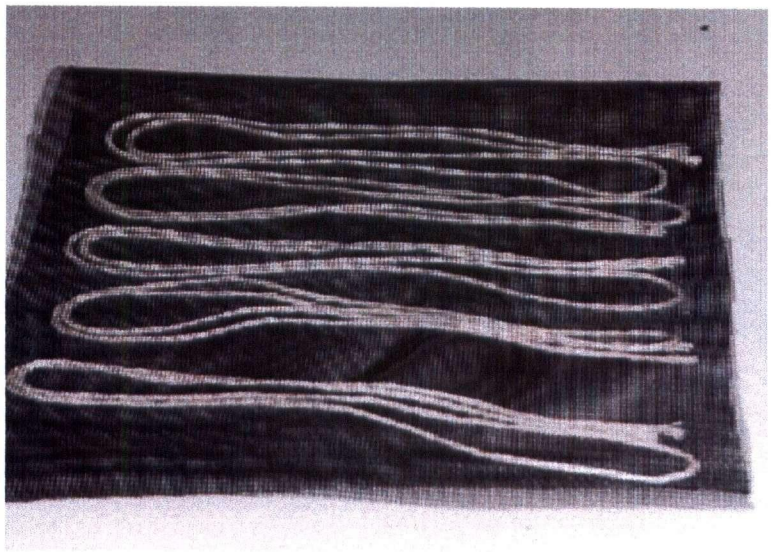

Figure IV.6 The bio-degradable twines (EcoPLA®2000D) in a screen-net before being placed into the composter

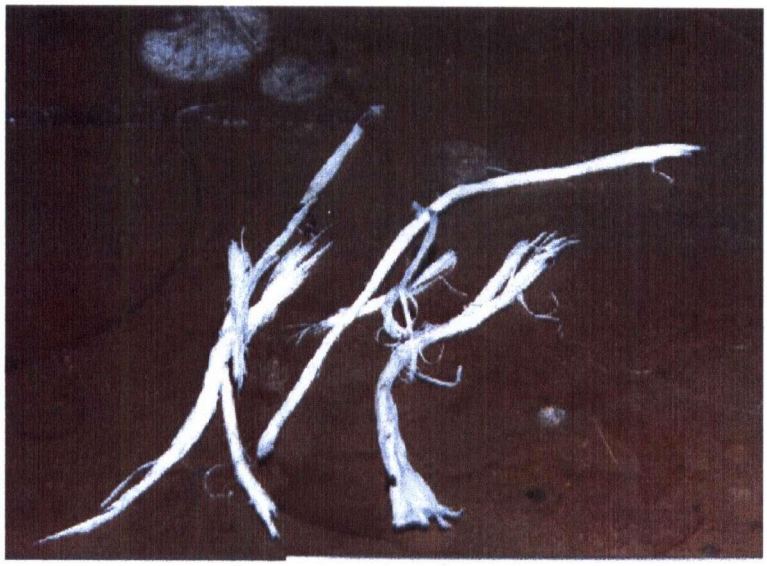

Figure IV.7 Example of fragmented twines (EcoPLA®2000D) after being placed into a composter

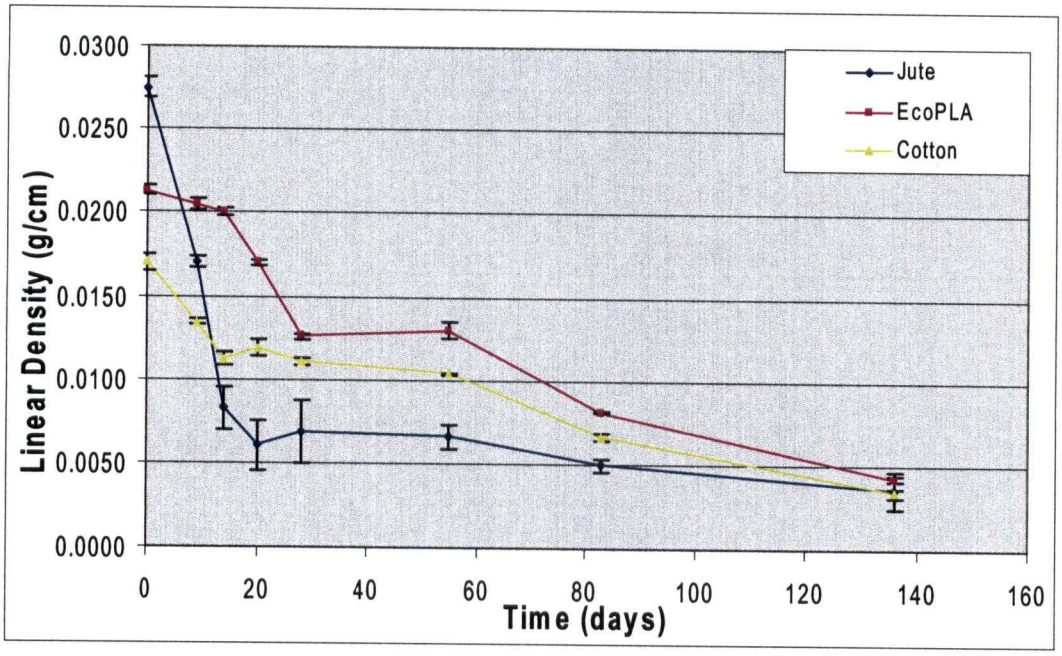

Figure IV.8 Linear Density of bio-degradable twines

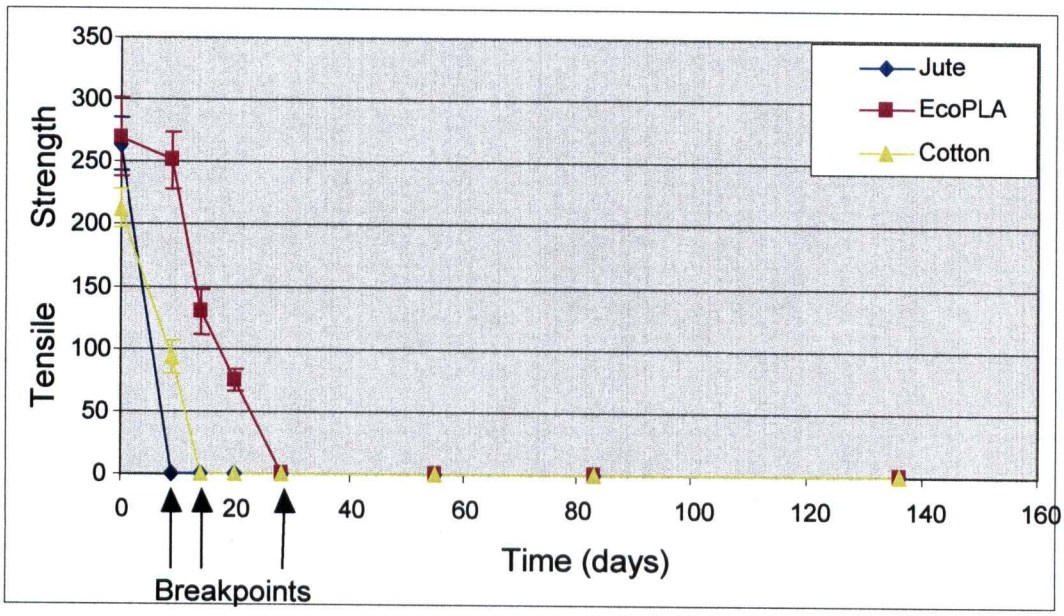

Figure IV.9 Tensile Strength of the bio-degradable twines

IV.5 CONCLUSIONS

A decision matrix (see Table IV.6) was constructed to evaluate the five twine candidates based on the criteria listed in Table IV.1. In the evaluation matrix, a scale of 1 to 5 was used - 1 being the least satisfactory and 5 being the most satisfactory among the five candidates. For the purpose of comparison, traditional plastic twine was included in the evaluation matrix.

Cost was based on the estimated price per unit length (100 m) of the products available in the fiber markets, However, since EcoPLA®2000D, Vertomil® and Ecolan® were still in their experimental stages, the price may be cheaper in the future when more greenhouses try to use them. It was also noted that the disposal cost for the conventional plastics was not accounted for since it might vary between different disposal methods. Should this cost be included, the mark for plastics would be lower. Tensile strength of the candidates was evaluated based on the information obtained from both the field study and the laboratory measurement of tensile strength. The assessment of handling was based on interviews with greenhouse workers, while biodegradability was evaluated based on the physical properties of the materials and the compostability study. Lastly, a white colour was preferable due to more sunlight reflection in the greenhouse. The resulting evaluation matrix concluded that EcoPLA®2000D had the highest score among the five potential substitutes of the traditional plastic twines. In short, this study found that EcoPLA®2000D was the most satisfying alternative twine. Nevertheless it was not as good as the plastic twine currently in widespread use. Upon completion, the evaluation

representatives from the greenhouse industry as well as academic professionals to ensure that scores were properly assigned.

Table IV.6 Evaluation Matrix

Factors/ Candidates	Jute	Cotton	EcoPLA® 2000	Vertomil®	Ecolan®	Plastic
Cost (1.0)	3	2	1	3	3	5
Tensile Strength (1.0)	4	2	5	3	3	5
Handling (0.8)	3	3	5	4	4	5
Biodegradability (0.8)	5	5	5	3	3	1
Colour (0.7)	2	5	5	3	5	5
Full Score	21.5	21.5	21.5	21.5	21.5	21.5
Score	14.8	13.9	16.7	13.7	15.1	18.3
Percent Satisfaction (%)	**69**	**65**	**78**	**64**	**70**	**85**

From the results obtained from the experimental in- greenhouse tests, laboratory measurements, and the compostability study, it was concluded that it was feasible to utilize alternative twines in greenhouse vegetable production. Furthermore, among the five types of twines, EcoPLA®2000D was found to be the most suitable substitute for the traditional plastic twines currently used in greenhouses.

It was hoped that the conclusion drawn from this study would encourage the use of biodegradable twines in the greenhouse vegetable production. The replacement of plastic twines with biodegradable alternatives could drastically increase the potential values of the organic waste generated from the greenhouse vegetable industry. It not only promotes the use of alternative renewable resources, but also makes the compost, generated from the greenhouse organic wastes, freer of impurities and more consistent in quality.

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Special Acknowledgement :

This part of the project is the joint effort of the author and Ms. Coby Wong, an undergraduate student who worked under the supervision of the author. This project could not have been successful without the cooperative work of Ms. Coby Wong, and the workers in Hazelmere Greenhouses Ltd.

CHAPTER V

BIO-CONVERSION PROCESS

V.1 BACKGROUND AND LITERATURE RESEARCH

V.1.1 COMPOSTING METHODS

Composting can be done using one of three following methods: aerobic, anaerobic, or vermiculture. They are briefly reviewed, separately in the following sections.

a) Aerobic Composting

Aerobic decomposition is a biological, exothermic, oxidation of organic matter, carried out by a dynamic and rapid succession of microbial populations. The organic matter is ultimately transformed into a final stable humus type product (compost) through its mineralization and humification, by which approximately 20 to 30% of the volatile solids are converted into CO_2 and H_2O (Hoyos, 2002). Thermophilic temperatures between 55°C and 70°C are commonly achieved, which results in pathogen kill and weed seed inactivation. Due to the oxidation that occurs, odor creation is limited compared to anaerobic systems.

b) Anaerobic Composting

Anaerobic decomposition occurs in the absence of oxygen, and temperatures of less than 55°C are achieved. The process yields only partially reduced and oxidized compounds that may continue to breakdown after treatment. During anaerobic digestion,

organic compounds can be transformed to an extent of almost 80% into biogas, for example methane gas. The anaerobic degradation of organic matter is a multi-phase process comprising acidogenesis and subsequent methanogenesis (Held, 2002). The main disadvantage of anaerobic decomposition is that the by-products of the process (such as fatty acids, aldehydes, hydrogen sulfide and ammonia) often create offensive septic odors.

c) Vermicomposting

Vermicomposting is a variation of aerobic composting in which earthworms are added to promote rapid decomposition of organic materials. During vermicomposting, earthworms eat, grind, and digest organic wastes with the help of aerobic and some anaerobic microflora, converting it into a much finer, humified, microbially active material (Maboeta, 2003). In addition to feeding on the microorganisms, the earthworms fragment particle agglomerations which results in a more homogeneous texture. After a period of 10 days or more, the earthworms are removed from the compost, the material is draught dried, filtered through a sieve, and then packaged and marketed.

Modern compost systems are mostly aerobic. One of the more important reasons for choosing the aerobic process is that aerobic processes are not characterized by objectionable odors. Some promoters of aerobic composting are prone to characterize it as being odorless, but by the very nature of the raw material and of the intermediates formed, some odor production is bound to occur. Even the claim of producing no objectionable odors may be inaccurate. A technology of Combined anaerobic/aerobic Composting Process (CCP) has been considered as an attractive alternative for aerobic

biowaste composting because of its 17 times lower overall emission of volatile compounds compared to single phase aerobic composting (Smet, 1999).

A second and perhaps more important reason for aerobic composting pertains to public health and crop production. Public health and crop safety come from the high temperatures that are the natural concomitants of a properly conducted aerobic compost operation. The temperature in an aerobic pile usually reaches levels above the thermal death point of most plant and animal pathogens and parasites. These elevated temperatures also are lethal for weed seeds.

A third reason for aerobic composting is that it is more rapid than anaerobic fermentation. In recent years great progress has been made in accelerating the anaerobic fermentation process through careful design of equipment and operational procedures. However, many organisms that occur in composting and that can rapidly break down refractory compounds are obligate aerobes and therefore obviously could not survive in an anaerobic environment. Moreover, all anaerobic processes need an aerobic stage eventually to stabilize (i.e., oxidize) the compost. During waste treatment, mass losses of carbon were highest in the aerobic treatment and lowest during anaerobic treatment. Following their application to soil, the amount of CO_2–C evolved from wastes was highest from anaerobically-treated material, intermediate from non-decomposed material and lowest from aerobically-treated material. The effect on carbon stabilization efficiencies of various waste treatment was ranked as follows : aerobically-treated and composted > non-decomposed > anaerobically-treated (Kirchmann, 1997). For reclaiming

degraded soils, aerobically composted wastes are better than anaerobically degraded wastes.

Naturally, aerobic composting is not without its drawbacks. For example, the maintenance of aerobic conditions involves more handling and greater spatial requirements than would be the case with anaerobic composting. Another downside is the inevitable loss of at least some nitrogen in aerobic composting. The loss is the accompaniment of the high temperature and eventual alkaline conditions reached in an aerobic pile. These two conditions promote the volatilization of ammonia during composting. Gaseous nitrogen losses during composting occur mainly as ammonia, but may also occur as nitrogen and NO_x. Nitrogen losses can be as much as 33% of the initial nitrogen during composting of poultry manure (Hansen, 1989).

Biological Stabilization

Biological stabilization by aerobic composting can be carried out using one of three systems, as described below. A comparison of these 3 systems is made in Table V.1.

i) Windrow

The most commonly used composting method is the windrow system which involves stacking organic wastes into elongated piles, windrows, that are periodically turned using mechanical equipment. Windrow operations are generally quite simple and require few control measures other than monitoring temperature and moisture. Aeration and moisture are two very important factors and therefore intensive management of the composting process by turning and moisture addition is likely to affect the nitrogen

fertilizer value of the finished compost (Shi, 1998). The major disadvantages associated with windrow operations include excess odor generation, susceptibility to upset from adverse weather, substantial land requirement, and a relatively long time for composting and curing for a given volume of material (Hay, 1990). In order to enhance the bio-conversion process, windrow piles are recommended to be turned 6-7 times during the whole thermophilic phase while turnings may not be necessary during the mesophilic phase (Diaz, 2002). The turning not only provides compost aeration but also homogenization of the compost mass can be achieved.

ii) Aerated Static Pile

Aerated static pile composting involves piling the material in a static windrow over a gallery of pipes which either introduce air into or the windrow compost pile by blowing air through it (active aeration) or by drawing air through the pile as a replacement for the heated air that rises out of the windrow. Forced aeration eliminates frequent turning but requires a compressor/blower and pipe network to distribute the air. Passive aeration occurs when air heated in the compost pile by the release of from the composting process, rises up and out of the pile and is replaced by cooler air drawn into the pile from outside of it. Passive aeration can save energy costs while being just as efficient as forced or active aeration. Passive aeration requires the proper design of aeration ducts, and thus, the proper prediction of the convective airflow rates created by the temperature differential between the compost and the ambient air (Barrington, 2003). Sartaj et al. (1997) reported that passive aeration had a higher composting rate than active aeration, and did not produce adverse cooling effects and high nitrogen losses, as did

active aeration. Aerated static pile and windrow are the most usually employed composting methods for agricultural wastes (Real, 1996).

iii) In-Vessel

The in-vessel system uses a specially designed, mechanized, enclosed unit that controls the temperature and flow of air. Following preparation, the material is slowly fed into the bays via wheel loaders, gravity-fed hoppers, or conveyor belts. Aeration within the vessel is done by mechanically turning the composting material, by forced draft compressors or blowers, or a combination of these two. Mechanical mixing or turning usually can be performed daily to ensure uniform decomposition. Two stages are distinguished in the in-vessel composting system: a high-rate phase and a curing phase. The first stage is performed in the bioreactors and the second one often in an exterior composting pile. No precise distinction exists between these two stages, but high bio-reaction rates (i.e. rapid biodegradation), high oxygen-uptake rates, high temperatures, and high potential for odour production are essential for the first step (Stelmachowski, 2003). The required decomposition time of an in-vessel system is relatively short -- 21 days. The main disadvantages of in-vessel methods are their high capital costs and the requirement for intensive and skilful management (Haug, 1993).

For greenhouse wastes application, capital and operating cost may not be an important issue since the greenhouses are required to pay high tipping fees to truck their wastes to landfill. However, space requirement, odour and the quality of the finished compost would be more important. Therefore, in-vessel composting is probably preferable for greenhouses.

V.1.2 CRITERIA AND SPECIFICATIONS OF COMPOSTING

Under natural conditions, the decomposition process of organic material can extend over a period of months or even years, depending on climatic conditions. However, the natural process can be accelerated by controlling the process factors. Each of these factors has the potential to significantly affect the composting process. Some of the more important factors in the composting operation are: carbon to nitrogen ratio (C:N), surface area and particle size, aeration, porosity, moisture content, temperature, pH of materials and nutrients.

Table V.1 Comparison of the Three Biological Stabilization Systems

	Windrow	Static Pile	In-Vessel
General	Active systems, most common on farms	Effective for farm and municipal use	Large-scale systems for commercial applications
Labor	Increases with aeration frequency and poor planning	System design and planning important Monitoring needed	Requires consistent level of management / product flow to be cost efficient
Capital Cost	Minimal	Medium	High
Site	Can require large land areas	Less land required given faster rates and effective pile volumes	Very limited land, due to rapid rates and continuous operations
Bulking Agent	Flexible	Less flexible Must be porous	Flexible
Active Period	> 9 months	Ranges 21- 40 days	Ranges 14 - 30 days
Curing	30+ days	30+ days	30+ days
Size Height Width Length	 1-2.8 m 3-6m Variable	 3-4.5m Variable Variable	 Dependent on bay design Variable
Aeration System	Turning the windrow and natural convection	Forced blowing or suction air flow through pile (passive aeration)	Mechanical systems turn and aerate material within compost bay
Process Control	Initial mix Turning (6-7 times during thermophilic stage)	Initial mix Aeration Temperature or time control	Initial mix, Aeration, Temperature or time control, turning
Odor Factors	From surface area of windrow Turning can be odorous during initial weeks	Odor can occur, but controls can be used such as pile insulation and filters on air system	Odor can occur, often due to equipment failure or system design limitations

Carbon: Nitrogen Ratio (C:N)

Carbon and nitrogen compounds are the components most likely to seriously limit the composting process if present in either excessive or insufficient amounts, or, in other words, when the C:N ratio is incorrect. Micro-organisms in compost digest (oxidize) carbon compounds as an energy source, and ingest nitrogen for protein synthesis. The optimum proportion of these two elements should approximate 30 parts carbon to 1 part nitrogen by weight (Hamoda, 1998). C:N ratios within the range of 25:1 to 40:1 should result in an efficient process.

Given a steady ratio, micro-organisms can decompose organic material quickly. When the C:N ratio is too high, there is too little nitrogen and decomposition slows. When the C:N ratio is too low, there is too much nitrogen and it will likely be lost to the atmosphere in the form of ammonia gas. This can lead to odour problems.

Most materials available for composting do not fit this ideal 30: 1 ratio. Table V.2 lists the C:N ratio of some of the wastes. Different materials must be blended to meet the proper ratio.

Table V.2 C/N Ratio of Various Wastes (Haug, 1993)

Material	Nitrogen As N (% dw)	C/N ratio
Night soil	5.5-5.6	6-10
Urine	15-18	0.8
Blood	10-14	3.0
Animal tankage		4.1
Cow manure	1.7	18
Poultry manure	6.3	15
Sheep manure	3.8	
Pig manure	3.8	
Horse manure	2.3	25
Raw sewage sludge	4-7	11
Digested sewage sludge	2-4	
Activated sludge	5	6
Grass clippings	3-6	12-15
Nonlegume vegetable wastes	2.5-4	11-12
Mixed grasses	214	19
Potato tops	4.5	25
Straw, wheat	0.3-0.5	128-150
Straw, oats	1.1	48
Sawdust	0.1	200-500

C:N ratio of a substrate can be calculated according to the following formula (B.C. Ministry of Agriculture, Fisheries and Food, 1991):

Equation V.1 Composite C:N ratio

$$\text{C:N ratio} = \frac{\text{weight of C in ingredient a + weight of C in b + weight of C in C + . . .}}{\text{weight of N in a + weight of N in b + weight of N in c + . . .}}$$

$$= \frac{[\%\ Ca*a*(1\text{-}Ma)] + [\%\ Ca*b*\ (1\text{-}Mb)] + [\%\ Cc*c*\ (1\text{-}Mc)] + \ldots}{[\%\ Na*a*(1\text{-}Ma)] + [\%\ Na*b*\ (1\text{-}Mb)] + [\%\ Nc*c*\ (1\text{-}Mc)] + \ldots}$$

where a = total weight of ingredient a
b = total weight of ingredient b
c = total weight of ingredient c
Ma, Mb, Mc, ... = moisture content of ingredients a, b, c, ...
% Ca, Cb, Cc, ... = % carbon of ingredients a, b, c, ... (% of dry weight)
% Na, Nb, Nc, ...= % nitrogen of ingredients a, b, c, ... (% of dry weight)

Surface Area and Particle Size

Microbial activity occurs at the interface of particle surfaces and air. The surface area of materials to be composted can be increased by breaking them into smaller pieces. Increased surface area allows the micro-organisms to digest more material, multiply faster and generate more heat. Generally, the smaller the size and more fragile the particle, the greater the biological activity and rate of composting are. However, Hamoda et al. (1998) reported a higher organic decomposition with 40 mm particle size than with 30 mm and 20 mm. This was because with larger particle sizes, the voids between the waste particles were bigger than with smaller sizes, thus oxygen had better access to the particles and degradation proceeded faster. This suggests that even though small particles have increased surface area for microbial activity, oxygen transfer can be limited when the sizes are too small. Haug (1993) developed a model showing that particles with 0.1 cm diameter and lower appeared to be small enough so that oxygen transfer limitations existed. In Table III.1 of Chapter III, both pepper and tomato year-end wastes after shredding showed less than 10% of particles smaller than 0.1 cm before they were processed in the composter; therefore, it should be able to fulfil the partcile size requirement for oxygen transfer.

Aeration

Aeration is necessary for a composting process for three basic reasons. First, air must be supplied to satisfy the oxygen demand from organic decomposition (stoichiometric demand). Aeration replaces oxygen-deficient air in the center of the

compost pile with fresh air. Rapid aerobic decomposition can only occur in the presence of sufficient oxygen. Second, aeration is necessary for removing water from wet substrates to provide drying (drying demand). Third, aeration is used to remove excess heat generated by organic decomposition to control optimal process temperatures (heat removal demand). Appendix C shows a sample of the aeration requirement calculation used in this study.

Aeration occurs naturally when air warmed by the compost rises through the pile, drawing in fresh air from the surroundings. Wind also stimulates aeration. Initial mixing of materials usually introduces enough oxygen to start composting. Oxygen requirements are greatest during the initial weeks of most vigorous activity. Air movement through the compost pile is affected by porosity and moisture content. Regular mixing of the pile, referred to as turning, enhances aeration in a compost pile.

Porosity or Free Air Space (FAS)

The concept of free air space was first adopted from soil science by Shulze (1962) to establish the relationship between moisture content and the physical structure of composting materials. Porosity refers to the spaces between particles in the compost pile and is calculated as the volume of spaces, or pores, divided by the total volume of the pile. If the material is not saturated with water, these spaces are partially filled with air that can supply oxygen to decomposers and provide a path for air circulation. As the material becomes water saturated, the space available for air decreases. FAS(%) and porosity (P) % are related through the following equation (Haug, 1993) :

Equation V.2 Free air space of compost mass

$$FAS = V_g/V_t \text{ or } (V_t - V_s - V_w) / V_t$$

where V_g is the gas volume, V_s is the solid volume, V_w is the water volume and V_t is the total volume.

Equation V.3 Porosity of compost mass

$$P = (V_t - V_s) / V_t \text{ or } 100 (1 - \rho_b/ \rho_p).$$

where ρ_b is the bulk density (gcm^{-3}) and ρ_p is the particle density (gcm^{-3}).

Compacting the compost pile reduces its porosity. Excessive shredding can also impede air circulation by creating smaller particles and pores. Turning can fluff up the material and increase its porosity. Adding coarse materials, such as straw or woodchips, can increase the pile porosity, although some coarse materials are slow to decompose. As the compost process proceeds, the porosity decreases restricting aeration.

By estimating the consumption of oxygen required for the composting of a wide variety of residues from municipal refuse with different MCs, a 30-36% FAS was recommended to obtain optimum composting (Jeris, 1973 and Madejon, 2002). For agricultural wastes, bulk densities of the mixture less than 550 to 640 kg/m^3 are usually adequate (BC Ministry of Agriculture, Fisheries, and Food, 1991). For greenhouse wastes, since shredding and addition of bulking agents are usually required, the compost operators could usually blend the substrates to an optimum bulk density.

Moisture Content

Moisture plays an essential role in the metabolism of micro-organisms and indirectly in the supply of oxygen. Micro-organisms tend to utilize only those organic

molecules that are dissolved in water. Although the maximum rate of transfer of nutrients and waste products takes place in a liquid environment (100 % MC), it is not possible to operate an aerobic composting system where solid substrates are used in this condition. Therefore, the optimum MC is a trade-off between moisture requirements of microorganisms and their simultaneous need for an adequate oxygen supply (Madejon, 2002). By conducting a set of well-controlled incubation experiments, Liang (2003) proved that moisture content was a more dominant factor in impacting aerobic microbial activity of composting than temperature. Even at lower temperatures such as 22 ^{0}C, higher moisture content treatments (50%, 60% or 70%) exhibited higher microbial activity (oxygen uptake rate) than those at below 40%. In contrast, at low moisture contents such as 30-40 %, microbial activity was consistently low, even under higher temperature regimes (43, 50 and 57 ^{0}C). Particularly, the enhancement of composting activities induced by temperature increment could be realized by increasing moisure content alone.

To ensure an adequate composting process, 50-60% is the recommended range for moisture content (Mckinley, 1985). Hamoda (1998) reported that the optimum moisture content for the composting process is 60%, as the largest decrease in TOC took place under this condition. If the moisture content fells below 40%, the bacterial activity would slow down and cease entirely below 15%. When the moisture content exceeds 60%, nutrients are leached, air volume is reduced, odors are produced (due to anaerobic conditions) and decomposition is slowed. If the pile becomes too wet, it should be turned and restacked. This allows air to circulate back into the pile and loosens the materials for

better draining and air drying. Adding dry material, such as straw, sawdust or finished compost, can also remedy an excess moisture problem. If the pile is too dry, water can be added and the pile can be remixed to re-start the composting process.

Moisture content of the composting mix can be calculated using the following formula (B.C. Ministry of Agriculture Fisheries and Food, 1993) :

Equation V.4 Composite moisture content of compost mass (wet basis)

$$\text{Moisture Content} = \frac{\text{Weight of water in ingredient a + water in b + water in c + .. .}}{\text{total weight of all ingredients}}$$

$$= \frac{(a * Ma)+(b * Mb)+(c * Mc)+ \ldots.}{a+b+c \ldots}$$

where a, b, c, Ma, Mb, Mc are the same as in the C:N ratio calculating formula.

Temperature

Heat generated by micro-organisms decomposing organic material increases the compost pile temperature. There is a direct relation between temperature and rate of oxygen consumption. Higher temperature is associated with a greater rate of oxygen uptake and a faster rate of decomposition. A large variety of mesophilic, thermo-tolerant and thermophilic aerobic microorganisms, including bacteria, actinomycetes, yeasts and fungi have been extensively reported to be present in composting studies. Under aerobic conditions, temperature is the major factor that determines the types of microorganisms, species diversity, and the rate of metabolic activities. For instance, pathogenic bacteria, like *Escherichia coli* and faecal *Streptococci* populations decreased, respectively, from

$2x10^7$ to $3.1x10^3$ and 10^7 to $1.5x10^3$ cells/g waste dry weight at the end of the thermophilic composting cycle (Hassen, 2001).

Under optimal conditions, composting proceeds through three phases : (1) the mesophilic phase, which can last for several days, (2) the thermophilic phase, which can last from a few days to several months, and (3) the cooling and maturation phase which lasts for several months (Figure V.1). The length of the composting phases depends on the raw materials being composted and the efficiency of the process. At the beginning of the composting process, mesophilic bacteria predominate, but after the temperature increases to over 40 ^{0}C, thermophilic bacteria take over and thermophilic fungi also appear in the compost. When the temperature exceeds 60 ^{0}C, microbial activity decreases dramatically, but after the compost has cooled, mesophilic bacteria and actinomycetes dominate again (Tuomela, 2000).

Mari et al. (2003) further determined the temperature requirements of the compost microflora at different stages by measuring the respiration rate in compost over a wide range of temperatures during the composting process (before and after each turning). At the start of composting the mean respiration rate at lower temperatures (17-42 ^{0}C) was more than two times greater than the mean respiration rate at higher temperatures (42-63 ^{0}C), indicating that mesophilic microorganisms initially predominated. However, the ratio of lower temperature respiration rate-to-higher temperature respiration rate dropped below 1 within 48 hours, indicating that a thermophilic microflora were established. The ratio was maintained between 0.5 and 1 for the rest of the active composting period,

indicating no further changes occurred in the temperature requirements of the compost microflora.

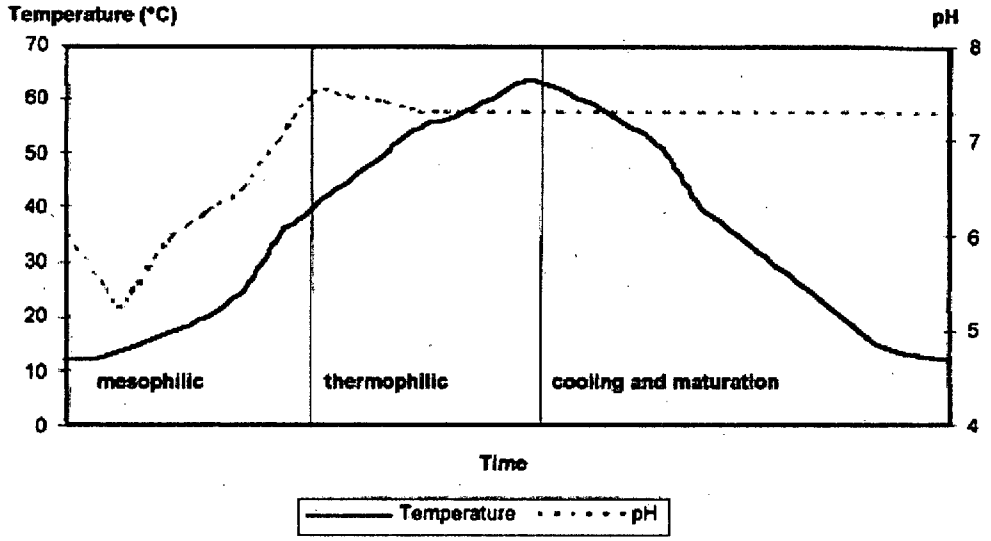


Figure V.1. Temperature and pH variation during natural composting process. (Golueke, 1991)

The typical composting temperature range is between 32°C and 60°C (Haug, 1993). Hamoda (1998) stated that the optimum temperature for decomposition, as judged by the amount of TOC reduction, was 40 ^{0}C. According to the Agricultural Composting Factsheets (B.C. Ministry of Agriculture, Fisheries and Food, 1991), a temperature of 55°C or above has to be achieved and maintained for three consecutive days for effective weed seed destruction. Animal health materials such as drugs and hormones are destroyed if the composting process remains thermophilic for a minimum of three days. Specific time and temperature requirements to eliminate pathogens can be found in Production and Use of Compost Regulations, B.C. Ministry of Environment, Lands and Parks.

The variability of temperature associated with composting can limit the ability to detect statistically significant differences between treatments. The use of an inoculum from a single source, e.g. biosolids from wastewater treatment plants, might decrease experimental temperature variations and thus improve process dynamics (Schloss, 2000).

pH of Materials

Composting may proceed effectively over a range of pH without seriously limiting the process. The optimum pH for micro-organisms involved in composting lies between 6.5 and 7.5. Composting itself leads to major changes in materials and their pH as decomposition occurs. For example (see Figure V.1), at the start of composting the mass is at ambient temperature and usually slightly acidic. Soluble and easily degradable carbon sources, such as monosaccharides, starch and lipids, are utilized by microorganisms in the early stage of composting. The pH decreases because organic acids are formed from these compounds during degradation. In the next stage, microorganisms start to degrade proteins, resulting in the release of ammonium with a resulting increase in pH (Tuomela, 2000). Studies have indicated that the activities in the initial phase of composting were reduced when the temperature was raised too quickly under low pH conditions (Smars, 2002). Figure V.1 shows how pH will typically change over the composting process. Whatever the pH measured in the starting materials, composting will always yield an end product with a stable pH usually near neutrality. Lime or other buffering agents have sometimes been added to prevent the pH from decreasing below 7, especially at the early stage of composting. The degradation rate of organic matter in pH

controlled environments was faster than in those without pH control. The optimum pH for the growth rate and degradation activity of proteins of the microorganisms is in the range of 7-8, while the decomposition of glucose proceeded rapidly at an early stage of composting in a pH range from 6-9 (Nakasaki, 1993).

Nutrients

Two factors enter into the determination of a suitable nutrient balance: the elemental composition of the microbial cell mass, and microbial metabolism. For reproduction and consequent decomposition to take place, all microorganisms must have access to a supply of the elements of which their cellular matter is composed. Other elements are required which enter into the metabolic activities of the organisms by serving as an energy source or as an enzyme constituent.

Many elements are utilized to some extent by microbes, and some are essential to their survival. The relative amount required of each element varies. Those needed in large amounts are termed macronutrients; those in minute amounts are designated as micronutrients or trace elements. The principal macronutrients are carbon(C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), and potassium (K). About 50% of the cell mass consists of carbon, and from 2 to 8 % is nitrogen. Potassium is present in only a fraction of a percent. Hydrogen and oxygen constitute a large percentage of the cellular mass in the form of water and as a part of the cellular material. Trace elements may even be toxic when present in above trace quantities. Generally, micronutrients are present in

most wastes in an abundance sufficient to permit satisfactory composting without the need for further additions.

Cation Exchange Capacity

The cation exchange capacity (CEC) is a measure of the nutrient holding (adsorptive) power of the material and is related to potential use of the compost as a fertilizer. It also is related to the state of decomposition, tending to increase as the material is progressively decomposed and is a useful humification index during composting (Sanchez-Monedero, 1999). However, it is not a measure of maturity or stability. Many other factors influence CEC, but the data provide a basis for comparative purposes and to estimate the potential use of the compost as a fertilizer of a compost-amended mixture. A field trial conducted by Ouedraogo (2001) showed that application of mature compost increased soil CEC from 4 to 6 cmol/kg (centimoles of + charge per kg soil), and improved soil properties and crop productivity.

V.2 SPECIFIC OBJECTIVES

The overall objective of this part of the project was to design and develop an appropriate technology for the composting of biodegradable wastes generated by greenhouses in the province of British Columbia. The specific objectives were:

- To test whether the greenhouse organic wastes could be composted in a well-controlled in-vessel bioreactor with or without the addition of inoculum and bulking agents.
- To evaluate the effects of relevant parameters and process controls on composting efficiency.
- To evaluate the effects of different substrate recipes, inoculum, bulking agents on the greenhouse wastes composting process with regard to heat generation and degradation of organic matter.
- To assess the quality of the finished compost product.
- To investigate the feasibility of adopting box-type (in-vessel) composting technology for on-farm operation and to evaluate the economic feasibility of the composting technology.

V.3 METHODOLOGY

V.3.1 LAB SCALE EXPERIMENT SYSTEM DESIGN

Four lab scale, experimental compost reactors were built and set up in the laboratories of the Department of Bio-Resource Engineering Department, UBC and were later (Lab 5 to Lab 9) moved to the warehouse of Hazelmere Greenhouses for the ease of feedstock loading. Their layout is presented in Figure V.2. Figure V.3 and Figure V.4 are photos of the lab scale reactors. They were constructed from 120 litre plastic barrels, with a perforated acrylic plenum which allowed upward, forced airflow, a removable lid with seal, and headspace exhaust and sample ports. The reactors were thermally insulated with an integral controlled heater to reduce heat loss from the compost mass. They were equipped with air compressors and air diffusers at the bottom.

The required aeration rate for the supply of oxygen and cooling was determined in each run by estimating the oxygen uptake from empirical data and calculating the heat output of the compost (Haug, 1993). Sample calculations are shown in Appendix C.

An air re-circulation system was set up to provide additional air cycle with or without cooling, inside the reactor, without introducing extra oxygen; a similar configuration was used in the industrial Herhof-Rottebox composting system (Weppen, 2001; Smars, 2001). The condensate from the recirculation system would be pumped to the bottom of the the reactor and mixed with the leachate.

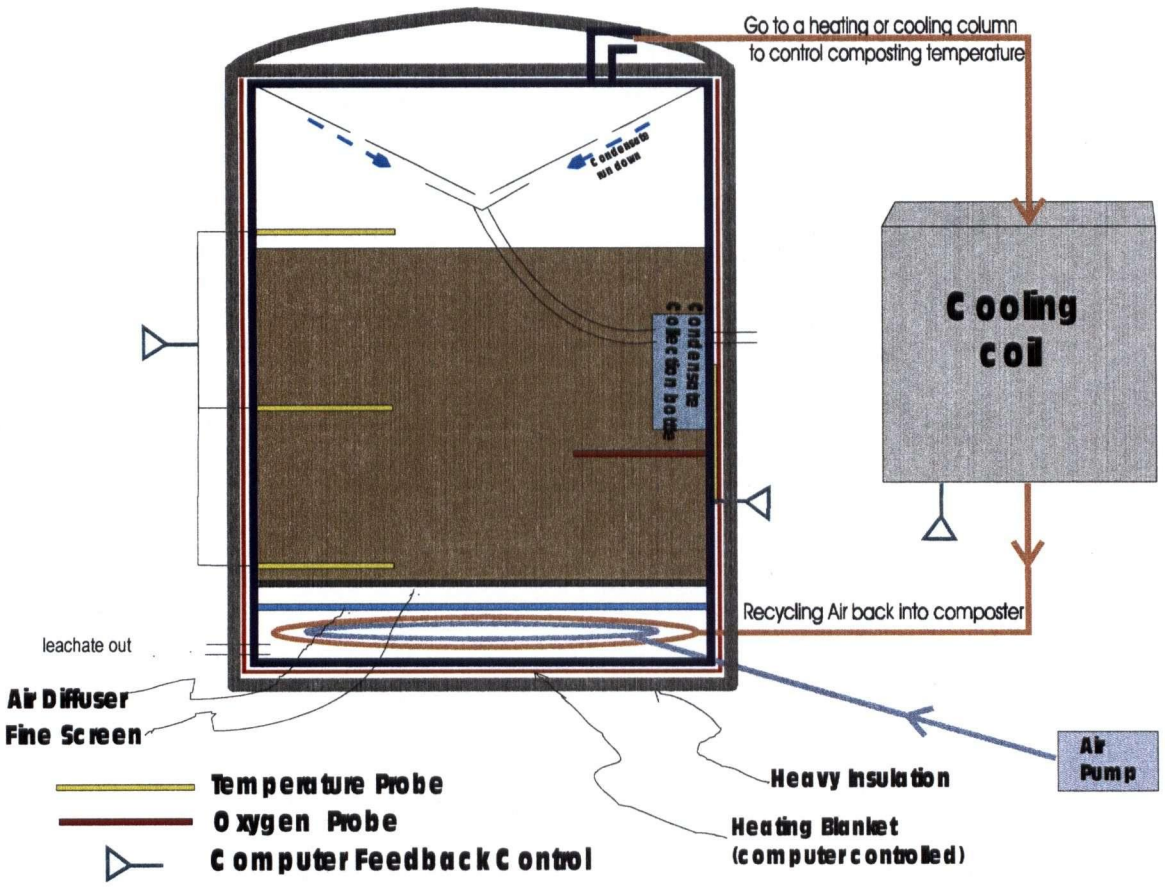


Figure V.2 Lab Scale Composter (Scale 11.5:1)

Leachate was collected at the bottom of each reactor and removed via a valve. Evaporated water was trapped as condensate from the inverted cone-shaped aluminum lid and the cooler outside (optional in different runs). This setup enhanced the collection and monitoring of the nutrient and pH changes of the leachate and condensate. Some studies indicated that pH in the condensate and leachate, at least during the pH-shift from below to above 7 in the material, related to the pH in the material (Smars, 2002). The leachate

and condensate could be re-circulated internally to increase the moisture content of the compost if necessary.

Three thermocouples were place at the top, middle and bottom of the reactors to record the compost temperature during the process. Oxygen levels could be monitored by putting an oxygen probe into one of the openings on the side of the reactors.

In the first part of the lab experiments, different process control strategies were used to test their efficiencies on composting greenhouse organic wastes. The purpose of the first set of experiments was to find out the most efficient and cost-effective control strategy. The following aeration control strategies were used in the study :

Figure V.3 Lab Scale Reactor (Outside)

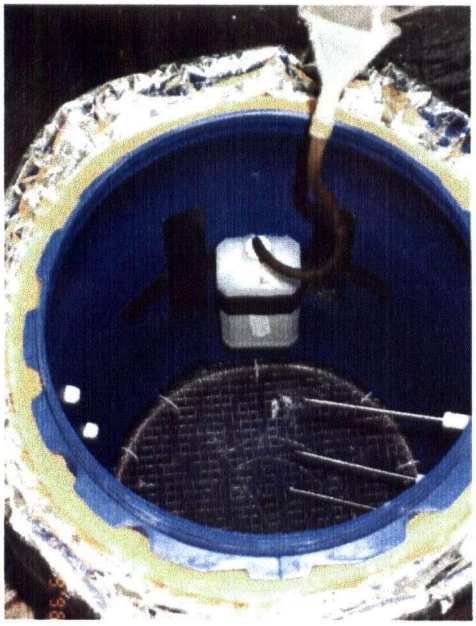


Figure V.4 Lab Scale Reactor (Inside)

Temperature Feedback Aeration Control (Rutgers method)

The Rutgers method is probably the most commonly used of all composting process control strategies (Monteoliva-Sanchez, 1996; Bernal, 1998; Paredes, 2002). The control objective of the Rutgers process is to maximize microbial activity by regulating temperature via controlled ventilation of the compost (Finstein, 1983). In the initial stage, rapid temperature rise is encouraged by timer-controlled aeration, usually on a 20 to 30% duty cycle. Once compost temperature reaches the desired setpoint, air is supplied at a sufficient rate to keep the temperature below the set point. Appendix D shows the flowchart and program code used in this study for temperature feedback aeration.

Recirculation

Air recirculation capability was added to the temperature feedback setup. This allowed aeration for cooling purposes to be controlled in a closed loop, separate from aeration for the supply of oxygen. The internal air recirculation also resulted in achieving a more uniform temperature distribution throughout the composting mass as compared to no recirculation, and thereby accelerated degradation of the organic matter (Bari, 2001). This system potentially also offers better management of exhaust gases and odour by reducing the volume of exhaust air and extending the residence time of exhaust gases in the compost (Mathur, 1994).

Linear Temperature Feedback Aeration Control

Linear temperature feedback (Fraser, 1997) was developed as an improvement to ordinary temperature feedback control. To help keep compost oxygen in the desired range, aeration through the pump at the bottom of the reactor was increased linearly based on compost temperature and a model coefficient. Once temperature reached a set point, it was kept below that limit by temperature feedback controlled aeration. As temperature decreased at the end of the process, aeration was decreased based on temperature and another model coefficient. Appendix E shows the flowchart and program code used in this study for linear temperature feedback aeration.

In the second part of the lab experiments, the focus was changed to the effects of different substrates on the process performance. Linear temperature feedback was used for aeration control.

Each of the lab-scale experiments consisted of an active composting phase, lasting approximately 2-4 weeks, followed by curing, in fabric bags, for 1-3 months. Capacity of each of the reactors was approximately 20 kg of feedstock. Greenhouse plant wastes were collected from Hazelmere Greenhouse (pepper and tomato) directly. Before the start of each experiment, the proper ratio of substrate mix was calculated where C:N ratio and bulking density were used as references. The wastes were weighed and mixed thoroughtly by hand on a concrete pad. Shredding and addition of bulking agents were done whenever necessary. The feedstocks were then fed into the composter carefully by hand. Feedstocks were sampled before and after active composting, and occasionally during curing; measurements were focused on the active composting phase since the lab system was primarily developed for this.

In total, there were 9 lab scale composting experiments investigated in a period of about 18 months. They were designed to investigate different parameters of composting and their effects on the process and compost quality. Table V.3 lists all the lab experiments with their purposes. There were 2 reactors built for Lab 1 and Lab 2, and 4 reactors built for Lab 3 to Lab 9. Even though all the reactors were built under the same configuations at the same time, minor variations were unavoidable, e.g. factory variations from the heating blanket, thickness of barrel, insulation, tubings, thermocouple wires, aeration pumps, etc. In any case, when one parameter was tested more than one time, different reactors were used in different runs to avoid variations coming from the reactors. For example, alder bark with non-shredded greenhouse waste was tested in

Reactor C in Lab 5 and was re-tested in Reactor A in Lab 6 in order to confirm the results were caused by the differences in substrates but not by differences in reactors.

Table V.3 List of Lab tests

Lab Test	Purpose	Sub Sets	Remarks
Testing of composting process strategies			
Test 1	Find out whether manure had to be added to start the greenhouse wastes composting; test composters	With manure vs without manure	Monitor odor problems with manure
Test 2	Investigate the effect of air recirculation	With air recirculation vs without air recirculation	
Test 3	Investigate the effect of air recirculation; investigate the efficiency of using curing compost as biofilter	With air recirculation vs without air recirculation	Track odor emissions
Test 4	Investigate the effect of air recirculation on cooling and aeration	Fresh air vs recirculated air aeration; Fresh air cooling vs recirculation cooling	
Testing of effects of various substrates			
Test 5	Find out whether shredding is needed; Investigate different bulking agents	Shredded vs non-shredded prunings ; Hemlock bark vs alder bark	Track studies (chemical analysis)
Test 6	Find out whether shredding is needed; Investigate different bulking agents	Shredded vs non-shredded prunings ; Hemlock bark vs alder bark	
Test 7	Find out whether shredding is needed; Investigate different bulking agents	Shredded vs non-shredded pruning ; Fresh alder bark vs composted alder bark	
Test 8	Find out the best mixing ratio of wastes and bulking agents	4 different mixing ratios	
Test 9	Finding out the best mixing ratio of wastes, bulking agents and used sawdust	4 different mixing ratios	

In the course of the experiments, some parameters were re-tested a couple of times, for example, air-recirculation was tested in Lab 2, 3 and 4, and alder bark as a bulking agent was tested in Lab 5, 6, and 7. However, those experiments could not be regarded as identical replicates based on two reasons :

First, the characteristics of the plant wastes changed during the season. For example, in the beginning of the year, there were only leaves in the wastes; in the middle

of the year, there was a lot of small cull fruit in the wastes, which caused higher moisture content and higher sugar content (readily biodegradable carbon); near the end of the year, there were a lot of vines, and therefore a higher C:N ratio; at the end of the year, the wastes were mixed with leaves, vines, cull fruit, and sawdust. Since each composting run might last for a month, storing the same batch of wastes for the next run might cause deterioration of the wastes, whereas using another batch could not guarantee exactly the same composition (C:N ratio, moisture content, bulking density, etc) of wastes.

Secondly, there were uncontrollable external factors, such as outside temperature and humidity, that could cause experimental variations in different runs. Even though each reactor was well insulated, there was still heat loss due to occasional low outside temperature. The temperature of the aeration from ambient air might affect the temperature profile of the composting process. This was especially significant when the reactors were moved to the warehouse of Hazelmere Greenhouses (no effective heating in winter months) for the ease of feedstock loading.

Due to the above reasons, each set of experiments was carefully planned. First of all, there were two sets of experiments: 1. Testing of composting process strategies; 2. Testing of effects of various substrates. The purpose was to find out the differences in control strategies and substrates, and to see whether similar results were able to be repeated.

Secondly, in each run, when there were two design parameters (e.g. X,Y), with two variables for each parameter, one of them would be kept constant (e.g. X) for two reactors so that the second parameter (e.g. Y) could be varied for comparing

independently, i.e. $\{(X_1,Y_1), (X_1,Y_2), (X_2,Y_1), (X_2,Y_2)\}$. By doing so, each variable could be tested twice, achieving 4 comparisons, i.e. test of parameter X : (X_1,Y_1) vs (X_2,Y_1) and (X_1,Y_2) vs (X_2,Y_2) ; test of parameter Y : (X_1,Y_1) vs (X_1,Y_2) and (X_2,Y_1) vs (X_2,Y_2) as shown below :

Parameter	$\mathbf{X_1}$	$\mathbf{X_2}$
$\mathbf{Y_1}$	*Reactor A* $X_1\ Y_1$ ↔	*Reactor B* $X_2\ Y_1$
	↕	↕
$\mathbf{Y_2}$	$X_1 Y_2$ ↔ *Reactor C*	$X_2\ Y_2$ *Reactor D*

Lab 4, 5, 6, 7 followed this design to compare different aeration and cooling methods, different bulking agents under shredded or non-shredded substrates conditions, etc. By doing so, a parameter could be compared in the same run and also re-tested in different lab runs.

V.3.2 PILOT SCALE EXPERIMENT SYSTEM DESIGN

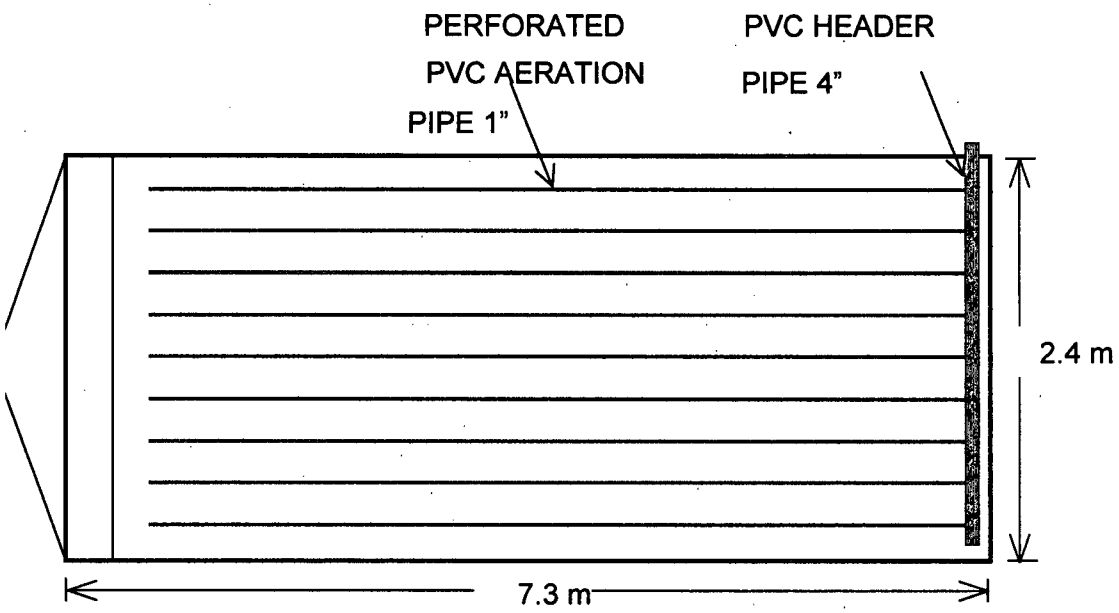
A scaled-up compost experiment was designed based on the findings of the lab-scale studies and the commercial Herhof-Rottebox composting system (Weppen, 2001; Smars, 2001). A used, standard 20', steel, refrigeration, shipping container (Cratex Container Sales Ltd., Coquitlam, BC) was modified to become the reactor, because it was already well-insulated for minimizing heat loss. First the refrigeration unit was removed and an epoxy painted, steel grating was installed on the floor. Thermocouple probe fittings and drain fittings were installed on the sidewall and bottom-end of the container. The bottom was lined with a leakproof PVC liner. An epoxy painted steel grating was installed on top of the PVC liner, suspended on top of 4" x 4" cedar beams running longitudinally. Nine sections of perforated 1" schedule 40 PVC piping were installed between the beams, with gravel on top for even air distribution under the steel grating. These 1" pipes were connected to the main aeration pipe, a 4" PVC schedule 80 pipe. The aeration floor was sloped down and in from its outer edges to encourage liquid formed during composting to collect under the perforated centre portion of the aeration floor. The perforated centre portion of the aeration floor was arched or peaked to direct more air toward the centre of the composting mass while minimizing the amount of air following the path of least resistance up the side wall (Brown, 1997).

A computer with data acquisition and control card (Advantech Co. Ltd –Model 711), running Labtech Control software was installed, with connections to thermocouples for temperature monitoring. A 110 VAC 1 HP centrifugal blower (Dayton Co. Ltd) was connected to the main aeration pipe for air supply. Leachate was collected in a 1200 L

plastic tank through a diaphragm pump. Temperature feedback control (Rutgers method) was used for aeration control.

Prior to each experiment, feedstocks were mixed by a Bobcat loader on an asphalt pad at the parking lot of Hazelmere Greenhouse. After mixing, the feedstock was loaded into the container, to a depth of approximately 4 feet. Any unused portion of the perforated floor was covered in plastic and heavy sawdust bags were put on top to avoid short circuiting of air flow. The container was closed, the aeration control program started and temperature monitored. At the end of the active phase, the material was unloaded using the Bobcat, and piled in the curing area to a height of approximately 5 feet. The pile was then covered with Compostex fabric (Texel Inc., Saint-Elzear-de-Beauce, PQ) to shed water and allow airflow, and allowed to cure. Periodic temperature and oxygen measurements were taken in the pile.

Figure V.5 provides the dimensions of the compost container. Figures V.6 and V.7 are photographs of it.



Notes:

Outside height	2.6 m
Usable inside floor dimensions	599 cm x 218 cm
Usable inside height (approx.)	1.5 m
Usable volume	18 m^3 (23.5 yd^3)

Figure V.5 Pilot Scale Bio-Conversion Reactor Design

Figure V.6 Pilot Scale Composter (outside)

Figure V.7 Pilot Scale Composter (inside – installing air piping)

Physico-chemical monitoring and analyses (lab and pilot experiments)

Temperature was continuously monitored inside every composter. Due to a limited budget, only one oxygen probe was available and therefore only one reactor could be monitored for the oxygen profile in each run. Chemical analysis of compost is a frequently used method for establishing the quality of a compost (Bidlingmaier, 1999). At the beginning and end of each lab composting test, the intial waste mixture and compost were analyzed with regard to the most relevant physico-chemical parameters, such as C/N ratio, moisture content, porosity (lab 6 only), ammonia, nitrates, pH.

In each case, 3 to 5 grab samples were taken and mixed as a composite sample for analysis (Johnson, 1993). Gravimetric moisture content was determined by evaporation at 105 ^{0}C for 24 hours (Amer. Sco. Agron, 1982). The pH was measured using distilled water dilution as Standard Methods (Amer. Soc. Agron., 1982). Total organic carbon (TOC) was measured by combustion at 680 ^{0}C and CO_2 measurement, using a Shimadzu TOC-5050 Total Organic Carbon Analyzer with SSM-5000 Solid Sampling Module. Water soluble ammonium, nitrate and phosphorus were measured using water extraction and the Technicon Autoanalyser II industrial method. Total nitrogen was measured using ignition at 950 ^{0}C in a Leco FP228 Nitrogen Determinator.

Statistical Analysis

The lab experiments were set up to compare different treatments of process controls and mixing substrates by the 4 lab reactors (except Lab 1 and Lab 2 had only two

reactors) as described in the methodolgy section. For physico-chemical analysis, means and standard deviations were calculated.

For the pilot scale experiments, since there was only one reactor, each run was analyzed and investigated separately without direct replication.

V.4 RESULTS AND DISCUSSION

V.4.1 LAB SCALE COMPOSTING DATA

TESTING OF COMPOSTING PROCESS STRATEGIES

V.4.1.1 Lab 1 Test

This was the first composting run, and was intended to test the compostabilty of greenhouse wastes in general. More specifically, it was designed to test whether an inoculation of microorganisms (chicken manure) was needed. Through this test, a preliminary idea of proper C:N ratio, bulking agent ratio, moisture content, temperature and aeration control could be established.

In this case, the major components were vines, leaves and sawdust (see Table V.4). The vines are the stems or branches of the tomato plants. They smelt like pickles and were very fibrous. The moisture content was about 60%. The leaves were less fibrous and looked like grass clippings. They were very wet (about 80% MC). The sawdust had been used as growing media, which thus contained a lot of roots, and was about 50% MC. The chicken manure was from the UBC farm and was used as an inoculum here. Chicken manure was found to support *Trichoderma (Gilocladium) virens* growth and viridiol production at levels capable of controlling weed emergence and growth in greenhouse trials (Hutchinson, 1999) and therefore has been one of the most common ingredients for compost. The wood shavings were dry and used to provide structure and porosity to the process.

The regulatory requirements for composting to be classified as a process to further reduce pathogens (PFRP), mandate that the minimum operating temperatures must be maintained at 55 ^{0}C or above for three days (USEPA, 1994). The provincial government of British Columbia (B.C.MWLAP, 2002) requires compost to be treated aerobically for 14 days or longer at 40 ^{0}C or above in order to classify the composting process as a vector attraction reduction process (VARP). These two requirements were only considered as guidelines in this study, but not a "success-determination" factor for the process since the lab scale composter showed limitations in achieving long-duration, high temperatures due to the small amount of organic mass and the high heat loss (Kaiser, 1996; Vinneras, 2003).

The compost mix recipe for Lab 1 is presented in Table V.4. Figure V.8 plots the temperature profiles recorded over the composting period.

Feachem et al. (1983) used 45 ^{0}C as a benchmark temperature for thermal inactivation of several kinds of common pathogens. By using the formulae given in Table V.5, the degree of inactivation could be calculated at temperatures above 45 ^{0}C, which can be easily attainable in aerobic digestion. For example, if the temperature of the compost mass was 50 ^{0}C, the hours required to inactivate *Salmonella* would be 13.94 hours, using the equation :

$$t = 75.4 \times 10^{-0.1466(T-45)}$$

where t is the time required to attain no viable *Salmonella* (hour)
T is the temperature above 45 ^{0}C

Table V.4 Lab 1 Compost Feedstock Recipes

Batch	Materials	Wt(lb)	Wt%	Moisture Content %	Composite MC (wet basis)	C:N Ratio	Composite C:N Ratio
Lab1A	Shredded vines	13	37%	82.0	78.9	18.8	24.0
	Shredded leaves and cull fruit	6	17%	87.2		5.2	
	Wood shavings	2	5.7%	32.8		99.4	
	Used sawdust	9	2.6%	75.0		73.4	
	Chicken manure	5	14%	65.4		23.0	
Lab1B	Shredded vines	14	40.0%	82.0	78.4	18.8	25.4
	Shredded leaves and cull fruit	7	20.0%	87.2		5.2	
	Wood shavings	2	5.7%	32.8		99.4	
	Used sawdust	12	34.3%	75.0		73.4	
	Chicken manure	0	0.0%	65.4		23.0	

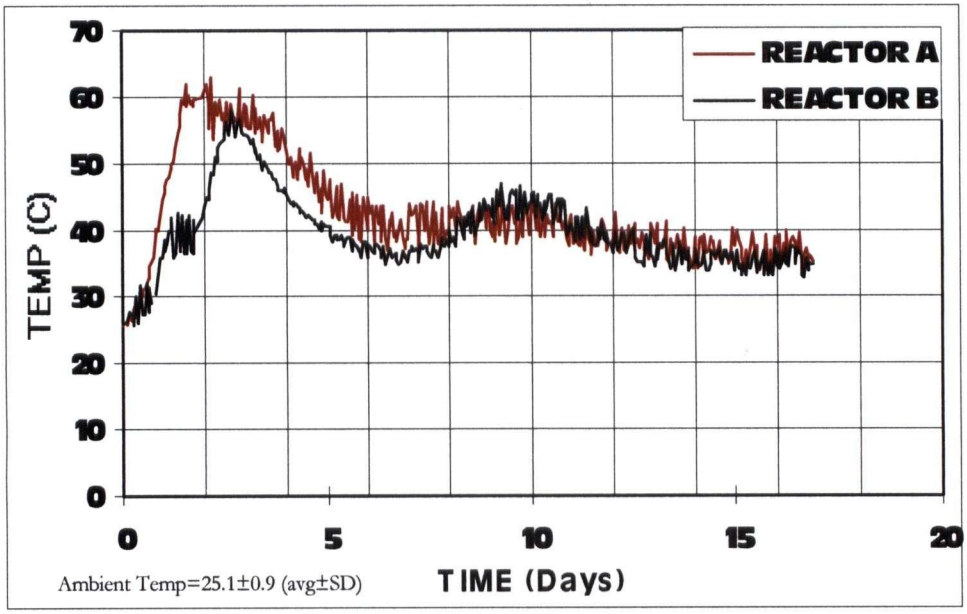


Figure V.8 Temperature Profiles of Lab 1

Salmonella is a very common pathogen, and is often used as an indicator for health hazardous compost (Watanabe, 1997; Tiquia, 1998; Sidhu, 2001). Therefore, the three

days at 45 ^{0}C (Duration$_{45°C}$), for inactivation of *Salmonella,* was also used as one parameter to compare compost processes in this study.

Table V.5 Equations for the time in hours (t) required to attain no viable organisms (equal to 12log $_{10}$)* of different pathogens at different temperatures (T) above 45 ^{0}C.

Organism	Type	Equation	When T=45^{0}C
Enteroviruses	Virus	$t = 55.9 \times 10^{-0.101(T-45)}$	Time (t) = 55.9 hr or 2.3 days
Salmonella	Bacteria	$t = 75.4 \times 10^{-0.1466(T-45)}$	Time (t) = 75.4 hr or 3.1 days
Vibrio cholera	Bacteria	$t = 0.89 \times 10^{-0.2117(T-45)}$	Time (t)=0.89 hr or 0.04 days
Shigella	Bacteria	$t = 13.8 \times 10^{-0.1369(T-45)}$	Time (t)=13.8 hr or 0.58 days
Ent. Hystolica	Protozoa	$t = 21.3 \times 10^{-0.2806(T-45)}$	Time (t)=21.3 hr or 0.89 days
Ancylostoma	Helminth	$t = 9.31 \times 10^{-0.1340(T-45)}$	Time (t) = 9.3 hr or 0.39 days
Ascaris	Helminth	$t = 177 \times 10^{-0.1944(T-45)}$	Time (t) = 177 hr or 7.4 days
Schistosoma	Helminth	$t = 10.0 \times 10^{-0.1844(T-45)}$	Time (t) = 10 hr or 0.42 days
Taenia	Helminth	$t = 6.6 \times 10^{-0.1306(T-45)}$	Time (t) = 6.6 hr or 0.28 days

Source : Feachem et al (1983)

*Note : The values with no viable organisms was interpreted as an inactivation of approximately 12log$_{10}$, which was considered to be a level that determines sterilization by the Parental Drug Association.

The parameters involved in the temperature record, that were used for discussion in this study, were : (1) maximum temperature (TEMP$_{max}$); (2) time required for temperature to reach 55^{0}C (TIME$_{55°C}$); (3) duration of the temperature above 55^{0}C (Duration$_{55°C}$); (4) duration of the temperature above 45^{0}C (Duration$_{45°C}$); (5) duration of the temperature above 40^{0}C (Duration$_{40°C}$).

When the temperature reached over 55 ^{0}C for both reactors, the oxygen contents inside the reactor were checked. Reactor A and Reactor B recorded oxygen levels of 18.2 % at 56.3 ^{0}C and 18.1 % at 55.5 ^{0}C respectively. This showed that the aeration rate was adequate to provide an oxygen level of above 16 %, which is said to enhance microbial activities and prolong the mesophilic phase in composting (Beck-Friis, 2003). At the peak

temperature, Reactor A (with chicken manure) gave some offensive ammonia odour, while Reactor B (without chicken manure) gave minimal odour.

The reactors were opened for remix and observations at Day 14. Reactor A still had some ammonia smell while Reactor B already showed a pleasant earthy "compost-like" smell. This might plausibly be caused by some undegraded chicken manure. Extensive fungal growth was noted inside the compost in both reactors which showed that the temperatures were not high enough to kill or suppress fungal growth.

As shown in Figure V.8, Reactor A heated up first and achieved an overall higher temperature in the thermophilic stage of the process (higher $TEMP_{max}$ and $TIME_{55°C}$). PFRP was achieved in Reactor A ($Duration_{55°C}$ =3 days) and was not achieved in Reactor B ($Duration_{55°C}$ < 1 day). This showed the chicken manure inoculation increased $TEMP_{max}$,$TIME_{55°C}$ and $Duration_{55C}$. Even though Reactor B did not heat up as quickly nor attain as high a temperature in the thermophilic stage and did not achieve PFRP, it still had a very good temperature profile and maintained a temperature of about 40 ^{0}C for the mesophilic stage of the process. The $Duration_{40°C}$ and $Duration_{45°C}$ were almost the same for Reactor A and Reactor B. In fact, the temperature of Reactor B spiked up again after Day 8 and surpassed that of Reactor A from Day 9 to 11. This implied a higher degradation rate of Reactor B during the mesophilic period since some readily degradable materials were not fully degraded in the relatively short thermophilic period of Reactor B. The overall degree of degradation can be indicated by the loss of carbon in the substrates, though a small amount might be lost in the leachate, as shown in Table V.6. Based on the

loss of carbon, both reactors achieved a similar degree of degradation at the end of the process (31.3% vs 32.0%).

Table V.6 Loss of carbon over composting period as calculated via mass balance (with manure vs without manure)

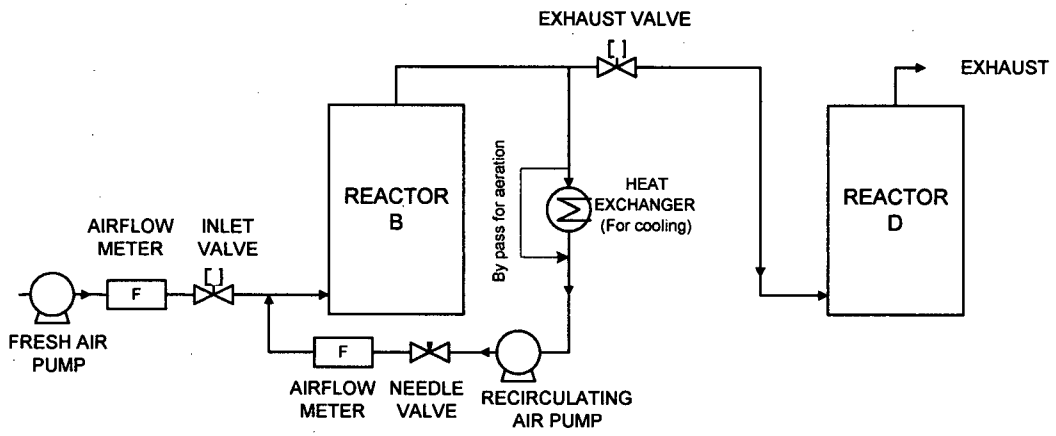
Reactor	Day	%MC	M	M_w	M_s	%C	M_c	ΔM_c	$\Delta M_c/M_c$
A (with manure)	1	78.89 ±1.13	35	27.60	7.40	40.82 ±0.58	3.02		
	16	77.00 ±1.11	23	17.71	5.29	39.22 ±0.93	2.07	-0.95	**-31.32 %**
B (without manure)	1	78.43 ±0.95	35	27.44	7.56	36.52 ±0.76	2.77		
	16	80.29 ±1.17	25	20.07	4.93	38.10 ±1.08	1.87	-0.88	**-32.01 %**

Notations : %MC = Mean Moisture Content ± standard deviation; M=Compost Mass; M_w=Water Mass; M_s=Solid Mass ; %C=Mean Percentage of Carbon ± standard deviation; M_c=Carbon Mass; ΔM_c=Change in Carbon Mass.

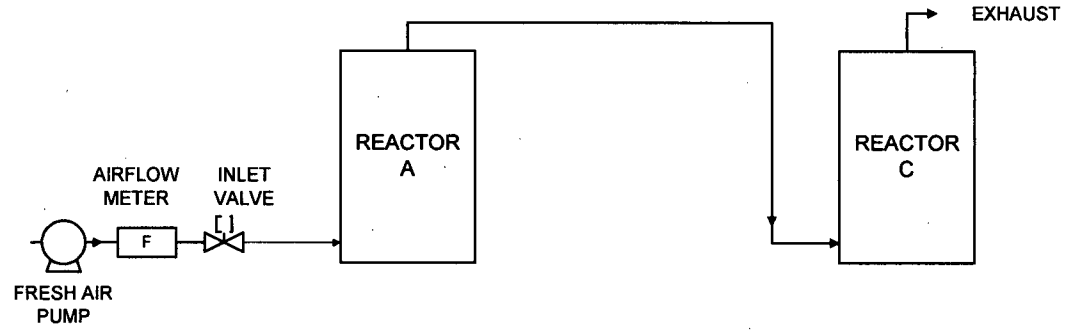
V.4.1.2 Lab 2 Test

After the first run, a potential odour problem resulting from using manure in the feedstock was recognized. Therefore, in this run, 2 modifications were made: no manure was added, and an air re-circulation system was added to one of the reactors. By doing air re-circulation, odour can be minimized, especially during the thermophilic stage. Internal recirculation of air has been said to achieve a more uniform temperature and moisture distribution and thereby an accelerated degradation of the organic matter (Bari, 2001). The overall aeration requirement should be reduced by recirculating air in composting (Das, 1997). Figure V.9 illustrates how the air recirculation system compares to the system without air recirculation in the following lab runs (Lab 2, 3 and 4). In Lab 2, there

were only two reactors (with and without recirculation). In Lab 3, two more reactors were added as biofilters. In Lab 4, all four reactors were used as composters.



AIR RECIRCULATION REACTOR SETUP
(Lab 2, 3 & 4)



NON-RECIRCULATION REACTOR SETUP

Figure V.9 Lab 2, 3, 4 Reactor Design (with and without air recirculation)

The air recirculation system was designed to provide both aeration and cooling. The aeration was first done by the fresh air pump and was evenly distributed from the diffuser at the bottom of the composter. Based on previous composting tests (Fraser,

1997) with the same size of reactor, the aeration control was set at a maximum of 7 min/L, instantaneous based on Linear Temperature Feedback Control as mentioned in Section V.3.1. The spent air from top valve of the reactor then either passed through a metal coil (for cooling) or by-passed (for aeration) back to the reactor.

Table V.7 presents the feedstock recipes for composting in Lab 2. Figure V.10 plots the temperature profiles.

Table V.7 Lab 2 Compost Feedstock Recipes

Batch	Materials	Wt (lb)	Wt%	Moisture Content %	Composite MC	C:N Ratio	Composite C:N Ratio
Lab2A Without air re-circulation	Shredded vines	20	50%	75.0	66.25	18.75	29.19
	Shredded leaves	10	25%	82.02		5.22	
	Hog fuel	10	25%	32.79		74.02	
Lab2B With air-recirculation	Shredded vines	20	50%	75	66.25	18.75	29.19
	Shredded leaves	10	25%	82.02		5.22	
	Hog fuel	10	25%	32.79		74.02	

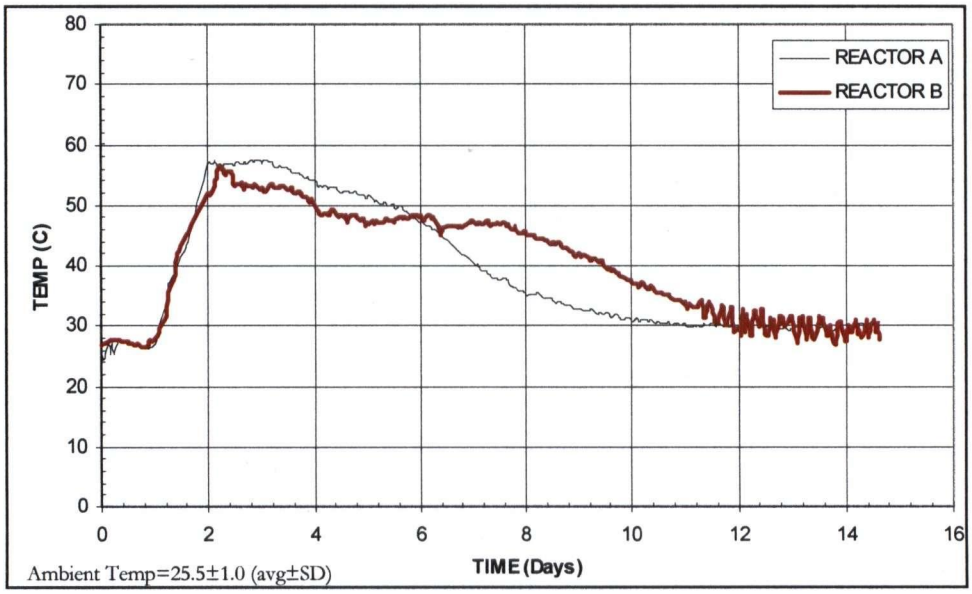


Figure V.10 Temperature Profiles of Lab 2

$TEMP_{max}$ and $TIME_{55°C}$ were about the same for both reactors (approximately 56 ^0C in 2 days). However, $Duration_{55°C}$ was longer in Reactor A than in Reactor B. Both reactors finished active composting in about 14 days. Reactor A remained longer in the thermophilic stage while Reactor B sustained longer in the mesophilic stage. The composts were dark brown and very wet in both reactors. Both reactors had a very strong odour of ammonia which was an unpleasant smell (even worse than the Lab 1 with manure). Filamentous fungi were observed on the surface of Reactor B.

Table V.8 Loss of carbon over composting period as calculated via mass balance (without air recirculation vs with air recirculation)

Reactor	Day	%MC	M	M_w	M_s	%C	M_c	ΔM_c	$\Delta M_c/M_c$
A (without air recirculation)	1	66.25 ±0.57	45.0	29.81	15.19	33.99 ±1.32	5.16		
	15	74.60 ±0.98	24.3	18.13	6.17	41.38 ±2.01	2.55	-2.61	**-51 %**
B (with air recirculation)	1	66.25 ±0.57	45.0	29.81	15.19	33.99 ±1.32	4.77		
	15	73.78 ±1.02	20.3	14.94	5.31	41.23 ±1.78	2.19	-2.97	**-58 %**

Notations : %MC = Mean Moisture Content ± standard deviation; M=Compost Mass; M_w=Water Mass; M_s=Solid Mass ; %C=Mean Percentage of Carbon ± standard deviation; M_c=Carbon Mass; ΔM_c=Change in Carbon Mass.

The loss of carbon was high in both reactors, as shown in Table V.8, with Reactor B having a higher loss. This could have been a result of air-recirculation (Bari, 2001).

Odour problems, especially of ammonia, were still present even without adding manure. Ammonia is the greatest nuisance odor compound among the exhaust gases that evolve during composting processes. It is generated by facultative and strict anaerobes, in raw materials with high concentrations of ammonium and nitrate (Nakasaki, 2000;

Ingham, 1998); in this case the vegetable leaves. The odour problem could have been improved by turning the compost more frequently in the beginning of the process (Illmer, 1997) or adding a biofilter made from compost (Liang, 2000; Delhoménie et al, 2002) to treat the off-gas. Better process control to avoid anaerobic conditions in the reactor can largely reduce odour. Air-recirculation helped in maintaining a more constant and higher temperature since hot air from the reactor was recycled as the aeration gas.

V.4.1.3 Lab 3 Test

Lab 3 was conducted to verify the advantages of air-recirculation for cooling and to test the use of re-used compost in a biofilter. Refer back to Figure V.9 for the reactor setup. In order to avoid odour in the material handling and composting process, composts from Lab 2 was used as inoculum instead of manure. Some studies have shown that the composting process could be enhanced by adding bacterial inoculum or compost which contained a diversified bacterial population (Faure, 1991; Lei, 2000; Ichida, 2001). The possibility of using finished compost (from Lab 2 and Lab 1) in external biofilters, to control odours was also investigated. The composition of the substrates is listed in Table V.9.

Table V.9 Lab 3 Compost Feedstock Recipes

Batch	Materials	Wt (lb)	Wt%	Moisture Content %	Composite MC	C:N Ratio	Composite C:N Ratio
Reactor A Without air re-circulation	Shredded vines	25	62.5%	82.02	82.83	9.60	9.13
	Shredded prunings	10	25%	87.77		5.58	
	Compost from Lab 2A	5	12.5%	77.00		13.86	
Reactor B With air-recirculation	Shredded vines	25	62.5%	82.02	82.83	9.60	9.13
	Shredded prunings	10	25%	87.77		5.58	
	Compost from Lab 2A	5	12.5%	77.00		13.86	
Reactor C (Curing reactor, also used as biofilter)	Compost from Lab 2B	20	80%	73.78	75.08	16.28	17.20
	Compost from Lab 1B	5	20%	80.29		20.86	
Reactor D (Curing reactor, also used as biofilter)	Compost from Lab 2B	20	80%	73.78	75.08	16.28	17.20
	Compost from Lab 1B	5	20%	80.29		20.86	

In this run ammonia that caused the odour problems was measured at different stages of the process.

Some bio-degradable twines were tested for bio-degradability in this test. The results have been analyzed in Chapter IV.

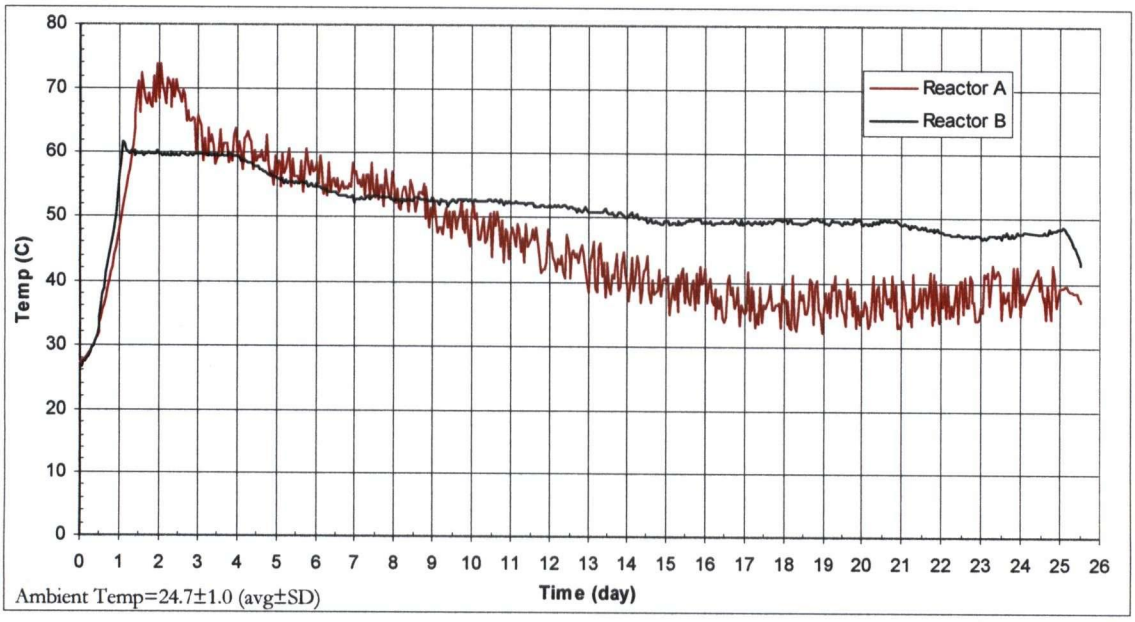


Figure V.11 Temperature Profiles of Lab 3

$TIME_{55°C}$ of both reactors were about the same, since the air-recirculation function did not start until the temperature had reached the set point temperature. Both reactors achieved PFRP (Reactor A $Duration_{55°C}$ = 6 days; Reactor B $Duration_{55°C}$ = 5 days). The $TEMP_{max}$ of Reactor A (without recirculation) overshot the set point temperature (60 ^{0}C) temperature even with a 100% aeration cycle (7 L/min) through Linear Temperature Control. On the other hand, $TEMP_{max}$ of Reactor B (with air recirculation at 7 L/min) could be effectively maintained at or below the set point. Resulting in a prolonged mesophilic degradation period, i.e. longer $Duration_{45°C}$, which resulted in a higher degree of carbon loss, i.e. 51% vs 36% for reactor A without air recirculation (see Table V.10). Smars et al (2002) have demonstrated that the degradation time could be reduced by preventing the temperature from rising until the pH had reached a certain value after the initial phase of the process, because microbes, active in the beginning of the process, were hampered by high temperature. Another advantage found for air recirculation in composting was that the temperature fluctuations were much less in each aeration cycle. With recirculation, the temperature was controlled to within 1 ^{0}C whereas without recirculation, temperature fluctuated up and down by 5 to 8 ^{0}C. This was due to the recirculation of hot air in Reactor B. The effect of temperature variations may cause qualitative shifts in microbial species composition and special tools for incubation of samples in a gradient of stable temperatures have a long record of use in the studies of microbiology (Thamdrup, 1998; Elsgaard, 2002). Recirculation of hot air inside the

reactor should also enhance the homogeneity of compost temperature and compost quality (Tiquia, 2000).

Table V.10 Loss of carbon over composting period as calculated via mass balance (without air recirculation vs with air recirculation) – Lab 3

Reactor	Day	%MC	M	M_w	M_s	%C	M_c	ΔM_c	$\Delta M_c/M_c$
A (without air recirculation)	1	82.83± 1.39	40.0	33.13	6.87	44.24 ±1.56	3.04		
	25	78.52± 0.81	25.7	20.20	5.52	35.19 ±0.65	1.94	-1.09	**-36%**
B (with air recirculation)	1	82.83± 1.39	40.0	33.13	6.87	44.24 ±1.56	3.04		
	25	77.06± 0.92	24.0	18.49	5.51	26.90 ±0.34	1.48	-1.56	**-51%**

Notations : %MC = Mean Moisture Content ± standard deviation; M=Compost Mass; M_w=Water Mass; M_s=Solid Mass ; %C=Mean Percentage of Carbon ± standard deviation; M_c=Carbon Mass; ΔM_c=Change in Carbon Mass.

Another purpose of this test was to verify whether odour problems could be mitigated by applying air-recirculation and a biofilter. Ammonia samples were taken at Day 3, Day 5 and Day 10. The concentrations of ammonia and air outflow rates were recorded and emissions were then calculated. All results are shown in Table V.11. The biofilters were arranged as shown in Figure V.9.

Table V.11 Comparison of Ammonia Emissions

	Inlet NH_3 (ppm) – before biofilter	Avg. Air out rate (L/min)	Emission Rate (µg/min)	Outlet NH3 (ppm) – after biofilter	% Removal
Reactor A Day 3	240	6.0	1034	40	83 %
Reactor B Day 3	250	2.3	413	40	84 %
Reactor A Day 5	270	3.9	756	30	89 %
Reactor B Day 5	360	2.3	595	80	78 %
Reactor A Day 10	230	1.8	297	0	100 %
Reactor B Day 10	270	1.8	349	0	100 %

The results presented in Table V.11 show that the emission rate of NH_3 was much higher from reactor A (no air recirculation) than from reactor B (with air recirculation) after 3 days of composting. Emissions from reactor A continued to be higher after 5 days of composting although the differences in emission trates between the two reactors became smaller after 5 days. Emissions from reactor A became slightly less than reactor B after 10 days during the mesophilic period.

The high emission levels of NH_3 at day 3 in reactor A are attributable to the high air flow rate in the beginning of the process when reactor A used a lot of fresh air (full cycle of 7 L/min) to cool down the compost mass while reactor B used air recirculation cooling. At day 5 the temperature was almost at the setpoint (60 ^{0}C), and therefore the difference in air flow rate between the two reactors became smaller. At day 10, the air flow rates became the same in both reactors since no cooling was needed. The emission rate was slightly higher in reactor B this time because the ammonia concentration was slightly higher in reactor B probably due to the recirculation of ammonia gas back into the reactor in the cooling periods. Since the emission rates from reactor B with air recirculation were less in the thermophilic period when cooling was needed, it would seem that air recirculation was effective in reducing ammonia emissions in the thermophilic period and hence in reducing at least part of the odour emissions.

The use of recycled compost (from Lab 2 and Lab 1) as media in the biofilters also proved effective in removing ammonia (odour) from the process. In most of the cases, especially when the ammonia concentrations were high, the removals ranged from 78% to 100%. Half of the compost from Lab 2 was "cured" in the biofilter and the other

half was cured in ambient air as a control. The ammonia and nitrate concentrations in the compost cured in the biofilters were higher (averaged 25 mg/L vs 7 mg/L and 480 mg/L vs 285 mg/L respectively). This showed that by using compost as a media for biofilter, the ammonia-N was absorbed in the compost media. This was a way to conserve nitrogen in the process.

V.4.1.4 Lab 4 Test

As a continuation of Lab 2 and Lab 3, Lab 4 test was designed to test the differences between cooling and aeration methods. Lab 4 was performed during the clean-up time of Hazelmere Greenhouses. Therefore, shredded year-end pepper wastes, which had about 75% vines and leaves, and 25% used sawdust medium, were used. All 4 reactors were filled with 40 lb (18.2 kg) of shredded year-end pepper wastes and 5 lb of compost from Lab 3 as inoculum. Table V.12 shows the different aeration methods used in each reactor.

Table V.12 Different aeration methods for Lab 4

	Aeration method	Fresh air instantaneous flow and flow control method	Cooling method and cooling control method	Recirculation instantaneous air flow rate	TF set point
Reactor A	Fresh air	7.0 L/min LTF**	Fresh air TF***	N/A	60 ^{0}C
Reactor B	Fresh air	7.0 L/min LTF	Recirculation TF	7 L/min	60 ^{0}C
Reactor C	Fresh air + non-cooling recirculation*	7.0 L/min LTF	Recirculation TF	7 L/min	60 ^{0}C
Reactor D	Fresh air	1.5 L/min (continuous)	None	N/A	N/A

*Air recirculated without passing through heat exchanger, to minimize cooling effect
**LTF- Linear Temperature Feedback (Fraser, 1997)
*** TF – Rutger's Temperature Feedback (Bernal, 1998)

A few comparisons could be achieved using the above matrix :

Reactor A vs Reactor B – Cooling method (fresh air vs recirculation);

Reactor B vs Reactor C – Aeration source (fresh air vs fresh air+recirculation);

Reactor D vs Reactor A,B,C – Aeration control (no control vs control of aeration and cooling).

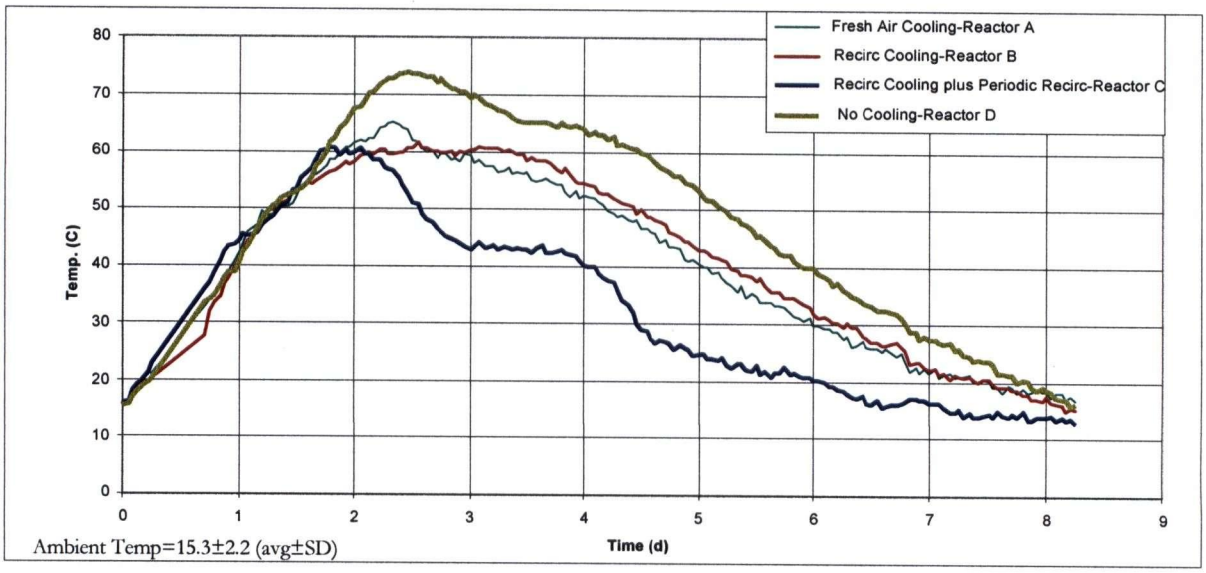


Figure V.12 Temperature Profiles of Lab 4

All 4 reactors began to heat up right away, and had reached 60 ^{0}C by around Day 2, while Reactor D (no cooling) reached almost 70 ^{0}C (see Figure V.12). Reactor A, with fresh air cooling (100% cycle at 7 L/min), over-shot the set point temperature (60 ^{0}C) for 12 hours and reached at maximum ($TEMP_{max}$) of 65 ^{0}C. Reactors B and C were well controlled below the maximum temperature set point ($TEMP_{max}$ = 60 ^{0}C) by air-recirculation cooling. This further confirmed the results from Lab 3 that air recirculation was an effective method for controlling the process temperature below the set point. $Duration_{55°C}$ of Reactors A, B, C and D were 2.2, 2.4, 0.9 and 3.4 days respectively, and therefore only Reactor D could pass the PFRP requirement. $Duration_{45°C}$ of Reactors A,

B, C and D were 3.7, 3.8, 2.0 and 4.6 days respectively, and therefore Reactors A, B and D passed the pasteurization requirement for *Salmonella.* Not much odour was released from these reactors. Reactor C seemed to finish the process at Day 6, while the rest of the reactors did not drop back to ambient temperature until Day 8.

The amounts of leachate and condensate were different in the different reactors (see Table V.13). Most composting processes try to minimize the volume of leachate and condensate since they are generally regarded as wastewaters, unless they are diluted to a non-toxic level (see Chapter VI.4.3). Studies have shown that the amount of leachate and condensate produced was dependent on the percentage of evaporative heat loss, the moisture content of the composting mass, the airflow applied, and the temperature decrease of the air used in the air conveying system prior to discharge to the atmosphere (Bari, 2001). Since the air recirculation was an upward air flow, it helped in keeping the moisture in the compost mass rather than dripping to the bottom since moist air kept recycling from bottom to top through the compost mass. In this case, Reactor C out-performed all the other reactors with only 400 ml of leachate (less than half of Reactor A and B, and only one-third of Reactor D) plus zero condensate. This obviously was one big advantage of air recirculation all the time which retains the moisture in the compost (79% MC with Compost C, 76% with Compost A, 77% with Compost B and 77% with Compost C – see Table V.13) and minimized the amount of wastewater products (leachate and condensate). Condensate was low and leachate was high in Reactor B when compared to Reactor A. It could plausibly because part of the condensate of Reactor B

was collected as leachate during the air recirculation periods, i.e. over 60^0C. All reactors were emptied at Day 8 since they all had dropped to ambient temperature at that point.

Table V.13 Leachate and Condensate from Reactors

	Reactor A	Reactor B	Reactor C	Reactor D
Leachate (ml)	750	850	400	1200
Condensate (ml)	200	15	0	210
Moisture content of finished compost	76.06±1.32	77.10±1.03	79.13±1.11	77.22±0.97

Many studies in composting have reported vertically non-homogenous temperature and moisture distributions in the composting mass (Koenig, 1998). Another purpose of this run was to investigate various aeration and cooling modes to try to improve the vertical distribution of temperature and moisture throughout the depth of the composting mass, and thereby increase the rate of organic degradation. Therefore the temperature differences between the upper (10 cm below the top surface) and lower portions (10 cm above the bottom) of the composting mass were monitored and compared throughout the process. As well the moisture contents were compared at the end of the process (Table V.14).

Table V.14 Vertical variation (top vs bottom) in temperature and moisture content in reactors with different aeration and cooling

	Reactor A	Reactor B	Reactor C	Reactor D
Aeration / cooling method	Fresh air/ Fresh air	Fresh air/ Recirculation	Fresh air + non-cooling recirculation/ Recirculation	Fresh air (fixed)
Average Temperature Variance	4.75 ^{0}C ± 1.85 (189) *	4.19 ^{0}C ± 1.97 (189)	2.86 ^{0}C ± 1.35 (189)	5.82 ^{0}C ± 2.30 (189)
Average Moisture Content Variation	3.7 % ± 1.24 (3)	3.2% ± 1.13 (3)	1.4 % ± 0.63 % (3)	2.3 % ± 0.94 (3)

* ±Standard Deviation (Number of samples, n), n for temperature : # of measurements in 8 days

Since Reactor D was under continuous aeration from the bottom, the compost temperature was always cooled by the ambient air (15-20 ^{0}C) at the bottom layer. Therefore, the vertical temperature variance in reactor D was the highest. Reactor A was under intermittent aeration, and when there was no aeration, air was mixed by natural convection inside the reactor. Therefore, the vertical temperature variance was less than Reactor D. Reactor B had an air recirculation period for cooling when the temperature was above 60 ^{0}C and that explained why the variance was a little less than Reactor A. Reactor C, with full-time air recirculation, achieved the lowest vertical temperature variance, and thus led to a more homogeneous temperature distribution.

In all the cases, moisture contents were higher at the bottom of the reactors since leachate and condensate were moving downward through the compost. Reactor D had a continuous airflow, and therefore moist air was removed from the reactor continuously. This explained why it had a lower variance than Reactors A and B. Reactor B, with limited air recirculation, had a lower variance than Reactor A, Reactor C, with full-time air recirculation, had the lowest variance.

Table V.15 shows the degree of C degradation in the different reactors. The ranking was Reactor C (highest), Reactor B, Reactor A and Reactor D. This coincided with the degree of homogeneity of temperature and moisture content in the different reactors. In conclusion, internal recirculation of air led to a more homogeneous temperature and moisture content distribution throughout the compost mass as compared to no recirculation, resulting in improved organic matter degradation.

Table V.15 Loss of carbon over composting period as calculated via mass balance (without air recirculation vs with air recirculation)

Reactor	Day	%MC	M	M_w	M_s	%C	M_c	ΔM_c	$\Delta M_c/M_c$
A (Fresh air aeration & Fresh air cooling)	1	71.75 ±0.86	45.0	32.29	12.71	33.58 ±0.78	4.27		
	8	76.06 ±1.32	40.0	30.42	9.58	35.23 ±1.53	3.37	-0.90	**-21%**
B (Fresh air aeration & air-recir. cooling)	1	71.75 ±0.86	45.0	32.29	12.71	33.58 ±0.78	4.27		
	8	77.10 ±1.03	36.0	27.76	8.24	37.42 ±1.37	3.08	-1.18	**-28%**
C (Fresh air + recirculation aeration	1	71.75 ±0.86	45.0	32.29	12.71	33.58 ±0.78	4.27		
& air-recirculation cooling	8	79.13 ±1.11	37.5	29.67	7.83	36.89 ±1.19	2.89	-1.38	**-32%**
D (Fixed aeration)	1	71.75 ±0.86	45.0	32.29	12.71	33.58 ±0.78	4.27		
	8	77.22 ±0.97	37.0	28.57	8.43	42.57 ±1.34	3.59	-0.68	**-16%**

Notations : %MC = Mean Moisture Content ± standard deviation; M=Compost Mass; M_w=Water Mass; M_s=Solid Mass ; %C=Mean Percentage of Carbon ± standard deviation; M_c=Carbon Mass; ΔM_c=Change in Carbon Mass.

Conclusions from Part 1 of Lab test results

Bacterial inoculation with manure is not necessary to start up the composting process (Lab 1). Not having to use manure as an inoculum resolves a lot of potential hygienic and transportation problems for greenhouse operators.

With good control of the aeration algorithm and heat loss, composting of greenhouse wastes could satisfy the requirement for a Process to Further Reduce Pathogens (PFRP - 55 ^{0}C for 3 days) and the requirement for inactivation of *Salmonella* (45 ^{0}C for 3 days).

Ammonia concentration could be over 300 ppm and might cause a serious odor problem. Ammonia emissions could be significantly reduced by air-recirculation which had a lower overall air outflow rate. Also, it was proven that the ammonia could be removed by a downstream biofilter with compost as the medium.

Less leachate and condensate were found in the reactors with air recirculation control. This could be a big advantage for greenhouse operators using on-site composting with the in-vessel system since both leachate and condensate were high in ammonia concentration and were required to be treated before land application.

The parameter of air recirculation control was tested in Lab 2, 3 and 4. Even though identical replicates were not done due to the variation in greenhouse waste streams at different times and the unpredictability of the external climate (see V.3.1 Methodology section), recirculation control was found to be a more effective method for maintaining process temperature below a set point than any kind of temperature feedback control in all the three lab runs. Biological agents typically do not survive the high temperature phase of the composting process (Bollen, 1993; Hoitink, 1999) and high temperature (e.g. above 60 ^{0}C) might hamper the microbial activity (Tuomela, 2000).

Morever, in the last three lab runs, systems with air recirculation for cooling and aeration showed higher degradation of C levels, and in Lab 4 particularly, showed more consistent temperatures and moisture contents within the compost mass (upper and lower section), which would plausibly maintain a more consistent compost quality throughout different sections of the compost mass (Tiquia, 2000) , e.g. degree of degradation, stability, achieving PFRP, etc.

Based on higher degradation of C levels (Lab 2, 3 and 4), effective control of maximum set point temperature (Lab 3, and 4), less ammonia emission (Lab 3), less leachate and condensate amount (Lab 4), less vertical variation of temperatures and moisture contents (Lab 4), the incorporation of air recirculation into the fresh air aeration was shown to be a better aeration strategy.

Even though the lab-scale air-recirculated reactor has a lot of advantages, it would require a lot more capital investment (e.g. air pumps, pipings, condensers, insulation, etc) and operating costs, i.e. electricity. For budget reasons, air recirculation devices were not installed in all the experimental setup for further lab tests nor in the pilot scale reactor. In Part 2 of the lab scale tests, the substrate recipe (C:N ratio, moisture content, porosity, etc) will be the focus of investigation.

TESTING OF EFFECTS OF VARIOUS SUBSTRATES

V.4.1.5 Lab 5 Test

After trying different reactor configurations and aeration strategies, the next target was to find out the best substrate recipes for composting greenhouse waste, especially the prunings that were generated everyday. How to maximize the usage of an existing plant waste stream and to minimize the addition of foreign bulking agents and carbon sources (since greenhouse wastes proved to have relatively low C:N ratios) were considered. At the same time, the effects of differences between bulking agents on the process and on the final compost quality were investigated.

Amendments have been used to condition wet substrates and can serve two purposes. First, they can be added to reduce bulk weight and increase void volume allowing for proper aeration. Second, they can be added to increase the quantity of biodegradable organics in the mixture and, thereby, increase the energy content of the mixture (Haug, 1993). A time series study of Carbon, Nitrogen, Moisture Content, Ammonia, Nitrate, Phosphate and pH was conducted during the composting process.

After an extensive search in local gardening and landscaping markets, two bulking agents were found to be most common and readily available in B.C.: alder bark (alder hog fuel) and hemlock bark mulch. So, these two materials were used in the following lab and pilot scale tests as bulking agents. For cost and practicality purposes, the necessity of shredding the prunings before composting was investigated as well. That posed a big concern to the greenhouse operator because shredding 10 acres of daily greenhouse prunings involves a lot of time and labour. In order to minimize errors and costs, all four

reactors used linear temperature feedback for aeration control (intermittent) and air flows were set at 7 L/min with a 100% cycle.

The compost formulations for the various reactors used in Lab 5 are shown in Table V.16.

Figure V.13 plots the temperature profiles. Compost samples (50 g) from each reactor were taken every day for the tracking study. Bio-degradable twines samples were tested in Lab 5 for the rate of bio-degradability (discussed in Chapter IV). All the track study results are shown in Figures V.14 to V.21.

Table V.16 Lab 5 Compost Feedstock Recipes

Batch	Materials	Wt(lb)	Wt%
Reactor A Non-shredded with Hemlock	Non-shredded prunings	22	47.6%
	Hemlock bark	17.6	38.1%
	Used sawdust	4.4	9.5%
	Recycled compost (Pilot 2)	2.2	4.7%
Reactor B Shredded with Hemlock	Shredded prunings	22	47.6%
	Hemlock Bark	17.6	38.1%
	Used sawdust	4.4	9.5%
	Recycled compost (Pilot 2)	2.2	4.7%
Reactor C Non-shredded with fresh alder	Non-shredded prunings	22	47.6%
	Alder bark	17.6	38.1%
	Used sawdust	4.4	9.5%
	Recycled compost (Pilot 2)	2.2	4.7%
Reactor D Shredded with fresh alder	Shredded prunings	22	47.6%
	Alder bark	17.6	38.1%
	Used sawdust	4.4	9.5%
	Recycled compost (Pilot 2)	2.2	4.7%

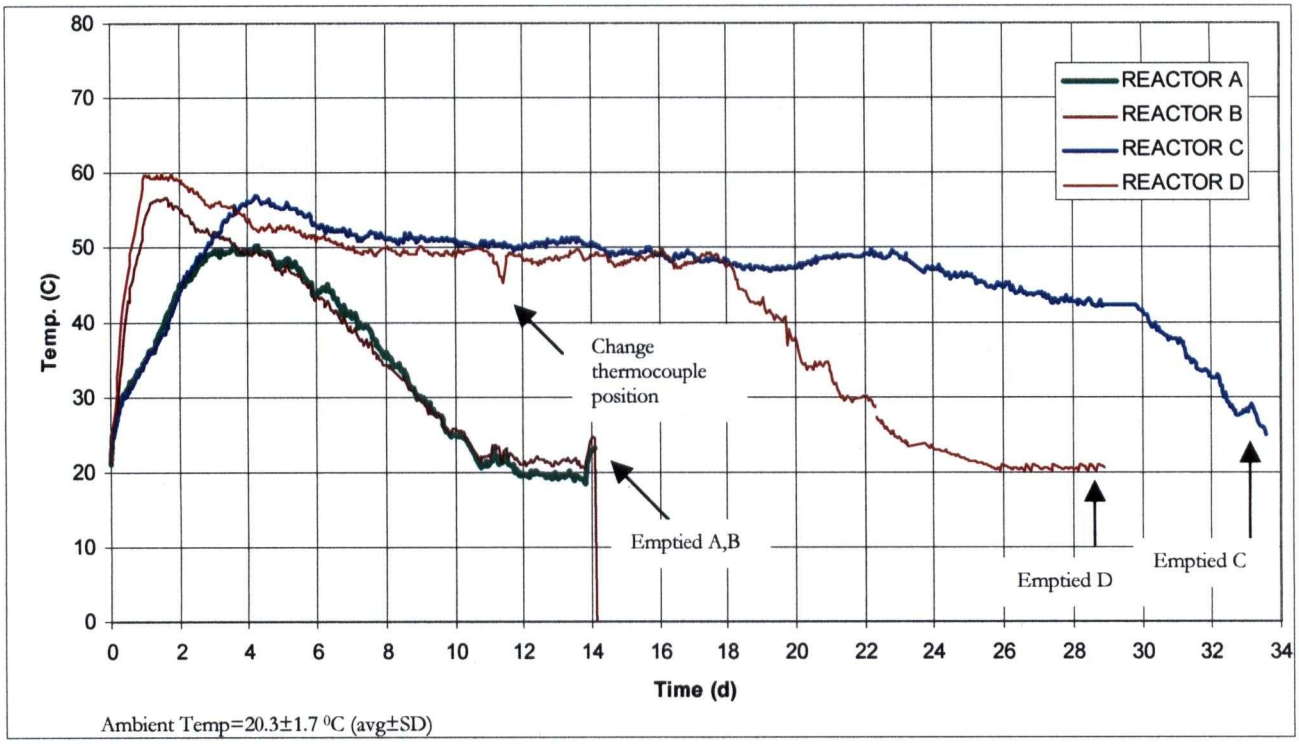


Figure V.13 Temperature Profiles of Lab 5

Both reactors with shredded wastes (reactors B and D) heated up faster (shorter $TIME_{max}$) and reached $TEMP_{max}$ (57 ^{0}C and 60 ^{0}C respectively) at Day 1, while both reactors with non-shredded wastes (reactors A and C) did not reach $TEMP_{max}$ (51 ^{0}C and 57 ^{0}C respectively) until Day 4 (see Figure V.13). This indicated that microbes could degrade carbon faster when the wastes were shredded to increase the surface area available for reaction. None of the reactors passed the PFRP requirement ($Duration_{55°C}$ >3 days). However $Duration_{45°C}$ for reactors A, B, C, D were 4.0, 5.3, 24.0 and 18.2 days, which passed the *Salmonella* pasteurization requirement. All the reactors were opened for re-mixing on Day 12, and since reactor A and B (with hemlock) did not re-heat, they were emptied on Day 14. During the mixing, it was found that the thermocouple in reactor D was not totally submerged into the compost mass; so, another thermocouple was used and

re-positioned properly. Both reactors with alder bark as bulking agent had a prolonged mesophilic stage; reactor C, with non-shredded wastes did not finish until Day 34 while reactor D, with shredded wastes, finished at Day 28. Composting with alder bark gave better temperature performance than composting with hemlock bark.

In Figure V.17 it can be seen that the moisture content in the reactors oscillated around somewhat but the trend was generally down as composting continued. Initially all 4 reactors had a moisture content of 70%. Reactors A and B, which as noted above, were emptied at day 14 had final moisture contents of about 68%, thus not much moisture loss ocurrred. Reactor C's final moisture content was 60% and reactor D's was 57%. Final moisture contents are summarized in Table V.18.

Figure V.14 plots % total carbon vs. composting time. There are no significant differences among the 4 reactor treatments. The final C losses were computed and are summarized in Table V.18. Again no significant differences were observed. Thus unshredded wastes performed as well as shredded wastes in terms of degradation of C containing compounds.

Figure V.15 is a plot of % total nitrogen vs composting time. Table V.19 compares the initial and final amounts of N. Figure V.15 shows an overall increase in total N over the course of the time of composting with some oscillations along the way. In the beginning of the composting process N was released in the form of ammonium-nitrate and some of it was taken up by the compost as can be seen in Figure V.18. The concentration of nitrate in the compost also built up as seen in Figure V.19. Thus near the start of the composting process proteins began to decompose early in the thermophilic

phase. Some of the resulting NH_3 can be oxidized to NO_3 in a nitrification process mediated by microorganisms.

Figure V.16 contains a plot of the C:N ratio over the duration of the composting period. Initially values of this ratio decreased for all 4 reactors. From Figure V.15 and Figure V.18, there were initial increases in total N and NH_3, and from Figure V.14, there was an initial decrease in total C. Therefore, overall there was an initial decrease in the C:N ratio. The C:N ratio of all 4 reactors had dropped to between 25 to 30 (from 30 to 35) at the end.

Figure V.20 shows the data for P concentration. Figure V.21 plots pH vs composting time. At the end of the active composting time (14 days for reactors A and B and 28-33 days for reactors D and C) the pH had dropped a little from its initial value but was always within 0.5 pH units of neutrality (pH 7.0). Lower levels of pH near the end of composting probably occurred because organic acids were generated during the process. For reactors C and D phosphate levels tended to go down during composting. For reactors A and B they more or less remained the same although there were oscillations. Possibly the PO_4 concentration was associated with PO_4 solubility as a function of pH.

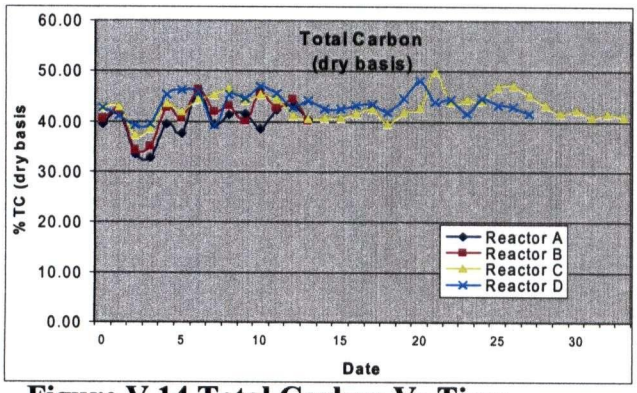


Figure V.14 Total Carbon Vs Time

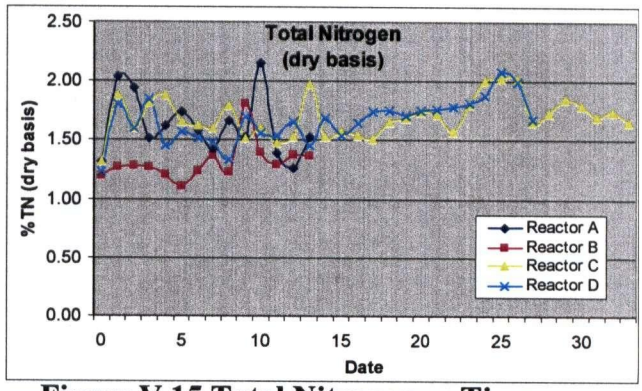


Figure V.15 Total Nitrogen vs Time

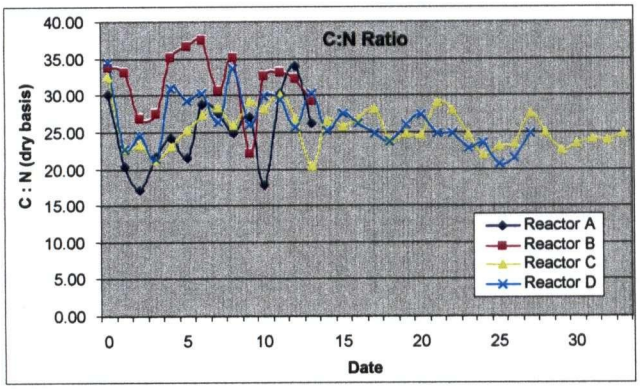


Figure V.16 C:N Ratio vs Time

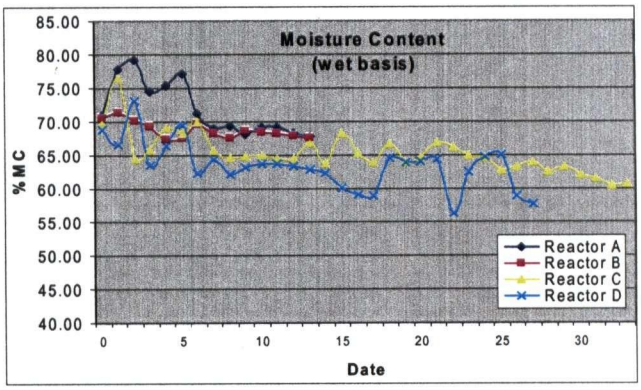


Figure V.17 MC (wet basis) vs Time

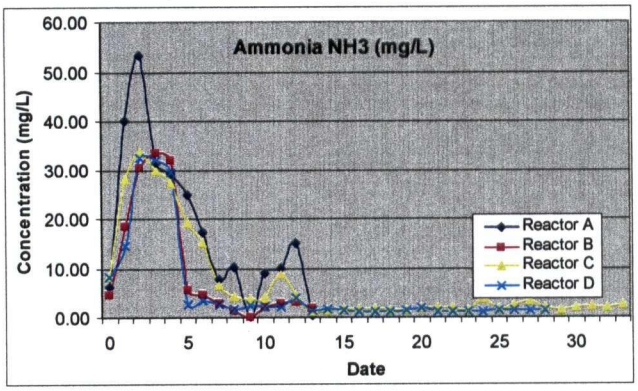


Figure V.18 Ammonia vs Time

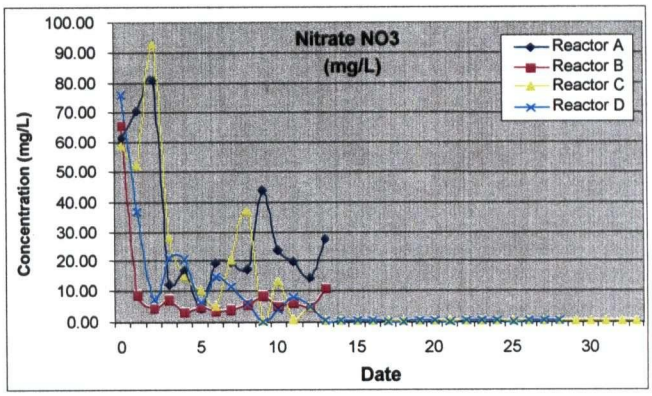


Figure V.19 Nitrate vs Time

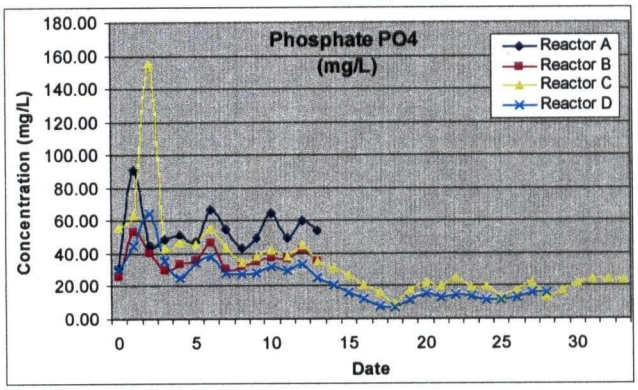


Figure V.20 Phosphate vs Time

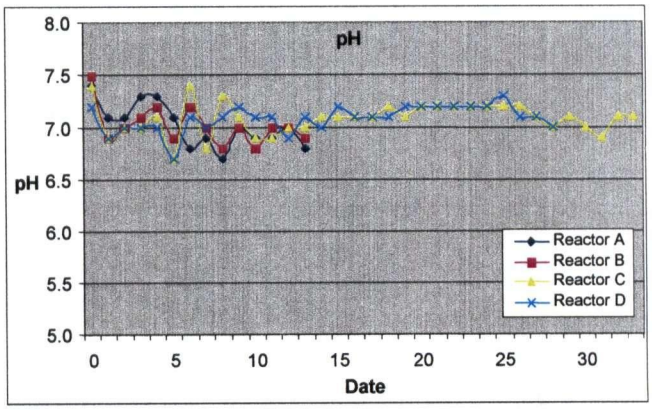


Figure V.21 pH vs Time

Table V.17 provides data on the amounts of condensate and leachate collected from the 4 reactors over the total active composting period.

Comparing the amount of leachate from reactor A (non shredded) with that of reactor B showed that shredding definitely resulted in more leachate. No doubt this occurred because the shredding process damaged the plant structure allowing its liquid contents to more readily leak out. This can also be seen by comparing reactors C and D. The amount of leachate produced did not seem to depend on whether the bulking agent was alder or hemlock bark.

Comparing the amounts of condensate generated between reactors A and B and reactors C and D again showed that the shredding process resulted in more condensate. This probably occurred because the shredding process released more plant liquids so more of it was evaporated leading to condensate. The greater amounts of condensate collected from reactors C and D merely reflect that they ran at a high temperature for more or less twice as long as reactors A and B. From the wastewater standpoint, the non-shredded wastes were preferable since less wastewater (leachate and condensate) would need to be treated.

Table V.17 Cumulative amounts of Leachate and Condensate from Reactors

	Reactor A Hemlock/Non-Shredded	Reactor B Hemlock/ Shredded	Reactor C Alder/Non-shredded	Reactor D Alder/ Shredded
Leachate (ml)	45	180	75	140
Condensate (ml)	410	830	1800	2710

Table V.18 Loss of carbon over composting period as calculated via mass balance

Reactor	Day	%MC	M	M_w	M_s	%C	M_c	ΔM_c	$\Delta M_c/M_c$
A (Non-shredded with hemlock)	1	71.07 ±0.81	46.2	32.83	13.37	39.51 ±1.15	5.28		
	14	67.95 ±1.01	32.6	22.15	10.45	40.32 ±2.01	4.21	-1.07	**-20%**
B (Shredded with hemlock)	1	70.77 ±0.94	46.2	32.70	13.50	40.31 ±1.41	5.44		
	14	66.76 ±1.32	33.0	22.03	10.97	39.98 ±0.99	4.39	-1.06	**-19%**
C (Non-shredded with alder)	1	70.19 ±0.73	46.2	32.43	13.77	42.75 ±1.16	5.89		
	34	60.72 ±0.69	28.6	17.37	11.23	40.93 ±0.87	4.60	-1.29	**-22%**
D (Shredded with alder)	1	68.95 ±1.26	46.2	31.85	14.35	42.61 ±1.18	6.11		
	28	57.80 ±0.95	26.4	15.26	11.14	41.58 ±1.20	4.63	-1.48	**-24%**

Notations : %MC = Mean Moisture Content ± standard deviation; M=Compost Mass; M_w=Water Mass; M_s=Solid Mass ; %C=Mean Percentage of Carbon ± standard deviation; M_c=Carbon Mass; ΔM_c=Change in Carbon Mass.

Table V.18 shows the loss of carbon for each reactor. Even though the total carbon concentration did not decrease (see Figure V.16), the total mass of carbon in the compost mass was reduced about 20% because of an overall weight loss (mass balance). Unshredded wastes seemed to be as good as shredded wastes in terms of degradation. The reactors using alder bark seemed to have a more complete bio-conversion than the ones using hemlock bark, considering the reaction temperature and the loss of carbon. The longer period at high temperature and a higher degree of degradation suggested a higher content of biodegradable organic matter in the alder bark. This is consistent with a typically higher biodegradable fraction in hardwood bark (alder) compared to softwood bark (hemlock) (Haug, 1993).

Table V.19 Loss of Nitrogen over composting period as calculated via mass balance

Reactor	Day	%MC	M	M_w	M_s	%N	M_n	ΔM_n	$\Delta M_n/M_n$
A (Non-shredded with hemlock)	1	71.07 ±0.81	46.2	32.83	13.37	1.31 ±0.18	0.18		
	14	67.95 ±1.01	32.6	22.15	10.45	1.53 ±0.21	0.16	-0.015	**-9%**
B (Shredded with hemlock)	1	70.77 ±0.94	46.2	32.70	13.50	1.19 ±0.09	0.16		
	14	66.76 ±1.32	33.0	22.03	10.97	1.36 ±0.15	0.15	-0.012	**-7%**
C (Non-shredded with alder)	1	70.19 ±0.73	46.2	32.43	13.77	1.31 ±0.11	0.18		
	34	60.72 ±0.69	28.6	17.37	11.23	1.65 ±0.14	0.19	0.005	**3%**
D (Shredded with alder)	1	68.95 ±1.26	46.2	31.85	14.35	1.23 ±0.08	0.18		
	28	57.80 ±0.95	26.4	15.26	11.14	1.67 ±0.13	0.19	0.010	**5%**

Notations : MC=Moisture Content; M=Compost Mass; M_w=Water Mass; M_s=Solid Mass ; %N=Mean Percentage of Nitrogen ± Standard Deviation; M_n=Nitrogen Mass; ΔM_n=Change in Nitrogen Mass.

The actual availability and the release potential of nitrogen are important factors in determining plant growth rate in the presence of compost. During aerobic composting, some of the initial nitrogen content in the feedstocks can be lost. Nitrogen loss can be reduced by using higher C:N mixtures that enhance N immobilization or by lowering the pH of the compost to increase ammonium solubility during the thermophilic stage (Raviv, 2002). Sawdust and bark were found to be efficient bulking agents to reduce the loss of nitrogen due to volatilization of ammonia during composting (Morisaki, 1989).

Table V.19 shows the nitrogen balance in each reactor. The reactors with alder bark as bulking agent showed a net increase in total nitrogen mass, compared to losses in the ones with hemlock bark. The reason for a net gain in nitrogen could be due to

nitrogen fixation, though much of the fixed nitrogen would have to be converted to organic form, i.e. microbial biomass, since the higher ammonium- and nitrate-nitrogen could only account for a portion of the increase. Since the experiments with alder bark contained more readily degradable carbon, as shown in Table V.18, it helped to immobilize nitrogen. One the other hand, the hemlock bark, containing less readily degradable carbon, allowed more nitrogen to be lost (Hansen, 1989). The relatively low pH (below 7) in the thermophilic stage, as shown in Figure V.21, would also help in conserving nitrogen by reducing ammonia volatilization.

V.4.1.6 Lab 6 Test

Lab 6 was an attempted repeat of Lab 5 in order to re-confirm that alder bark would be a better choice than hemlock bark as the bulking agent. In order to minimize any experimental errors caused by variation in reactors, the alder and hemlock barks were put in different reactor orders this time (see Table V.20). The porosities of shredded and non-shredded wastes were also compared. According to the BC Provincial composting guidelines, bulk densities of the mixture less than 550 to 640 kg/m3 are usually adequate (Ministry of Agriculture, Fisheries, and Food, 1991). This was only achieved when the substrates were not shredded (reactor A and B) (see Table V.20).

The oxygen profile was monitored in one of the reactors (reactor A, in this case) in order to see the oxygen consumption at different stages of the process (see Figure V.23).

During this testing period, it was extremely cold inside the warehouse of the greenhouse since the greenhouse production had ceased during that period, and thus there were substantial heat losses from the reactors. Therefore the reactors, in spite of being insulated, were unable to reach the desirable high temperature as they did in the Lab 5 tests (see Figure V.22).

Table V.20 lists the feedstock recipes used in this set of experiments as well as the measurements of initial bulk density and porosity. From the data in Table V.20, it can be noted that shredding the prunings resulted in higher bulk density compared with not shredding them. Compare reactor A with reactor C and reactor B with reactor D. As would be expected from the bulk density observations, shredding (reactors B and D) resulted in lower porosities when compared to the non-shredded reactors (A and C).

Use of alder bark as bulking agent produced greater bulk density than hemlock bark. Compare reactors A and B, and C and D. With the non-shredded prunings hemlock bark gave a higher porosity (reactor B vs reactor A), but with the shredded prunings alder bark resulted in a slightly higher porosity.

Table V.20 Lab 6 Compost Feedstock Recipes

Batch	Materials	Wt (lb)	Wt%	Bulk Density (kg/m3)	Porosity (%)
Reactor A Non-shredded with alder	Non-shredded prunings	22	47.6%	588±24(3)	45.6±2.3 % (3)
	Alder bark	17.6	38.1%		
	Used sawdust	4.4	9.5%		
	Recycled compost (Pilot 2)	2.2	4.7%		
Reactor B Non-shredded with hemlock	Non-shredded prunings	22	47.6%	419±21(3)	57±2.1% (3)
	Hemlock bark mulch	17.6	38.1%		
	Used sawdust	4.4	9.5%		
	Recycled compost (Pilot 2)	2.2	4.7%		
Reactor C Shredded with alder	Shredded prunings	22	47.6%	778±35(3)	34.7±1.8 % (3)
	Alder bark	17.6	38.1%		
	Used sawdust	4.4	9.5%		
	Recycled compost (Pilot 2)	2.2	4.7%		
Reactor D Shredded with hemlock	Shredded prunings	22	47.6%	704±29 (3)	30.4±1.5 % (3)
	Hemlock bark mulch	17.6	38.1%		
	Used sawdust	4.4	9.5%		
	Recycled compost (Pilot 2)	2.2	4.7%		

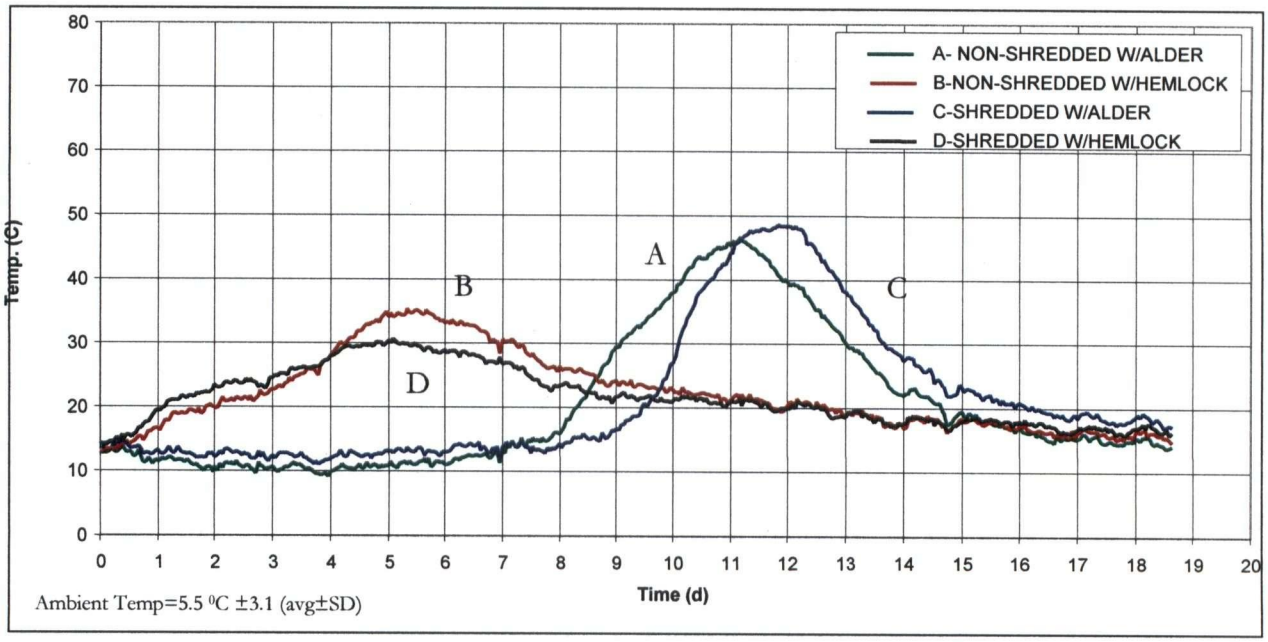


Figure V.22 Temperature Profiles of Lab 6

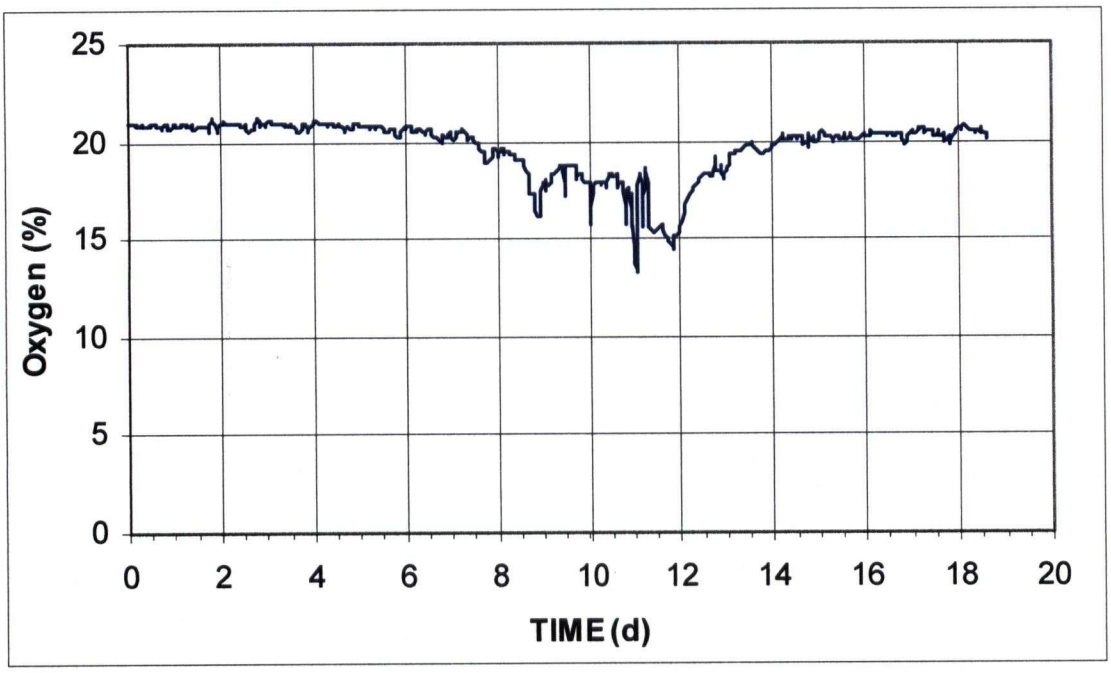


Figure V.23 Lab 6 Reactor A Oxygen Concentration (%) vs. Time

Both reactors with hemlock bark as bulking agent (reactors B and D) heated up faster than those with alder (A and C) (See Figure V.22) (shorter $TIME_{max}$) but only reached $TEMP_{max}$ of 35 ^{0}C and 31 ^{0}C for the non-shredded and shredded wastes respectively. On the other hand, in the other two reactors, with alder bark as bulking agent, non-shredded waste (reactors A and C) heated up more slowly but reached a higher $TEMP_{max}$ (47 ^{0}C and 49 ^{0}C respectively) at Day 11 and Day 12. None of the reactors passed the PFRP requirement ($Duration_{55°C}$ >3 days) nor the *Salmonella* pasteurization requirement ($Duration_{45°C}$ >3 days), due to the heat losses during the process. In reactor A, the oxygen level (Figure V.23) was at about 21 % over the beginning 8 days, when there was no apparent heating up of the process. It then began to deplete when the process temperature went up from Day 8 to Day 14. Oxygen consumption was higher

during the high temperature period of the process. However, in that high rate of degradation period, the oxygen level still maintained above 14% throughout the process which is within the ideal range for optimal aerobic degradation (VanderGheynst, 1997; Bari, 2001). All the reactors were emptied on Day 18 since no re-heating had occurred after mixing.

After the active composting process, the substrates were cured in a covered and ventilated shed. It was interesting to discover that seedlings were found in the curing piles from reactors B and D, both of which did not achieve high enough temperatures to kill seeds. This showed that when the composting temperature was not high enough, seeds in the greenhouse wastes would not be killed and would germinate during curing. This would not be desirable for any compost users. Therefore this would be an important factor to consider in deciding whether the process was able to make good quality compost.

The results of Lab 6, with the same substrate recipe as Lab 5, are consistent with those presented in Lab 5. First of all, they showed that shredding was not necessary since the reaction times and temperatures were about the same. Secondly, it showed that with alder bark as the bulking agent, the microbial activities were higher (higher temperature) and led to a higher degradations of organic C, as shown in Table V.21. : 26 % and 29 % with alder bark versus 9 % and 10 % with hemlock bark, even though this lab run was conducted in a extremely cold environment (average 5^0C ambient temperature).

Table V.21 Loss of carbon over composting period as calculated via mass balance

Reactor	Day	%MC	M	M_w	M_s	%C	M_c	ΔM_c	$\Delta M_c/M_c$
A (Non-shredded with alder)	1	70.05 ±1.38	46.2	32.36	13.84	42.59 ±1.86	5.89		
	18	76.06 ±1.57	39.5	30.04	9.46	46.10 ±1.45	4.36	-1.53	**-26%**
B (Non-shredded with hemlock)	1	74.30 ±1.12	46.2	34.33	11.87	38.92 ±0.93	4.62		
	18	77.10 ±0.98	38.4	29.61	8.79	47.73 ±0.86	4.20	-0.42	**-9%**
C (Shredded with alder)	1	70.05 ±1.54	46.2	32.36	13.84	41.32 ±1.15	5.72		
	18	79.13 ±1.63	41.2	32.60	8.60	47.21 ±1.36	4.06	-1.66	**-29%**
D (Shredded with hemlock)	1	74.30 ±1.29	46.2	34.33	11.87	39.14 ±1.28	4.65		
	18	77.22 ±1.41	38.1	29.44	8.68	48.22 ±1.13	4.19	-0.46	**-10%**

Notations : %MC = Mean Moisture Content ± standard deviation; M=Compost Mass; M_w=Water Mass; M_s=Solid Mass ; %C=Mean Percentage of Carbon ± standard deviation; M_c=Carbon Mass; ΔM_c=Change in Carbon Mass.

V.4.1.7 Lab 7 Test

In Lab 5 and Lab 6, it was determined that alder bark was a better choice of bulking agent than hemlock bark. There are 2 kinds of alder bark available on the market: fresh alder bark and composted alder bark with the latter being more expensive. In this lab run, these two different alder barks were tested using the same mixing ratios as in the previous lab runs. Table V.22 shows the mixing ratios for reactors A to D.

Table V.22 Lab 7 Compost Feedstock Recipes

Batch	Materials	Wt(lb)	Wt%
Reactor A shredded with fresh alder	Shredded prunings	22	47.6%
	Fresh alder bark	17.6	38.1%
	Used sawdust	4.4	9.5%
	Recycled compost (Pilot 2)	2.2	4.7%
Reactor B non-shredded with fresh alder	Non-shredded prunings	22	47.6%
	Fresh alder bark	17.6	38.1%
	Used sawdust	4.4	9.5%
	Recycled compost (Pilot 2)	2.2	4.7%
Reactor C shredded with composted alder	Shredded prunings	22	47.6%
	Composted alder bark	17.6	38.1%
	Used sawdust	4.4	9.5%
	Recycled compost (Pilot 2)	2.2	4.7%
Reactor D Non-shredded with composted alder	Non-shredded prunings	22	47.6%
	Composted alder bark	17.6	38.1%
	Used Sawdust	4.4	9.5%
	Recycled compost (Pilot 2)	2.2	4.7%

A few comparisons could be achieved using the above matrix :

Reactor A vs Reactor B and Reactor C vs Reactor D – Unshredded vs Shredded waste.

Reactor A vs Reactor C and Reactor B vs Reactor D – Fresh Alder vs Composted Alder Bark as bulking agents

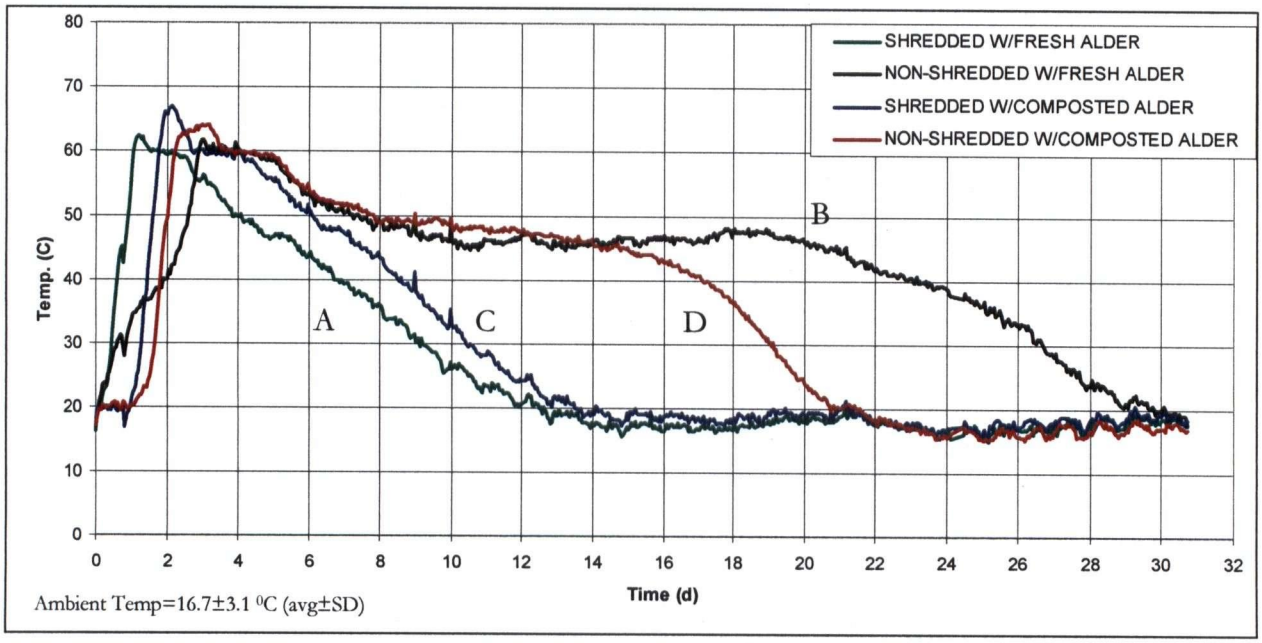


Figure V.24 Temperature Profile of Lab 7

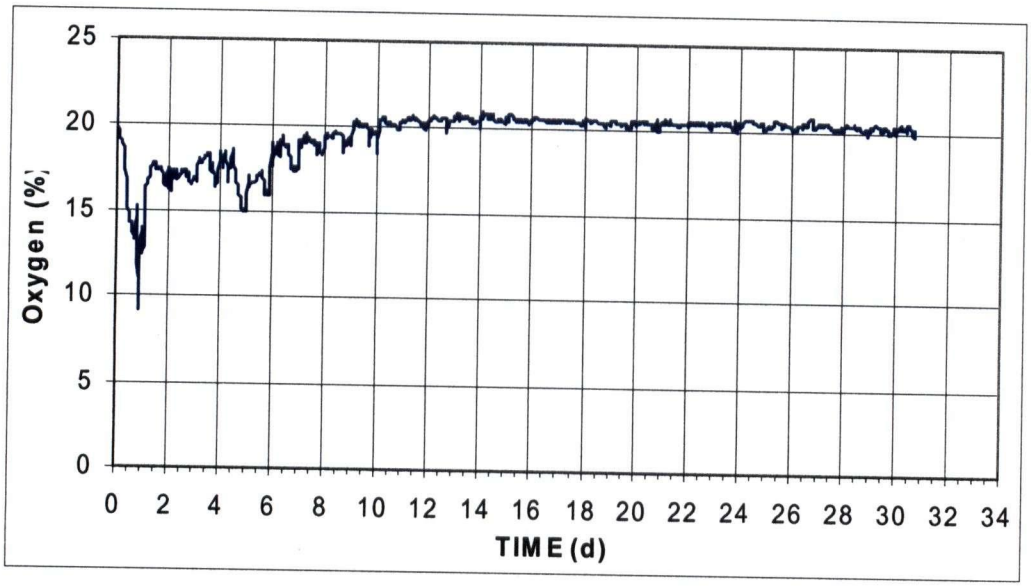


Figure V.25 Lab 7 Reactor A Oxygen Concentration vs. Time

Both reactors with shredded wastes began to heat up before those containing non-shredded waste (see Figure V.24) (shorter $TIME_{max}$), similar to the results observed in Labs 5 and 6. The $TEMP_{max}$ of reactors A, B, C, and D were 63 ^{0}C, 62^{0}C, 68 ^{0}C and 65 ^{0}C respectively. The $Duration_{55°C}$ of reactors A, B, C and D were 2.2, 3.0, 3.4 and 3.6 days respectively. So all of them, except reactor A, passed the PFRP requirement ($Duration_{55°C}$ >3 days). $Duration_{45°C}$ of reactors A, B, C and D were 5.2, 18.6, 6.4 and 14.1 days respectively and therefore all of them passed the *Salmonella* pasteurization requirement ($Duration_{45°C}$ >3 days). All the reactors had similar temperature profiles in the thermophilic stage but the ones with non-shredded wastes had longer mesophilic periods. The active composting finished at day 14 for reactors A and C, at day 21 for reactor D and at day 28 for reactor B, i.e. the non-shredded wastes with fresh alder bark had the longest reaction times. All the reactors over-shot their set point temperatures (60

^{0}C) in the beginning of the thermophilic stage and were able to be cooled down to 60 ^{0}C or below shortly after (within 24 hours) by applying full cycle aeration from the linear temperature feedback control. During those short periods when the temperature had over-shot the set point, the oxygen content went below 15% (between 10 to 15%). It went back up to above 15 % when the temperature was successfully kept below the set point as shown in Figure V.21. This showed that it was important to have a control strategy capable of supplying enough oxygen, as well as cooling in the thermophilic stage. In this case the linear temperature feedback control was again proven to be effective.

The purpose of this experiment was to find out whether using composted alder basrk would enhance the process and whether shredding was necessary before composting the greenhouse prunings.

Table V.23 shows the loss of carbon in each reactor after the composting process. The substrates with fresh alder bark had a slightly higher degree of degradation of C than the ones with composted alder bark (36% vs 33% for shredded, and 38% vs 35% for non-shredded waste). This could have been due to the lower initial biodegradable carbon content in the composted alder bark since it had already gone through a degradation process. The process times with the shredded prunings were the same for both when using fresh alder or composted alder (14 days) bark. The process times of the non-shredded prunings were slightly shorter for the composted alder than for the fresh alder (24 days vs 28 days). So, the process time did not appear to be much affected by whether fresh alder or composted alder bark was used. But it was affected by whether the prunings were shredded or not. Process time would be a less important issue than cost for greenhouse

operators. Therefore, fresh alder bark (less expensive) as bulking agent and non-shredded prunings (less material handling cost) would be preferable.

Table V.23 Loss of carbon over composting period as calculated via mass balance

Reactor	Day	%MC	M	M_w	M_s	%C	M_c	ΔM_c	$\Delta M_c/M_c$
A (shredded with fresh alder)	1	70.89 ±1.43	46.2	32.75	13.45	40.58 ±0.82	5.46		
	14	71.75 ±1.13	28.0	20.09	7.91	44.13 ±0.85	3.49	-1.97	-36%
B (Non-shredded with fresh alder)	1	71.32 ±0.94	46.2	32.95	13.25	41.32 ±0.96	5.47		
	28	70.51 ±1.41	27.0	19.04	7.96	42.59 ±1.17	3.39	-2.08	-38%
C (Shredded with composted alder)	1	72.35 ±1.16	46.2	33.43	12.77	38.65 ±0.57	4.94		
	14	72.90 ±1.12	28.0	20.41	7.59	43.38 ±0.74	3.29	-1.65	-33%
D (Non-Shredded with composted alder)	1	72.98 ±1.29	46.2	33.72	12.48	39.14 ±0.68	4.89		
	24	70.27 ±1.38	24.5	17.22	7.28	43.76 ±0.83	3.19	-1.70	-35%

Notations : %MC = Mean Moisture Content ± standard deviation; M=Compost Mass; M_w=Water Mass; M_s=Solid Mass ; %C=Mean Percentage of Carbon ± standard deviation; M_c=Carbon Mass; ΔM_c=Change in Carbon Mass.

V.4.1.8 Lab 8 Test

In this test, since fresh alder bark and no shredding had been decided upon from previous tests, different amounts of fresh alder bark were used in order to find out the best mixing ratio. Table V.24 provides the feedstock makeup and Figure V.26 provides the temperature profiles in the 4 reactors.

Table V.24 Lab 8 Compost Feedstock Recipes

Batch	Materials	Wt(lb)	Wt%
Reactor A	Non-shredded prunings	22	100 %
Reactor B	Non-shredded prunings	18.7	85%
	Fresh alder bark	3.3	15%
Reactor C	Non-shredded prunings	15.4	70%
	Fresh alder bark	6.6	30%
Reactor D	Non-shredded prunings	12.1	55%
	Fresh alder bark	9.9	45%

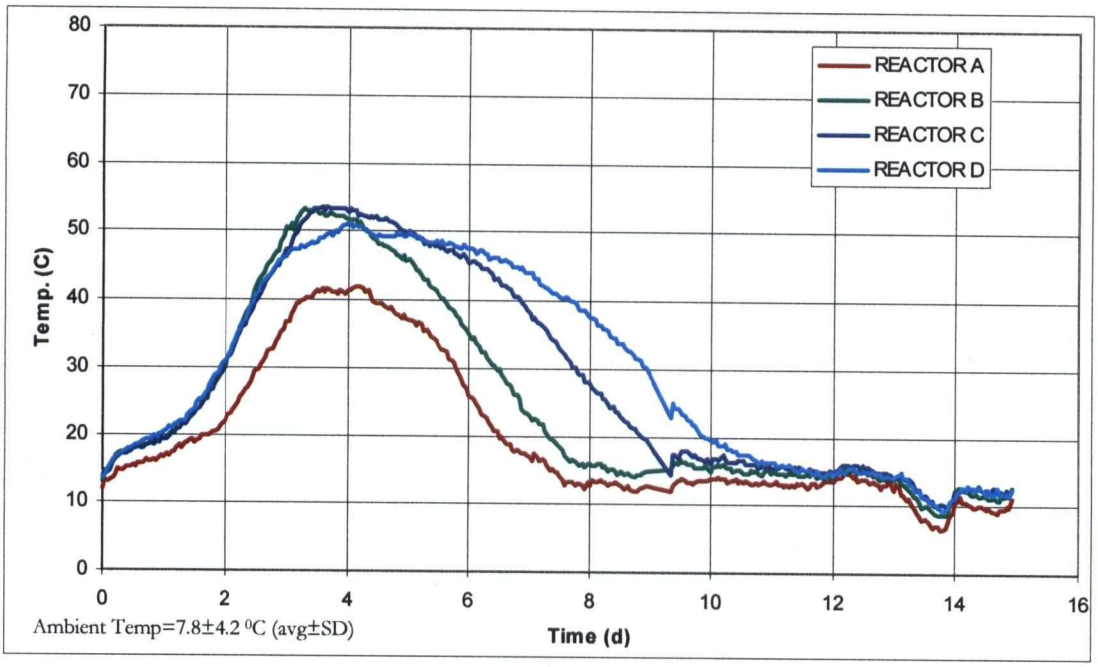


Figure V.26 Temperature Profile of Lab 8

All the reactors reached the $TEMP_{max}$ by about day 3 or 4. The $TEMP_{max}$ of reactors A, B, C, and D were 41.8 ^{0}C, 53.2^{0}C, 53.6 ^{0}C and 50.9 ^{0}C respectively. None of reactors passed the PFRP requirement ($Duration_{55°C}$ >3 days), which was probably due to the extremely cold ambient temperature. Even though all the reactors were well-insulated, the fresh air supplied to the reactors cooled down the substrates significantly.

$Duration_{45°C}$ of reactors A, B, C and D were 0, 2.4, 3.5 and 4.1 days respectively and therefore only reactors C and D passed the *Salmonella* pasteurization requirement ($Duration_{45°C}$ >3 days).

Reactor A, with no bulking agent, took longer to get started then the other 3 reactors, displayed lower temperatures throughout the active composting period and finished the active composting phase the soonest. This implies that addition of a bulking agent was beneficial as far as temperature profile was concerned.

Reactor D, with 45% bulking agent, maintained a relatively high temperature over the longest time compared to the other reactors. Reactor C, with 30% bulking agent was next, followed by reactor B, with 15% bulking agent.

Table V.25 shows the amounts of leachate and condensate collected from each reactor. The amount of leachate seemed to be related to the initial moisture content of the substrate – the higher the initial moisture content, the higher the leachate amount. The initial moisture content was dependent on the amount of bulking agent used since the bulking agent moisture content was lower than that of the prunings (60.39% vs 87.88%). So, it was reasonable to conclude that the more bulking agent used (alder bark), the less leachate would be generated. The amount of condensate tended to correlate with the duration at high temperature of the process. It was highest with the highest sustained temperature reactor (reactor D) i.e. the higher the temperature and longer it was sustained, the more condensate that was generated.

Table V.25 Leachate and Condensate from Reactors

	Reactor A 100 %	Reactor B 85% / 15%	Reactor C 70% / 30%	Reactor D 55% / 45%
Leachate (ml)	3000	1950	1550	1100
Initial MC	87.88±0.94	87.20±1.25	82.38±1.05	75.51±0.92
Final MC	85.56±2.24	84.03±1.20	73.86±0.93	72.77±1.12
Condensate (ml)	210	400	400	870
$Duration_{45°C}$ (D)	0	2.4	3.5	4.1

Table V.26 Loss of carbon over composting period as calculated via mass balance

Reactor	Day	%MC	M	M_w	M_s	%C	M_c	ΔM_c	$\Delta M_c/M_c$
A (100 % non-shredded pruning)	1	87.88 ±0.97	22.0	19.33	2.67	30.33 ±0.56	0.81		
	14	85.56 ±1.23	10.6	9.04	1.52	31.18 ±0.85	0.48	-0.33	**-41%**
B (85% non-shredded pruning/ 15%fresh alder)	1	87.20 ±0.85	22.0	19.18	2.82	36.65 ±1.16	1.03		
	14	84.03 ±0.59	14.5	12.20	2.32	31.51 ±1.11	0.73	-0.30	**-29%**
C (70% non-shredded pruning/ 30%fresh alder)	1	82.38 ±0.68	22.0	18.12	3.88	41.37 ±1.74	1.60		
	14	78.89 ±0.83	15.0	11.80	3.16	36.73 ±0.84	1.16	-0.44	**-28%**
D (55% non-shredded pruning/ 45%fresh alder)	1	75.51 ±0.48	22.0	16.61	5.39	42.22 ±0.93	2.27		
	14	72.77 ±1.13	16.7	12.17	4.55	36.51 ±0.79	1.66	-0.61	**-27%**

Notations : %MC = Mean Moisture Content ± standard deviation; M=Compost Mass; M_w=Water Mass; M_s=Solid Mass ; %C=Mean Percentage of Carbon ± standard deviation; M_c=Carbon Mass; ΔM_c=Change in Carbon Mass.

Table V.26 shows the carbon loss from each reactor with the different bulking agent mixing ratios. The one with zero bulking agent, reactor A, demonstrated the highest carbon loss (41%), while the rest of other reactors had more or less the same loss at 27 to 29%. Reactor A had largest loss of carbon, likely because the prunings have greater amount of available carbon as compared to alder having more lignocellulose content.

Even though reactor A had the highest carbon loss over the active composting period, it had the highest phyto toxicity, i.e. lowest germination rate and root index compared to the others (see Figure VI.5 from Chapter VI). Therefore, the percentage of carbon loss might not always be a good indicator of compost maturity and quality.

Moreover, reactor A had a much higher nitrogen loss (52%) than did reactors B, C and D (18%, 18%, 12% respectively) (see Table V.27). Nitrogen loss occurring during composting is a key issue and nitrogen volatilization reduces the fertilizer value of the finished compost and thus constitutes an economic loss. Barrington et al. (2002) measured the effect of carbon source on nitrogen losses by volatilization during composting and found that the moisture content of the bulking agents and aeration regime had no consistent significant effect on N and C losses by volatilization; only the type and amount of bulking agent had a significant effect. Martin et al.(1993) investigated the effects of peat and sawdust, employed as bulking agents, in composting and found that mixing enough bulking agent to absorb the moisture of substrate was an important element in controlling nitrogen losses during composting. This agrees with the results found in this lab study.

Table V.27 Loss of Nitrogen over composting period as calculated via mass balance

Reactor	Day	%MC	M	M_w	M_s	%N	M_n	ΔM_n	$\Delta M_n/M_n$
A (100 % non-shredded pruning)	1	87.88 ±0.97	22.0	19.33	2.67	3.89 ±0.18	0.10		
	14	85.56 ±1.23	10.6	9.04	1.52	3.25 ±0.07	0.05	-0.05	-52%
B (85% non-shredded pruning/ 15%fresh alder)	1	87.20 ±0.85	22.0	19.18	2.82	2.33 ±0.16	0.07		
	14	84.03 ±0.59	14.5	12.20	2.32	2.31 ±0.21	0.05	-0.01	-18%
C (70% non-shredded pruning/ 30%fresh alder)	1	82.38 ±0.68	22.0	18.12	3.88	2.01 ±0.13	0.08		
	14	78.89 ±0.83	15.0	11.80	3.16	2.17 ±0.09	0.07	-0.01	-12%
D (55% non-shredded pruning/ 45%fresh alder)	1	75.51 ±0.48	22.0	16.61	5.39	1.77 ±0.06	0.10		
	14	72.77 ±1.13	16.7	12.17	4.55	1.85 ±0.15	0.08	-0.01	-12%

Notations : MC=Moisture Content; M=Compost Mass; M_w=Water Mass; M_s=Solid Mass ; %N=Mean Percentage of Nitrogen ± Standard Deviation; M_n=Nitrogen Mass; ΔM_n=Change in Nitrogen Mass.

V.4.1.9 Lab 9 Test

At the end of a crop year (December), all the vines, leaves and the sawdust growing medium (yellow cedar) are removed from the greenhouses. Since the vines could be as long as 30 to 40 feet, they had to be shredded before putting them into the composter. Moreover, 75 tonnes per hectare of sawdust had to be treated as well. The sawdust could be a good carbon source to supplement the relatively low C:N ratio of the vines; however, it would not be as a good a bulking agent as fresh alder bark since it lacked the necessary structure and porosity. It would be beneficial for greenhouse operators to know how much the sawdust could be utilized without affecting the compost

process and compost quality. In this test, different ratios of alder bark and sawdust medium were used in order to find out the best mixing ratio. Table V.28 lists the components and their proportions in the compost mix for this test.

Table V.28 Lab 9 Compost Feedstock Recipes

Batch	Materials	Wt(lb)	Wt%
Reactor A	Shredded year-end vines	26.4	60%
	Alder bark	0	0%
	Used sawdust	17.6	40%
Reactor B	Shredded year-end vines	26.4	60%
	Alder bark	6.16	14%
	Used sawdust	11.44	26%
Reactor C	Shredded year-end vines	27.28	62%
	Alder bark	11.0	25%
	Used sawdust	5.72	13%
Reactor D	Shredded year-end vines	28.6	65%
	Alder bark	15.4	35%
	Used sawdust	0	0 %

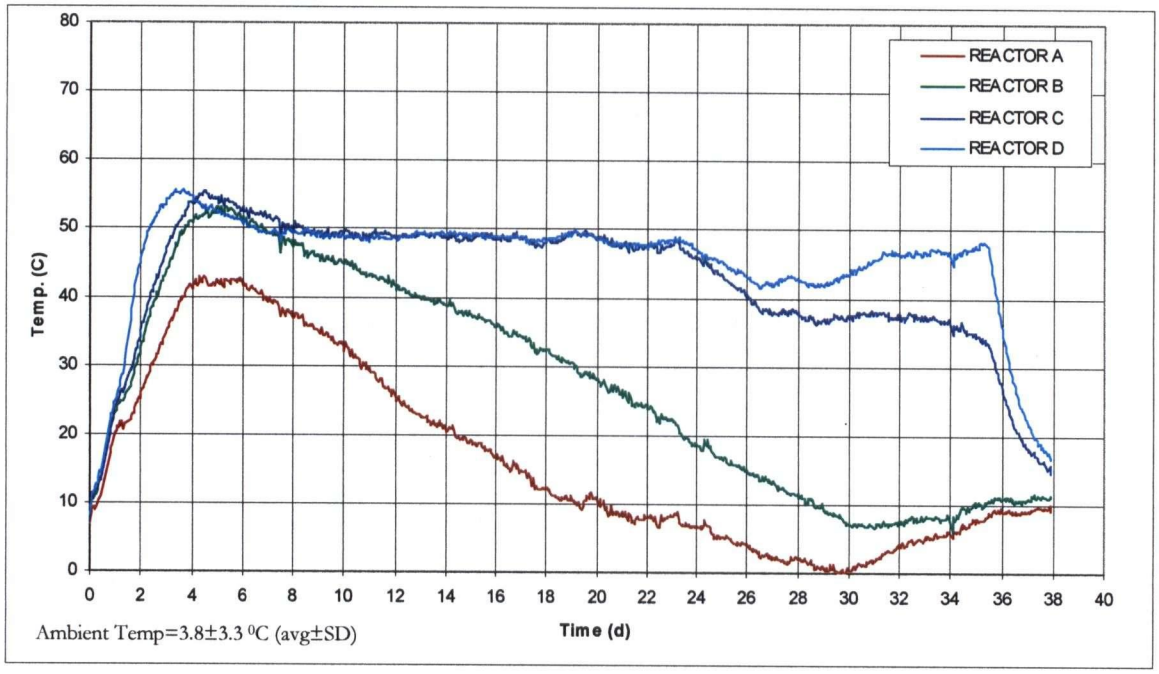


Figure V.27 Temperature Profiles of Lab 9

The reactors started to heat up at different times, see Figure V.27. The $TIME_{max}$ of reactors A, B, C, D were 5, 4.8, 4.3 and 3.6 days respectively. The $TEMP_{max}$ of reactors A, B, C, and D were 42.6 ^{0}C, 52.7^{0}C, 55.2 ^{0}C and 55.6 ^{0}C respectively. None of reactors passed the PFRP requirement ($Duration_{55°C}$ >3 days), which was probably due to the extremely cold ambient air temperature (0-5 ^{0}C) at the time. $Duration_{45°C}$ of reactors A, B, C and D were 0, 7.1, 21.6 and 29.2 days respectively and therefore reactors B, C and D passed the *Salmonella* pasteurization requirement ($Duration_{45°C}$ >3 days).

Reactor D (35% alder bark, no sawdust) heated up most quickly and maintained the highest temperature longest implying that sawdust was detrimental to the composting process. Reactor C (25% alder bark, 13% sawdust) gave the next best thermal performance which was not greatly different from that of reactor D except near the end of the composting. Thus, it was shown that it was possible to tolerate some sawdust. Reactor B (14% alder bark, 26% sawdust) and reactor A (no alder bark, 40% sawdust), in that order, gave rise to worse thermal performances. As a result, the temperature profiles trends were as follows : 1. The substrate heated up faster with more fresh alder bark($TIME_{max}$ D<C<B<A); 2. The substrate heated up to higher temperature with more fresh alder ($TEMP_{max}$ D>C>B>A); 3. The high temperature period sustained longer with a greater fresh alder bark ratio ($Duration_{45°C}$ D>C>B>A).

Table V.29 Leachate and Condensate from Reactors

	Reactor A 60%, 0%, 40%*	Reactor B 60%, 14%, 26%	Reactor C 62%, 25%, 13%	Reactor D 65%, 35%, 0%
Leachate (ml)	2800	3000	1600	900
Initial MC	85.02±1.20	82.37±1.53	80.75±0.84	77.38±0.97
Final MC	82.91±0.94	79.92±1.32	78.42±1.15	71.91±1.25
Condensate (ml)	660	780	2700	3720
$Duration_{45°C}$ (D)	0	7.1	21.6	29.20

*vines, bark, sawdust

Table V.29 shows the amounts of leachate and condensate collected from each reactor. Again, similar to the results presented in Lab 8, the amount of leachate appears to be correlated with the initial moisture content of the substrate – the higher the initial moisture content, the higher the leachate amount. The initial moisture content was dependent on the amount of fresh alder bark used instead of sawdust (moisture contents of 60.40% and 82.77% respectively). So, it was reasonable to conclude that the higher the alder bark to sawdust ratio used, the less leachate would be generated. Also, the amount of condensate correlated directly with the duration of high temperature of the process. It was highest in highest sustained temperature reactor (reactor D) i.e. the higher the temperature and the longer it sustained, the more condensate generated.

Table V.30 shows the carbon loss from each reactor with different sawdust to alder bark mixing ratios. All the reactors showed quite similar carbon losses (between 25 and 29%) and were relatively lower than for the substrates used in Lab 8. This was

because the year-end vines and sawdust did not contain as much readily biodegradable carbon and were not as easy to degrade as the daily prunings (leaves and cull fruit).

Reactors A and B, with the greater proportions of sawdust demonstrated slightly lower carbon losses (24% and 25%), while the ones with the greater proportions of alder bark (reactors C, and D demonstrated slightly higher carbon losses (29% and 28%).

Reactor D also showed the highest germination rate and root index compared to the others (see Figure VI.6 in Chapter VI).

Table V.31 shows that reactors A and B had much higher nitrogen losses (44% and 34%) than reactors C and D (14% and 7%). Most of the nitrogen losses were due to NH_3 volatilization. Leaching has been said to account for about one fifth of the N losses and only a little N is lost due to denitrification (Sommer, 2001). In this case, the relatively high volume of leachate, which contained a high concentration of ammonia and nitrate (see Table VI.9 from Chapter VI), from reactors A and B (2800 and 3000 ml) than from reactors C and D (900 and 1600 ml) would probably account for part of the high N losses.

Barrington et al. (2002) also recorded their highest N losses in compost substrate with shavings (sawdust) as bulking agent, compared to wheat straw, hay and oat straw. This showed that sawdust is not a good amendment to control nitrogen loss. A greenhouse operator would like to get rid of the waste sawdust by incorporating it into compost and, at the same time, produce high quality compost. With this in mind a mixing ratio of 62% vines, 13% sawdust and 25% alder bark is recommended as being a reasonable mixture to achieve good results.

Table V.30 Loss of carbon over composting period as calculated via mass balance

Reactor	Day	%MC	M	M_w	M_s	%C	M_c	ΔM_c	$\Delta M_c/M_c$
A 60%, 0%, 40%	1	85.02 ±1.47	44.0	37.41	6.59	40.33 ±0.87	2.66		
	30	82.91 ±1.83	31.2	25.90	5.34	38.06 ±0.65	2.03	-0.63	-24%
B 60%, 14%, 26%	1	82.37 ±1.76	44.0	36.24	7.76	43.66 ±0.58	3.39		
	30	79.92 ±0.96	30.8	24.62	6.18	40.89 ±0.81	2.53	-0.86	-25%
C 62%, 25%, 13%	1	80.75 ±1.25	44.0	35.53	8.47	45.32 ±1.03	3.84		
	38	78.42 ±0.89	31.2	24.50	6.74	40.48 ±1.08	2.73	-1.11	-29%
D 65%, 35%, 0%	1	77.38 ±0.78	44.0	34.05	9.95	48.56 ±0.91	4.83		
	38	71.91 ±1.27	29.9	21.52	8.40	41.39 ±0.38	3.48	-1.35	-28%

Notations : %MC = Mean Moisture Content ± standard deviation; M=Compost Mass; M_w=Water Mass; M_s=Solid Mass ; %C=Mean Percentage of Carbon ± standard deviation; M_c=Carbon Mass; ΔM_c=Change in Carbon Mass.

Table V.31 Loss of Nitrogen over composting period as calculated via mass balance

Reactor	Day	%MC	M	M_w	M_s	%N	M_n	ΔM_n	$\Delta M_n/M_n$
A 60%, 0%, 40%	1	85.02 ±1.47	44.0	37.41	6.59	1.87 ±0.12	0.12		
	30	82.91 ±1.83	31.2	25.90	5.34	1.30 ±0.05	0.07	-0.05	-44%
B 60%, 14%, 26%	1	82.37 ±1.76	44.0	36.24	7.76	1.81 ±0.12	0.14		
	30	79.92 ±0.96	30.8	24.62	6.18	1.50 ±0.09	0.09	-0.05	-34%
C 62%, 25%, 13%	1	80.75 ±1.25	44.0	35.53	8.47	1.74 ±0.15	0.15		
	38	78.42 ±0.89	31.2	24.50	6.74	1.89 ±0.13	0.13	-0.02	-14%
D 65%, 35%, 0%	1	77.38 ±0.78	44.0	34.05	9.95	1.46 ±0.09	0.15		
	38	71.91 ±1.27	29.9	21.52	8.40	1.60 ±0.07	0.13	-0.01	-7%

Notations : MC=Moisture Content; M=Compost Mass; M_w=Water Mass; M_s=Solid Mass ; %N=Mean Percentage of Nitrogen ± Standard Deviation; M_n=Nitrogen Mass; ΔM_n=Change in Nitrogen Mass.

Conclusions from Part 2 of Lab test results

Following the plan of testing different substrates and bulking agents, even though there was no identical replicate of each lab run, each parameter was tested and re-confirmed in at least 2 different lab runs.

In Lab 5 and Lab 6, alder bark was found to be a better choice of bulking agent than hemlock bark in terms of better substrate structure, more carbon degradation, less nitrogen loss, and higher process temperature.

In Labs 5, 6 and 7, shredding was shown not to be necessary before composting of prunings and non-shredded prunings also helped in minimizing the amount of leachate. A longer mesophilic temperature regime was maintained after peak temperatures had been

attained in the composting of non-shredded wastes. Since prunings are generated every day from the greenhouses, composting without shredding means a lot of cost savings.

As shown in Lab 8 and Lab 9, the amount of leachate was correlated with the initial moisture content of the substrate and the amount of condensate was correlated with the duration of the high temperature part of the process.

Fresh alder bark was found to be as good as composted bark in terms of process time and loss of carbon (extent of degradation) when used as the bulking agent in Lab 7. Morever, fresh bark is less expensive compared to composted bark. Lab 8 was designed to test the minimum amount of bulking agent needed for composting daily prunings and results indicated that using 30% alder bark (by weight) as bulking agent was best for composting prunings.

Lab 9 was designed to investigate the best amount of used sawdust and alder bark to blend for composting year-end wastes. For year-end wastes, shredding is necessary, and a ratio of 62% vines, 13% used sawdust and 25% alder bark was recommended based on observations made over a range of bark to sawdust to waste plant material ratios. This was in consideration of good thermal performance (via temperature profile), less leachate, greater loss in carbon and smaller loss in nitrogen. Composting without sawdust was in fact the best recipe, however, for practical purposes, greenhouse operators need to have the used sawdust composted.

V.4.2 PILOT SCALE COMPOSTING DATA

In total, there were 8 pilot scale composting tests done in this part of the study. Each of them used from 5 to 10 tonnes of greenhouse waste. They were designed to fine-tune the in-vessel composting process until it reached the objectives of processing the greenhouse wastes produced at different times of the year. Table V.32 shows the composition of each batch in the pilot scale compost tests.

Table V.32 Pilot Scale Compost Feedstock Recipes

Batch	Materials	Proportion by Volume
P1	Unshredded tomato and/or pepper prunings (leaves and vines)	75%
	Shredded prunings and cull fruit	17%
	Used sawdust	8%
P2	Shredded year-end pepper vines	67%
	Used sawdust	33%
P3	Unshredded tomato and/or pepper leaf prunings (partially rotted)	27%
	Cull tomatoes	31%
	Used sawdust medium	38%
	Compost recycle	4%
P4	Unshredded tomato and/or pepper leaf prunings (partially rotted)	43%
	Used sawdust medium	14%
	Alder bark	43%
P5	Shredded year-end cucumber vines and fruit	66%
	Alder bark	34%
P6	Unshredded tomato and/or pepper leaf prunings	60%
	Used sawdust	10%
	Alder bark	30%
P7	Shredded year-end tomato vines	87%
	Used sawdust	13%
P8	Unshredded tomato and/or pepper leaf prunings and fruit culls	50%
	Used sawdust	10%
	Alder bark	20%
	Compost coarse fragment recycle	20%

The pilot scale tests were not designed to test or compare the effects of any parameters as was done in the lab scale tests; but instead, their purpose was to serve as a real demonstration for greenhouse operators. In some cases, they also served as a second proof of some of the lab test results. There were limitations in pilot tests as compared to lab tests, for example, weighing input wastes and output compost were not possible in the pilot tests because of the volume of the wastes and lack of proper device. Table V.33 summarizes the results obtained from the pilot scale compost tests.

Table V.33 Pilot Composting Experimental Details and Results Summary

Batch	# of days of active composting	Continuous airflow setting (% of maximum)	Intermittent airflow duty cycle (%)	Temp. setpoint	Feed-stock vol. m^3	Final Vol. m^3 (volume reduction)	PFRP Achieved	Leachate generated (litres)
P1	43	80	20	60	9	4.5 (50%)	Y[1]	800
P2	51	60	20	60	9	6.9 (23%)	Y	200
P3	29	90	20	65	10	8.8 (12%)	N	1200
P4	35	60	20	65	7	5.7 (20%)	Y[2]	200
P5	34	60	20	65	10	6.1 (39%)	Y	210
P6	30	100	20-40	65	11	8.8 (20%)	Y[2]	400
P7	28	50-100	20	60	10	6.9 (31%)	Y	1200
P8	38	50-100	20	60	12	9.3 (23%)	Y[2]	750

[1]Based on data from a single thermocouple.
[2]Achieved in some but not all the thermocouple locations.
Note: PFRP is Process to Further Reduce Pathogens, and requires 3 days at 55 °C minimum.

Figures V.28, V.29, V.30, V.31, V.34, V.35, V.37 and V.38 are the compost temperature vs. time plots for the 8 pilot scale tests. Since the compost was replaced by new material after each run, the thermocouples were not always in the same place inside the composting pile in each experiment, nor were the same number of thermocouples always used. The location of thermocouples were dependent on the dimension of waste mass inside the reactor. For example, sometimes the volume of wastes could only occupy rear half of the container, and therefore the thermocouple would be placed at the back.

No replicate tests were performed because of (i) the large scale at which the experiments were carried out, and in some cases year-end crop wastes were used, rendering replication impractical; (ii) the time limit due to the long duration of the experiments (almost one month per experiment); (iii) the need to test a wide range of different substrates and operational variables and (iv) budget constraints. VanderGheynst et al. (1997) faced similar difficulties in their pilot composting studies, and concluded that as long as the composter showed similar temperature profiles with similar initial conditions, the composter was then considered able to duplicate behaviour well. Pilot 1, 6 (Fig. V.28, Fig. V.35) and Pilot 4, 8 (Fig. V.31, Fig.V.38) in this study had similar initial conditions and showed similar temperature profiles.

Pilot 1 – prunings/ vines /fruit/sawdust

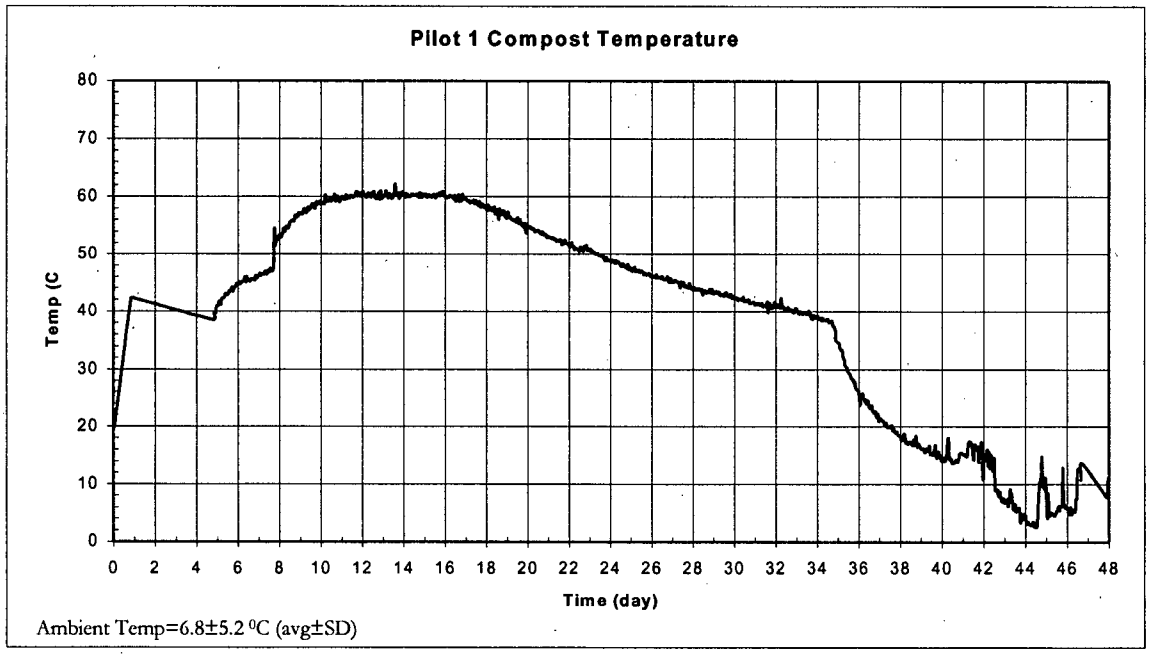
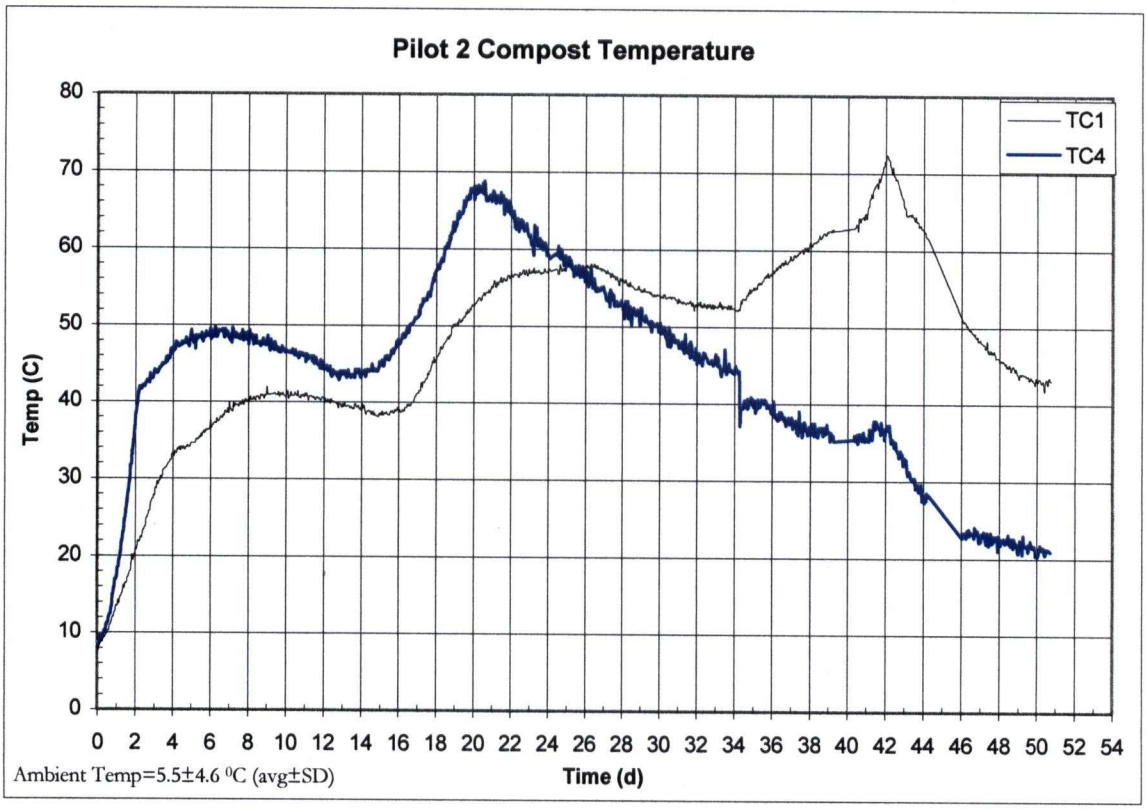


Figure V.28 Pilot 1 Temperature Profile

In this run the first mixture of feedstocks was composted in the pilot composter, using pruning waste and used sawdust growing medium. However during active composting, the material collapsed and became anaerobic at the bottom, due to a lack of physical structure and porosity in the mixture. Because of excessive wetness and odour, the composter was left open with the fan on (100% cycle) for three days at the end of the active cycle. The material was mixed with more sawdust prior to placing in a curing pile.

This failure demonstrated the need for a bulking agent with this mixture of prunings, vines, culled fruit and sawdust.

Pilot 2 – year-end vines/sawdust



TC1 - Centre depth, near back
TC4 - Centre depth, near front

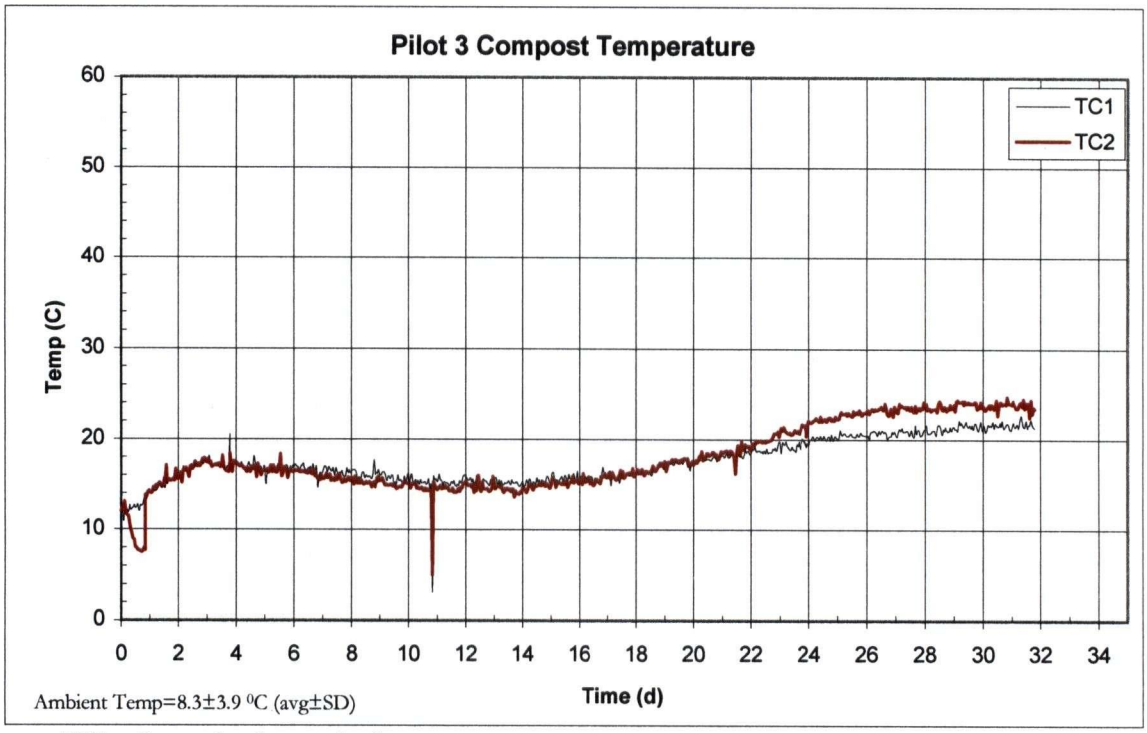
Figure V.29 Pilot 2 Temperature Profiles

In the second run, rather than using tomato prunings, year-end pepper vines were used, which were available because of the crop cleanup underway at that time. The vines were shredded and mixed with used sawdust growing medium. The year end vines, which would be expected to have greater porosity, provided a compost pile with better structure since the vines would be more resistant to collapse.

During the process, some uneven heating was observed. The thermocouple close to the door (TC4) showed heating sooner than TC1, which was closer to the rear of the

composter. This may have been due to uneven aeration or non-uniform mixing of the compost before loading it into the composter. However, the temperatures did reach PFRP and the resulting compost had a pleasant smell and medium to dark brown colour, suggesting a good composting process. Leachate production was smaller than in Pilot 1 (200 L vs 800 L).

Pilot 3 – prunings/fruits/ sawdust/ compost



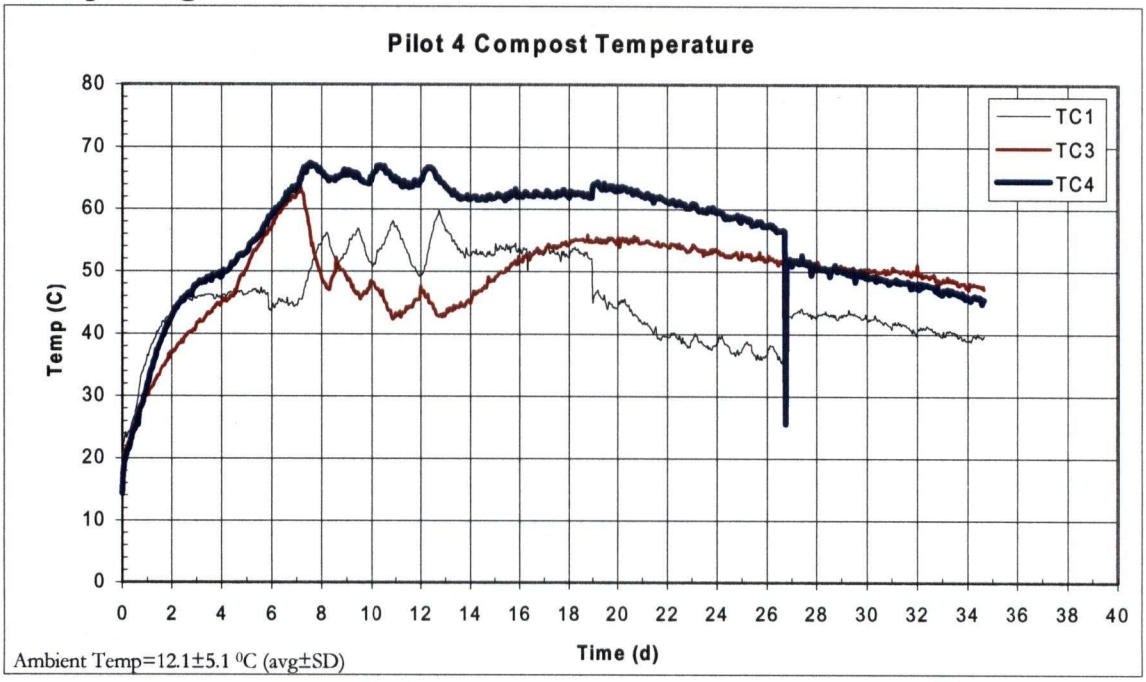
TC1 - Centre depth, near back
TC2 - Near surface, near front

Figure V.30 Pilot 3 Temperature Profiles

In this batch, the feedstock materials were similar to those of batch 1, but incorporating more tomato fruit, and a much larger proportion of sawdust in an attempt to utilize more of the greenhouse used sawdust waste as requested by the greenhouse operator. A small amount of finished compost was also included.

During the active composting process, the materials again proved to be too dense and too wet, and became anaerobic. As a result, thermophilic temperatures were not reached. Large amounts of leachate and odour were also generated (1200 L). After one month, the materials were removed, remixed with alder hog fuel, and placed in a windrow. The problems encountered appear to have been due to inadequate physical structure in the mixture (too much sawdust instead of alder as bulking agent), compounded by the partially rotted leaves and a larger amount of fruit. This was quite similar to the situation in Lab 8 Reactor A, which had 100% prunings and no bulking agent, and could not reach thermophilic temperatures. Again, the lack of sufficient bulking agent was obvious.

Pilot 4 – prunings/ sawdust/ alder bark



TC1 - Centre depth, near back
TC3 - Centre-lower depth, near centre
TC4 - Centre depth, near front

Figure V.31 Pilot 4 Temperature Profiles

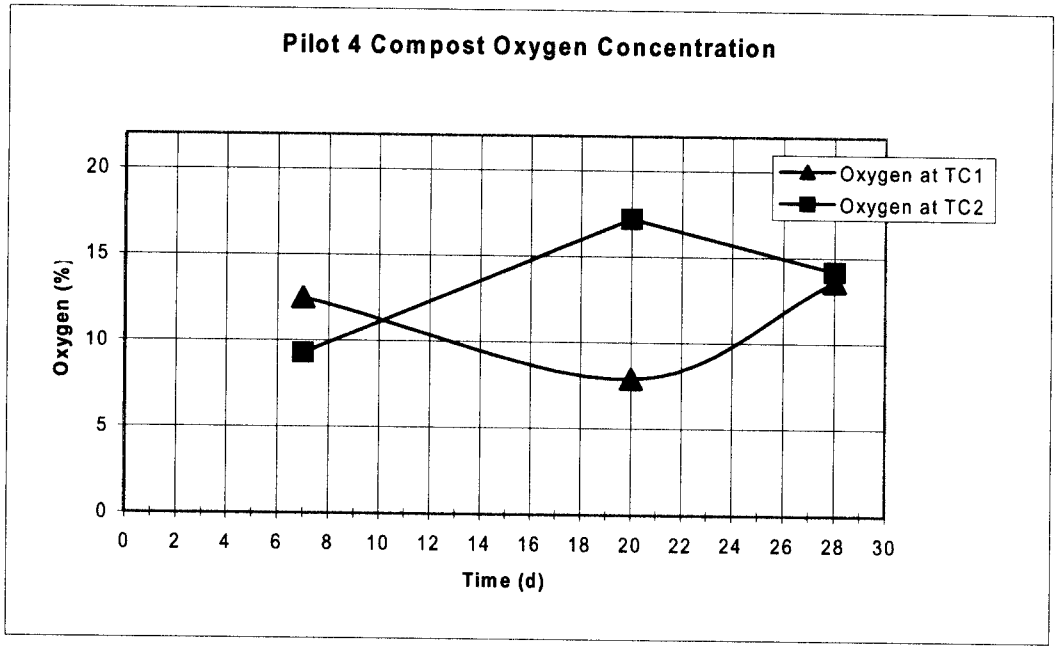


Figure V.32 Pilot 4 Oxygen Profiles

Based on the negative experiences with batches 1 and 3, it was determined that for composting fresh prunings and fruit in the pilot scale composter, an additional bulking agent was required. For batch 4, alder bark, as recommended from Labs 5 and 6, was added in equal parts by volume to the leaf prunings.

Addition of the alder bark proved successful in preventing collapse and anaerobic conditions. Thermophilic temperatures were reached, though there was still some uneven heating, with PFRP reached in some areas and not in others.

There was also extensive growth of visible fungus, including mushrooms on the surface during active composting.

Several oxygen measurements confirmed conditions were aerobic but values as low as 8% were noted which are less than the recommended minimum of 14% (VanderGheynst, 1997).

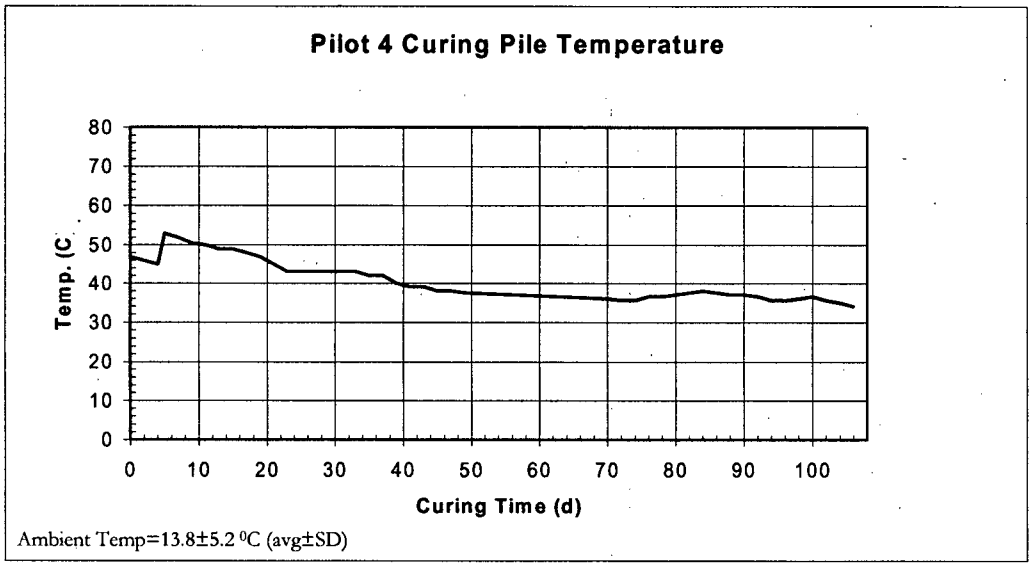
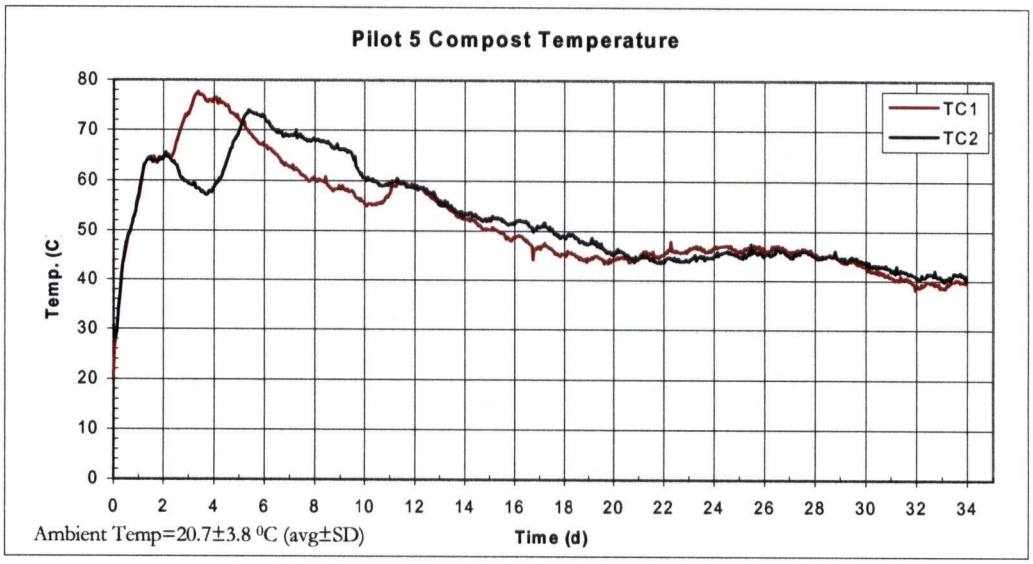


Figure V.33 Pilot 4 Temperature Profile of Curing

For this batch, temperature in the curing pile was also logged. The results showed limited reheating to about 53 °C initially, then the temperature dropped gradually to below 40 °C after 6 weeks, and to about 36 °C after 10 weeks (see Figure V.33).

Pilot 5 – year-end vines/ fruit/ hemlock bark mulch



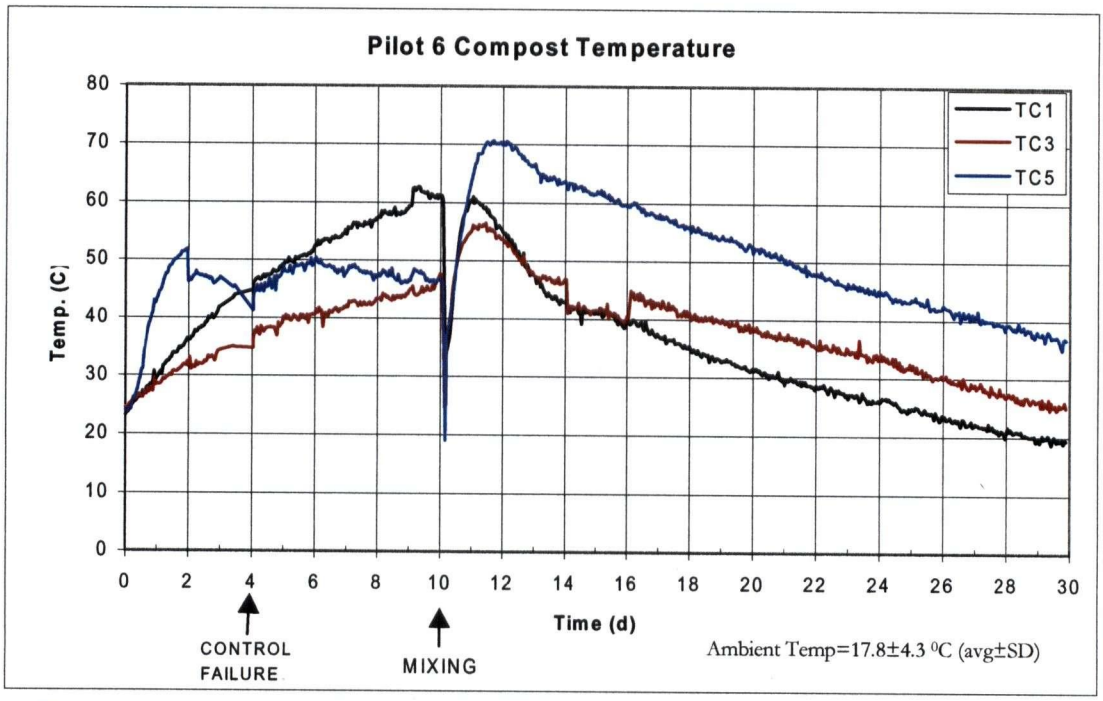
TC1 - Centre depth, near back
TC2 - Centre depth, near centre

Figure V.34 Pilot 5 Temperature Profiles

For this batch, composting of shredded year-end cucumber vines and fruit was attempted. Some alder bark was mixed with the shredded waste to ensure porosity was adequate, based on the apparent high density of the shredded material.

Thermophilic temperatures were achieved, reaching nearly 80 °C and satisfying PRFP. Higher temperatures compared to shredded pepper and tomato vine composting could have been due to more energy available from the cucumber waste, or an increased oxidation rate due to the higher porosity resulting from the added bulking agent. Small amounts of leachate were generated (210 L). The appearance of the finished compost was slightly different, in that it had a stringy texture, probably due to the fibrous cucumber vines. Again, addition of a bulking agent resulted in improved performance.

Pilot 6 – prunings/ sawdust/ alder bark



TC1 - Near surface, near back
TC3 - Centre depth, near centre
TC5 - Near surface, near front

Figure V.35 Pilot 6 Temperature Profiles

In Pilot 6 the proportion of bark mixed with prunings was decreased to 1/2 (volume basis) to determine the minimum amount required. During active composting, some anaerobic conditions and odour developed due to inadequate porosity and physical structure. Figure V.36 plots % O_2 vs time and shows that indeed near anaerobic conditions occurred early in the cycle. After 10 days the material was removed and remixed with additional bark. Following remixing, thermophilic temperatures were reached, with PFRP achieved in some parts of the material. A moderate amount of leachate was generated.

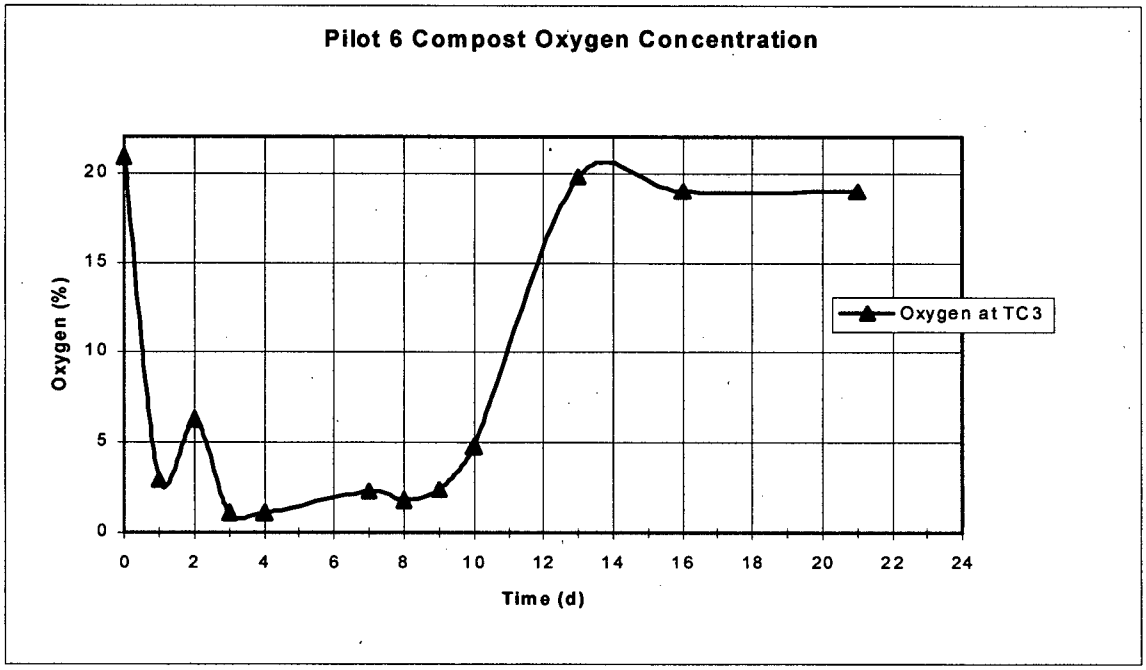
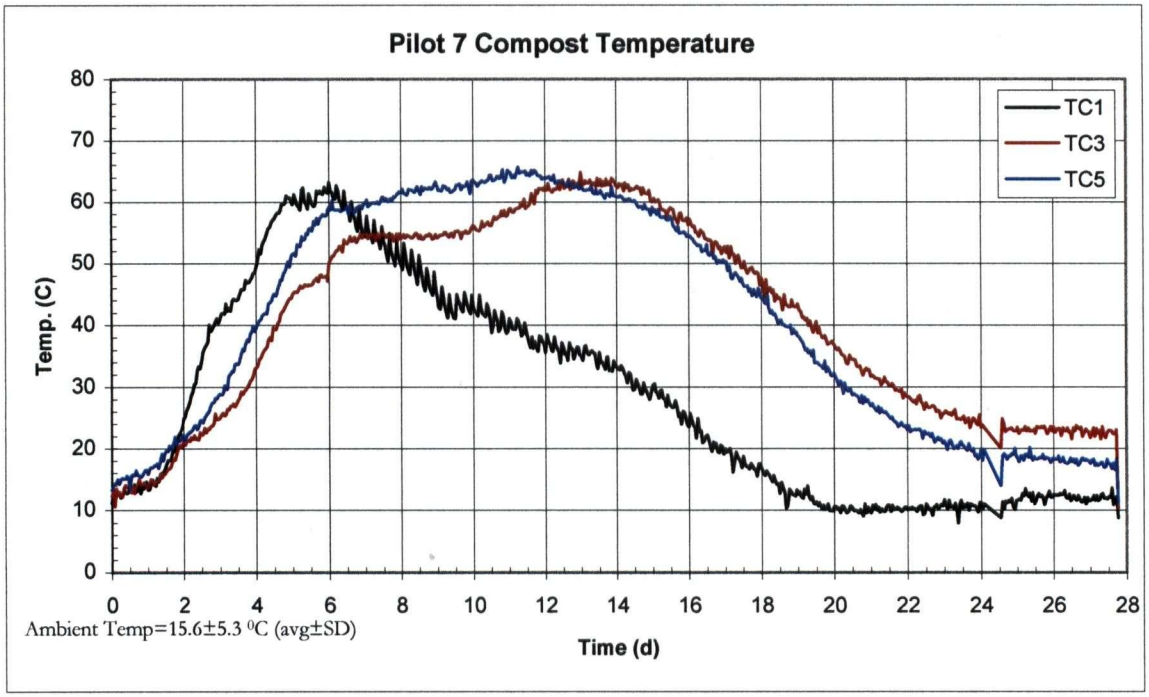


Figure V.36 Pilot 6 Oxygen Profile

Pilot 7 – year-end vines/ sawdust

Pilot 7 took advantage of the availability of year-end waste from the pepper greenhouse at that time. The shredded vines were mixed with a small amount of used sawdust. During active composting, thermophilic temperatures and PFRP were reached. Though large amounts of leachate were generated, it appeared that aerobic conditions were maintained and odour was not a problem. Thus it was concluded that year end tomato vines with some sawdust could be acceptably composted without adding a bulking agent.

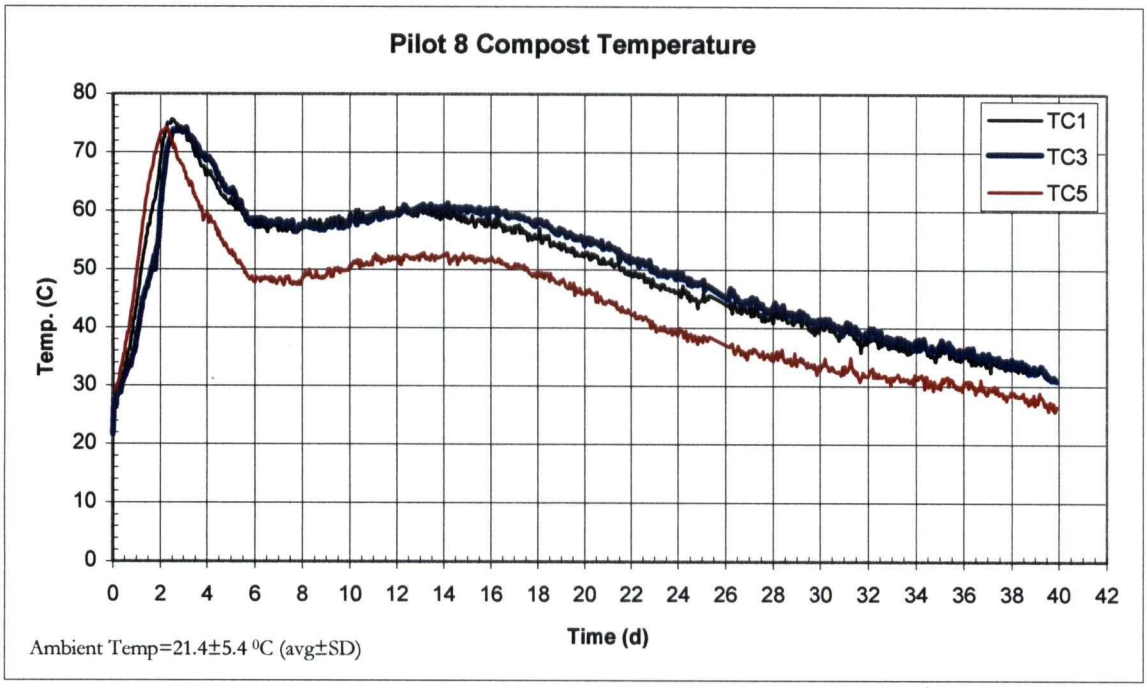


TC1 - Near surface, near back
TC3 - Centre depth, near centre
TC5 - Near surface, near front

Figure V.37 Pilot 7 Temperature Profiles

Pilot 8 - prunings /fruit /sawdust/ alder bark / Compost

Pilot 8 was conducted in mid-summer, several months after pilot 7. In this batch, leaf prunings and fruit culls were mixed with alder bark, recycled coarse compost material, and used sawdust. This was based on experiences and results from the previous 7 runs, and the recommendations from the lab scale tests. This turned out to be a very successful run. This mixture composted very well, with PFRP met in most of the material, and a final product with a pleasant smell.

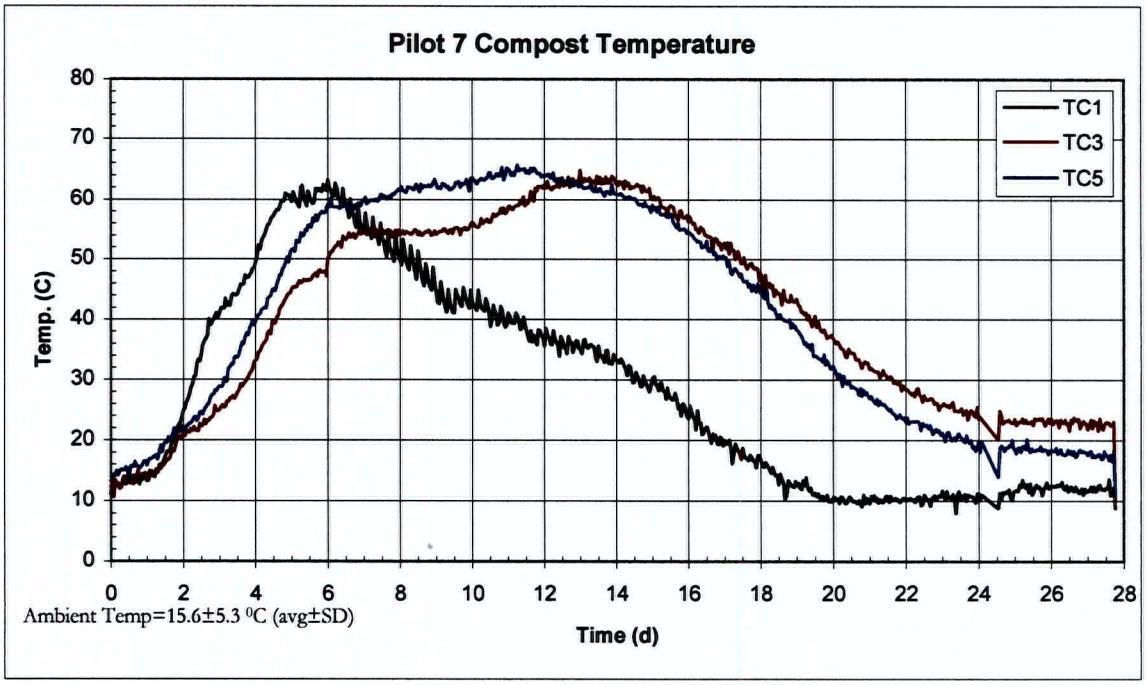


TC1 - Near surface, near back
TC2 - Near surface, near centre
TC5 - Near surface, near front

Figure V.38 Pilot 8 Temperature Profiles

Conclusions from Pilot scale test results

The pilot scale tests were not meant to be as analytical as the lab scale tests since there were not as many reactors as in the lab tests and the pilot scale tests were even more affected by external factors, e.g. larger differences in ambient temperatures, different mixings by different Bobcat operators, etc. However, several observations were made that were quite similar to those noted in the lab scale compostings and serve as re-confirmations of the lab scale findings.

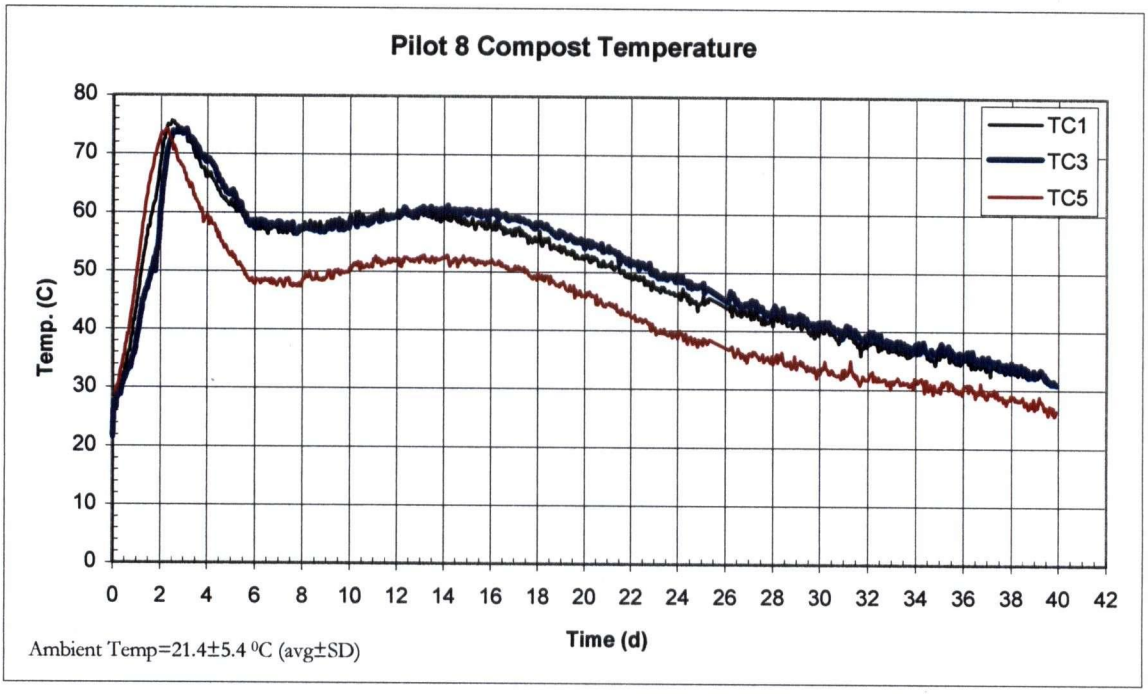


TC1 - Near surface, near back
TC3 - Centre depth, near centre
TC5 - Near surface, near front

Figure V.37 Pilot 7 Temperature Profiles

Pilot 8 - prunings /fruit /sawdust/ alder bark / Compost

Pilot 8 was conducted in mid-summer, several months after pilot 7. In this batch, leaf prunings and fruit culls were mixed with alder bark, recycled coarse compost material, and used sawdust. This was based on experiences and results from the previous 7 runs, and the recommendations from the lab scale tests. This turned out to be a very successful run. This mixture composted very well, with PFRP met in most of the material, and a final product with a pleasant smell.



TC1 - Near surface, near back
TC2 - Near surface, near centre
TC5 - Near surface, near front

Figure V.38 Pilot 8 Temperature Profiles

Conclusions from Pilot scale test results

The pilot scale tests were not meant to be as analytical as the lab scale tests since there were not as many reactors as in the lab tests and the pilot scale tests were even more affected by external factors, e.g. larger differences in ambient temperatures, different mixings by different Bobcat operators, etc. However, several observations were made that were quite similar to those noted in the lab scale compostings and serve as re-confirmations of the lab scale findings.

First of all, at the beginning of the tests, the greenhouse operator worried that large amounts of manure would have to be mixed with the greenhouse vegetable wastes in order to get high themophilic temperatures. However, the pilot tests proved that without any inoculum, the greenhouse plant wastes (both daily prunings and year-end wastes) could be composted with temperatures passing PFRP.

The greenhouse operator always would like to utilize the used sawdust growing medium as a bulking agent and additional carbon source, since it was part of the wastestream (costless) while alder bark could be a cost burden. However, it was reconfirmed that alder bark was needed to mix with daily prunings to provide good structure and porosity for composting otherwise the compost pile would become anaerobic and cause lot of odor and leachate problems. It was also reconfirmed that daily prunings could be composted without shredding, and this should mean cost savings for a greenhouse operator.

The year-end wastes contained a lot of woody vines, and they provided the structure and porosity for proper aeration. So, the year-end wastes, with some used sawdust, could be composted without adding a bulking agent. This should make for another significant cost saving.

In most of the pilot tests, temperatures went over the setpoint even when the aeration was on 100% cycle for cooling. This again proved that fresh air cooling might not be able to cool the compost pile effectively below the setpoint temperature. For the purpose of cooling (without tremendously increasing the fresh air aeration, which would increase the emission of odour), air recirculation is still the best option.

V.4.3 COST ANALYSIS OF GREENHOUSE IN-SITU COMPOSTING SYSTEMS

The feasibility of in-vessel composting technology for on-farm use

To minimize capital equipment costs, a relatively simple container system was selected for study. Some commercial in-vessel systems include mixing, which is a desirable feature, however it adds significant complexity and cost. The limitation of a containerized system is that it is a batch operation and cannot be continuously fed, therefore several units are required to handle an ongoing waste stream. However it is simple to operate, requires little maintenance, and can be loaded with standard, relatively low-cost materials handling equipment such as a small tractor or a Bobcat.

The in-vessel design proved to be well-suited for prunings and rejects waste, which was high in moisture, putrescible and was generated over a long period. Forced aeration maximized aerobic conditions, odours were minimized, and leachate was contained. Compost of consistent, high quality could be produced. Year-end waste on the other hand was less putrescible, and a large amount was generated in a very short period at the end of the season. This pattern of waste generation was difficult to handle with the in-vessel system, as it would require stockpiling of waste for potentially long periods. Moreover, stockpiling the wastes without proper treatment would introduce disease and pest back into the greenhouse. An alternate, lower cost batch system with large capacity, such as aerated static pile, would be more cost-effective and manageable for year-end waste.

A practical solution would therefore be to use the in-vessel system for prunings and rejects waste during most of the season, producing a high-quality product suitable for potential use as a greenhouse growing medium. A lower-cost alternate system would be used for year-end waste, producing a good quality product but under less controlled conditions and therefore suitable for less critical or intensive applications such as farm soil amendment. Coarse, woody material present in shredded year-end waste can be screened out of the final product, and re-used as a bulking agent for composting prunings and rejects, thereby reducing the requirement for bulking agents from outside.

Economic Feasibility

Economic feasibility of on-site composting for growers will depend primarily on the following factors:

- existing organic waste disposal costs
- cost of composting
- market demand and value for compost product

Conventional Disposal Costs

Due to the variety of disposal methods used by growers, the existing organic waste disposal costs for growers vary widely. In some cases, the disposal cost at some greenhouses (especially some small operations) was reported as zero if the greenhouse operators could stockpile the wastes on their own land for a long time. Based on the limited cost information from surveys, and information from Hazelmere greenhouses, existing disposal costs were estimated as shown in Table V.34. As mentioned earlier,

conventional disposal costs are likely to increase with more reliance on off-site landfill disposal. In the case of all waste being trucked off-site, projected costs are also shown in Table V.34. These costs were based on the assumption that all plant waste would be landfilled at $70/T, plus $55/T trucking; and sawdust waste would be trucked to a local site at $23/T for land application.

Table V.34. Conventional Disposal Costs.

	Generation	Hazelmere Disposal Costs		Average Existing Disposal Costs		Projected Conventional Disposal Costs	
	T/ha	$/T	$/ha	$/T	$/ha	$/T	$/ha
Prunings and rejects	45.1	80	3,600	27	1,200	125	733
Year end	55.3	39	2,160	46	2,552	125	6,916
Sawdust medium	74.6	10	750	12	898	23	1,715
Total	175		6,510		4,650		11,016

Note : 1. Average existing disposal costs were calculated based on the surveys from 8 greenhouses.
2. For projected conventional costs, plant waste would be landfilled at $70/T, plus $55/T trucking; and sawdust waste would be trucked to a local site at $23/T for land application.

Composting Costs

Composting costs are made up of capital equipment costs and operating costs. Capital costs includ primarily composting system equipment (capacity-dependent) and materials handling equipment. Operating costs included labour costs for shredding, mixing, loading and unloading, and screening, plus maintenance.

Capital costs would obviously also depend on the selection of composting technology. Table V.35 summarizes estimated capital costs of an in-vessel container composting system, aerated static pile composting system, and materials handling equipment. The in-vessel system costs are based on those found for the study system,

with some additional costs to up-grade from pilot to commercial scale. The static pile system cost is based on a covered, concrete pad with forced aeration.

Table V.35 Composting System Component Costs

Component	Cost ($)	Annual Raw Waste Capacity
In-vessel container system, 3 containers	69,000	180 T [2]
Covered aerated static pile system	25,000	225 T
Site paving, storage sheds	13,000	-
Shredders	20,000	-
Screen and conveyor	15,000	-
Total	142,000	405 T

Note that the above costs did not include those of a loader (eg small tractor or skid-steer). The overall cost of in-vessel composting was estimated at approximately $200 to $250 per tonne of compost produced (see payback example later) including operating costs.

Alternative Systems

Alternative commercial systems, including different types of in-vessel systems, are available. Similar systems using batch containers without mixing are available from suppliers in the USA, including NaturTech (Seattle, WA) and Green Mountain Technologies (Seattle, WA). A two-container Green Mountain system with a total single batch capacity of approximately 30 T is estimated to cost US$100,000 (C$155,000), not

[2] 8.5 T/unit x 10 batches/year = 85 T/unit/year; 85 T – 30% (bulking agent) = 60 T/unit/year

including the roll-off truck required for unloading, shredder, screen, or site-related costs. Agitated (mixed) in-vessel systems are also available, for example Wright Environmental (North Vancouver, BC), or Transform Compost Systems (Abbotsford, BC); generally the cost of agitated in-vessel systems will be higher than non-agitated systems.

Product Value and Marketing

A market survey for greenhouse compost products was done and is reported in Chapter IX. Market demand and product value are key factors in the economic equation. Potential benefits to users include improved soil quality, disease suppression (Cheuk, 2003a), water and nutrient conservation, and improved yield (Haug, 1993; Hoitink, 1997). Based on site visits to existing composting facilities and other greenhouses and nurseries, a significant potential market exists in the lower Fraser Valley. The potential market for bulk product includes:

- flower and vegetable greenhouses
- nurseries
- organic farms
- landscapers

At the time of the study, a compost product made from hog manure was being marketed to flower and vegetable greenhouses in the Abbotsford area. Though the typical price for bulk compost was historically near $60/T, this product sold for over $100/T. According to Composting Factsheets from B.C. Ministry of Agriculture (1991), a market value of good quality manure compost could be approximately $100/T.

Demonstration of high-quality greenhouse compost as a growing medium that can enhance production would obviously increase the market value of the product. On-site production using an in-vessel system would be advantageous in this respect, since the feedstocks are consistent, do not contain unknown components, and are processed under controlled conditions. Compost produced on-site could be partly utilized at the greenhouse, and the surplus marketed to other users.

When compost is utilized as a growing medium amendment, even a small improvement in yield can lead to significant revenue increase. For example, 5% yield improvement for a 4 ha tomato greenhouse could lead to an annual revenue increase of nearly $200,000 based on 1996 figures (B. C. Agdex 257-810).

ANNUAL COST ANALYSIS

Based on a 4 ha tomato or pepper greenhouse, and amortizing the capital equipment over five years, the net annual cost of composting represents a savings of $8,000 (Cheuk, 2003b) annually as shown in the example in Table V.36.

This analysis is based on the following assumptions:

1. Most prunings, rejects and year-end waste are currently hauled for local landfill disposal.
2. Separate in-vessel/aerated static pile systems are used for prunings and rejects, and year-end waste respectively. Materials handling equipment and site costs are included with each, not including a tractor/loader.

3. Weight reduction after composting are 50% for prunings and sawdust, and 40% for year-end wastes based on the results from lab and pilot scale tests.
4. Small percentages of sawdust are included in the composting feedstocks as shown; the rest is land applied at the disposal cost indicated.
5. Variable costs include production labour, maintenance, and electricity/fuel.
6. The annual fixed cost is calculated as amortization of the capital cost over 5 years with interest rate of 8%.
7. The compost selling price is $60/ton for the compost made from the aerated static pile and $130 for the compost made from in-vessel composter since the later one would have better and more consistent quality. However, these prices are still very conservative since a lot of good quality of composts have been selling between $133/T to $312/T (wholesale) and between $200/T to $562/T (retail) (see Table IX.1 in Chaper IX).

Cost savings could be made by sharing materials handling equipment between greenhouses, since shredding and screening would typically be done only for short periods. Also, the analysis did not take into account potential financial benefits due to re-use of compost on site as a growing medium amendment, which may be more financially attractive than marketing the same material to other users.

Table V.36 Annual Cost Analysis Example

Waste Parameters	Waste Generation Tons	Disposal Cost $/Tons	% Composted		Compost production Tons		
			ASP	In-vessel	ASP	In-vessel	Total
Prunings and rejects	180	80	0%	100%	0	90	90
Year-end plants	221	80	80%	20%	115	22	137
Sawdust medium	298	10	10%	20%	15	30	45
Total	699				130	142	272

Compost Selling Price ($/Tons)	
ASP	60
In-vessel	130

System Costs Amortization Period: 5 years								
	Capital Costs	Annual Fixed Costs (amrt. 5 yrs @ 8% int. rate)	Variable Costs	Total Annual Costs		Annual Disposal Savings	Annual Compost Revenue	Annual Net Cost
	$	$	$/T comp.	$	$/T comp.	$	$	$
ASP	52,500	12,805	30	16,825	126	14,400	7,800	(5,375)
In-vessel	89,500	21,829	85	33,899	239	18,000	18,460	(2,561)
Total	142,000	34,634		50,724		32,400	26,260	(7,936)

V.5 CONCLUSIONS

The results of this study can be used for a better understanding of the effects of different modes of forced aeration and substrate recipes on the composting process and may help in the design and operation of future on-site greenhouse composting plants.

The greenhouses wastes contained enough bio-degradable carbon to start the self-heating process and no manure nor bacterial inoculation was needed for the composting process. This resolves a lot of potential hygienic and transportation problems for greenhouse operators because provincial regulation does not allow on-farm composting to process foreign material, e.g. manure.

The application of recirculation cooling and aeration created a more homogeneous vertical distribution of temperature in the composting mass and was a more effective method for maintaining the process temperature and caused much less temperature variations between each aeration period, thus enhancing the stability of the process.

The greenhouse wastes contain a lot of seeds, from rotten fruit, in the waste stream. If the compost process temperature was not high enough to kill the seeds, the seeds would germinate in the curing pile, and this would be unfavourable in terms of selling the final product.

Less leachate and condensate were generated by the air recirculation control, and this would mean less problems for the greenhouse operators.

In the time series study, the NH_3 concentration in the compost somehow followed a similar path to the temperature profile. As the process activity increased in the beginning, NH_3 release increased, as proteins in the organic matter were broken down.

This peaked early during the thermophilic phase, then decreased as the amount of degradable organic matter and proteins decreased. So, NH_3 could be a good indicator of compost maturity.

By investigating the substrate structure, carbon loss, nitrogen loss, and process temperature, fresh alder bark was found to be the best bulking agent of those tested.

Shredding was not necessary for composting the prunings and this would mean a significant savings for greenhouse operators.

The amount of leachate was related to the initial moisture content of the substrate and the amount of condensate was correlated with the duration of the high temperature phase of the process. A bulking agent (alder bark) in amounts of about 20-30% (in weight) was necessary for composting prunings. For year-end wastes, a ratio of 62% vines, 13% used sawdust and 25% alder bark was recommended.

The results of the pilot scale investigations enabled one to prove the usefulness of the in-vessel containerized system for composting greenhouse wastes. A variety of greenhouse waste materials and blends were able to be composted successfully and efficiently in the in-vessel system. The composting process sanitized the material sufficiently (55 ^{0}C for 3 days), and the time of composting was significantly shorter than any windrow or aerated static pile composting. Addition of bulking agents to pruning waste (leaves and cull fruit) was critical to maintain an aerobic process. With maintenance of proper porosity and aerobic conditions, odour was not a problem during composting or curing. The on-site composting of greenhouse wastes provided an environmentally and economically sustainable solution for the greenhouse industry. It not

only cut down on waste hauling costs, but also generated good quality compost for re-use in the greenhouse and for sale in the commercial market.

V.6 REFERENCES

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CHAPTER VI
COMPOST QUALITY

VI.1 BACKGROUND AND LITERATURE RESEARCH

One of the purposes of composting is to produce an organic soil amendment that is beneficial to plants. All composting process should be designed and operated to produce a stable product that is beneficial to plants and not phytotoxic. Organic components of compost undergo several transformations during the composting process, producing metabolities which exhibit inhibiting or stimulating effects on plant growth (Wong, 2001). Haug (1993) defined compost as an organic soil conditioner that has been stabilized to a humus-like product, that is free of viable human and plant pathogens and plant seeds, that does not attract insects or vectors, that can be handled and stored without nuisance, and that is beneficial to the growth of plants. A number of approaches have been used to measure the degree of stabilization and to judge the quality of the compost product, including temperature decline, C:N ratio, chemical characteristics, and plant bioassays.

Temperature Decline

The rate of heat production from the compost mass should be proportional to the rate of organic oxidation. The composting process first undergoes a thermophilic stage (high temperature, i.e. above 55^0C), then a mesophilic stage (medium temperature, i.e. 40~45 ^{0}C), and finally drops back to ambient temperature. As materials are decomposed,

less bio-degradable carbon is available, and the rate of oxidation decreases. The maturation of compost is accompanied by a decline in pile temperature (Tiquia, 2002). Such a decline indicates that the process is nearing completion and that the compost has been stabilized enough to reduce its nuisance potential and its level of phytotoxic metabolities.

C:N Ratio

A carbon to nitrogen (C/N) ratio of less than 20 is often used as an indicator of compost maturity. However, the actual C/N ratio depends largely on the C/N ratio of the starting material as well as the proportion of degradable carbon, so a final C/N ratio of less than 20 is only a guideline, but not an absolute condition for compost maturity (Jimenez, 1989). If the organic matter in compost has a high C:N ratio and decomposes continuously, it can rob the soil, to which it is added, of the nitrogen needed to support plant growth. Moreover, if the organic matter has a low C:N ratio, it can release ammonia which can be phytotoxic.

Chemical characteristics

Chemical characterization of compost is generally based on two criteria, agronomic value and heavy metal content (Soumaré, 2003). Agronomic values usually refer to the availability of major elements, such as N, P, K and trace elements (e.g. Cu, Zn, Mn, Fe, Co, Mo). For heavy metal content, different guidelines and rules have been established for compost specification.

Ammonia is usually present in the early stage of composting as organic nitrogen is decomposed. The ammonia concentration is eventually reduced through volatilization or oxidation to the nitrate form. During the composting process ammonia production decreases in the later stages, and production of nitrate increases. The presence of nitrate and the absence of ammonia can therefore be used as an indicator of compost maturity (Haug, 1993).

Soluble phosphorus (phosphate) is an important nutrient for plant growth and is often lost through the leachate of composting (Eghball, 1999). Therefore, the concentration of phosphate is sometimes used for compost analysis as well.

Phytotoxicity

Studies have shown that toxicity during organic matter decomposition was strongly associated with the initial 3-4 weeks, subsequently decreasing rapidly and disappearing after 2 months (Zucconi, 1981). Plant bioassays are probably the most direct method to determine whether the compost product has been sufficiently stabilized. Potting growth trials could be very time consuming. Therefore, many researchers have used a cress seed phytotoxicity bioassay as a standard germination test for compost evaluation to determine compost maturity and to detect the presence of phytotoxic compounds (Baca, 1990; Fang, 1999; Ball, 2000). Cress seeds (*Lepidium sativum* L.) were chosen because of their sensitivity to toxic substances and their speed of germination (Murillo, 1995). Seeds are incubated in compost extract with distilled water

as control. Germination rates and root elongation are measured to determine the phytotoxicity of compost.

Compost By-Products – Leachate, Condensate and Compost Extract

Apart from the compost mass produced from the bio-degradation process, a few other "by-products" should also be investigated. These are leachate, condensate and compost extract. The leachate is commonly known as "compost tea" because of its brown colour, opacity and the analogy of water drawing nutrients and organics out of the compost as it passed through the compost piles. Condensate could be collected from the ceiling of an in-vessel composter and from the aeration outlet when the gases from the composter are condensed before emission. These compost by-products have been considered waste products but may prove to be beneficial. These liquids contain nutrients and organics that have the potential to pollute surface water, but also can be used to improve soil quality and fertilize plants, even in greenhouses, if applied properly. Considering the trend to return organics to agricultural soils in order to stem soil erosion, and the effort to reduce industrial fertilizer use, the reuse of this material should become a high priority (Clean Washington Center, 1997).

Compost extracts are made by soaking compost with water and filtering out the solids afterwards. Compost extracts can suppress disease in plants via a number of mechanisms, including competition, antibiosis, hyperparasitism, and induction of systemic acquired resistance (SAR) in some host plants (Hoitink, 1997). Competition and hyperparasitism mechanisms would require the presence of active microorganisms, while

antibiosis and SAR could potentially be effective in a sterilized medium. Soilless media such as sawdust or peat support limited microbial populations, compared to properly prepared compost. For this reason, these suppressive mechanisms of compost can be effective for soilless media, due in part to the high microbial activity and biomass of the compost.

The effectiveness of a compost amendment and compost extract is largely determined by the feedstock materials and the method of processing and storage, as well as the type of crop. As previously reported (Mathur, 1996), compost can be phytotoxic if it is not processed or applied correctly. Parameters including moisture, pH, carbon to nitrogen ratio, and maturity impact the effectiveness of disease suppression; low moisture content during curing favours fungal growth and development of Pythium diseases (Hoitink, 1997). Curing time was found to be important to the microbial populations and the disease suppression characteristics; inoculation of suppressive organisms early in the curing phase has also been found to improve disease suppression characteristics (Hoitink, 1997). In addition, selection of appropriate feedstock and processing methods can help optimize the microbiological makeup of the product for a particular crop in order to give the best results (Grobe, 1998). A high bacteria to fungi ratio has also been suggested as a desirable characteristic for increasing disease suppression (Kai, 1990).

Beneficial liquid extracts of compost would provide another important avenue for application of beneficial compost products. Water extracts of compost were found to significantly reduce the severity of grey mould (Botrytis) for lettuce and grapevine (Ketterer, 1992; McQuilken et al., 1994). However, there are a number of variables

involved in the production of extract that may impact the product effectiveness, including aeration, steeping time, and provision of a carbon source (McQuilken, 1994; Ingham, 1999). The effect of storage and dilution when applying are also important for commercial application.

VI.2 SPECIFIC OBJECTIVES

The overall objective of this part of the project was to correlate the compost quality to the process control and substrate recipes, so that the compost and by-products generated from the process could be fully utilized. The specific objectives are:

- Investigate any correlation between compost quality and process control.
- Investigate any correlation between compost quality and substrate recipe.
- Investigate the compost maturity and quality in terms of seed germination (compared to water).
- Investigate the phytotoxicity level of the bio-conversion by-products, i.e. leachate and condensate, and thus find out the level of dilution for application onto plants.
- Investigate whether the compost extract would enhance seed germination and shoot growth (for nursery use).

VI.3 METHODOLOGY

Chemical Analysis

Parameters, such as C:N ratio, pH, EC, ammonia, nitrate, phosphate were analyzed and compared in different lab and pilot tests. Total Organic Carbon was measured by combustion at 680 ^{0}C and CO_2 measurement, using a Shimadzu TOC-5050 Total Organic Carbon Analyser with an SSM-5000 Soild Sampling Module. Total Nitrogen was measured using ignition at 950 ^{0}C in a Leco FP228 Nitrogen Determinator. pH and EC were measured by Hach pH and EC meters compensated for temperature. Water soluble Ammonium, Nitrate and Phosphate were measured using water extraction and the Technicon Autoanlyser II industrial method.

Bio-Assay for Compost Extract

Bioassays were carried out to determine the toxicity of compost using cress seeds (*Lepdium sativum* L.) and tomato seeds (*Lycopersicum esculentum* L.). Compost was collected from the greenhouse composting reactors and was sent to UBC Lab (Chemical and Bioloigcal Engineering) in transparent plastic bags immediately after collection. Approximately 15 grams of fresh compost were placed in a 250 ml Erlenmeyer flask and 135 ml of distilled water were added to the flask. The flask was placed on a shaker table and shaken for one hour. The liquid was then pipetted off and centrifuged for 15 minutes. The extract, with solids settled out, was collected. The extract was refrigerated at about 4^{0}C for not more than 14 days if it was not used immediately.

To begin the bioassay, a Whatman no. 3 filter was placed in a 10 cm Petri dish and 2.5 ml of compost extract were added. Twenty-five seeds were added to the plate, arranged in a five by five square. Four dishes, i.e. a total of 100 seeds, were used for each test. For cress seeds, the plates were incubated in the dark in a temperature controlled incubator at 28.5°C for 24 hours. The number of cress seeds that germinated and the length of each seed's root were recorded for each plate. For tomato seeds, since they took a longer time to germinate, the plates were incubated in the dark in a temperature controlled incubator at 28.5°C for 144 hours (6 days). An additional 2.5 mL of the compost extract under testing were added after two days to the tomato seeds to prevent drying out of the seeds. The number of tomato seeds that germinated after 6 days and the length of each seed's root were recorded for each plate. Germination index (GI) was calculated according to the following formula (Zucconi, 1981; Tiquia, 1996) :

Equation VI.1 Germination index

$$GI = \frac{\text{Seed germination \% X Root length of treatment X 100}}{\text{Seed Germination \% X Root length of control}}$$

Bio-Assays for Leachate and Condensate

Bioassays were carried out to determine the toxicity of leachate and condensate from the composting process using cress seeds (*Lepdium sativum* L.) and tomato seeds (*Lycopersicum esculentum* L.) Leachate and condensate were collected from the greenhouse composting reactors and stored at about 4^0C for not more than 14 days. Various dilutions were made with distilled water.

To begin the bioassay, a Whatman no. 3 filter was placed in a 10 cm Petri dish and 2.5 mL of a given leachate or condensate concentration were added. Twenty-five seeds were added to the plate, arranged in a five by five square. Four replicates (total 100 seeds) were done for each dilution. For cress seeds, the plates were incubated in the dark in a temperature controlled incubator at 28.5°C for 24 hours. The number of cress seeds that germinated and the length of each seed's root were recorded for each plate. For tomato seeds, since they took a longer time to germinate, the plates were incubated in the dark in a temperature controlled incubator at 28.5°C for 144 hours (6 days). An additional 2.5 mL of diluted leachate/condensate were added after two days to the tomato seeds to prevent drying out of the seeds. The number of tomato seeds that germinated after 6 days and the length of each seed's root were recorded for each plate. In some cases, both distilled water and nutrient water (from greenhouse operation) were used as control comparison.

Statistical Analysis

When data were subjected to statistical analysis, comparison of the mean was performed by the Student's t test. A significance level of $P<0.05$ was used throughout the study. The following formula was used in the *t*-test for comparing two means :

Equation VI.2 *t*-test

$$t = \frac{(x_1 - x_2)}{\sqrt{((S_1^2/N_1) + (S_2^2/N_2))}}$$

where x_1 and x_2 are the means of two samples, S_1 and S_2 are the standard deviations of the two samples, and N_1 and N_2 are the sizes of the two samples. The degrees of freedom are the smaller of $N_1 - 1$ or $N_2 - 1$.

In the bioassay study, this test was used to confirm whether the mean root length of one sample group was significantly larger or smaller than another group. For example, the mean root length of the seeds (N_A=100) germinated from compost extract of Lab 8C is 4.87 mm with a standard deviation of 1.20 mm, and the mean root length of the seeds (N_c = 100) from compost extract of Lab 8D (distilled water) is 5.24 mm with a standard deviation of 0.94 mm. The t-value ($t_{8C,8D}$) is then calculated to be 2.43, which is larger than $t_{0.05,100}$, i.e. 1.660. This means the root lengths of 8D are significantly longer than that of 8C, with a confidence level of 95%.

VI.4 RESULTS AND DISCUSSIONS

VI.4.1 COMPOST ANALYSIS

All the compost analyses for the different batches of composting described in Chapter V, are listed in Table VI.1. Generally, most of the finished composts had a reduced C:N ratio from the initial values, except for a few occasions that started with low C:N. A lower final C:N meant the rate of carbon loss was higher than the rate of nitrogen loss in the process, which was a good indication of significant bio-degradation with some nitrogen conservation. Most of the C:N ratios were within the desirable range of 15 to 30 C:N (Haug, 1993).

The ammonia and nitrate concentrations were much higher in the compost inoculated by manure. That was to be expected since the manure contained high concentrations of ammonia and nitrate (Krapac, 2002). Thus, it is often used as nitrogen amendment source for fertilizers. The ammonia concentrations of compost from reactors with air recirculation were higher than from those without air-recirculation. This was due to less leachate generation and recirculation of the volatized ammonia during the beginning of the process (Bari, 2001). Ammonia concentration was highest with continuous, constant aeration in Lab 4 (reactor D), which indicated that the compost was not as stabilized as the others produced in the air-recirculated reactors (reactors B,C). In Lab 8 and Lab 9, the greater was the percentage of bulking agent (alder), the less was the ammonia and nitrate concentration in the finished compost, which also showed that the compost was more stabilized.

Studies have shown that phosphate should decrease with degradation of substrate by microbial consumption for cell assimilation (Yun, 2000). Enrichment of partially composted crop wastes could be achieved by phosphate solubilizers to improve the nitrogen, available phosphorus and humus content of finished compost (Gaur, 1987). However, there was no particular trend nor correlation found in this present study for phosphate concentration.

Yun et al. (2000) also showed that it was possible to predict a slurry-phase bioreactor's performance, under various conditions, from pH and DO measurements. The pH began to increase as degradation of solids began and the DO began to increase when the degradation process was completed. It was inferred that the reactor operated with a

stable decomposition of food wastes when the pH was about 8 and the DO greater than 2 mg/L . For most cases of the lab runs in this study, the pH values were at about 8, which provided a stable degradation.

Table VI.2 shows a comparison of analyses made by a commercial laboratory, between compost from year-end wastes (Lab 9C), compost from daily pruning (Lab 8C) and the un-used yellow cedar sawdust medium. In each case, 3 to 5 samples were taken and mixed as a composite sample of 250 grams for analysis (Johnson, 1993). It is obvious that the pH values of both composts were higher (alkaline) than sawdust. This was unfavourable for a greenhouse vegetable crops, which prefer a pH value of 6 to 6.5 (slightly acidic) (BC Ministry of Agriculture, 1997). So, pH adjustment needed to be made before utilizing the compost in greenhouse.

The EC was much higher in the daily prunings (15.02 mS/cm) than in the year-end wastes (1.18 mS/cm) and the year-end waste was slightly higher than sawdust (0.46 mS/cm). So, there were much more macro and micro-nutrients in the compost of daily prunings, which contained a lot of leaves and culled fruit, than in the compost of year-end vines and sawdust.

The Cation Exchange Capacity (CEC) values, which are a measure of the nutrient holding (adsorption) power of the material and are related to potential fertility, were much higher in both compost (162.2 meq/100g and 143.8 meq/100g) than in the sawdust medium (8.2 meq/100g). So, the compost made from greenhouse wastes had a higher potential fertility and humification (Sanchez-Monedero, 1999).

The nutrient contents (N, P, K, Ca, Mg ,S) of both composts were considerably higher than that of the sawdust. All these nutrients are favourable to plants and could be used in combination with other media and fertilizers for plant production (Vogtmann, 1993).

The organic matter content and C:N ratio were lower in the composts because a lot of the organic carbon had already been oxidized (degraded) in the composting process.

The heavy metals concentrations (Fe, Cu, Mn, Zn) tended to be higher in the composts. However on the basis of seed germination, there was no obvious phytotoxicity, with seed germinations of 100% and 98% in the year-end and prunings composts respectively. Even though the composts had lower porosity than the sawdust (53.1% and 49.7% vs 63.4%), they showed higher water holding capacity (22.8% and 26.9% vs 16.6%) which reduced the leaching out of nutrients.

Table VI.1 Analysis from different Lab tests

Sample	Ammonia mg/L	Nitrate mg/L	Phosphate mg/L	pH	C:N Ratio Input	C:N Ratio Output
Lab 1A with manure	41.2	80.2	119	-	24.0	23.7
Lab 1B w/o manure	23.1	60.3	53.3	-	25.4	20.9
Lab 2A w/o air-recirculation	230	250	298	-	29.2	10.2
Lab 2B w/air-recirculation	270	150	322	-	29.2	16.3
Lab 3A w/o air-recirculation	92.4	75.4	311	8.29	9.13	13.7
Lab 3B w/ air-recirculation	187	45.1	277	8.64	9.13	17.1
Lab 4A fresh air aeration/fresh air cooling	38.1	75.2	72.3	8.39	12.8	18.9
Lab 4B fresh air aeration/ air-recirculation cooling	49.3	60.2	138	8.04	12.8	12.2
Lab 4C fresh air + recir. aeration/recir. cooling	56.1	75.1	89.1	8.43	12.8	13.2
Lab 4D fresh air continuous constant aeration	102	90.1	121	7.94	12.8	14.1
Lab 5A Non-shredded with hemlock	0.58	27.6	54.5	6.82	30.2	26.4
Lab 5B Shredded with hemlock	1.93	11.2	35.6	6.81	33.9	29.4
Lab 5C Non-shredded with alder	1.06	0.31	23.3	6.92	32.6	24.8
Lab 5D Shredded with alder	1.21	0.33	16.2	7.03	34.6	24.9
Lab 6A Non-shredded with alder	0.00	25.7	14.5	7.94	30.9	22.7
Lab 6B Non-shredded with hemlock	2.33	27.9	26.4	7.60	24.1	23.0
Lab 6C Shredded with alder	4.87	23.6	2.98	8.19	30.9	23.7
Lab 6D Shredded with hemlock	16.2	27.6	3.32	7.59	24.1	23.5
Lab 7A Shredded with fresh alder	24.3	56.4	245	8.36	38.2	20.2
Lab 7B Non-shredded with fresh alder	29.4	209	169	9.33	38.2	18.4
Lab 7C Shredded with composted alder	39.5	254	23.9	8.73	26.9	18.4
Lab 7D Non-shredded with composted alder	38.1	157	109	8.66	26.9	16.2
Lab 8A Non-shredded	170	24.4	21.9	7.92	7.80	9.60
Lab 8B Non-shredded with 15% alder	108	11.7	15.2	7.91	15.7	13.6
Lab 8C Non-shredded with 30% alder	84.3	10.3	15.1	7.91	20.6	16.9
Lab 8D Non-shredded with 45% alder	29.9	1.79	8.67	7.72	23.9	19.7
Lab 9A 60% Prunings, 40% sawdust	8.68	37.3	27.9	6.92	21.6	29.3
Lab 9B 60% Prunings ,14% alder, 26% sawdust	5.34	10.1	15.9	7.51	24.1	27.3
Lab 9C 62% Prunings , 25% alder, 13% sawdust	2.13	5.93	16.7	7.74	26.0	21.4
Lab 9D 65% Prunings , 35% alder	2.50	5.72	15.5	7.62	33.3	25.9

Table VI.2 Growing Medium and Amendment Analysis (Compost)

	Unit	Compost from Year End Wastes (from Lab 9C after composting process)	Compost from Daily Prunings (from Lab 8C after composting process)	Un-used Yellow Cedar Sawdust Growing Medium
pH		7.93	9.43	5.88
SMP Buffer pH		7.67	8.02	7.67
EC	mS/cm	1.18	15.02	0.46
Sodium-Na	ppm	1110	1390	80
CEC	meq/100g	162.2	143.8	8.2
Ammonia-N	ppm	2.62	4.28	0
Nitrate-N	ppm	907	1470	8.4
Phosphate-P	ppm	846	1874	20
Potassium-K	ppm	24000	29300	190
Calcium-Ca	ppm	14000	9200	1300
Magnesium-Mg	ppm	3100	2000	100
Sulphate-S	ppm	2010	12040	296
Organic Matter	%	52.2	62.7	98.6
TOC	% db	30.2	38.2	52.4
TN	% db	2.2	1.6	0.71
C/N ratio		23.9	13.7	73.8
Moisture	%	57.3	62.7	65.9
Iron-Fe	ppm	740	220	200
Manganese-Mn	ppm	122	83.7	78.2
Zinc-Zn	ppm	31.9	26.1	21
Copper-Cu	ppm	4.1	2.8	3.5
Chloride-Cl	ppm	3300	3000	4200
Seed Germination	%	100%	98	98
Bulk density	kg/m3	570	587	409
Total Porosity	%	53.1	49.7	63.4
Water-holding capacity	%	22.8	26.9	16.6
Particle Size				
>4.8 mm		17	19	14
2.4-4.8 mm		35	36	42
1.0-2.4 mm		40	35	40
<1.0 mm		7	10	4

VI.4.2 BIOASSAYS ON COMPOST EXTRACT

Chemical analysis before and after composting could not fully reflect compost quality nor be used correlate with the compost process. Therefore, bioassays were done as another means of comparing compost quality and maturity in the following sections. In this section, compost extracts from different compost runs were investigated by bioassays. The objectives were to investigate any beneficial nutrient values in compost extract and also, to compare quality variations in each test run. The bioassays were done in terms of the % germination, root length and germination index of cress and tomato seeds (in Lab 7 only). Table VI.3 and Figure VI.I present the bioassay results for Lab 5.

Table VI.3 Bioassay results from Lab 5

	% germ, 1-day cress seed	avg length, mm (mean±SD)	G.I. ,% of control	t-value to control	t-value to others
Control, distilled water	96	4.06±0.52	-	-	-
Lab 5A Non-shredded with hemlock	95	4.85±0.79	118	$t_{c,5A}>3$	$t_{5A,5B}>3$, $t_{5A,5C}>3$, $t_{5A,5D}>3$
Lab 5B Shredded with hemlock	99	5.25±0.81	133	$t_{c,5B}>3$	$t_{5B,5C}>3$, $t_{5B,5D}>3$
Lab 5C Non-shredded with alder	98	6.73±1.07	169	$t_{c,5C}>3$	$t_{5C,5D}>3$
Lab 5D Shredded with alder	99	6.28±0.60	160	$t_{c,5D}>3$	-

* $t_{c,5A}$ is the *t*-value of comparing Control and 5A, etc. t-value at 95 % confidence level of sample number 100, i.e. $t_{0.05,100}$ is 1.660.

In the Lab 5 bioassay test, all the compost extracts showed no phytotoxicity (95-99% vs 96% for the control). All compost extracts showed beneficial growth effects compared to the control (*t*-values >3) with G.I. (germination index) higher than 100. Both compost extracts from shredded and non-shredded wastes showed similar G.I. which further proved that there were not much difference in quality between composts made shredded and non-shredded prunings, as concluded in Chapter V. Also the results showed that composting with alder bark (G.I.=169, 160), whether or not with shredded or non-shredded wastes, was better than with hemlock bark (G.I.=118, 133). This further proved that alder bark was a better choice, as bulking agent, than hemlock bark as concluded in Chapter V.

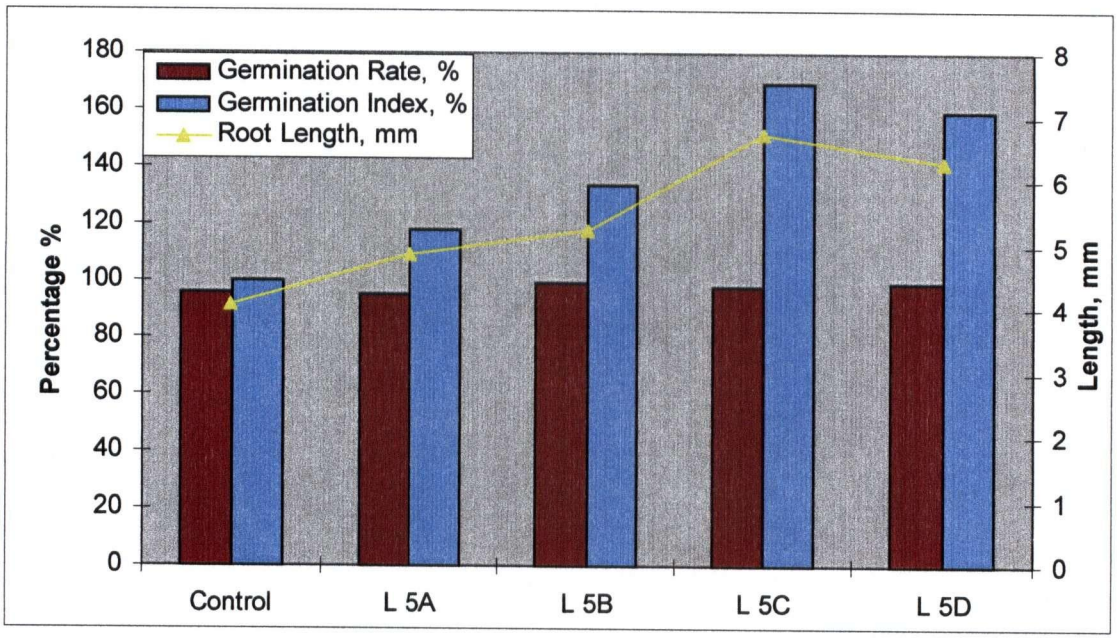

Figure VI.1 Bioassay on Lab 5 – 1-day cress seeds

Table VI.4 and Figure VI.2 present the bioassay results for Lab 6. In the Lab 6 bioassays, all the compost extracts showed no phytotoxicity (96-100% vs 100% for control). All the compost extracts showed beneficial growth effects significantly greater than the control (t-values >3), except that one, non-shredded with hemlock bark, did not pass the 95% confidence level test (t=0.51), with a G.I. of 100. Also, it is shown that the non-shredded prunings with alder bark as bulking agent stood out to be significantly the best among the other 3 combinations. This again further proves the argument that alder bark with non-shredded waste was found to be a better combination in Chapter V.

Table VI.4 Bioassay results from Lab 6 (t-test compared to distilled water)

	% germ, 1-day cress	avg length, mm (mean±SD)	G.I. % of control	t-value to control	t-value to others
Ctrl, distilled water	100%	8.0±2.75	100	-	-
Lab 6A Non-shredded with alder	98%	11.2±2.42 t>3	137	$t_{c,6A}>3$	$t_{6A,6B}>3$, $t_{6A,6C}>3$, $t_{6A,6D}>3$
Lab 6B Non-shredded with hemlock	98%	8.2±2.84 t=1.22	100	$t_{c,6B}=0.51$	$t_{6B,6C}>3$, $t_{6B,6D}>3$
Lab 6C Shredded with alder	96%	9.7±2.46 t>3	116	$t_{c,6C}>3$	$t_{6C,6D}=1.48$
Lab 6D Shredded with hemlock	100%	9.2±2.30 t=2.47	115	$t_{c,6D}>3$	-

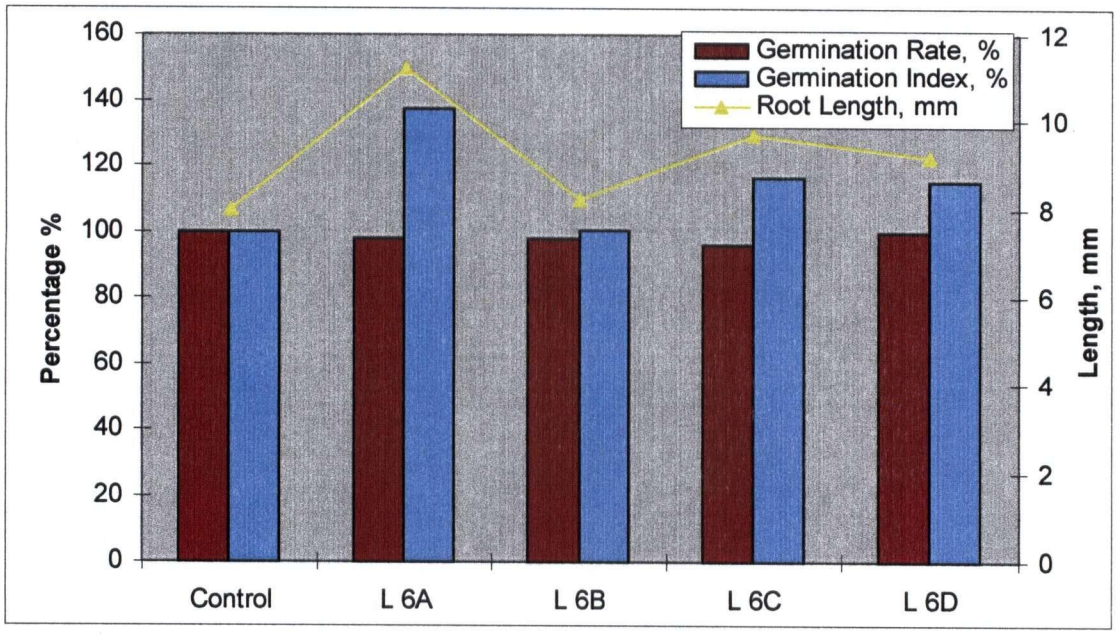

Figure VI.2 Bioassay on Lab 6 – 1-day cress seeds

Tables VI.5 and VI.6 and Figures VI.3 and VI.4 present the bioassay results for Lab 7. In the Lab 7 bioassays, two kinds of seeds were used: cress and tomato. They were allowed to germinate in the Petri dishes for 1 and 6 days respectively. The results are shown in Table VI.5, and Table VI.6. The compost extracts again showed no phytotoxicity (98-100% germination vs 98% for the control; GI between 116 and 132) in the cress seeds and even higher difference in germination rate in tomato seeds (90-97% vs 85% for control; GI between 270 and 439). This should be of interest to propagation companies since using compost extract could then cut down their seed loss through failure to germinate. The results from cress seeds and tomato seeds are very similar in

terms of germination index. This shows that both cress ands tomato seeds can be used for compost bioassay, except that cress seeds can give much faster results.

There were improvements in growth and germination rate when using compost extract, especially with tomato seeds. Within the different extracts, the one composted with non-shredded prunings and fresh alder bark showed significantly better results. This correlates with the results from Chapter V, where it was shown that reactor B had the highest degradation rate and longest reaction period.

Table VI.5 Bioassay results from Lab 7 (Cress seeds)

	% germ. 1-day cress seed	avg length, mm (mean±SD)	G.I. % of control	t-value to control	t-value to others
Control, distilled water	98%	9.2±0.99	100	-	-
Lab 7A shredded with fresh alder	99%	10.9±0.93	120	$t_{c,7A}>3$	$T_{7A,7B}>3$, $t_{7A,7C}>3$, $t_{7A,7D}=1.34$, $t_{7A,PAB}=2.52$
Lab 7B non-shredded with fresh alder	100%	11.9±0.76	132	$t_{c,7B}>3$	$t_{7B,7C}=2.45$, $t_{7B,7D}>3$, , $t_{7B,PAB}>3$
Lab 7C shredded with composted alder	98%	11.5±1.44	125	$t_{c,7C}>3$	$T_{7C,7D}>3$, $t_{7CPAB}>3$
Lab 7D non-shredded with composted alder	100%	10.7±1.17	119	$t_{c,7D}>3$	$t_{7D,PAB}=0.72$
Pure alder bark	99%	10.6±0.74	116	$t_{c,PAB}>3$	-

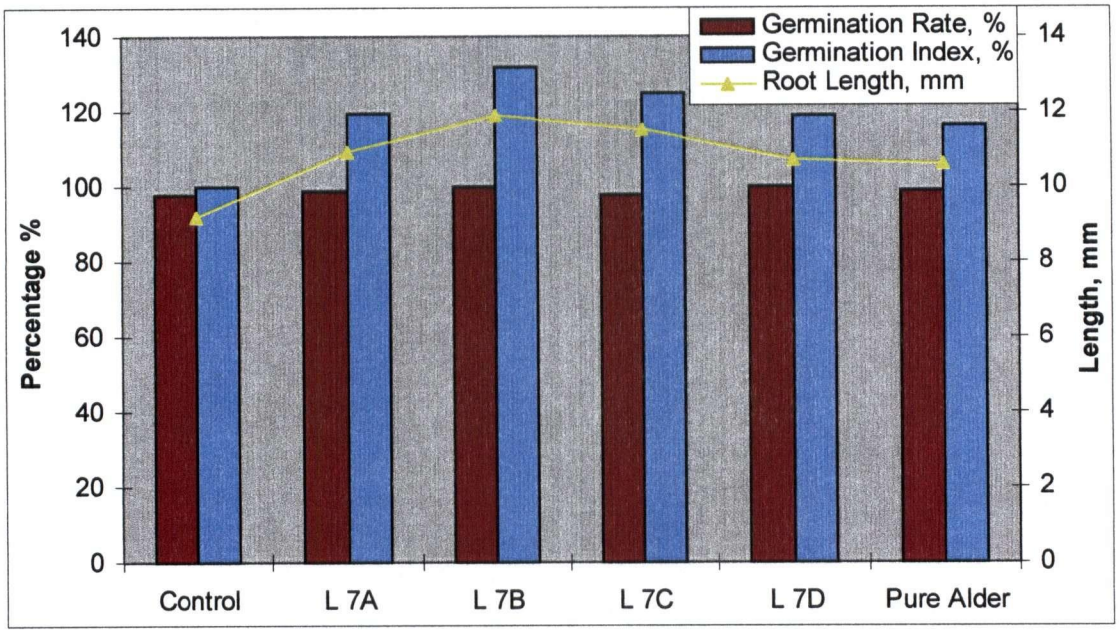

Figure VI.3 Bioassay on Lab 7 – 1-day cress seeds

Table VI.6 Bioassay results from Lab 7 (Tomato seeds)

	% germ, 6-day tomato seed	avg length, mm(mean±SD)	G.I. % of control	t-value to control	t-value to others
Control, distilled water	86%	11.3±4.88	100	-	-
Lab 7A shredded with fresh alder	97%	38.3±16.38	382	$t_{c,7A}>3$	$t_{7A,7B}=2.78$, $t_{7A,7C}=1.31$, $t_{7A,7D}=2.11$, $t_{7A,PAB}>3$
Lab 7B non-shredded with fresh alder	94%	45.4±19.57	439	$t_{c,7B}>3$	$t_{7B,7C}=2.45$, $t_{7B,7D}>1.54$, $t_{7B,PAB}>3$
Lab 7C shredded with composted alder	96%	41.4±17.05	408	$t_{c,7C}>3$	$t_{7C,7D}=0.93$, $t_{7C,PAB}>3$
Lab 7D non-shredded with composted alder	90%	43.9±20.75	406	$t_{c,7D}>3$	$t_{7D,PAB}>3$
Pure alder bark	95%	27.7±10.80	270	$t_{c,PAB}>3$	-

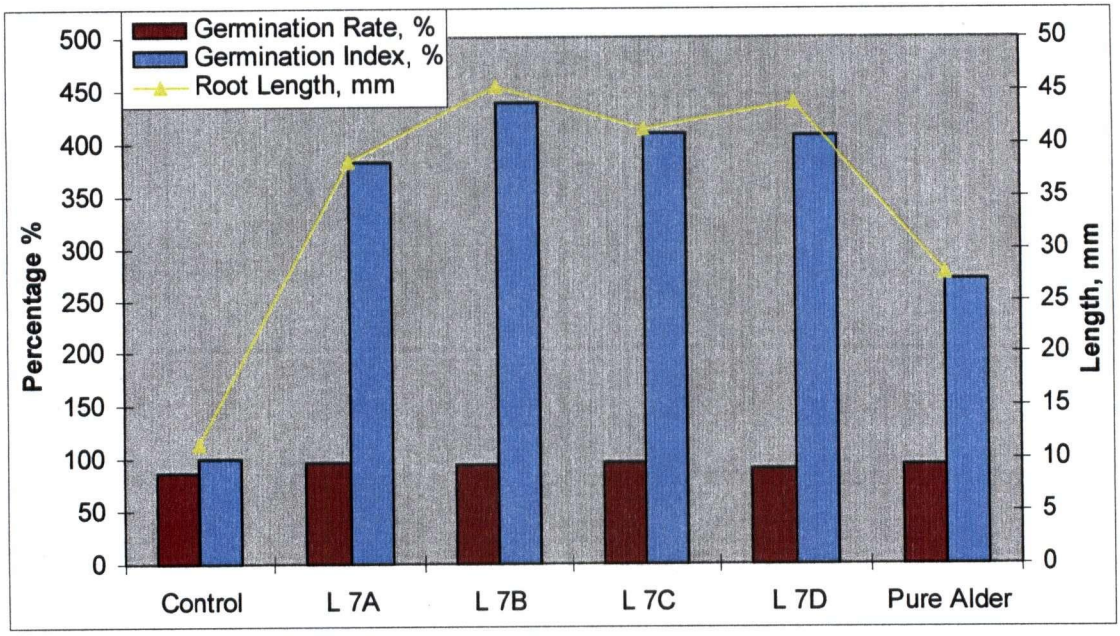

Figure VI.4 Bioassay on Lab 7 – 6-day tomato seeds

Table VI.7 and Figure VI.5 present the bioassay results for Lab 8. The Lab 8 bioassays verified the results discussed in Chapter V. The reactor A compost, which could not even attain a temperature above 45 ^{0}C, showed the highest phytotoxicity (70% vs 96% for the control; GI=64). Then came reactor B with 75% germination (GI=76), and reactor C with 78% germination (GI=98). Reactor D, which had the highest and longest sustained temperature, showed much lower phytotoxicity (92%) and much higher GI (124) than the others. Reactor A compost extract inhibited the growth of seeds (3.53 mm vs 4.04 mm for control), while Reactor D compost extract enhanced the growth of seeds (5.24 mm vs 4.04 mm for control). The Lab 8 bioassay showed an obvious trend: the lower the ratio of bulking agents, the lower the quality of the finished compost. The germination rate, root length, germination index and the number of days of thermophilic

and mesophilic reactions were correlated, i.e. they all showed an upward trend from A, B, C, and D, with A being the lowest.

Table VI.7 Bioassay results from Lab 8

	% germ, 1-day crest seed	avg length, mm (mean±SD)	G.I. % of control	t-value to control	t-value to others
Control, distilled water	96	4.04±0.48	100	-	-
Lab 8A non-shredded	70	3.53±0.78	64	$t_{c,8A}>3$	$t_{8A,8B}>3$, $t_{8A,8C}>3$, $t_{8A,8D}>3$
Lab 8B non-shredded with 15% alder	75	3.95±0.89	76	$t_{c,8B}=0.89$	$t_{8B,8C}>3$, $t_{8B,8D}>3$
Lab 8C non-shredded with 30% alder	78	4.87±1.20	98	$t_{c,8C}>3$	$t_{8C,8D}=2.43$
Lab 8D shredded with 45% alder	92	5.24±0.94	124	$t_{c,8D}>3$	-

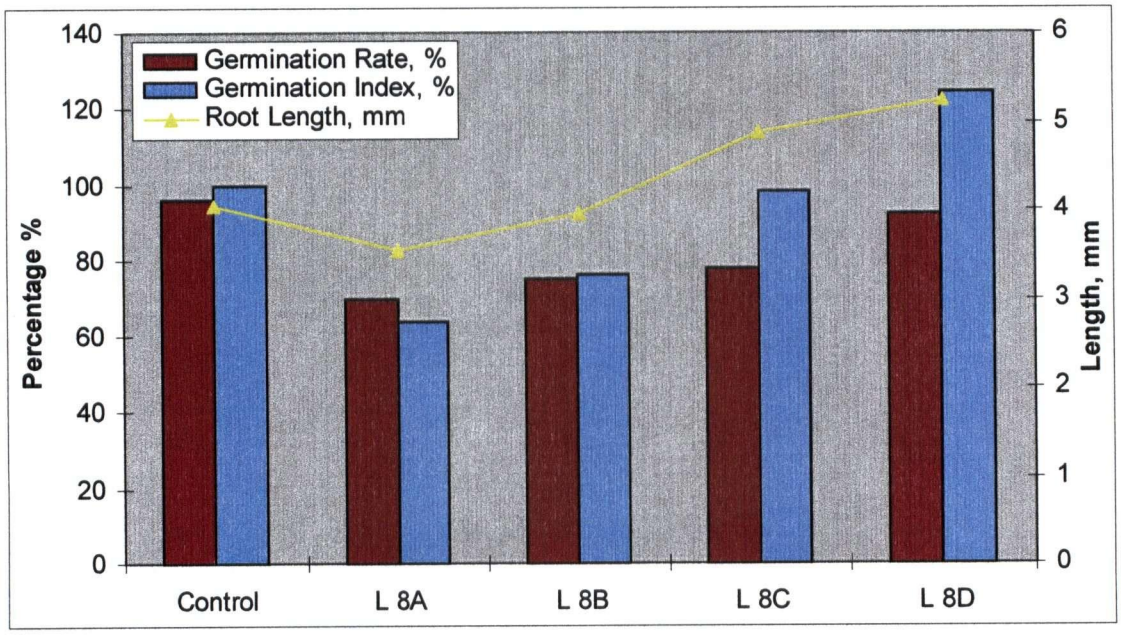

Figure VI.5 Bioassay on Lab 8 – 1-day cress seeds

Table VI.8 and Figure VI.6 present the bioassay results from Lab 9. In Lab 9, used sawdust from the greenhouse waste stream was tested as an alder bark replacement. However, the best results were still the ones with high proportions of alder bark. Reactors A and B, with low proportions of alder bark, showed higher phytotoxicity (88% and 76% respectively than 94% for the control). Reactors C and D, with more alder bark, showed low phytotoxicity (90% and 92% vs 94% for control), significantly higher growth rates and GI than the control. This also correlated with the results and recommendations in Chapter V (the recommend best ratio was about 25% alder, 13 % sawdust, and 62% raw wastes) and there is nothing in the bioassay results that would suggest modifying this recommendation.

Table VI.8 Bioassay results from Lab 9

	% germ, 1-day crest seed	avg length, mm (mean±SD)	G.I: % of control	t-value to control	t-value to others
Control, distilled water	94	4.25±0.96	100	-	-
Lab 9A prunings, 40%sawdust	88	4.35±1.55	96	$t_{c,9A}$=0.54	$t_{9A,9B}$=0.484, $t_{9A,9C}$>3, $t_{9A,9D}$>3
Lab 9B prunings ,14%alder, 26%sawdust	76	4.25±1.36	80	$t_{c,9B}$=0	$t_{9B,9C}$>3, $t_{9B,9D}$>3
Lab 9C prunings ,25% alder, 13%sawdust	90	5.3±1.49	119	$t_{c,9C}$>3	$t_{9C,9D}$=1.75
Lab 9D prunings,35%alder	92	5.65±1.33	130	$t_{c,9D}$>3	-

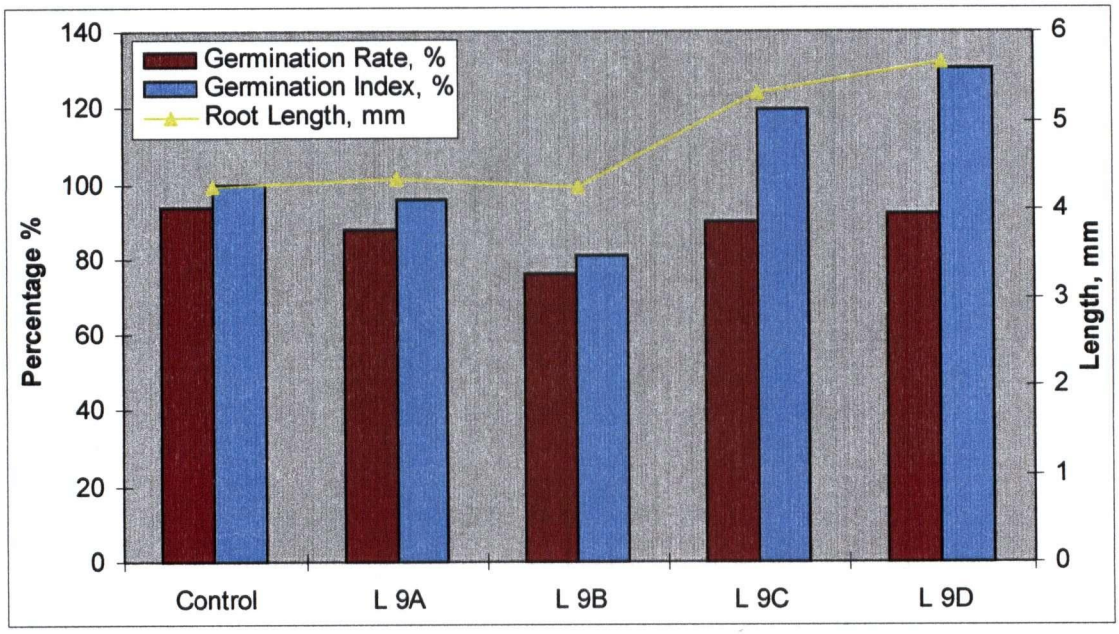

Figure VI.6 Bioassay on Lab 9 – 1-day cress seeds

VI.4.3 BIOASSAYS ON WASTES, LEACHATE AND CONDENSATE

Studies have shown that leachate and condensate from composting facilities were phytotoxic and they were treated as water pollutants (Peot, 1997; Agassi, 1998; Tyler, 2000; Kaschl, 2002). High levels of nitrogen, phosphorus and potassium in these by-products of composting can have detrimental effects on surrounding surface waters. However, for the same reasons, they can be used to improve soil quality and fertilize crops if applied at proper rates. The leachate from greenhouse wastes should be considered as much "cleaner" than leachate from any municipal wastes composting sites since it contains no human pathogens, food debris, or dead animals. This study was designed to examine more closely the by-products - leachate and condensate from a greenhouse waste composting facility and investigate their potential as a marketable source of plant nutrients.

Table VI.9 Analysis of Wastewater from Rotten Wastes, Leachate, and Condensate

	Ammonia, mg/L	Nitrate, mg/L	Phosphate, mg/L	pH	EC, ms
Wastewater from rotten wastes	314.7±53.7	29.2±7.1	123.8±24.55	7.15±0.57	2.63±0.67
Leachate (mix of Pilot 1,2,3)	376.0±226.4	43.7±18.1	55.55±21.41	8.29±0.63	15.85±4.71
Condensate (mix of Pilot 1,2,3)	110.5±72.1	2.42±2.36	253.3±115.4	5.73±0.52	1.07±0.23

*mean±standard deviation

Rotten Waste

In most cases, if greenhouses do not treat their wastes properly, for example, stockpiling them at the available land beside the greenhouse, the wastes will be rotten and create undesirable smells and water contamination. Water samples collected from a rotten pile at a greenhouse site were used for a bioassay test, and the results are shown in Figure VI.7. Table VI.9 provides some analysis made on this compared to leachate and condensate.

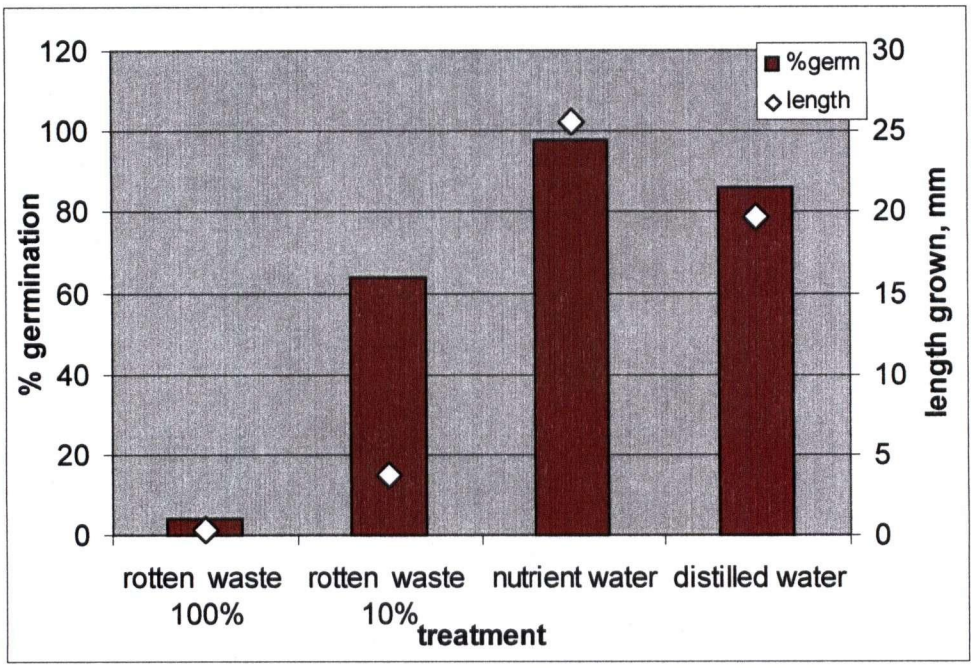

Figure VI.7 Bioassay on Rotten Greenhouse Waste – 1-day cress seeds

These data (Figure VI.7) showed that the "juice" created by the rotten greenhouse wastes, without any dilution, was highly contaminated and created infertility of the land on which they were stored (close to zero germination and growth). Even with 10 times

dilution, they only showed a 64% germination rate, compared to 86 % with distilled water and 98% with a nutrient water used in conventional greenhouse operation.

Leachate / Condensate

The following tests were done to investigate the toxicity of by-product leachate and condensate, the main by-products from an in-vessel composting process, and the dilution at which they could become non-toxic and possibly beneficial to seed growth. Since the leachates and condensates from Pilot 1 to 3 had been collected into the same leachate tank (1200 L tank) and condensation barrel (200 L plastic barrel) and mixed together, they probably represented an average concentration and therefore were used in these tests. Figures VI.8, VI.9 and VI.10 show the bioassay results with leachate at different dilutions.

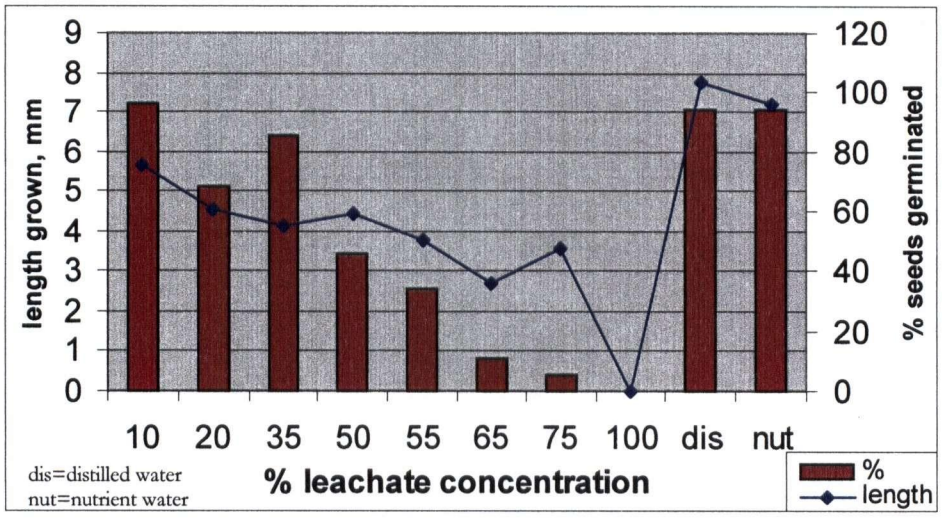

Figure VI.8 Bioassay on Leachate, 1-day Cress seeds

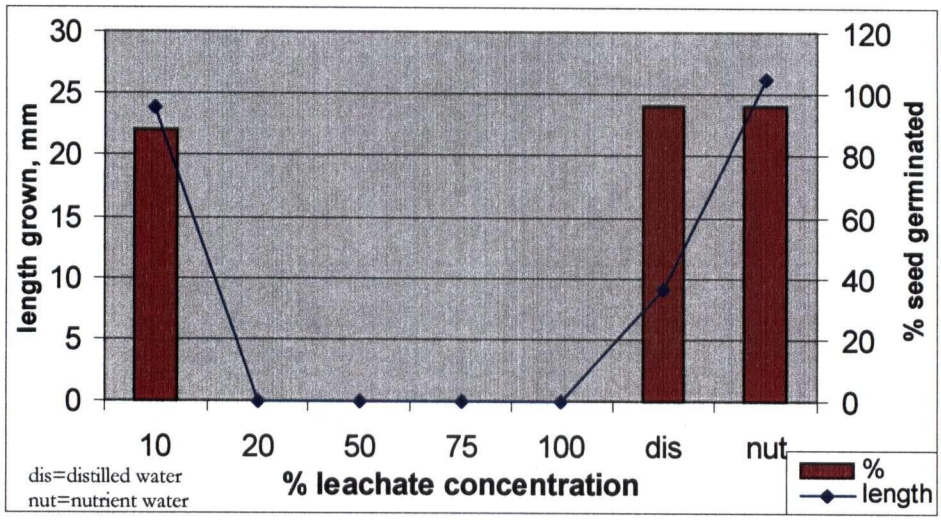

Figure VI.9 Bioassay on Leachate (10%-100%), 6-day tomato seeds

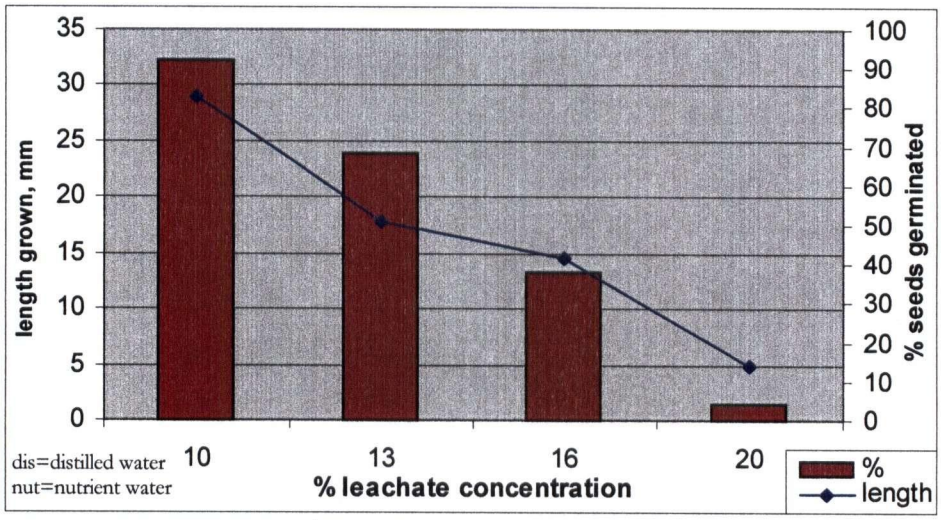

Figure VI.10 Bioassay on Leachate (10%-20%), 6-day tomato seeds

Undiluted leachate completely suppressed germination of both cress and tomato seeds. Dilution with distilled water improved germination and root length performance for cress seeds. For tomato seeds dilutions to 20% leachate still totally suppressed

germination. This could be due to the presence of humic acids in the leachate, which are known to stimulate shoot and root growth, accelerate water uptake, and enhance cell elongation and mobilization of microelements (Inbar, 1992). At 10% dilution of leachate germination of cress seeds and tomato seeds were approximately equal to the control seeds exposed to distilled water or a nutrient solution.

For the cress seeds exposed to leachate diluted to 10%, the root lengths were less than those of controls (distilled water and greenhouse nutrient water). For the tomato seeds the root lengths were less than those of the controls but not by much (24mm vs 26mm). Figure V.10 shows a repeat of the test on tomato seeds between 10 and 20 % dilution. It still shows that only 10% dilution is the threshold dilution, with germination rate above 90%.

Another set of tests was then done on leachate, diluted to 10%, from the pilot scale composting (pilot tests 1,2,3), to verify the above results. The results are shown in Figure VI.11 and Figure VI.12.

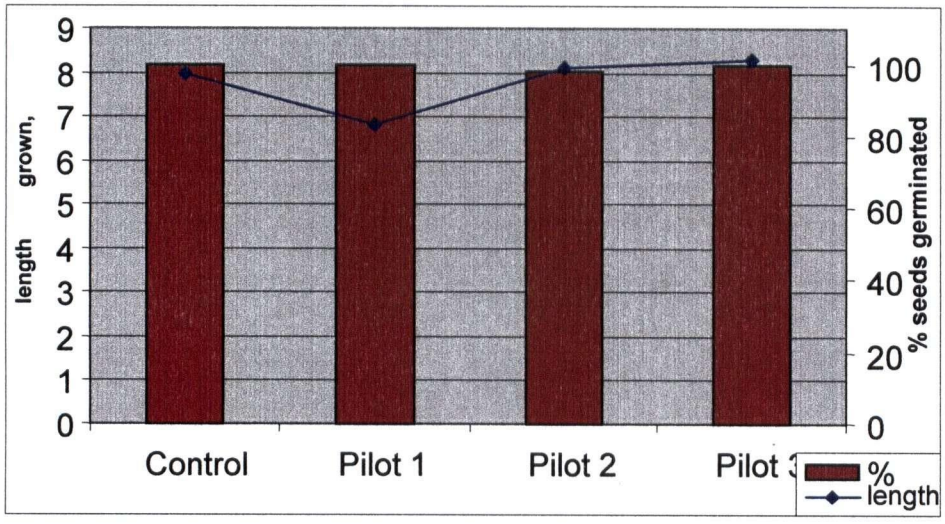

Figure VI.11 Bioassay on 10% Leachate from Pilot 1-3 (1-day cress seeds)

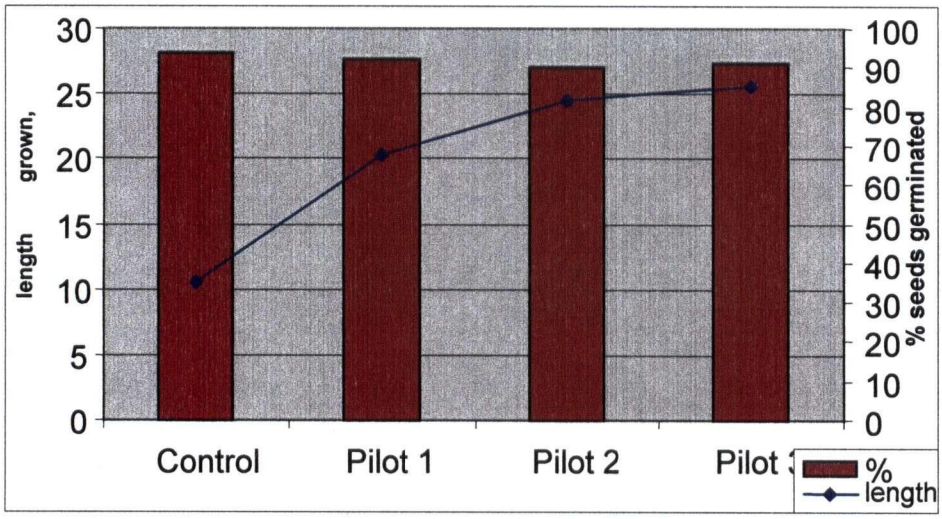

Figure VI.12 Bioassay on 10% Leachate from Pilot 1-3 (6-day tomato seeds)

It can be seen that at 10% dilution, the leachate did not inhibit germination and growth of cress seeds. On the other hand, the tomato seeds improved their growth rates when treated with leachate. At concentrations up to 10%, the tomatoes showed an increase in total length grown while maintaining consistent germination rates of compare with the control values. As the leachate proved beneficial to the tomatoes, there could be a potential to market the diluted leachate.

When grown in condensate (mix of Pilot 1, 2, and 3) at various dilutions, a percentage of cress seeds germinated, which was comparable to the control values but somewhat lower. There was a decrease in the length of seed roots as the concentration of condensate increased (see Figure VI.13). No pattern was observed between the percentage of seeds germinating and the concentration of condensate in which the seeds were grown.

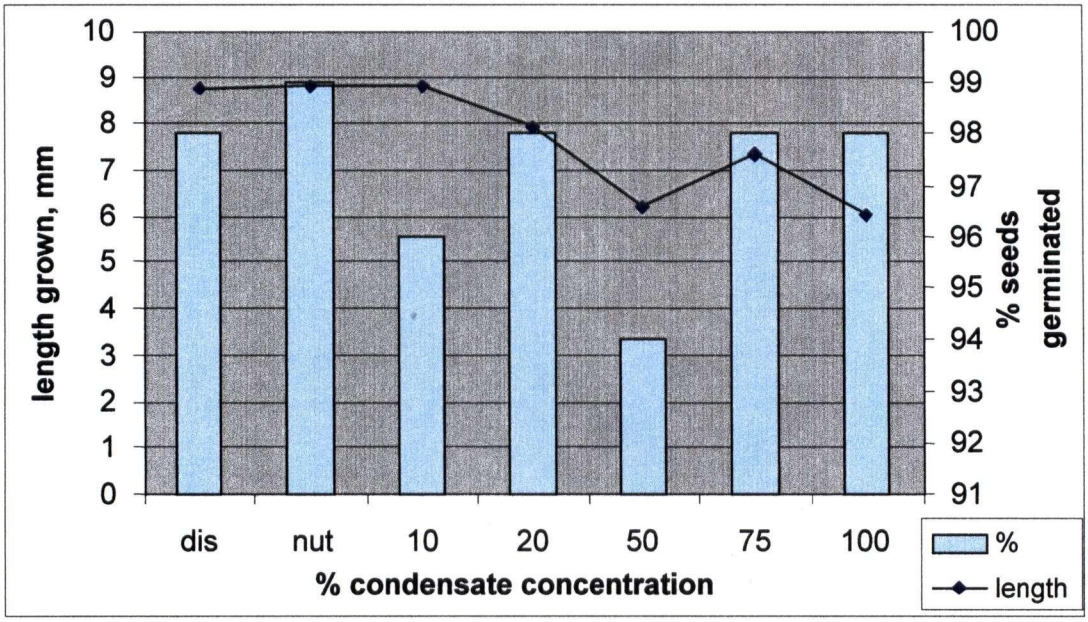

Figure VI.13 Bioassay on Condensate, 1-day cress seeds

The tomato seeds grown in the presence of condensate showed a more favourable response. Figure VI.14 shows that the percentage of seeds germinating was fairly high in all the tests with the tomatoes seeds. The best germination (100%) was noted with a 75% condensate concentration. This was even better than the control germination. The length of seed roots was higher than the distilled water control and was similar to the nutrient water control value. From the relative comparison of the nutrient water control with the condensate, it appears that the condensate must contain some nutrients that the tomatoes use.

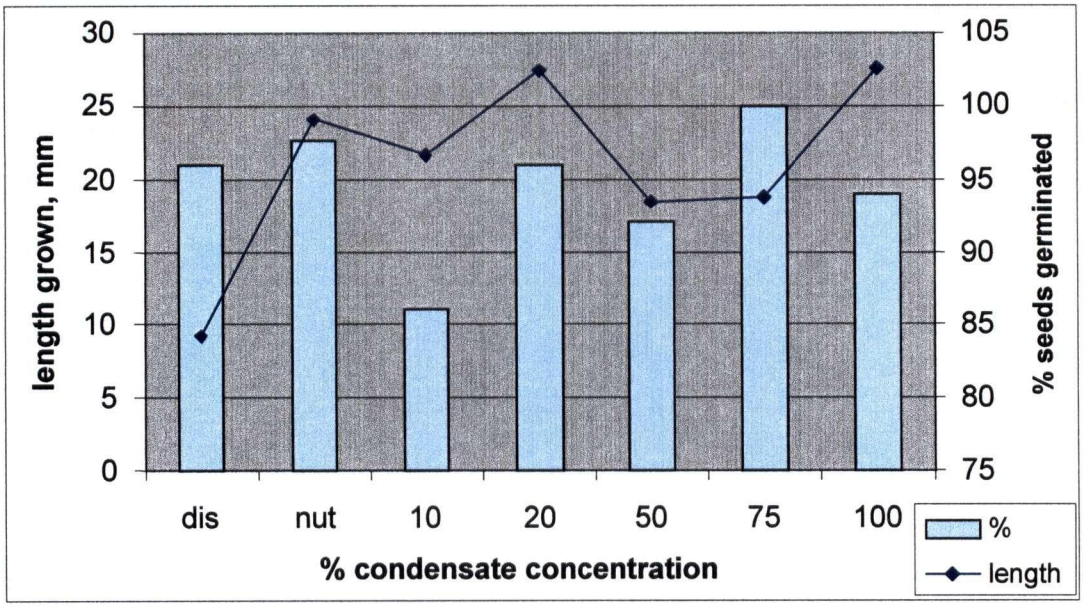

Figure VI.14 Bioassay on Condensate, 6-day tomato seeds

Based on the above results, the by-products from the greenhouse wastes composting process could be re-used as fertilizer supplements depending of the application rate and dilutions. An important step in any such reuse plan is a complete analysis of the liquids. The parameters listed in Table VI.10 profile the nutrients contained in the leachate and condensate (collected from Pilot 1, 2 and 3 as a mix). The leachate has very high nutrient values in macro-nutrients (Potassium, Nitrigen, Phosphorus), and micro-nutrients (calcium, magnesium, zinc, etc). When utilized in a balanced loading, these nutrients could be use as nutrients to enhance plant growth.

Table VI.10 Compost Leachate and Condensate Analysis (from Pilot 1, 2, and 3)

Analysis: den Haan Hort. Consultancy, NL, via Westgro Sales Inc.

Parameter, ppm	Leachate (no dilution)	Condensate (no dilution)	Approx. Target*
pH	8.5	5.9	5.5
EC, ms	18.9	0.9	3.7
NO_3	60	229	1400
Cl	920	7	142
SO_4	2210	10	384
HCO_3	6770	31	30
P	45	210	39
NH_4	310	97	1.8
K	4730	4	313
Na	340	9	184
Ca	20	8	401
Mg	290	4	97
Si	28	2.8	0
Fe	4.6	0.01	1.4
Mn	0.8	<0.01	0.5
Zn	0.3	0.08	0.5
B	2.4	0.08	0.8
Cu	0.1	<0.01	0.04
Mo	0.4	<0.01	0

* Target based on recommended concentrations for greenhouse tomato crop, Westgro Sales.

From the analysis of the nutrient contents of leachate and condensate from the greenhouse wastes composting process, quite a few parameters were either too high or too low for the agronomic needs of greenhouse crop. Seed germination bioassay is only a short test to show acute phytotoxicity. Growth trials are still needed to fully understand the effects on plants after applying the compost by-products. However, studies have shown positive results from application of leachate on field crops (Clean Washington Center, 1997). The greenhouse operator can possibly sell these by-products to field crop farmers, especially those organic farmers who are constantly looking for organic nutrient sources.

VI.5 CONCLUSIONS

Bioassays are a relevant way of proving compost quality. Compost extracts from different batches of compost showed different phytotoxicities and growth rate of seeds, which correlated to the degree of degradation and stability of the finished products. Chemical analysis of compost extract, leachate and condensate showed that they contained a number of valuable nutrients. It was generally accepted that there is an inhibitory effect on germination and early plant growth, as a consequence of using non-stabilized compost, which might contain ammonium and short-chain fatty acids (Murillo, 1995). However, the data presented in this study indicates that there is potential for the reuse of the leachate and condensate from the composting process. Leachate, when diluted to a desired level, could be reused as nutrient supplement for plants. In the case of greenhouse waste, a 10 time dilution was non-toxic or even beneficial in the case of tomato seed. Condensate from composting could be reused for plants without dilutions. If the reuse is possible, costs for disposal of these by-products may be reduced, and they can be instead benefit an end user, e.g. organic farmers. Based on the nutrient content of leachate and condensate and the agronomic needs of the crop, the farmer can calculate a loading rate suitable for the crop.

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CHAPTER VII
UTILIZATION OF COMPOST

VII.1 BACKGROUND AND LITERATURE RESEARCH

On-site composting and re-use of greenhouse waste as a growing medium amendment provides an end use for a waste that might otherwise require disposal, thereby reducing trucking costs and associated environmental impacts, and reducing the reliance of growers on externally supplied growing medium materials (Cheuk, 2002). Currently, most BC vegetable greenhouses use yellow cedar or hemlock sawdust, which are in limited supply, as growing medium.

In addition, utilisation of compost in growing media potentially offers significant benefits to growers in terms of disease suppression (Szczech, 1993; Zhang, 1996; Hoitink, 1997). Concurrent with this study, a disease suppression study carried out at the University of BC using the same amendments demonstrated significant yield improvement through reduction of soil-borne crown rot disease caused by *Fusarium oxysporum* on greenhouse tomatoes (Cheuk, 2003). Suppressing disease by utilizing organic amendments would reduce dependence on chemical disease control.

VII.2 SPECIFIC OBJECTIVES

The overall objective of this part of the study was to evaluate the feasibility of utilising high-quality compost manufactured from greenhouse wastes as an amendment or replacement to sawdust growing medium for greenhouse tomatoes.

VII.3 METHODOLOGY

The study comprised two main elements: first, comparing the characteristics of the compost amendment and conventional sawdust growing medium; and second, demonstration of the feasibility of incorporating the compost amendment in a commercial greenhouse operation.

VII.3.1 GROWING MEDIA ANALYSIS

Compost of Pilot 4 test (Chapter V.4.2), produced from a mixture of waste tomato leaves and culled fruit, red alder tree bark mulch, and used yellow cedar sawdust growing medium, was used throughout this study. The materials were composted using a pilot-scale, in-vessel composting system. The materials were composted for approximately 30 days in the container, cured for several months, and screened to ½". Maximum temperature in the composting vessel was approximately 65 °C, and the composting process had passed the PFRP requirements (Process to Further Reduce Pathogens) of 55 ^{0}C for 3 days.

Prior to starting the growing trials, the physical, the chemical and microbiological characteristics of the sawdust, compost amendment (from Pilot 4), and sawdust plus amendment mixture (2:1 by volume) were measured using the methods described in Table VII.1. Measurements were conducted both before and after the season.

Table VII.1 Growing Media Analysis Methods

Test	Laboratory	Method
Moisture	UBC	Oven-drying gravimetric (Amer. Soc. Agron., 1982)
Bulk density	UBC	Gravimetric/volume estimation (Kasica, 1997)
Particle size – pre-season	UBC	Manual dry sieving
Porosity – pre-season (aeration porosity and water holding porosity)	UBC	Gravimetric water saturation and drainage using bulk materials (Kasica, 1997)
Porosity – post-season (water holding porosity)	Soilcon Laboratories (Richmond, BC)	In-situ samples from 2.5cm depth analysed using desorption from saturation under 10 kPa
Total nitrogen	UBC	Ignition at 950 °C in Leco FP228 nitrogen determinator
Total organic carbon	UBC	Combustion at 680 °C in Shimadzu total organic carbon analyser with solid sampling module
Nutrients	Norwest Labs (Langley, BC)	CMPT-Turf
CEC	Norwest Labs	CL11
pH, electrical conductivity (EC)	UBC	10x dilution distilled water extraction (shaken and centrifuged)
Total bacteria and fungi	Cantest Laboratories (Burnaby, BC)	Bacteria: standard plate count for solid materials Yeast and mold: analysis in solid samples - peptone water rinse, PDA medium

VII.3.2 GROWING TRIAL

The growing trial was conducted in the test greenhouse operated at Hazelmere Greenhouse, Surrey, BC. Seedlings were planted on 25 February 1999 (week 8) and removed at the end of the season on 10 December 1999 (week 49). The test greenhouse environment, covering 153 m^2, was similar to the commercial greenhouse, with computer control of climate and irrigation. The growing medium was enclosed in cylindrical polyethylene bags of approximately 18 litres each; seedlings were rooted in rock wool blocks, placed on the growing medium through an opening in the bag. Four main treatments were used, testing the two media and nutrient solutions as shown in Table VII.2. Each treatment was divided into 3 north-south rows that were interspersed as evenly as possible in the east-west direction. Two more treatments using pure amendment were included, each using only a single end row. "Mississippi" beefsteak tomato cultivar was used, with three plants per bag, and each plant double-headed on a "V" crop wire system. Figures VII.1 and VII.2 show the experimental layout.

Table VII.2 Growing trial treatments – medium, nutrient solution & number of rows

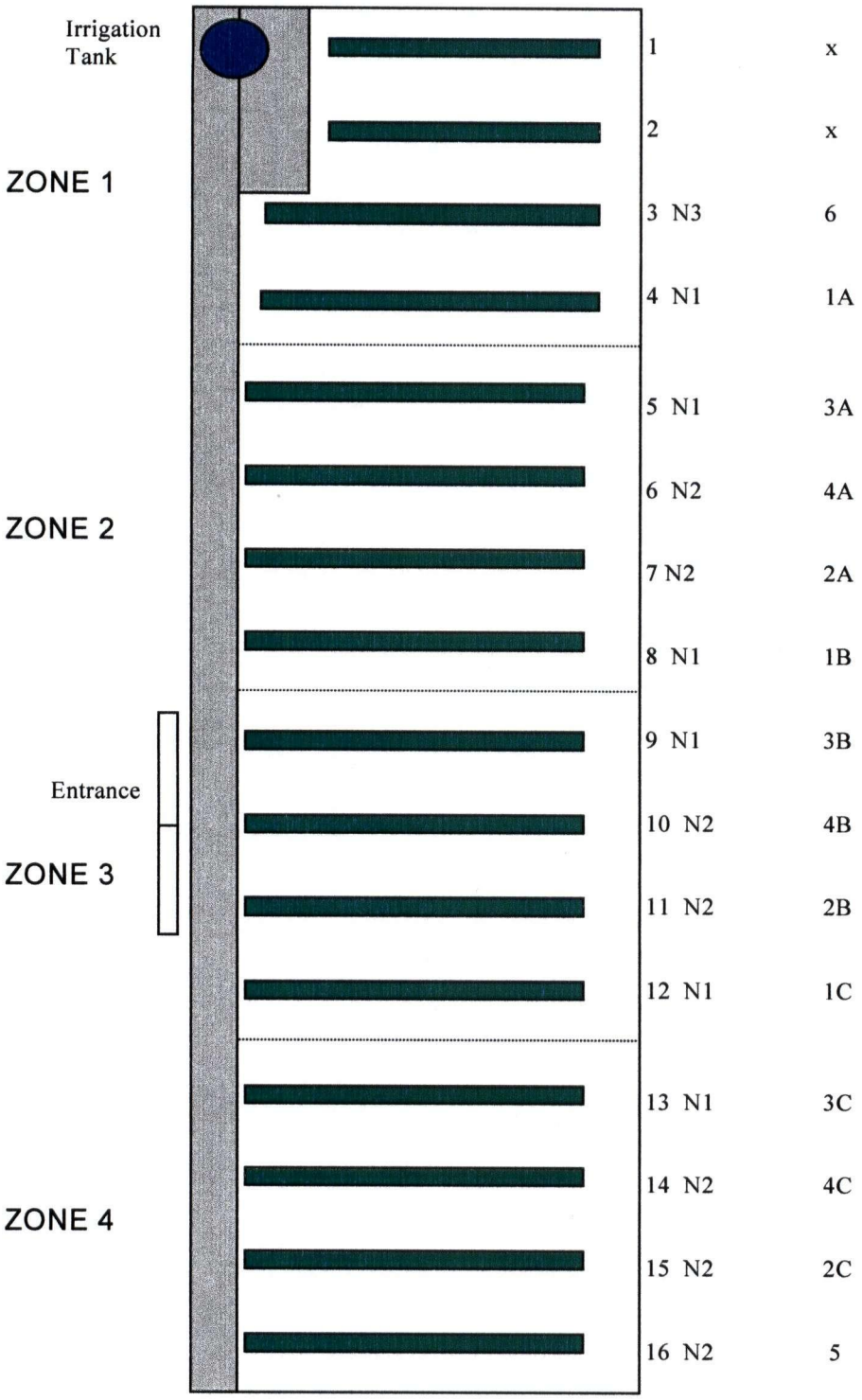
Treatment	Growing medium	Nutrient solution	No. of rows	No. of bags	No. of plants
1	Sawdust	N1	3	24	72
2	Sawdust	N2	3	24	72
3	Sawdust + amendment 2:1 v/v	N1	3	24	72
4	Sawdust + amendment 2:1 v/v	N2	3	24	72
5	100% Amendment	N2	1	8	24
6	100% Amendment	N3	1	8	24
Total			14	110	336

Nutrient solution 1 was intended to be as close to a typical commercial feed as possible and was based on the one used by the grower at Hazelmere Greenhouse. A sample recipe is shown in Appendix F. As a recommendation from the professional grower, another recipe (nutrient solution 2) with higher ammonium concentration (by adding ammonium nitrate) was used. According to the grower, the addition of ammonia would possibly increase the yield on tomatoes; however, it would create problems with high EC and low pH. Nutrient solution 3 was the same recipe as nutrient solution 2, with a lower EC to compensate for the higher drain EC expected from the pure amendment. The ECs of all the nutrient solutions were controlled by an irrigation control unit (PRIVA) through different ratios of dilution. Table VII.3 shows that nutrient solution 3 always had a lower average EC than both the conventional solution and nutrient solution 2. Nutrient solutions 2 and 3 had a higher percentage of ammonia.

The irrigation feed and drain streams were monitored and analyzed regularly. The nutrient recipes, volume, and EC of the feed were adjusted where necessary to maintain drain parameters within acceptable ranges.

Table VII.3 Growing Trial Nutrient Solutions – EC, Recipe And Ammonia Concentration

Nutrient Solution	Average EC	Average ammonia as % of nitrogen
N1 – Conventional	3.2	4.3
N2 – Modified	3.1	6.4
N3 – Modified	2.8	6.4



Rows 3-16: 7.3m (8 bags x 3 plants/bag)

Figure VII.1 Test Greenhouse Layout

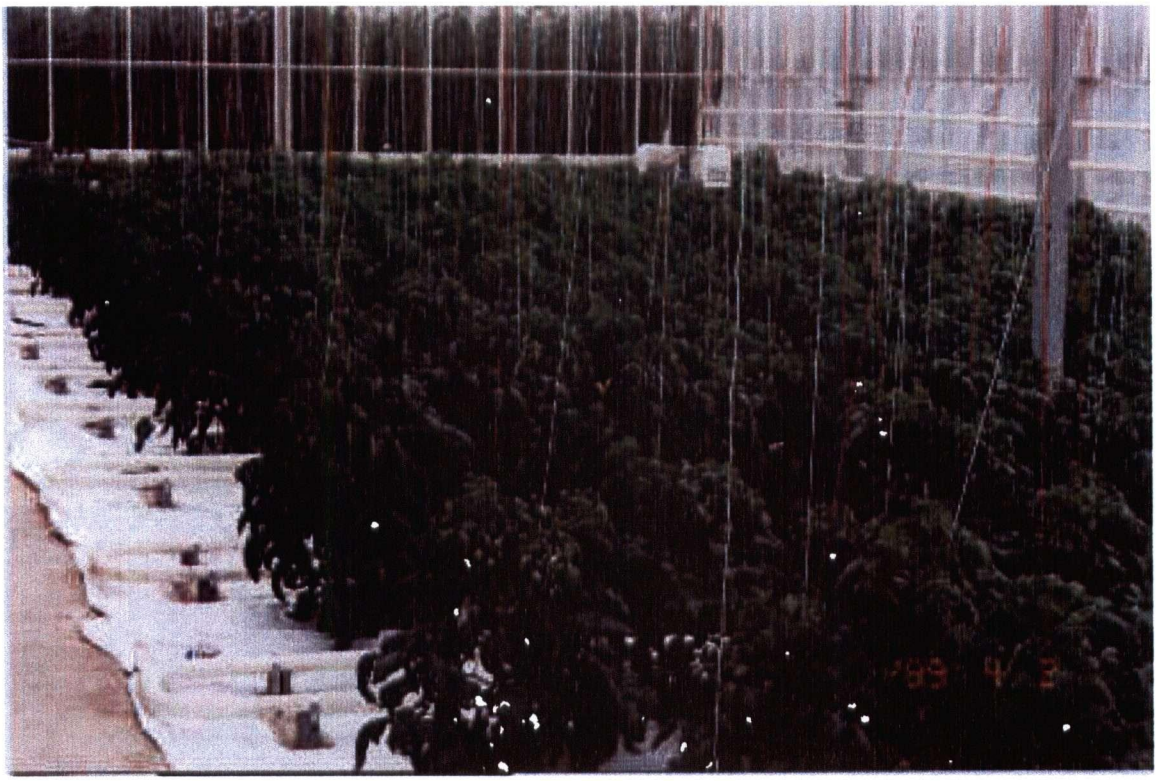


Figure VII.2 Test Greenhouse for Growth trial

Tomato yield was recorded per row, after harvesting one to three times per week depending on the season. Changes in the number of plants due to human intervention (for example breakage due to lowering) were recorded, and the actual yields corrected. Plants lost to disease were recorded separately and not included in yield corrections, with the exception of three plants that were removed shortly after planting due to a viral infection that likely occurred prior to planting. Plant growth parameters of shoot height, leaf length, and stem diameter were monitored on one plant (two shoots) in each row, weekly through the season and they are shown in Appendix G.

VII.3.3 FRUIT QUALITY

A tomato shelf life test was also performed at BC Hot House Quality Assurance also in June, 1999. Three, approximately 5 kg, composite samples of similarly sized and ripened tomatoes were sampled from each row, and grouped according to growing medium. The tests performed included observation of colour development, tray weight, calyx condition, firmness, wrinkles, soft spots, and mold or rot, and were conducted in both laboratory (18–19 °C) and warehouse (12–13 °C) conditions. Each test was conducted after 1, 5, 8, and 14 days of storage.

STATISTICAL ANALYSIS

Statistical data analysis was performed using SPSS 7.5 for Windows software, including ANOVA in Appendix G (analysis of variance) to compare data means.

VII.4 RESULTS AND DISCUSSIONS

VII.4.1 GROWING MEDIA TESTS

VII.4.1.1 Pre-Season Media Analysis

Density and porosity characteristics of sawdust and compost amendment are compared in Table VII.4. The compost amendment showed significantly higher bulk density, lower total and aeration porosity, and higher water holding porosity than sawdust; the sawdust-amendment mixture displayed characteristics generally between the two.

Table VII.4 Pre-Season Physical Characteristics Of The Growing Media

Media status	Parameter	Unit	Sawdust	Sawdust + amendment	Amendment
Moist	Bulk density	kg m^{-3}	409	476	587
	Total porosity	%	63.4	58.6	49.7
	Aeration porosity	%	46.8	35.8	22.8
	Water holding porosity	%	16.6	22.8	26.9
Air-dried	Bulk density	%	171	200	332
	Total porosity	%	76.0	72.4	74.1
	Aeration porosity	%	39.4	36.1	28.5
	Water holding porosity	%	36.6	36.3	45.6

Table VII.5 shows the particle sizes of different media and Figure VII.3 shows the distribution. The sawdust was the ordinary growing media for greenhouses. The compost was from Pilot scale test 4 and a commercial compost from HOME DEPOT (Envirowaste

Mushroom compost) was used for comparison purpose. The amendment (compost) has higher percentage of large particles (>4.8), which provided better structure for the media.

Table VII.5 Particle size of different media (Pre-season)

Mesh (mm)	Pilot 4 compost	Commercial Compost	Sawdust	Sawdust + Pilot 4 compost
	Mass (g)			
4.8	80	50	45	40
2.4	110	95	135	110
1.0	90	150	120	145
0	30	10	10	20
Total	310	305	310	315
	Percentage (%)			
Fraction	Pilot 4 compost	Commercial Compost	Sawdust	Sawdust + Pilot 4 compost
>4.8	26	16	15	13
4.8-2.4	35	31	44	35
2.4-1.0	1029	49	39	46
1.0-0	10	3	3	6
Total	**100**	**100**	**100**	**100**

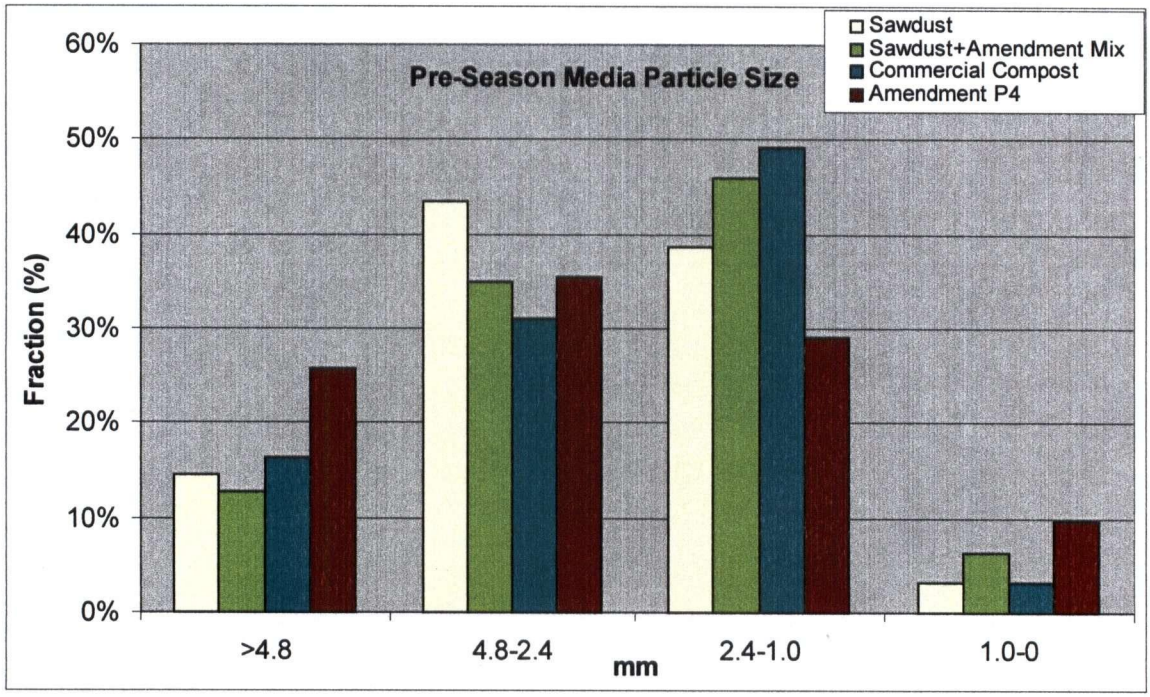


Figure VII.3 Particle size distribution of different growing media

Tables VII.6 and VII.7 show the media nutrient and chemical characteristics. The compost amendment was relatively rich in macro- and micro-nutrients, most of which were 10 to 20 times higher in concentration compared to sawdust. EC and pH were also higher than sawdust, as expected; however they were both within an acceptable range for use as a growing medium. Cation Exchange Capacity (CEC) was significantly higher for the amendment compared to sawdust. The compost amendment had a much lower C:N ratio than sawdust.

Table VII.6 Pre-Season Nutrient Characteristics Of The Growing Media Materials

Measurement	Unit	Sawdust	Amendment
CEC	meq $100g^{-1}$	8.2	127.1
Sodium-Na	ppm	80	2460
Ammonia-N	ppm	0	25.8
Nitrate-N	ppm	8.4	94
Phosphate-P	ppm	20	716
Potassium-K	ppm	190	14200
Calcium-Ca	ppm	1300	12000
Magnesium-Mg	ppm	100	2400
Sulphate-S	ppm	296	1626
Iron-Fe	ppm	20	560
Manganese-Mn	ppm	6.3	149
Zinc – Zn	ppm	0	35.4
Copper - Cu	ppm	0	2.6
Chloride-Cl	$\mu g\ g^{-1}$	44	4800

Table VII.7 Pre-season chemical characteristics of the growing media materials

Medium	Moisture (% wet basis)		Total organic carbon (% dry basis)		Total nitrogen (%dry basis)		EC (mS/cm)		pH		C/N ratio
	Mean (n=3)	Std. dev.	Mean (n=3)	Std. dev.	Mean (n=3)	Std. dev.	Mean (n=3)	Std. dev.	Mean (n=3)	Std. dev.	
Sawdust	65.9	0.2	52.4	0.6	0.7	0.1	<0.1	0.02	6.2	0.2	74.9
Sawdust + compost	65.1	1.0	49.3	0.6	0.8	0.1	0.2	0.03	6.8	0.2	61.6
Compost	63.8	2.8	43.7	1.4	2.0	0.3	0.9	0.0	7.3	0.2	21.9

Another batch of sample from Pilot 4 compost was sent to a commercial laboratory for bacteria and fungi counts as shown in Table VII.8. The microbial counts indicate an approximately 50 times higher bacterial population for the amendment compared to the sawdust, while the amendment fungal populations (as reflected by yeast and mold counts) were slightly lower. The resulting bacteria to fungi ratio was approximately 100 times higher for the amendment. This higher bacterial population and bacteria to fungi ratio of the amendment compared to sawdust may contribute to disease suppression capability - for vegetable crops, a high ratio of bacteria to fungi in the medium is beneficial (Kai, 1990). However, in this study, there was no evidence of significant soil-borne disease; therefore no yield improvements due to disease suppression would be expected.

Table VII.8 Microbial counts of compost amendment

Medium	Bacteria CFU g^{-1}	Yeast CFU g^{-1}	Mold CFU g^{-1}	Bacteria/fungi ratio (calculated)
Sawdust	8×10^4	1.6×10^4	7×10^2	5
Amendment (Pilot 4)	4.5×10^6	2.1×10^3	7.1×10^3	489

VII.4.1.2 Post-Season Media Analysis

Post-season analysis results of the media used in the growing trial are shown in Tables VII.9 and VII.10. For the post-season density and porosity, the commercial laboratory (Soilcon) had the media air dried before analysis. The bulk density of the post season sawdust, mix and amendment were all much less than the pre-season values. Since there was not much change in volume (the plastics bag were still full of media), there must be some weight loss due to degradation of the media (loss of carbon) during the growing season. Nevertheless, the post season amendment's bulk density was greater than that of the mix which, in turn, was greater than that of the sawdust. See Tables VII.4 and VII.9.

At season-end, the sawdust had the lowest water holding porosity and lowest total porosity, those of the sawdust/compost mix and compost were higher. This shows the amendment media would have better water retention ability than sawdust even at the end of the growing season.

Table VII.9 Post-season media density and porosity

Parameter	Sawdust		Sawdust + compost		Compost	
	Mean	Range	Mean	Range	Mean	Range
Bulk density (kg m-3)	144.0	11.6	183.1	9.6	209.9	17.5
Total Porosity %	63.9	2.9	73.8	1.3	79.0	1.8
Aeration Porosity %	28.1	2.5	20.7	4.7	25.5	0.9
Water Holding Porosity (% by volume)	35.8	0.6	53.0	3.3	53.4	0.8

Mean and range based on n=2 samples.

Table VII.10 Post-season media chemical characteristics

Growing medium	Nutrient solution	Moisture (%)		Total organic carbon (%)		Total nitrogen (%)		EC (mS cm-1)	pH	C/N ratio
		Mean (n=3)	Std. dev.	Mean (n=2)	Range	Mean (n=3)	Std. dev.	(n=1)	(n=1)	
Sawdust	N1	75.3	1.4	50.8	0.1	1.41	0.06	0.70	6.3	36.1
Sawdust	N2	79.9	0.6	49.7	0.1	1.59	0.09	0.50	6.4	31.2
Sawdust + compost	N1	78.2	0.5	44.8	1.6	2.13	0.17	0.80	6.7	21.1
Sawdust + compost	N2	78.3	0.3	42.4	0.8	2.56	0.11	0.90	6.7	16.6
Compost	N2	78.3	0.6	42.3	3.0	2.38	0.26	0.50	6.3	17.7
Compost	N3	79.4	0.3	38.8	1.6	2.78	0.05	0.40	6.8	13.9

The post-season moisture contents were all higher than the pre-season since the media had absorbed a lot of nutrient solution. The total organic carbon had decreased which confirmed there must be some loss of carbon during the season as discussed above. Also, since there were losses of carbon and absorption of nitrogen from the nutrient solution, the C:N ratio would decrease. Over the season, the carbon to nitrogen (C/N) ratio of the sawdust medium decreased by approximately 57 %, the mixture approximately 69%, and the amendment approximately 28%.

A white fungus was also observed immediately under the rock wool block and on the surface of the medium in many of the sawdust-amendment mix bags. A few of the sawdust bags had smaller amounts, and virtually none was observed in the pure amendment. The fungus appeared to be more common in Treatment 4, bags which had higher feed ammonia than Treatment 3. Analyses at government and commercial laboratories both identified the fungus as non-pathogenic and saprophytic.

VII.4.2 GROWING TRIAL

VII.4.2.1 Fruit Yield

The total marketable yield for all treatments harvested was 7642 kg, or, on an area basis 49.8 kgm^{-2}. Table VII.11 compares the marketable yield, culls, and average fruit size for all treatments.

Table VII.11 Tomato yield, size and culls for the trial growing season

Nutrient solution	Medium	Corrected marketable yield (kg)		Average fruit size (g)		Culls (%)	
		Mean (n=3)	Std. dev.	Mean (n=3)	Std. dev.	Mean (n=3)	Std. dev.
N1	Sawdust	51.4 (A)	2.0	173.6 (A)	3.1	8.6 (A)	3.2
N1	Sawdust + compost	52.6 (A)	1.0	177.7 (A)	1.8	6.5 (A)	1.5
N2	Sawdust	52.5 (A)	0.8	176.3 (A)	3.8	7.9 (A)	0.5
N2	Sawdust + Compost	47.7 (B)	1.5	170.2 (A)	1.0	10.2 (A)	1.4
N2	Compost	43.7	n/a	171.1	n/a	10.4	n/a
N3	Compost	53.3	n/a	186.2	n/a	9.7	n/a

(A), (B) indicate which treatment means are statistically the same(A) or different (B) for $p < 0.05$.

For conventional feed, differences in yield between sawdust and sawdust-amendment mix were not significant, while for modified feed (higher ammonia N2), the sawdust-amendment mix and compost had a 9% and 17% lower yield respectively (significant for $P<0.05$). This is could be due to the high EC in the medium caused by both the compost and additional ammonium nitrate. The yield in the EC-reduced compost media achieved the highest yield. It has to be noted that each row's yield data

were collected from 24 plants. So, even though treatment 6 (compost, N3) had only one row it's yield data represented the total yield of 24 plants.

The comparison of the 100% compost amendment treatments (treatment 5 and 6) is as representative as the other 4 treatment since they were single rows on the periphery of the greenhouse; however yield results are encouraging in that Treatment 6 showed a larger fruit size in addition to higher yield.

VII.4.2.2 Fruit Quality

Shelf life results are shown in Table VII.12. The conclusion drawn by the shelf life tester (the quality supervisor at BC Hothouse Food Inc.) was that there was very little difference between the groups, and all groups showed acceptable quality. The data also suggest that increased use of amendment might have contributed to slight increases in softness and weight loss during storage; however further study would be required to confirm this.

Table VII.12 Tomato shelf life results

	Colour stage	Tray weight loss	Calyx condition	Firmness (hand)	Sugars	Number wrinkled	Number with soft spots	Number with mold/rot
Range/Unit	1 - 12	%	1 - 5	0 - 5	1 - 6	-	-	-
Key	1-Green	-	1-Fresh	0-Hard	1-Lowest	-	-	-
Sawdust	8.38	3.9%	3.25	0.75	5	0	0.75	0
Sawdust+ Amendment	8.25	4.7%	3.25	0.88	5	0	0.88	0
Amendment	8.38	5.3%	3.25	1.00	5	0	1.13	0

VII.4.2.3 Plant Growth

Results for cumulative plant growth, leaf length, and stem diameter were analyzed. Statistical analysis of Student's *t* test of the growth results did not show any significant differences between the treatments ($P<0.05$), and therefore they are not further discussed here. The results can be found in Appendix G.

VII.4.2.4 Disease

Botrytis stem rot, with only a few exceptions, was the cause of losses due to disease. The relatively high losses largely occurred near the end of the season (approximately half in the last 5 weeks); the losses were consistent with the outbreaks in the main greenhouse to which the test greenhouse is attached. Although there were differences in the number of diseased plants between treatments, they were not statistically significant. This suggests that the growing media and nutrient combinations tested did not impact *Botrytis* development.

VII.4.2.5 Medium Acidity

The modified feed with increased ammonium concentration depressed yield slightly. This may have been due to excessive amounts of ammonia nitrogen (up to 12% of TN) that were used during a period in June. In that period, the grower recommended to increase the ammonia concentration in order to see whether that could cause any yield increase (Cheuk, 2003b). Unfortunately, because of that, the pH in the media (drain)

dropped to an undesirable level. The minimum recorded drain pH was 4.2 for Treatment 2 (sawdust), and 5.0 for Treatment 4 (sawdust-amendment mix), both using the same feed. Subsequent to the minimum pH occurring in the sawdust medium, bicarbonate buffering was added to all nutrient solutions to maintain a minimum feed pH. In that period the sawdust medium fluctuated between pH 4.2 to 6.1 (Range=1.9) while the amendment fluctuated between pH 5.0 to 6.0. This showed that the amendment mix demonstrated a significant buffering capability (see Figure VII.4). This agrees with other research works done on buffering capacity of compost (Stamatiadis, 1999; Shojaosadati, 1999; Jakobsen, 1996). Stabilization of pH enhances the nutrient uptake by plants and root health.

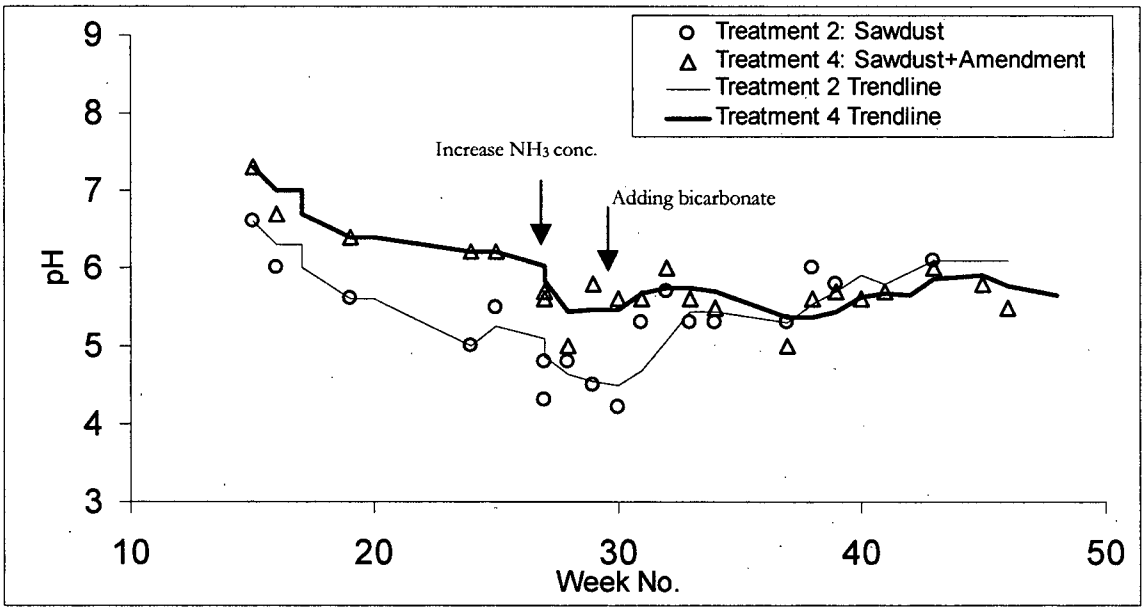


Figure VII.4 Drain pH comparison of Treatments 2 (sawdust) and 4 (sawdust plus amendment), both using nutrient solution N2 (higher ammonia).

VII.5 CONCLUSIONS

There are likely several factors related to the growing medium that may have contributed to the yield positively or negatively. Positive effects provided by amendment may include nutrient retention (as reflected by CEC), additional nutrients or other compounds, and effects of beneficial microorganism populations for disease suppression. Negative factors may include lower porosity and oxygen diffusion, and excessive moisture retention. Further optimization of fertilizer and irrigation schedules to take into account the different physical and chemical medium characteristics could potentially increase yield, or alternatively allow a larger proportion of amendment in the medium mix.

The combination of increased ammonium concentration with compost amendment had a negative effect on yield, suggesting an interaction between the feed composition and the medium; this may be related to the white fungus observed, but could not be confirmed. However, addition of the compost amendment to the conventional sawdust growing medium can provide mitigation of excessively low pH. Also, the positive results from the 100% compost with lower EC should encourage further research on the optimum use of compost.

This study found that compost manufactured from greenhouse crop waste in a controlled process can be suitable for use as a growing medium amendment in soil-less tomato greenhouses. Using conventional management techniques, a similar yield could be

achieved compared to conventional sawdust medium using a 2:1 sawdust to amendment mix by volume. By demonstrating the feasibility of compost as a growing medium amendment in a commercial setting, the results of this study could form the first step in moving soil-less vegetable greenhouses in BC toward more sustainable waste management and growing practices.

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Special Acknowledgements

This project was implemented pursuant to the British Columbia Investment Agriculture Foundation Program, funding for which is provided through Agriculture and Agri-Food Canada's (AAFC) Safety Net Program and Canadian Adaptation and Rural Development Fund. The authors also thank Houweling Nurseries Ltd., Delta, BC for tomato seedlings, materials and time; Mr. Bud Fraser and Mr. Raymond Wong for research assistance and field crop management; Mr. Kevin Haddrell and Ms. Jennifer Miller at UBC for their dedication; and Mr. Jim Portree of the B.C. Ministry of Agriculture and Food for his support.

CHAPTER VIII

DISEASE SUPPRESSION TRIALS

VIII.1 BACKGROUND AND LITERATURE RESEARCH

Disease is an ongoing problem that continues to impact greenhouse productivity and product quality. Historically, diseases such as *Fusarium* crown rot in greenhouse tomatoes have accounted for significant crop losses, in some cases as high as 30 to 50%. Pathogenic organisms continue to change and adapt to new cultivars and controls, developing resistance to chemical agents. These pathogen adaptations mean that plant resistance genes often give protection only for a few years (Campbell, 1989).

Positive disease suppression results with compost products in terms of disease suppression have been observed in recent studies. Pythium root rot in cucumbers grown in peat was decreased when the peat was amended with a composted pine bark mix (Zhang, 1996). A floriculture study (Mathur, 1996) concluded that good quality compost can replace peat, increase nutrient availability, and increase plant growth and survival, though many of the commercial composts were found to be unsatisfactory due to poor quality.

Compost can suppress disease in plants via a number of mechanisms, including competition, antibiosis, hyperparasitism, and induction of systemic acquired resistance (SAR) in some host plants (Hoitink, 1997). The effectiveness of the compost amendment is largely determined by the feedstock materials and the method of processing and

storage, as well as the type of crop. As previously reported (Mathur, 1996), compost can be phytotoxic if it is not processed or applied correctly. Parameters including moisture, pH, carbon to nitrogen ratio, and maturity impact the effectiveness of disease suppression (Hoitink et al., 1997). In addition, selection of appropriate feedstocks and processing methods can help optimize the microbiological makeup of the product for the particular crop in order to give the best results (Grobe, 1998). A high bacteria to fungi ratio has also been suggested as a desirable characteristic for increasing disease suppression (Kai, 1990).

VIII.2 SPECIFIC OBJECTIVES

As part of a larger project evaluating the feasibility of utilising high-quality compost amendment manufactured from greenhouse wastes as an amendment to soil-less growing medium for greenhouse tomatoes, this part of the study focuses on the disease suppressive abilities of the compost amendment. In the Lower Mainland of British Columbia, most vegetable greenhouses currently use yellow cedar sawdust as the growing medium. The specific objectives are :

- Find out whether compost has any disease suppressive abilities on seedlings, and if so, find out what the best way of application;
- Find out whether compost has any disease suppressive abilities on adult plants, and if so, investigate the improvement in plant health and yield.

VIII.3 METHODOLOGY

The study comprised two main components – seedling growth tests, and a yield test. In both cases, FORL spores were introduced into the growing media, and the plants monitored for growth, health, and yield parameters, depending on the test. Media treatments compared the conventional growing medium (yellow cedar sawdust) with a medium amended or replaced with compost.

Compost amendment was produced from a mixture of greenhouse waste materials and other amendments, as shown in Table VIII.1. The materials were composted using a pilot-scale, in-vessel composting system (indicated by "P" in the batch number) which was designed by the author for greenhouse use, and a laboratory scale system (indicated by "L" in the batch number), depending on the batch. Materials were composted for 3-4 weeks in the vessel, then cured for several months, and screened to ½". The composting system provided controlled environmental conditions designed to ensure sufficient reduction or elimination of potential pathogens in the raw materials (BC MWLAP, 2002). Maximum temperature in the composting vessels was approximately 65 °C. The controlled process used in the laboratory scale vessels was similar to that of the pilot-scale vessel (see Chapter V).

Table VIII.1 Recipes and dates of compost amendment batches

Amendment batch number	Recipe
P4	Tomato leaves and cull fruit Alder bark hog fuel Used sawdust medium
P6	Same as P4
P7	Shredded whole tomato plants Used sawdust medium
P8	Tomato leaves and cull fruit Hemlock bark mulch Used sawdust medium
5A	Tomato leaves and cull fruit Hemlock bark mulch Recycled compost coarse fragment Sawdust
5C	Tomato leaves and cull fruit Alder bark hog fuel Recycled compost coarse fragment Sawdust

VIII.3.1 TOMATO SEEDLING TESTS

Seedling propagation generally followed established greenhouse methods (Portree, 1996) as follows. Rock wool plugs were pre-soaked and flushed twice over 48 hours with EC=0.5 mS/cm nutrient solution. Rock wool plugs and amendment plugs were then seeded and the seeds were covered with either vermiculite or amendment, and the trays were covered until 90% of the seeds had germinated. Aliquots (1 ml) of spore suspensions (2 x 10^8 spores/ml of *Fusarium oxysporum* f. sp. *radicis- lycopersici* (FORL) Race 1[3]) were then inoculated into selected plugs. Nutrient solution EC was increased to

[3] Isolated from diseased Dombito plants in 1985

1.5 mS/cm after inoculation, then 2.5 to 3.0 mS/cm after one more week. Seedlings were removed and evaluated according to a scoring system for root disease after several weeks. All tests used Dombito (a FORL susceptible greenhouse beefsteak tomato) cultivar.

To construct plugs from amendment, rock wool plugs were cut into three cylindrical wafers. One wafer was placed in the bottom of each hole in the plug tray; amendment was then added on top of the rock wool, filling the hole 4/5 full. Seeds placed on the amendment were then covered with either vermiculite or amendment. In later tests, a "sandwich" method was tested, where ¼" of the rock wool plug was cut from the top and replaced with amendment; this results in the seed being sandwiched between two layers of amendment. Plug trays were separated into small groups, and placed in 25 cm plastic trays, to avoid cross-contamination between groups.

VIII.3.2 PREPARATION OF FORL SPORES

Two week old FORL cultures grown on potato dextrose agar (PDA) at 20 °C were used. Sterile distilled water (10 ml) was added to each culture. A sterile glass rod was rubbed lightly over the fungal colonies to release the spores. The spore suspension was collected, filtered through cheesecloth, diluted and the spore concentration was determined by a haemocytometer. This suspension was then further diluted to the levels used in the individual experiments.

VIII.3.3 SEEDLING SCORING

The following parameters were recorded for scoring of tomato seedlings.

1. Plant height: root crown to plant apex.
2. Stem diameter: measured approximately 2 cm above crown.
3. Leaf colour: three measurements were taken on upper leaves of each plant using a Minolta SPAD-502 chlorophyll meter.
4. Root health : a visual observation to reflect the overall root health, recorded as 1 to 3, corresponding to good, fair and poor. However, this parameter was not used for discussion (only shown in Appendix K) since it is not as systematic and objective as the root disease score.
5. Root disease score: a visual scoring system reflecting the severity of crown and root rot symptoms on each plant, as shown in Table VIII.2.

Table VIII.2 Seedling test root scoring

Score	Interpretation
1	White, healthy roots; no sign of disease
2	Slight browning of vascular tissue in the crown
3	Extensive browning of vascular tissue in the crown
4	Extensive necrosis of the crown
5	Dead plant with typical symptoms of crown and root rot

Six individual tomato seedling disease tests were conducted. The first two were "dry runs" to help establish the method. To compare treatments in terms of disease, a significant amount of disease must be created, at least in some of the plants. In Tests 3, 4 and 6, disease was evident in the plant roots; in Test 5 no disease was observed in any plants, thus the results of this test have not been included in the analysis. The time

required to develop disease, and the growth rate of the plants, also varied somewhat from test to test.

Note that the number of seedlings scored was usually less than the starting number of replicates planted, due to seeds that did not germinate or develop. For Tests 4 and 6, 10 extra replicates were provided in the inoculated control group; these were used to monitor disease development prior to full scoring.

Treatments and experimental conditions for tests 3, 4 and 6 are shown in Tables VIII.3, VIII.4 and VIII.5.

Table VIII.3 Treatments and conditions for seedling test 3 - amendment as plug and covering

Location			UBC Pathology greenhouse		
Temperature			18 - 25 °C		
Lighting			18 hour photoperiod, sodium vapour lamps		
Inoculation time (days from seeding)			4		
Scoring times (days from seeding) and number of replicates per scoring per treatment			21, 28, 35, 42, 50 days 5-6 replicates each		
Tray plug type			Keem plug (2.5 cm dia. cylinder)		
Trays (blocks) per treatment			2		
Treatments					
No.	Medium	Covering	Nutrient solution	Inoculation	No. of replications scored*
1	Rock wool	Vermiculite	Nutrient	None	15
2	Rock wool	Vermiculite	Nutrient	FORL	15
3	Rock wool	Amendment P6	Nutrient	None	15
4	Rock wool	Amendment P6	Nutrient	FORL	15
5	Amendment P6	Vermiculite	Nutrient	None	15
6	Amendment P6	Vermiculite	Nutrient	FORL	15

*There were at least 30 plants per treatment total, of which 15 were included in the scoring results.

Table VIII.4 Treatments and conditions for seedling test 4 - amendment as plug and covering, second trial.

Location			Growth chamber (UBC Plant Science)	
Temperature			24 °C (1st two weeks); 23 °C (subsequent)	
Lighting			18 hour photoperiod, fluorescent grow-lights (after germination)	
Inoculation time (days from seeding)			8	
Scoring times (days from seeding) and number of replicates per scoring per treatment			46, 53 days 14 – 17 replicates each	
Tray plug type			Small cube, 4 cm	
Trays (blocks) per treatment			3	
Treatments				
No.	Medium	Covering	Inoculation	No. of replications scored
1	Rock wool	Vermiculite	None	40
2	Rock wool	Vermiculite	FORL	50
3	Rock wool	Amendment P6	FORL	40
4	Amendment P6	Vermiculite	FORL	40
5	Amendment P7	Vermiculite	FORL	40

Table VIII.5 Treatments and conditions for seedling test 6 - amendment comparison, sandwich covering method

Location	Growth chamber (UBC Plant Science)
Temperature	24 °C (1st two weeks); 23 °C (subsequent)
Lighting	18 hour photoperiod, fluorescent grow-lights (after germination)
Inoculation time (days from seeding)	7
Scoring times (days from seeding) and number of replicates per scoring per treatment	48 days 28 replicates each
Tray plug type	Small cube, 4 cm
Trays (blocks) per treatment	2

Treatments

No.	Medium	Covering	Inoculation	No. of replications scored
1	Rock wool	Vermiculite	None	40
2	Rock wool	Vermiculite	FORL	50
3	Rock wool	Amendment P6 (sandwich)	FORL	40
4	Rock wool	Amendment 5A (sandwich)	FORL	40
5	Rock wool	Amendment 5C (sandwich)	FORL	40

VIII.3.4 YIELD TEST

The disease suppression yield test, conducted in the UBC Horticulture Greenhouse, investigated the effect of the sawdust-amendment mix growing medium on yield, over a full growing season, and under severe disease pressure from FORL inoculation. The horticulture greenhouse is a modern glass research greenhouse, with a controlled climate, automatic sunshade, and misting system. The greenhouse provides conditions as close to a commercial greenhouse as are available at UBC. However the climate control and irrigation system available were not as sophisticated as those of a commercial greenhouse. Climate could not be controlled separately from the main greenhouse; temperatures were typically near 20 °C except on sunny summer days, when they could reach the high 20's. Nutrient solution was delivered from a manually mixed tank, typically at EC 2.8 mS/cm, through drippers controlled by a timer with a manually set program. Later in the season, feeding was controlled by a photo-sensitive controller. No artificial lighting was provided.

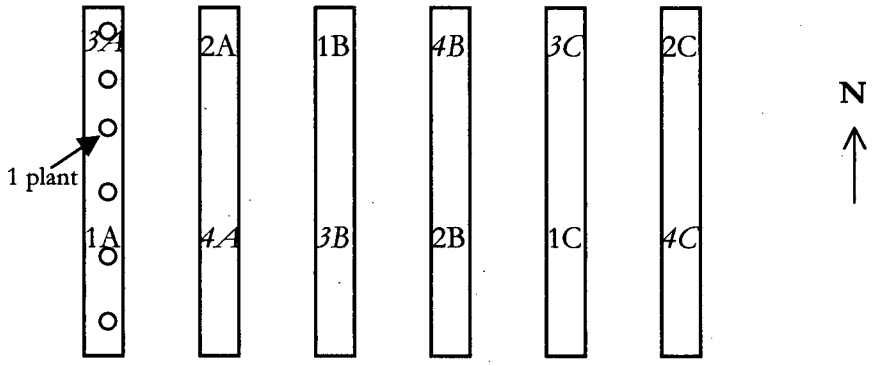
Dombito tomato seedlings, seeded in rock wool plugs, were transplanted to rock wool blocks on March 8. In the horticulture greenhouse, the bags of yellow cedar sawdust growing medium were inoculated on March 19 by distributing 30 ml of FORL suspension (2×10^3 spores/ml) into the medium directly under the future locations of each rock wool block. The seedlings were then planted on the bags on March 21, and grown under the same irrigation and climate conditions until December 6.

Each treatment, shown in Table VIII.6, was separated into three bags of three plants each, and distributed as evenly as possible over an area of approximately 12 m^2.

Table VIII.7 lists that number of treatment. All treatments were located randomly in the greenhouse test site. Figure VIII.1 shows the experimental layout and Figure VIII.2 is a picture of the greenhouse site.

Table VIII.6 Procedures - Disease Suppression Yield Test

Location :	UBC Horticulture Greenhouse
Cultivar:	Dombito tomato
Layout :	2 bags per row
	3 plants per bag
	9 plants per treatment (i.e. 9 replicates)
	36 plants total
	Bags distributed, but inoculated plants all kept in the same rows.
Monitoring :	Fruit Yield - Total mass per plant and number of fruit per plant
	Plant measurements - height, stem diameter
	Plant health scoring - external indicators



Note : Italics indicate sawdust/compost medium.
Fertilizing and watering regime were the same (conventional) for all treatments.

Figure VIII.1 Experimental Layout of Yield Test

Figure VIII.2 Greenhouse site of disease suppression yield test

Table VIII.7 Yield test treatments

Treatment	Growing medium	Inoculation
1	Sawdust	**None**
2	Sawdust	**FORL**
3	Sawdust, amendment P4, 2:1 v/v	**None**
4	**Sawdust, amendment P4, 2:1 v/v**	**FORL**

After planting, weekly growth measurements were taken on each plant. Fruit yield was measured for each plant, with the yield divided into cull and marketable fruit, based on the BC Hot House grading guidelines.

Microbial counts on medium materials were conducted by a commercial laboratory (Cantest Labs, Burnaby, BC) using a standard plate count for bacteria and peptone water rinse and PDA medium for yeast and mold.

STATISTICAL ANALYSIS

Statistical data analysis was performed using SPSS 7.5 for Windows software, including ANOVA (analysis of variance) to compare data means.

VIII.4 RESULTS AND DISCUSSIONS

VIII.4.1 TOMATO SEEDLING TESTS

VIII.4.1.1 *Test 3* (see Table VIII.3 for treatments and conditions)

The scoring was done weekly for 5 weeks starting at week 3, using 5-6 replicates, so that progression of the disease could be observed. The first symptoms of crown and root rot began to appear 4 weeks after seeding, then developed so that after 6 and 7 weeks, the disease was very apparent in some of the seedlings. Table VIII.8 shows the average root disease score and shoot height for each treatment, based on the last 3 scorings. Reduced disease symptoms were evident in compost amendment treatments, but no clear relationships with shoot height were apparent (Cheuk, 2003). This test also incorporated FORL negative (no FORL inoculation) controls in every treatment; the results for the negative controls were all similar. In future tests, the number of scorings would be reduced and the number of replicates increased; also a FORL negative control would only be included in the rock wool control group. Test 3 statistical analysis of root health, shoot length and leaves color is shown in Appendix H. Figure VIII.3 shows sample pictures of the seedling tests.

Table VIII.8 Results summary for test 3 - amendment as plug and covering (week 3 to week 8)

Treatment No.	Medium-covering-inoculation	Root disease score		Mean shoot height cm
		Mean	SD	
1	Rockwool/vermiculite/FORL-	1.00	0.00	55.1
2	Rock wool/vermiculite/FORL+	1.85	0.88	48.9
3	Rock wool/amendment P6/FORL-	1.00	0.00	51.6
4	Rock wool/amendment P6 /FORL+	1.40	0.20	46.1
5	Amendment P6/vermiculite /FORL-	1.00	0.00	49.7
6	Amendment P6/vermiculite /FORL+	1.13	0.23	49.6

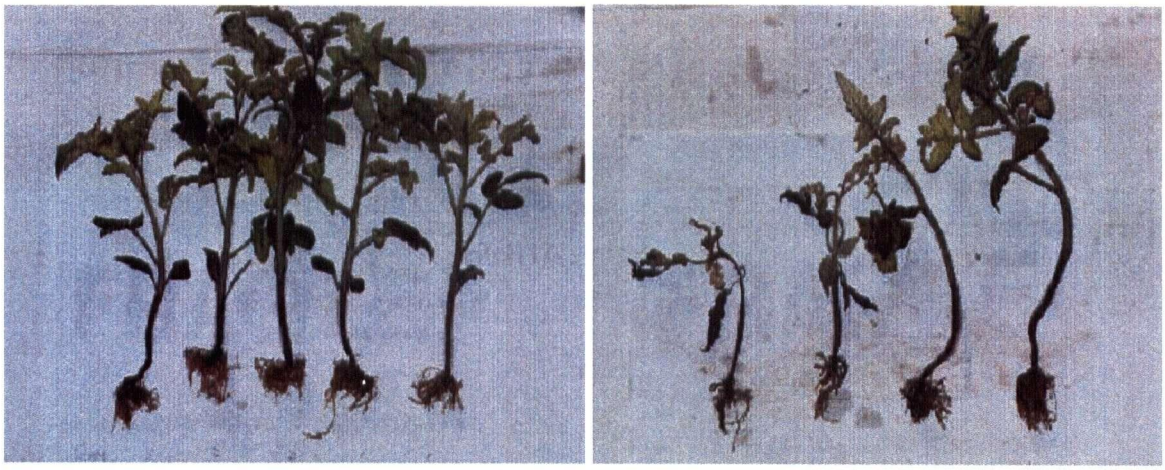


Figure VIII.3 Sample seedlings with FORL (left: treatment 6, right: treatment 2)

VIII.4.1.2 *Test 4* (see Table VIII.4 for treatments and conditions)

Results for Test 4 scorings are shown in Table VIII.9. The scoring of disease clearly shows reduced disease in seedlings treated with amendment. The increased root disease in the rock wool inoculated treatment was significantly greater than in the non-inoculated control. However the root disease in the amendment inoculated treatments was significantly lower than in the rock wool inoculated treatment ($P<0.01$ in all cases). Test 4 statistical analysis of root health, shoot length and leaves color is shown in Appendix I.

Table VIII.9 Results summary for test 4 - amendment as plug and covering, second trial

Treatment No.	Medium-covering-inoculation	Root disease score		Mean shoot height cm
		Mean	SD	
1	Rock wool/vermiculite/FORL-	1.33	0.96	53.8
2	Rock wool/vermiculite/FORL+	2.14	1.11	53.7
3	Rock wool/amendment P6/FORL+	1.35	0.63	59.0
4	Amendment P6/vermiculite /FORL+	1.00	0.00	46.5
5	Amendment P7/vermiculite /FORL+	1.00	0.00	46.8

VIII.4.1.3 *Test 6* (see Table VIII.5 for treatments and conditions)

Results from test 6 are shown in Table VIII.9. Similar to Test 4, the visual scoring of disease clearly showed reduced disease in seedlings treated with amendment, using the sandwich method. The increased root disease in the rock wool inoculated treatment was significantly greater ($P<0.01$) than in the non-inoculated control, based on the root disease score. The root disease score in the amendment inoculated treatments was

significantly lower than in the rock wool inoculated treatment ($P<0.01$ in all cases). There was also significantly less ($P<0.05$) root disease for amendment L5A compared to amendment P6, but it did not differ significantly from L5C. Germination rates for all treatments were similar.

Table VIII.10 Results summary for test 6 - amendment comparison, sandwich covering method

Tmt. No.	Medium-covering-inoculation	Root disease score 1-5		Mean shoot height cm	Mean stem dia. mm	Germination rate %
		Mean	SD			
1	Rock wool/ Vermiculite/ FORL-	1.00	0.00	49.7	6.3	88.0
2	Rock wool/ Vermiculite/ FORL+	2.18	1.02	55.1	5.8	92.5
3	Rock wool/ amendment P6/ FORL+	1.25	0.59	52.5	6.0	92.5
4	Amendment L5A/ Vermiculite/ FORL+	1.00	0.00	46.9	6.3	95
5	Amdendment L5C/ Vermiculite/ FORL+	1.11	0.31	52.4	5.9	87.5

It is interesting to note that shoot height (both Tests 4 and 6) and stem diameter (Test 6 only) measurements consistently showed that plants with more visible disease (higher root score) were taller and thinner (larger shoot height, and smaller stem diameter). In many but not all cases, these differences were statistically significant for

$P<0.05$. The reasons for this trend are not clear, however reduced height and diameter do not appear to be an indicator of disease in the FORL seedling tests. Leaf colour measurements (SPAD meter) did not provide significant differences between treatments. Test 6 statistical analysis of root health, shoot length and leaf color are shown in Appendix J.

Disease scoring was limited mainly by the time required to develop disease. Based on the observations of all the disease tests including the yield test, it is very likely that in spite of the size trends mentioned above, seedlings with a high disease score would soon die, given more time. Characteristics of the FORL crown and root rot disease on tomato were such that the plants showed little external symptoms, then begin a very rapid decline and death follows quickly. This end result could not be achieved in the seedling tests due to the size limitation of the seedlings growing in the small plug trays in the growth chamber.

VIII.4.2 YIELD TEST (see table VIII.6 for procedure)

During the approximately 9 month course of the growing season, a substantial number of plants died. In each case, death was attributed to *Fusarium* crown and root rot, as shown in Table VIII.11.

Table VIII.11 Diseased plants during yield test by treatment

Treatment No.	Medium-inoculation	Dead or dying plants by number and date
1	Sawdust-FORL-	None observed
2	Sawdust-FORL+	2A-2 Died 26-May 2A-3 Died 26-May 2A-1 Died 31-May 2B-1 Died 31-May 2B-2 Wilting-Dec (FORL Infection) 2B-3 Wilting-Dec(FORL Infection)
3	Sawdust-amendment P4-FORL-	None observed
4	Sawdust-amendment P4- FORL+	4A-1 Died 21-Apr

With the exception of a single plant in treatment 4, all of these deaths occurred in treatment 2, conventional sawdust medium with FORL inoculation. It is reasonable to assume that the treatment 4 plant, 4A-1, was accidentally infected with FORL at the propagation stage, and would have died regardless of the subsequent treatment, based on the following observations:

1. Death occurred 1 month after inoculation. Of all disease suppression tests conducted, not one case was observed of plant death within one month of inoculation; at this stage symptoms are usually only visible internally.

2. The seedling was over 5 weeks old at inoculation; it is generally accepted that an older, healthy plant will take longer to develop the disease after inoculation than a small seedling.

3. Examination showed necrotic crown tissue and visible *Fusarium* spores, indicating the disease was well developed.

4. All other plants exhibiting *Fusarium* infection symptoms or death required at least 2 months after inoculation.

The infection of 4A-1 may have occurred in the pathology greenhouse where the seedlings were propagated, and which was also used previously for FORL disease tests. With this in mind, 4A-1 was not included in the statistical comparison of yield, in that treatment 4 had one less replicate in the calculated average yield.

Table VIII.12 shows the marketable yield and fruit size for the four treatments; Figure VIII.4 illustrates the time-trend for total marketable yield for the inoculated control and amendment mix treatments. Statistical analyses of the yield data showed that the 50% decrease in yield of the inoculated control compared to the non-inoculated control was significant ($P<0.05$), and the 74% increase in yield of the inoculated sawdust plus amendment treatment over the sawdust control was significant ($P<0.05$). The 10% decrease in yield for the non-inoculated sawdust plus amendment treatment compared to the non-inoculated sawdust treatment was not significant. The data also suggest a larger fruit size for sawdust plus amendment medium, but this difference was not statistically significant. The yield test statistical analysis is shown in Appendix K.

Table VIII.12 Tomato yield fruit size results by treatment

Treatment No.	Medium–inoculation	Average yield per plant - kg	Average yield per plant - kg (adjusted)*	Average fruit size g
1	Sawdust-FORL-	10.69	10.69	152
2	Sawdust-FORL+	5.39	5.39	146
3	Sawdust-amendment P4-FORL-	9.79	9.79	158
4	Sawdust-amendment P4-FORL+	8.34	9.38	155

*Does not include plant 4A-1.

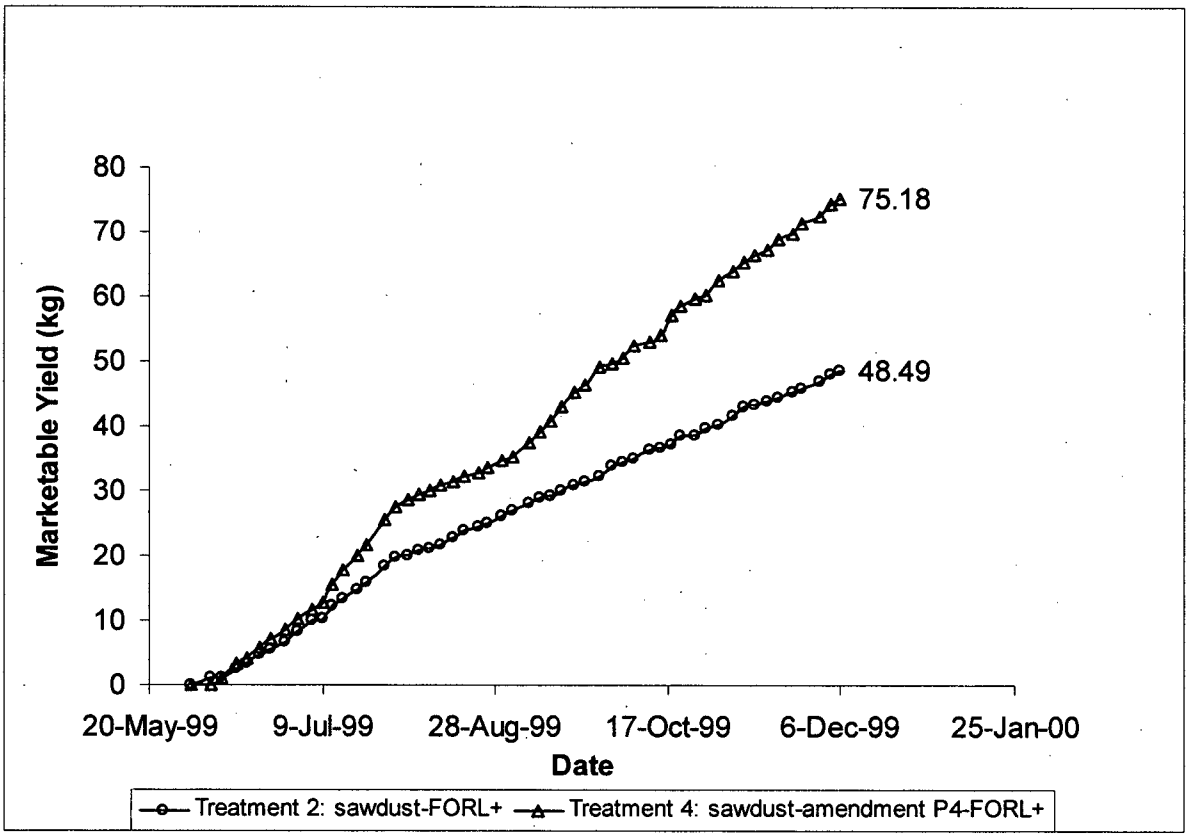


Figure VIII.4 Cumulative marketable tomato yield for sawdust medium vs. sawdust and amendment mixture, both inoculated with FORL

VIII.4.3 MICROBIAL ANALYSIS

Samples from compost amendment batch P4, and fresh sawdust, were taken to commercial laboratory for microbial analysis and the results are shown in Table VII.8 (Chapter VII). The microbial counts indicated an approximately 100 times higher bacteria to fungi count for the amendment compared to the sawdust.

VIII.5 CONCLUSIONS

Significant reduction of crown and root rot disease caused by *Fusarium oxysporum* f. sp. *radicis- lycopersici* in susceptible tomatoes was achieved by addition of the greenhouse compost amendment to seedling plugs or blocks, and by mixing with the sawdust medium. For propagation, the compost amendment can be used as a rock wool plug covering, or a rock wool plug replacement. For growing, the compost amendment can be mixed with sawdust growing medium; a mixture of 2:1 sawdust to amendment by volume was shown to be effective. The reduction in disease resulted in 74% improved yield over a full growing season under high disease pressure (Cheuk, 2003). In the absence of high disease pressure, addition of the compost to the growing medium did not have a significant effect on yield.

Based on the microbial counts, the compost amendment likely increased the microbial population and bacteria to fungi ratio in the growing medium; this may have contributed to the suppressive effect, however determining the suppression mechanisms would require further study.

Positive effects were observed with several different batches of compost amendment produced using the in-vessel composting systems; this encouraging result suggests that the disease suppression effects observed are reproducible using the appropriate materials and composting process. The results of this study will help provide greenhouse vegetable growers with alternative solutions to manage soil-borne disease.

VIII.6 REFERENCES

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CHAPTER IX
MARKETING STUDY OF COMPOST AND COMPOST EXTRACT

IX.1 BACKGROUND

Increasing numbers of communities and businesses are turning to composting to divert materials from landfills, reduce pollution, and lower waste management costs Composters are converting a wide variety of otherwise wasted materials into safe, valuable, and marketable soil amendment products. Researches have shown that the use of compost as supplements has produced higher yields in crops than use of fertilizers alone (Maynard, 1989; Ribeiro, 2000; Korboulewsky, 2002; Tejada, 2003). Some governments also considered using compost to reduce raindrop impact and erosion and to retain moisture (Garner, 1985). Compost was used or distributed in one of four ways : used internally by the farm (greenhouse), sold in bulk, sold in bags, or given away free. Compost must be marketed as a resource which can benefit plants in order to get high returns (Faucette, 2003). The horticultural market has a great potential for compost utilization. Since the plants produced by nurseries, greenhouse industries, landscapers and home gardeners are high-value crops, it is important that the compost used be of the highest quality. These markets usually utilize mostly peat moss, pine bark, composted hardwood bark and spent mushroom soil (Gouin, 1985). The feedstock of greenhouse compost is very consistent and homogenous, unlike that of the municipal wastes. Since compost produced from greenhouse wastes showed positive results in plant growth and

disease suppression (Cheuk, 2003), it was proposed to develop a series of products, manufactured by crop waste composted from vegetable greenhouses. These products include:

1. An organic amendment product (OAP), suitable as a growing medium for many types of plants including vegetables and flowers.
2. A liquid growth promoter, which would be an OAP extract (a type of compost tea) derived from the same process.

The author planned and has commissioned a study to assess the market for OAP and liquid growth promoter in the retail, floriculture and nursery markets, with market information to include: the size of the market, key market segments, potential interest in the product for each segment, competitor products (description, purpose, pricing, etc.) and distribution channels. The marketing research was assisted by Ference Weicker & Co., a company specialized in agricultural product marketing research and was funded by MART (a marketing research assistance program from National Research Council of Canada).

IX.2 METHODOLOGY

First a review of readily available information was conducted. Then questionnaires and sampling strategies, that were used for the interview programs were prepared. The major steps involved in the field research included:

- Review of studies, reports and other materials relevant to the study issues.

- Conducted interviews with government representatives, industry association representatives, and other selected experts.

A partial list of the organizations contacted includes:

- BC Ministry of Agriculture and Food
- BC Landscape & Nursery Association
- United Flower Growers Co-operative Association
- B.C. Horticultural Coalition
- B.C. Vegetable Marketing Commission
- Agriculture and Agrifood Canada
- Statistics Canada

Structured interviews were conducted with a sample of potential buyers and distributors. The sample was stratified to include a cross section of distributors, retailers (primarily garden centres) and large flower greenhouses and nursery producers. The sample included:

- 12 representatives serving the retail market including 6 big box stores (i.e. Home Depot, Revy), 5 garden centres, and one custom soil supplier
- 14 representatives associated with the nursery industry including 4 container only growers, 2 field only growers, 4 field and container growers, 1 container grower of seedlings for reforestation and 3 bulk suppliers of soils and growing medium

- 12 representatives associated with floriculture industry, consisting of 3 cut flower producers, 5 potted flower producers, 2 produces of both cut and potted flowers and two bulk soil suppliers

A profile of key competitive products was developed. To do so, the followings were to be reviewed : the results of the market research, the product materials produced by other suppliers, market pricing, and a sample of the competing suppliers.

IX.3 RESULTS AND DISCUSSIONS

IX.3.1 MARKET FOR THE ORGANIC AMENDMENT PRODUCTS

IX.3.1.1 RETAIL MARKET

According to Statistics Canada, the average household in Canada spent $26 annually on fertilizers, soils and soil conditioners in 1997. It was estimated that the average household in the Greater Vancouver area spends about $34 annually on fertilizers, soils and soil conditioners (Agri. Statistics, 1997). Given that there are more than 700,000 households in the Greater Vancouver area, it was estimated that the value of the retail market for fertilizers, soils and soil conditioners for home use totals approximately $24 million annually in that area alone. The survey of the various retail outlets indicated that premium soil conditioner products such as 100% organic soils, specialty soil mixes, worm castings and liquid growth promoters accounted for slightly less than 10% of their total soil conditioner sales. Based on these figures, it was roughly estimated that the value of the retail market for premium soil conditioners was approximately $2.4 million.

The retail market for fertilizer and soil conditioner products consists of retail nursery outlets, hardware stores and home improvement centres, department stores and grocery store chains. Common wholesale and retail prices for premium soil conditioner products were summarized in the table below:

Table IX.1 Wholesale And Retail Prices For Premium Soil Conditioner Products

Product	Wholesale Price	Retail Price
Pride - 100% organic potting mix (45 litre bag)	$6.50	$9.50
Pride - All Purpose Potting Mix (45 litre bag)	$6.50	$9.50
Pride - Soil Builder (35 litre bag)	$6.95	$9.95
Eddi's – Potting Mix (25 litre bag)	$3.60	$5.95
Eddi's – Potting Mix (40 litre bag)	$5.40	$7.95
Black Gold - Earthworm Castings (8 litre bag)	$2.50	$4.50
Black Gold - Earthworm Castings (32 litre bag)	$4.95	$7.95
Steer Manure Compost (10 kg bag)	$1.50	$2.50
Mushroom Manure Compost (15 kg bag)	$1.99	$3.00
Sure Gro - Plant Food (250ml)	$8.00 approx	$12.00
Sea Spray - Plant Food (250ml)	$8.00 approx	$12.00
Alaska - Fish Fertilizer (1/2 gallon)	$7.00	$10.00
Alaska - Fish Fertilizer (1 gallon)	$13.00	$20.00
Later's - Fish Fertilizer (1 litre)	$4.00	$6.00
Black Crystal - Humic Acid (1 litre)	n/a	$9.00
Black Crystal - Humic Acid (4 litres)	n/a	$30.00
Guardian Angel - Growth Promoter (500ml)	n/a	$24.95
Guardian Angel - Growth Promoter (4 litres)	n/a	$169.95

Source: Industry interviews, January 2000

The following paragraphs described some of the main types of products, their use and the most common brands available.

Specialty Potting Soils

This is one of the largest categories. They contain a blend of soil conditioning products such as peat moss, bark mulches, manure composts, perlite, vermiculite and slow release fertilizers. Major brands carried by local retail outlets are Pride, Scott's, Bell's and Eddi's. Based on the representatives surveyed, the smaller independent retail outlets sell around 100 bags per year while the bigger stores with central buying sell over 2,000 bags per store (40 litre size equivalent).

Manure Composts

Steer and mushroom manure are the two compost manure products carried by most retail nurseries and home improvement stores. Like potting soils, manure is normally sold in 20 and 40 litre bags. The volume of manure compost sold per store ranges from about 100 bags in small retail nurseries to more than 2,500 bags in the larger retail nurseries. Pricing is closer to the standard peat moss and topsoil mixes.

Earth Worm Castings

Earthworm castings are sold in bag sizes of 8, 11, 20 and 32 litres. The two most common brands carried by local retail outlets are Walter Worms and Black Gold. Only about 25% of the retail outlets surveyed carried earthworm castings but all were aware of the products. Most stores said that sales were too low at 10 to 100 bags per year to continue stocking the earthworm casting products.

Other Composts

Several bagged composts made from organic waste materials such as yard wastes are available through horticultural product wholesalers. Most retail buyers knew of one or more compost products but none carried them due to the small volume of sales.

Liquid Organic Growth Promoters/Humic Acids

Common brands carried are Sure-Gro, Sea Spray, Alaska Fish Fertilizer and Later's Plant Food. Liquid organic growth products usually come in 500ml, one, two and four litre sizes. Most retail outlets said that less than 1% of their sales of premium soil conditioner products are liquids. Volume sold ranges from about 10 to 500 litres per year depending on the size of the retail outlet.

Distribution Channels

The products handled by retailers in BC come primarily from garden wholesalers such as Eddi's Wholesale Garden Supplies and Green Leaf Garden Supplies or direct from manufacturers. For example, 85% of the products handled by retail nurseries are sourced through garden wholesalers. Most manufacturers provide the selling function for their products in the form of product representation and marketing programs.

Larger retailers (usually with central buying power) preferred to purchase directly from the manufacturer because the product is less expensive. Smaller stores, however, sourced almost all of their product through the wholesalers.

Most of the leading manufacturers for soil conditioner products sold in the Lower Mainland were based in British Columbia or Alberta. Some of the leading manufacturers included Greenleaf Products Inc. (Burnaby), Eddi's Wholesale Garden Supplies (Surrey), Evergro (Delta), Sun Gro Horticulture Inc. (Surrey), Green Valley (Abbottsford), Consolidated Envirowaste (Aldergrove), Fison's Horticulture, Keefer Greenhouses (Richmond), Later's Chemicals (Richmond), Garden Friendly (Surrey), Premier Horticulture (Sask) and Bell's (Olds, Alta).

INTEREST IN THE PROPOSED PRODUCT

Ten of the 12 retailers that were surveyed expressed at least some interest in the proposed products. The most common reasons given for this interest were:

1. The ability to position the product as an organic product. Most of the retailers noted a strong consumer trend towards organic products.
2. The increasing demand for premium soil conditioner products. This increased demand was attributed to greater interest in both organic products and in gardening in general. The home gardening market segment is the fastest growing market segment for most of the retailers surveyed.
3. The product would be manufactured locally. This could benefit the appeal of the product to consumers, improve the ability of the retailers and/or distributors to manage the supply chain, and reduce transportation costs.

The decision of whether to purchase the product would be based on a number of key factors including price, product characteristics, promotional support, and service. If the decision was made to purchase, the potential volumes that could be purchased annually ranged from around 50 bags (1 skid) for smaller stores to several truckloads (1,000+ bags) for the larger stores.

RETAILER RECOMMENDATIONS AND COMMENTS

The retailers also provided a number of recommendations and comments regarding the proposed products. These are summarized below:

1. The retail buyers which were under survey suggested that it would be better to focus on a bagged product or at least start first with a bagged product (finished compost) and perhaps try a liquid product (compost extract) later once brand recognition has been established.
2. The characteristics that buyers want in a bagged product are 'quality', sterilized product, truly organic without a lot of fillers, disease free, weed free, and conforms to pesticide and other regulatory requirements.
3. Packaging in clear plastic, high quality bags with colourful text and graphics was strongly recommended by buyers.
4. The soil conditioner market tends to be very sensitive to price.
5. Maintaining adequate supply for reorders is considered critical, given the seasonal nature of soil conditioner products.
6. Retailer awareness of the product is usually created through sales reps, mailings and faxes, and advertisements in trade publications.

7. Targeting specific market segments was recommended to create demand for the product.
8. The main barriers to penetrating the premium soil conditioner market were identified as the large variety of products already on the market and the highly price competitive nature of the industry.

IX.3.1.2 FLORICULTURE MARKET

The floriculture industry is one of the fastest growing sectors of the horticultural industry in British Columbia. The current rate of growth in the industry has leveled off to around 5% per annum. According to Statistics Canada, floriculture production is a $200 million industry in British Columbia. The businesses encompass a production base of over 200 hectares of greenhouse space and 100 hectares of field production. Ninety percent of the industry is located in southwestern British Columbia in the Fraser Valley. The leading product categories include cut flower, potted flowers and bedded plants.

The size of individual greenhouse operations varies from a few hundred square metres to over 80,000 square meters. The average size is around 4,000 square metres (just over one acre).

Cut flower production differs from potted plant production in that most production is ground based, either in field or greenhouse operations. The potential size of the market for compost type soil conditioner products needed would be around 375 yards. Unlike cut flower production, container plant production in the floriculture industry

consumes large quantities of soil medium products. A rough estimate of the amount of growing medium used in the industry is about 60,000 yards.

PRODUCTS CURRENTLY USED

The growing media used by the companies surveyed varies depending upon whether they produce cut flowers or potted flowers as outlined below:

1. Of the 5 cut flower producers, 4 add liquid fertilizer or manure to the soil primarily for nitrogen boosting. One of the firms, Houweling's, produced its flowers in rock wool blocks. Two of the cut flowers producers also added coconut fibre and sawdust to the soil to improve aeration.
2. Four out of seven of the potted flower producers surveyed use brand name potting mixes (Sun Gro, Pro Mix) while the other three producers use custom mixes. Only Burnaby Lake Greenhouses currently used compost, which they make themselves.
3. Brookside Greenhouses in Langley indicated that they have tested a sample of the compost from this project (compost from one of the pilot scale test) for seedling growth and obtained good results. They indicated an interest in testing the compost for propagating and as potting mix.

None of the floriculture producers uses liquid organic growth promoters as it is too difficult to quantify the nutrients and other elements getting to the plant.

The volume of growing medium used in potted flower production varied according to the size of pots used and the length of time to plant maturity for wholesaling. Smaller operations generally used between 20 yards and 100 yards per acre, while some of the larger high production operations such as Burnaby Lake Greenhouses (30 acre) indicated that they used hundreds of yards of potting soil per acre.

SOURCES OF SUPPLY

The leading brands of potting soil appear to be Pro-Mix, which is manufactured by Premier in Manitoba and distributed by Westgro Sales in Vancouver; and Sun Gro Mix, which is distributed by Sun Gro Horticulture Inc. of Surrey.

Prices to the grower are $12 to $14 per 3.8 cu.ft compressed bale. Custom mixes are supplied by West Creek Farms of Fort Langley at a price of $37 per yd for standard mixes ranging up to about $70 per yd depending on the additives requested.

POTENTIAL INTEREST IN THE PROPOSED PRODUCT

Nine of the 10 floriculture producers who expressed an opinion indicated at least possible interest in purchasing the proposed compost product. However, it should be stressed that the floriculture producers are generally satisfied with their current growing regimes; as a result, the new product would need to demonstrate significantly better performance or significant savings before the producers could be induced to try the product.

In terms of performance, the growers are primarily interested in yields and controlling the length of time to maturity. Only two growers expressed an interest in the disease suppression capability of the compost, reflecting the perception that diseases are not generally a major issue for the industry. Because the compost would represent only one of several ingredients used in a mix, the growers were very uncertain as to what volumes they may purchase if the decision was made to use it. The estimates ranged widely from several yards up to over 1000 yards.

RESPONDENT RECOMMENDATIONS AND COMMENTS

The floriculture producers also provided a number of recommendations and comments regarding the proposed product. These are summarized below:

1. The selection criteria identified the most often included price, aeration, sterilization, weed free, consistency, good particle size, and durability for plants such as roses that have a longer growing cycle.
2. The effectiveness of the product must be clearly demonstrated in growth trials.
3. Most of the growers surveyed have no direct experience in using a compost product.
4. The growers are viewing the compost product as a replacement product, not as an additional ingredient.
5. Interest in a liquid product was very limited.
6. The best way to make buyers in the floriculture industry aware of the product would be visits by sales reps bringing samples for trial, advertising in grower

magazines, attending key industry trade shows (such as the Can West Horticulture Show), faxes and mailings, and promoting word-of-mouth (encouraging growers to talk to other growers).

7. A quality product was identified as key to market success.
8. The growers indicated that the greatest barriers to entry for a new supplier is strong competition (especially price competition) and the reluctance of growers to try a new, unproven product.

IX.3.1.3 NURSERY MARKET

The nursery industry has been one of the fastest growing segments of Canadian agriculture. Current growth rate is forecast at 4% to 5% per annum, as the market has matured following the explosive growth of over 13% that existed through the 1980s and early 1990s. According to Statistics Canada, nursery stock production was a $115 million industry in British Columbia in 1998. There are approximately 2,500 hectares of production area for nursery stock in BC.

Nursery plant production is either done in the field or in containers and may be open or in greenhouses. Most growers are active in both field and container production. A principal advantage of container production is that three to eight times the number of plants can be produced in containers on the same area of land as in the field.

There are considerable differences in the volume of media required for field production versus container production. In field production, plants are grown in rows

directly in the ground. Using an estimate of 50% nursery production area for field crops (3,000 acres) the potential volume of compost and manure type soil conditioners needed for adding organic content to the soil is roughly estimated at around 45,000 yards. For container production, growers use a soil-less mix for planting consisting of about 75% composted bark mulch and 25% peat with other additives such as perlite and vermiculite. Using an estimate for area of container production at around 50% of total nursery production area (3,000 acres) and 50 yards per acre as an average usage rate, the volume of growing medium used in container production is roughly estimated at about 150,000 yards.

PRODUCTS CURRENTLY USED

The products used by nursery producers vary depending upon whether the focus is container production or field production as described below:

1. The most common growing media used by the container growers surveyed is a blend of peat, composted bark mulch and perlite. Coconut fibre is also frequently used in place of peat when a more durable medium is required for plants such as roses that have to be in containers for 4 to 5 years. None of the growers add compost to their potting mixes. The only liquid growth enhancers mentioned were liquid fertilizers.
2. None of the growers involved in field production use compost products. Normally steer or chicken manure is tilled into the soil between plantings to increase the nitrogen and other nutrients.

The volume of various soil conditioners and mixes used annually ranged from a minimum of approximately 30 yards/acre to over 100 yards/acre. It depends on the size of the pots used and the number of crop rotations per year.

Prices for bagged products were provided earlier in this chapter. Delivered prices for various bulk growing medium products, which was obtained from three suppliers based on a minimum of 7.5 yards of product, are as follows:

Pricing for coconut fibre is around $18 for a 6 kg block, that expands to approximately 3 cubic feet of growing medium.

Table IX.2 Bulk Prices For Selected Growing Media

Media	Bulk Pricing (CdS)
Composted bark mulch	$18.00 yd
Screened peat moss	$22.50 yd
Potting soil mix (with trace elements)	$37.00 yd
Organic soil amendment	$22.50 yd
Decorative bark mulch	$22.50 yd
Customized mixes	$40 to $70 yd

SOURCES OF SUPPLY

Five of the container growers have their potting soils custom mixed by West Creek Farms of Fort Langley. All the growers said that they were very satisfied with the service and quality provided by West Creek Farms. The other three container producers buy the individual components and mix their own soils. The major components are sourced from Augustine Trucks in Pitt Meadows. Interestingly enough, Augustine Trucks also supplies bark mulch and peat to West Creek Farms for their custom mixes.

POTENTIAL INTEREST IN THE PROPOSED PRODUCT

Some interest in the proposed product was expressed by both container and field growers as outlined below:

1. The key criteria used by container producers for deciding what to use in the soil mixes is aeration and drainage/water retention. Other key considerations are past growing success (plant health and yields) and cost. Several growers mentioned the need for sterilized and weed free mixes.
2. Six of the 9 container producers said they would possibly be interested in a compost but the product would have to have proven benefits in growth trials or be as good as and cheaper than their current mix.
3. Two field producers said that they might be interested in adding compost to increase the organic content of the soil. To be competitive, the cost would have to be comparable to other methods such as planting selvage crops to till into the soil.

Three of the container growers and the two field growers said that they were not interested in the compost product. Some of the concerns that were expressed about a compost product included:

- The possibility of introducing disease;
- The fine particle size, which would result in poor drainage;
- Uncertainty regrading how to incorporate it into their current custom mixes; and
- Cost effectiveness.

Any of the growers who had previous experience with compost found it to be too costly.

RECOMMENDATIONS AND COMMENTS FROM THE NURSERY INDUSTRY

The nursery producers also provided a number of recommendations and comments regarding the proposed product. These are summarized below:

1. Although the growers surveyed do not currently use compost in their operations, most growers were aware of other compost products available for adding to potting mixes.
2. The potential disease suppression aspects of the proposed product generated little response from the growers.
3. Certification would be very important for accessing this market.
4. The consistency of the product would also be an important consideration is deciding whether to use it.
5. Direct marketing, in the form of having sales representatives bring samples for testing and information on the product, was identified as the best means to create grower awareness of the product and induce trial.
6. Growers are satisfied with their current growing media.
7. The factors that most growers felt would make it difficult for a new supplier to gain entry into the market were grower reluctance to try a product and the level of satisfaction with current soil mixes and suppliers.

IX.4. CONCLUSIONS

The major findings and conclusions arising from this review of the market for organic amendment products are as follows:

1. *While there are a variety of compost products sold in the retail market, most nursery and floriculture producers are not currently using compost as a growing media.*

Only one of the floriculture or nursery products currently used compost in their mixes. Burnaby Lake Greenhouses manufactures the compost themselves from their own wastes and blends it in with a purchased mix. They have found that this approach not only reduces their waste stream but also serves to reduce the overall cost of their mixes. However, they claimed that the composting system need to be re-designed to give consistent high quality compost, which was one of the main objectives of this research project.

2. *Potential interest in the proposed compost product was expressed by all three of the markets reviewed.*

Ten of the 12 retailers expressed at least some interest in the proposed product, noting that:

- The product could be positioned as an organic product;
- The retail demand for premium soil conditioner products is increasing;
- The product would be manufactured locally, which could increase the appeal of the product to consumers, improve the retailers ability to manage the supply chain, and reduce transportation costs.

Nine of 10 floriculture producers and 6 of 9 container nursery producers expressed potential interest in purchasing the proposed compost product. The producers are generally satisfied with their current growing regimes but would be open to a new product that could demonstrate better performance, e.g. improvement in yield, shelf life, etc, or cost savings.

3. *The potential impact of the product in suppressing disease was not of direct interest to most of the buyers.*

Retailers felt that most consumers would not appreciate the disease suppression qualities of the product. The floriculture and nursery producers generally indicated that diseases are not a major issue for their industry. However, all the buyers recognized that, if the compost were to outperform other media, regardless of the reason, they would be interested in the product.

4. *Positive results from product trials and product certification will be key to penetrating the nursery and floriculture markets.*

Formal testing will be required to demonstrate that the product is effective and safe. The testing should identify for what applications, and in what mixes, it will be most effective. The nursery and floriculture producers and customer mixers noted that they would need to know what is in the compost in order to adjust the slow release fertilizers and other components of their mixes. It should also be noted that a compost product may not be appropriate for some applications. For example, some concern was expressed that compost may compact too easily, plug up drain holes, or not be durable enough for plants will long growth cycles. Other possible concerns that were expressed included

consistency (the possible variable nature of its nutrient content) and sterility (the possibility of introducing disease). However, compost produced from the greenhouse plant wastes in an in-vessel composter would be acceptable since it is produced from consistent wastestream and has passed through the requirements for pathogen reduction.

Several growers said that, even with certification and testing, they would still conduct their own tests. Certification is also important for retailers due to liability and other issues.

5. *The biggest barriers to market entry are that other products are well established in the marketplace and the perceived risk of altering growing regimes can be significant.*

The level of price competition in most segments is very high; a product has to either provide superior benefits or provide direct costs savings in order to be successful. It was noted that the garden centre retail market tends to be less price competitive and more focused on quality than are the big box home centres.

6. *The broad and fairly rapid acceptance of cocunut fibre as a new growing media demonstrates that producers are willing to vary their regimes when trial results indicate that significant benefits exist.*

Coconut fibre is now used extensively in the nursery industry for plants with a long growing cycle.

7. *Direct marketing is a key to introducing the product in all three markets.*

Visits by sales representatives (bringing samples and information materials), direct mail programs, advertisements in trade publications, and attendance at industry trade shows were identified as the best means to introduce new products.

8. *Packaging and, to a lesser extent, consumer advertising are also key for introducing a new retail product.*

Packaging in clear plastic, high quality bags with colourful text and graphics was strongly recommended by buyers as a means to create in-store demand for the product. A co-op fee would have to be paid to many of the retailers to have the product advertised in flyers.

9. *The level of service provided by the supplier is also important.*

Retailers noted that, if there were problems obtaining supply, they would discontinue the product. An option for serving the nursery and floriculture industry would be to work through custom mixers such as West Creek Farms.

10. *Interest in a liquid product was limited.*

Even in the retail segment, the buyers recommended that it would be better to focus on a bagged product or at least start first with a bagged product and perhaps try a liquid product later once brand recognition has been established.

IX.5. REFERENCES

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CHAPTER X

OVERALL CONCLUSIONS

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RECOMMENDATIONS FOR FUTURE WORK

This is a comprehensive project that investigated and transferred the science of composting into the modern application of agriculture. The project developed and demonstrated an appropriate technology for the bio-conversion of wastes generated by greenhouses in B.C. Wastes related to crop production were categorized and the box-type (in-vessel) bio-conversion technology was investigated both in lab scale and pilot scale. The quality of the finished compost and the benefits of utilizing the bio-converted products as high-quality organic medium amendment for growing vegetable crops in greenhouses were evaluated.

Greenhouse wastes, when not handled properly, can become a threat to the environment. Current practices are polluting the agricultural lands and ground waters. The greenhouse industry has a continuous organic waste stream, and a consistent waste characteristic. This project showed a very efficient way to treat the wastes, i.e. turning the wastes into valuable compost. By doing so, it not only reduces the disposal costs for farmers and mitigates the landfill space problem for the government, but also creates a new kind of organic growing media for the farmers. Greenhouse year-end waste, mostly composed of stems, leaves, fruit rejects, pruning and twines, needs to be shredded to proper sizes prior to the bio-conversion process. In this study it was found that a shredder

with a rotating bladed drum would be most suitable for greenhouse applications. Not only because it can handle twines and clips, but also it is economical and mobile inside a greenhouse, whereas most of other commercial composting shredders were too big and too expensive. Shredding the conventional plastic twine along with the organic waste would reduce the quality and resale value of the compost. Therefore, utilization of 5 different bio-degradable twine products were evaluated. They were tested for their physical properties during the greenhouse usage and their compostabilites in an in-vessel composting system. From the results obtained from both tests, it was concluded that it was feasible to utilize alternative twines in greenhouse vegetable production. Furthermore, among the five types of twines, EcoPLA®2000D, a synthetic bio-degradable plastics, was found to be the most suitable substitute for the traditional plastic twines currently used in greenhouses.

In total, there were 9 lab scale and 8 pilot scale composting experiments being investigated. The lab scale experiments were designed to investigate different parameters of composting and their effects on the process and compost quality, while the pilot scale only served as a demonstration for the greenhouse operators. In the first part of lab scale experiment, different control logarithm of composting were tested. Bacterial inoculation was found not necessary to start up the composting process which helped resolved a lot of hygienic and transportation problems for greenhouse operators. With a good control of algarithm and heat loss, composting of greenhouse wastes could reach satisfactory temperatures for pathogen reduction and carbon losses for compost stabilization. Ammonia emission might be a problem but it could be reduced by using air-recirculation

or removed by biofilter with compost as media. Recirculation cooling control was a more effective method to maintain the process temperature not to go beyond the set point than any kind of temperature feedback control. Less leachate and condensate were found from the reactors with air recirculation control, and this would be a big advantage for greenhouse on-site composting. System with air recirculation for cooling and part of the aeration showed higher degradation rate, and also more consistent moisture content of final compost. In Part 2 of the lab scale test, different substrate recipes (C:N ratio, moisture content, porosity, etc) were investigated. Alder bark was found to be a better choice of bulking agent than hemlock bark in terms of better substrate structure, more carbon loss, less nitrogen loss, and higher process temperature. Shredding was proven not necessary before composting of pruning wastes and it also helped minimizing the amount of leachate. The amount of leachate was directly correlated with the initial moisture content of the substrate and the amount of condensate was directly correlated with the duration of high temperature of the process. Bulking agent (alder bark) of about 20-30% (in weight) was necessary for composting pruning wastes. For year-end wastes, a ratio of 62% vines, 13% used sawdust and 25% alder bark was recommended. Pilot scale tests demonstrated the successful use of in-vessel system, the proper control algorithm and substrate recipe developed in the lab scale. A cost analysis was done based on the current disposal cost, investment on composting facility and sale of compost. Based on a 4 ha tomato or pepper greenhouse, and amortizing the capital equipment over five years, the net annual cost of composting represented a savings of $8,000 annually.

Bioassay successfully showed that the growth rate of seeds correlated to the degree of degradation and stability of the finished products. Chemical analysis of compost extract, leachate and condensate showed that they contained a number of valuable nutrients. Leachate, when diluted to 10 times was proven non-toxic or even beneficial in the case of tomato seed. Condensate from composting could be reused for plant without dilutions.

In order to enhance the economic and environmental sustainability of on-farm greenhouse composting, a growth trial and disease suppression trial were done by using compost as growing media in a greenhouse. These studies found that compost manufactured from greenhouse crop waste in a controlled process could be suitable for use as a growing medium amendment in soil-less tomato greenhouses. Using conventional management techniques, a similar yield can be achieved compared to conventional sawdust medium using a 2:1 sawdust to amendment mix by volume. Significant reduction of crown and root rot disease caused by *Fusarium oxysporum* f. sp. *radicis- lycopersici* in susceptible tomatoes was achieved by addition of the greenhouse compost amendment to seedling plugs or blocks, and by mixing with the sawdust medium. The reduction in disease resulted in 74% improved yield over a full growing season under high disease pressure. The results of this study helped provide greenhouse vegetable growers with alternative solutions to manage soil-borne disease. Through the marketing study, it was found that selling the compost in another market like nursery, retail store required great amount of marketing and selling skill. So, greenhouse re-utilization might be the best ultimate goal and it also formed the first step in moving soil-

less vegetable greenhouses in BC toward a more sustainable waste management and growing practice.

It is recognized that continued efforts in the subject areas are needed to expand the current knowledge and understanding of the composting process and utilization of compost in the greenhouse application. The followings are recommended:

1. To investigate the mass balance and track study of carbon and nitrogen loss with air-recirculated compost reactor; therefore to find out more about the degradation process related to process and aeration control.
2. To conduct a bioassay track study to understand the change of level of phytotoxicity during composting.
3. To carry out a full scale growth trial with compost as growth media for different greenhouse crop, especially for organic farming greenhouses.
4. To carry out different disease suppression trial using other common greenhouse diseases, e.g. pythium, botrytis, etc.

APPENDIX A

Waste Tracking Data Sheet

PRUNING WASTES EVAULATION DATA SHEET					
Month :					
		Number of Totes			
Day		Leaves	Vines	Culls	Total
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
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APPENDIX B
Greenhouse Solid Waste Management Survey

Survey Information

This survey was created as part of a project studying composting of greenhouse wastes, conducted for the Western Greenhouse Grower Society, in conjunction with the University of B.C. The aim of the study is to determine the feasibility of composting vegetable greenhouse crop waste as an economically viable solution to waste disposal.

This is a voluntary survey. You may choose to fill out all or none of the fields, including identification, at your option.

Identification Information

Greenhouse Name	Address
Contact name(s)	Telephone
Date	

Waste Characterization

Please note, this survey pertains to **crop (organic) waste**, and does not include plastic film or other non-crop wastes, except where the crop waste contains limited amounts of other materials such as plastic.

Please fill in the crop type(s) at the top. If you are not sure of the numbers for individual crops, you may fill only the total.

Amounts may be specified by mass or volume using either Imperial or SI units. Please indicate which units you are using (tons (t), Tonnes (T), cubic yards (cy), cubic metres (m^3))

	Crop 1:	Crop 2:	Crop 3:	Total
Area (Acres or Ha)				
Growing season (Start-Finish)				
	Crop 1	Crop 2	Crop 3	Total
Amount of Prunings (during growing seas.)				
Amount of Rejects				
Amount of Year-end Waste				
Type of Growing Medium				
Amount of Growing Medium Waste				
Most significant pathogen organisms				
Pesticides used (please identify				

Does any crop waste contain contamination, such as twine or plastic clips? If so, which type of waste and which types of contaminants?

Waste Collection

Please describe the method of waste collection that you use in the greenhouse, including what type of equipment is used (forklift, tractor, type of bins, etc.).

Prunings
Year-end

Waste Disposal

Please indicate how waste is disposed and the approximate cost of disposal (including trucking), for the different waste types.

	Disposal method - landfill, land application, composting, or other (please describe)	Cost
Prunings		
Rejects		
Year-end		
Growing Medium		
Total		

If you are using land application of wastes, is it on-site or trucked to another location?

If you are composting waste, is it composted on-site or trucked to another location?

If it was an economically competitive waste disposal method, would you have an interest in composting on your property?

If no, why?

If yes, what concerns would you have about composting?

APPENDIX C
Sample Aeration Requirement Calculations

1. Compost Mass:

   1.4t/d*21 days = 200 tonnes
   Compost Mixture is 60% greenhouse waste, 40% bulking agents, therefore

   Total Mass = 200 tonnes/0.60
   =333 tonnes

2. Compost component weights:
   Based on 333 tonnes of total compost: 200t waste + 133t of bulking agents

Moisture	199.8 tonnes
Solids	143.2 tonnes
Volatile Solids	123.1 tonnes
BVS	69.6 tonnes

3. Chemical Composition:

   $C_{129}H_{184}O_{80}N$

4. Stoichiometric Demand

   $C_{129}H_{184}O_{80}N + 134.25\ O_2 \rightarrow 129CO_2 + 90.5\ H_2O + NH_3$

3029 g: 2148 g

Specific Oxygen demand:
x = 2148/3029 or 0.71g O_2/g BVS oxidized

When all of the BVS is oxidized, total O_2 requirement is :
0.71*069.6*1000
= 49416kg O_2

Aeration Rate Required:
Air required = specific oxygen demand*degradability*VS content*(g air/g O_2)
= (0.71gO_2/g BVS)* (0.565 g BVS/g VS)* (0.86g VS/g ds)*(1g air/0.23 g O_2)
= 1.50 g air/ g ds

5. Moisture Removal:

Initial Mass, $M_i = 333$ Initial Solids Content, $S_i = 0.43$
Initial VS content, $V_i = 0.86$

Assume: Final solids content, $S_f = 0.65$ Final VS Content, $S_f = 0.50$

Net water loss per unit mass of dry substrate:
$M_n = (1-S_i/S_i)-[(1-V_i/a-V_f)*(1-S_f/S_f)]$
$= (1-0.43/0.43)-[(1-0.86/0.50)*(1-0.65/0.65)$
$=1.17$ t H_2O/t ds
$= 1.17$ g H_2O / g ds

From psychrometric chart,
Assumptions: - ambient air supplied to process is 20°C, 75% relative humidity
- exit gas is 55°C, 100% relative humdiity

Net Moisture Removal $= w_2-w_1$
$= (0.1147-0.011)$ g H_2O / g dry air
$= 0.1037$ g H_2O / dry air

Mass of air required to remove 1.17 g H_2O:
(1.17 g H_2O/g ds)/(0.1037 g H_2O / g air) = 11.28 g air / g ds

6. Heat Removal:
0.71 g O_2/g BVS oxidized $=$ x b s
=(0.71 g)* degradability * VS content
= (0.71 g)* (0.86)*(565)
= 0.3450 g O_2/g ds

Heat Production, based on a rule of thumb:
(3620 cal/g)*(0.3450g O_2/g ds) = 1124.66 cal/g ds

Enthalpy values:

Assumptions: -ambient air supplied to process is 20°C, 75% relative humidity
-exit gas is 55°C, 100% relative humidity

From psychrometric chart: $h_1 = 48$kJ/kg and h2 = 353 kJ/kg

Change in enthalpy = $h_2 - h_1$ = 305 kJ/kg
= 305 J/g
= 73 cal /g air

Air requirement for heat removal is:
(1124.66 cal/g ds)/ (73 cal/g air) = 15.406 g air /g ds

7. Aeration Rate:

Since the greatest amount of aeration is required for heat removal, the aeration rate calculations is based on this value.

Aeration rate = (air/BVS)*(dM_{BVS}/dt)

air/BVS:
(15.406 g air/ g ds)*(69.6t BVS/143.2 t solids)-1 = 31.697 g air / g BVS

dM_{BVS}/dt:

$dM_{BVS}/dt = -k_{B1}M_{B1}-k_{B2}M_{B2}$

$k_{B1} = k_{B1},20\ (1.066^{T-20}-1.21^{T-60})F_1F_2$ Fast fraction
$k_{B2} = k_{B2},20(1.066^{T-20}-1.21^{T-60})F_1F_2$ Slow fraction

$M_{B1} = (0.35)*(69.6t) = 24.36$ t $k_{B1,20} = 0.019$
$M_{B2} = (0.65*(69.6t) = 45.24$ t $k_{B2,\ 20} = 0.0024$

From Figure 11.9 of Haug, 1993 $F_1 = 0.95$
From Figure 11.11 of Haug, 1993 $F_2 = 0.882$ (Assume O_2 in FAS = 15%)

Assuming initial compost temperature, T = 20°C:

$k_{B1} = 0.01592\ d^{-1} = -78621$ g BVS/d^{-1}

Aeration Rate = (31.697 g air/g BVS)*(78621 g BVS/d)
= 2492049 g/(28*0.79*32*0.21)g/mol
= 86409.5 mol
= 86409.5 mol * 25.4 L/mol * 1/1000 mol/L
= 2194.8 m^3/d
= 1.52 m^3/min
or 53 cfm

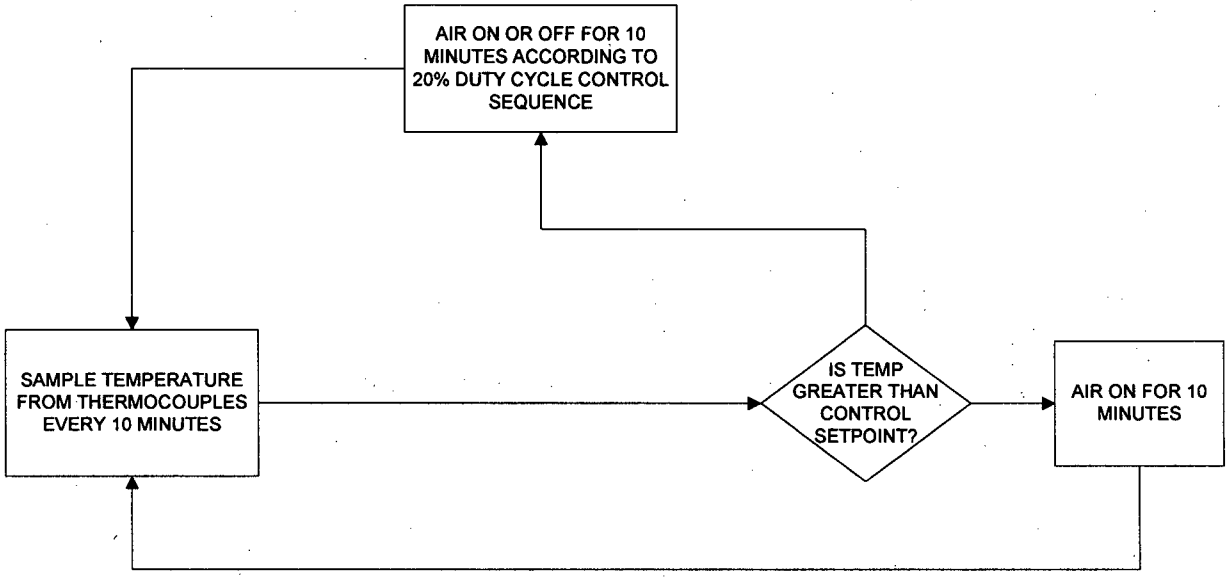
Reference:
Haug, Roger T. (1993) *The Practical Guide to Compost Engineering*. Boca Raton: Lewis.

APPENDIX D
Rutgers Temperature Feedback :
C-Program Code of control Algoritm and Flowchart

```
/* TMP_CTl1 */

/* This program accepts the following inputs:
        - temperature (from X input)
        - temp. setpoint and default duty cycle (user def. inputs)
  and outputs a flag (0 or 1) indicating whether the aeration should
  be off (0) or on (1), according to temperature feedback and
  a fixed schedule when the temperature is below the setpoint.

        It is based on the example code provided (rbv.c) which reads the
        current value of the block specified as the
   X input block in the menu.  */

#define temp_sp UsDefVar1        /* temperature setpoint (int) */
#define duty_percent UsDefVar2    /* duty cycle in percent (int) */

#include "windows.h"
#include "math.h"
#include "ltuserw.h"

/* global variables */

int counter;
int max_count;
float temp;
int air_flag;
int duty_count;
int air_array[10][10]=        {1,0,0,0,0,0,0,0,0,0,  /* array that determines air on/off cycle */
                                                      1,0,0,0,0,1,0,0,0,0,  /* a given duty cycle uses a single
row   */
                                                      1,0,0,1,0,0,1,0,0,0,  /* eg. duty cycle 20% uses row 2
      */
                                                      1,0,1,0,0,1,0,1,0,0,
                                                      1,0,1,0,1,0,1,0,1,0,
                                                      1,0,1,0,1,1,0,1,0,1,
                                                      1,1,0,1,1,0,1,1,0,1,
                                                      1,1,1,1,0,1,1,1,1,0,
                                                      1,1,1,1,1,1,1,1,1,0,
                          1,1,1,1,1,1,1,1,1,1};


struct ReadBlockInput Data_block;
struct ReadBlockOutput Value;

void FAR PASCAL LT_CIcon_init(fn_name, ptr, call_back)
```

```
char *fn_name;
CICONDATA *ptr;
void *call_back(int fn, void far *inp_data, void far *outp_data);
  {
  int i;
  Ciconptr = ptr;

  /* initialize algorithm variables */

  counter = 1;
        max_count=10;


  Data_block.usNum=Xin;   /* set X input block as the block to read */
  }

void FAR PASCAL LT_CIcon_close(handle)
int handle;
  {
  }

void FAR PASCAL LT_CIcon_Open(ptr)
CICONDATA *ptr;
  {
  int i;
  Ciconptr = ptr;
  }

void FAR PASCAL temp_fb1(ptr, call_back)
CICONDATA *ptr;
void *call_back(int fn, void far *inp_data, void far *outp_data);
  {

  /* run time */
  Ciconptr = ptr;

  call_back(READ_BLOCK_VAL,(void *)&Data_block,(void *)&Value);  /* get current value */
        if(Value.error) /* check for error condition */
          {
          error_status=Value.error;
          BlockValReadErr;  /* use LABTECH error macro to return correct
                    error code                    */
          LTReturn;  /* pass back error information and return to LABTECH */
          }


  /* start algorithm */

  duty_count = floor((duty_percent/10)+0.5); /* duty cycle represented by integer eg 20% is 2 */
```

```
        if ( counter == max_count + 1 )
                counter = 1;    /* reset at end of cycle */

        temp = Value.dData;     /* input temperature */

        if ( temp >= temp_sp )
                air_flag = 1;       /* air on when temp exceeds setpoint */
        else
                {
                if ( duty_count > 0 )

                        air_flag = air_array[duty_count-1][counter-1];  /* air on when temp below setpoint based
on duty cycle */

                else
                        air_flag = 0;
    }
        dCalcResult = air_flag;     /* output air flag */

        counter++;

        /* end algorithm */

  LTReturn;
  }
```



DUTY CYCLE CONTROL TABLE

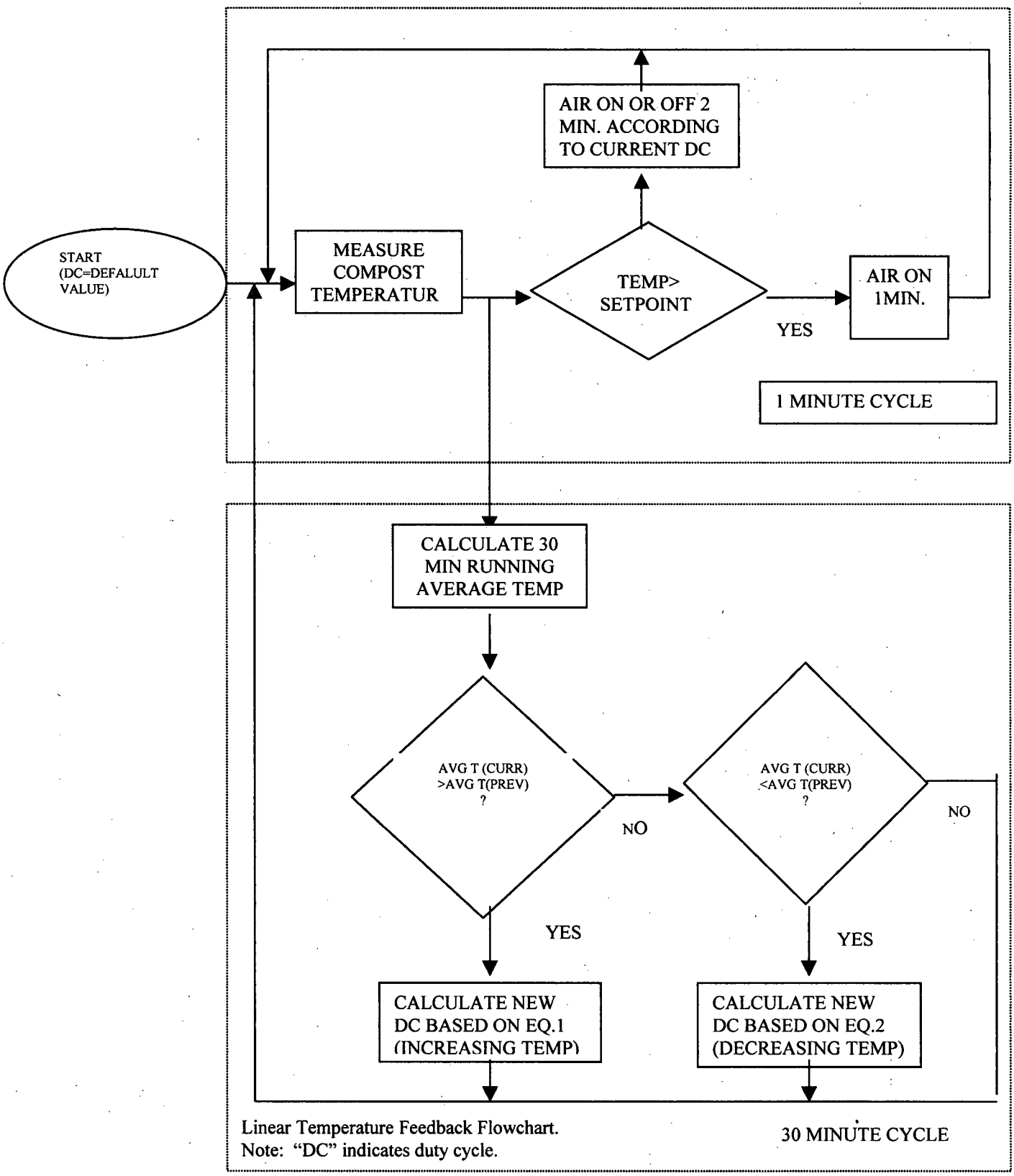
APPENDIX E
Linear Temperature Feedback :
C-Program Code of control Algoritm and Flowchart

```
/*t2_CTL3 */

/*This program accepts an input of temperature (Xin), and outputs a flag (0 or 1) indicating whether the aeration
should be off (0) or on (1) during each cycle based on the temperature and the temperature trend (increasing or
decreasing).

Air duty cycle is checked and potentially adjusted once every "long cycle" (maxcount2 counts).

Aeration is off when temperature exceeds the setpoint.

Based on the sample code rbv.c and example.c  */

#define temp_sp UsDefVar1        /*temperature setpoint (int) */
#define duty_percent UsDefVar2   /* duty cycle in percent (int) */


#include "windows.h"
#include "math.h"
#include "ltuserw.h"

/*global variables*/

int counter;
int counter;
int max_count;
int max_count2;
int air_interval;          /*interval(#counts) between air on cycles */
int temp_interval;         /*#counts since temperature exceeded setpoint*/
int dc_adj_delay;          /*#counts temp must be <setpoint before
                                                    adjusting aeration duty cycle*/

float temp_curr;           /*current temp*/
float temp_avg_curr;                    /*average temperature current period*/
float temp_avg_prev;       /*average temp. from previous period*/
float temp_sum;                         /*sum used to calculated first temp.average*/
float temp_change;                              /*change from previous to current period*/;
                           /*sum used to calculated temp.average*/
int air_flag;              /*output (0 or 1)*/
int duty_count;
int duty_count_incr;
int duty_count_min;
int air_array[10][10]=                  {1,0,0,0,0,0,0,0,0,0, /*array that termines air on/off cycle*/
                                         1,0,0,0,0,1,0,0,0,0, /*a given duty cycle uses a single row */
                                         1,0,0,1,0,0,1,0,0,0, /*eg. Duty cycle 20% uses row 2  */
                                         1,0,1,0,0,1,0,1,0,0,
```

```
                                        1,0,1,0,1,0,1,0,1,0,
                                        1,0,1,0,1,1,0,1,0,1,
                                        1,1,0,1,1,0,1,1,0,1,
                                        1,1,1,1,0,1,1,1,1,0,
                                        1,1,1,1,1,1,1,1,1,0,
                                        1,1,1,1,1,1,1,1,1,1};

struct ReadBlockInput Data_block;
struct ReadBlockOutput Value;
void FAR PASCAL LT_Cicon_init(fn_name,ptr,call_back)
char *fn_name;
CICONDATA *ptr;
Void *call_back(int fn, void far *inp_data, void far * outp_data);
{
inti;
Ciconptr = ptr;
/*initialize algorithm variables */

counter = 1;
counter2 = 1;
 max_count = 10;
 max_count2 = 30;
 dc_adj_delay = 60;
 temp_interval = 0
 duty_count_min = 1;
 temp_sum = 0
 temp_avg_prev = 0;

 duty_count=floor((duty_percent/10)+0.5); /* duty cycle represented by integer eg 20% is 2*/
if (duty_count ==0)
 duty_count = duty_count_min;

}

void FAR PASCAL LT_Cicon_close(handle)
int handle;
{
}

void FAR PASCAL LT_Cicon_Open(ptr)
CICONDATA *ptr;
 {
 int I;
 Ciconptr = [tr;
 }

void FAR PASCAL model3 (ptr, call_back)
CICONDATA *ptr;
Void*call_back(int fn, void far *inp_data, void far *outp_data);
 {
```

```
/*run time*/
Ciconptr = ptr;

Data_block.usNum=Xin; /*set X input block as the block to read*/

Call_back(READ_BLOCK)VAL,(void*)&Data_block,(void*)&Value); /*get current value*/
 If(Value.error)/*check for error condition*/
 {
 error_status=Value.error;
 Block ValReadErr; /*use LABTECH error macro to return correct
                Error code                              */
 LTReturn; /* pass back error information and return to LABTECH*/
 }

temp_curr=Value.dData;


/*start algorithm*/

 if( counter==max_count+1)
    counter = 1;  /*reset at end of small cycle */

 if (counter2==max_count2+1)
    counter2=1; /*reset at end of large cycle*/

 if ( counter2<=30&&counter2>=2)          /*add temp.value to sum*/

        temp_sum=temp_sum+temp_curr;

 if (temp_curr>=temp_sp)
        temp_interval = 0;          /*check for temp exceeding setpoint*/
 else
        temp_interval++; /*increment temp interval if below setpoint*/


 if ( counter2==1)

        { /*check temp. averages and adjust duty cycle once per maxcount2 counts */

temp_avg_curr=temp_sum/29;                  /*calculated temp.averages*/
        temp_change=temp_avg_curr-temp_avg_prev;

        temp_sum=0;     /*reset temp.sum value*/

        if(temp_change<-0.02&&temp_interval>dc_adj_delay) /*decreasing trend*/

                duty_count=floor(((temp_avg_curr*0.0286-1.26) *10)+0.5);

        if(temp_change>0.2&&temp_interval>dc_adj_delay: /*increasing trend*/

                duty_count=floor(((temp_avg_curr*0.00686+0.06)*10+0.5);
```

```
if(duty_count<1)

        duty_count=duty_count_min;

if(duty_count>10)

        duty_count=10;
 }

if(temp_curr>temp_sp)
 air_flag=0;                /*air on when temp exceeds setpoint*/
else
     air_flag=air_array[duty_count-1][counter-1]; /*air on when temp below setpoint based on duty cycle*/

 dCalcResult = air_flag;   /*output air flag*/

 temp_avg_prev=temp_avg_curr;

 counter++;
 counter2++;
 /*end algorithm*/

LTReturn;
}
```



Linear Temperature Feedback Flowchart.
Note: "DC" indicates duty cycle.

APPENDIX F
Sample Fertilizer Recipe of Growth Trial (Chapter VII)

	Concentrated (100x)					Diluted	
			Per				
Tank A	Per 1000 litre		No. of litres:	100		Per litre	
15.5% TN Calcium Nitrate - 1% Amm./14.5% Nitrate	125	kg	12.5	kg		1.25	g
13% TN Calcium Nitrate	0	kg	0.0	kg		0.00	g
Calcium Chloride	0	kg	0.0	kg		0.00	g
Iron chelate - solid	0	kg	0.0	kg		0.00	g
Iron chelate - liquid	6	l	600	ml		0.06	ml
Urea	1	kg	100.0	g		0.01	g
Tank B							
Potassium Nitrate	25	kg	2.5	kg		0.25	g
Mono-Potassium Phosphate	25	kg	2.5	kg		0.25	g
Magnesium Sulphate (Epsom Salts)	50	kg	5.0	kg		0.50	g
Potassium Chloride	15	kg	1.5	kg		0.15	g
Potassium Bicarbonate	0	kg	0.0	kg		0.00	g
Manganese Sulphate	175	g	17.5	g		0.0018	g
Zinc Sulphate	200	g	20.0	g		0.0020	g
Boron (Borax, 20.5% B)	300	g	30.0	g		0.0030	g
Copper Sulphate	25	g	2.5	g		0.0003	g
Sodium Molybdate	20	g	2.0	g		0.0002	g
Urea	1	kg	100.0	g		0.01	g

APPENDIX G

ANOVA-Plant Growth (for Chapter VII)

Case Processing Summary(a)

Cases					
Included		Excluded		Total	
N	Percent	N	Percent	N	Percent
12	85.7%	2	14.3%	14	100.0%

a Cumulative Growth by Medium, Nutrient Strategy, Row Number

Cell Means(b,c)

			Cumulative Growth	
Medium	Nutrient Strategy	Row Number	Mean	N
Sawdust	Conventional	Total	563.97	3
	Modified	Total	601.33	3
	Total	A	553.65	2
		B	607.15	2
		C	587.15	2
		Total	582.65	6
Sawdust +Amendment	Conventional	Total	568.27	3
	Modified	Total	577.03	3
	Total	A	568.40	2
		B	580.55	2
		C	569.00	2
		Total	572.65	6
Total	Conventional	A	546.90	2
		B	580.55	2
		C	570.90	2
		Total	566.12	6
	Modified	A	575.15	2
		B	607.15	2
		C	585.25	2
		Total	589.18	6
	Total	A	561.03	4
		B	593.85	4
		C	578.08	4
		Total	577.65(a)	12

a Grand Mean

b Cumulative Growth by Medium, Nutrient Strategy, Row Number

c 3-way and higher means are not computed due to the limit on maximum order interaction.

ANOVA(a)

			Experimental Method				
			Sum of Squares	df	Mean Square	F	Sig.
Cumulative Growth	Main Effects	(Combined)	4052.26	4	1013.07	5.11	.17
		Medium	300.00	1	300.00	1.51	.34
		Nutrient Strategy	1596.21	1	1596.21	8.05	.11
		Row Number	2156.05	2	1078.02	5.44	.16
	2-Way Interactions	(Combined)	1683.35	5	336.67	1.70	.41
		Medium * Nutrient Strategy	613.47	1	613.47	3.10	.22
		Medium * Row Number	954.55	2	477.27	2.41	.29
		Nutrient Strategy * Row Number	115.33	2	57.67	.29	.78
	Model		5735.61	9	637.29	3.22	.26
	Residual		396.47	2	198.23		
	Total		6132.07	11	557.46		

a Cumulative Growth by Medium, Nutrient Strategy, Row Number

Plant Growth ANOVA - Conventional Feed

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Cumulative Growth	Medium	Sawdust	3	563.97	24.53	14.16	503.04	624.90	538.80	587.80
		Sawdust+ Amendment	3	568.27	11.60	6.70	539.45	597.08	555.00	576.50
		Total	6	566.12	17.32	7.07	547.94	584.29	538.80	587.80
Leaf Length - mm	Medium	Sawdust	3	37.72	.83	.48	35.66	39.79	37.11	38.67
		Sawdust+ Amendment	3	38.59	1.05	.61	35.97	41.20	37.94	39.80
		Total	6	38.16	.97	.40	37.14	39.17	37.11	39.80
Stem Diameter - mm	Medium	Sawdust	3	9.33	.44	.25	8.24	10.43	8.88	9.76
		Sawdust+ Amendment	3	9.91	1.07	.62	7.26	12.56	9.26	11.14
		Total	6	9.62	.79	.32	8.79	10.46	8.88	11.14

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Cumulative Growth	Between Groups	27.74	1	27.74	.08	.80
	Within Groups	1472.29	4	368.07		
	Total	1500.03	5			
Leaf Length - mm	Between Groups	1.12	1	1.12	1.24	.33
	Within Groups	3.60	4	.90		
	Total	4.71	5			
Stem Diameter - mm	Between Groups	.50	1	.50	.75	.44
	Within Groups	2.66	4	.67		
	Total	3.16	5			

Plant Growth ANOVA - Modified Feed

		Sum of Squares	df	Mean Square	F	Sig.
Cumulative Growth	Between Groups	1138.82	2	569.41	1.06	.43
	Within Groups	2150.09	4	537.52		
	Total	3288.91	6			
Leaf Length - mm	Between Groups	1.10	2	.55	1.03	.44
	Within Groups	2.13	4	.53		
	Total	3.23	6			
Stem Diameter - mm	Between Groups	.35	2	.18	1.06	.43
	Within Groups	.66	4	.17		
	Total	1.01	6			

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min.	Max.
							Lower Bound	Upper Bound		
Cumulative Growth	Medium	Sawdust	3	601.33	29.75	17.18	527.43	675.24	568.50	626.50
		Sawdust+ Amendment	3	577.03	13.78	7.96	542.79	611.27	561.50	587.80
		Amendment	1	572.00	.	.	.	.	572.00	572.00
		Total	7	586.73	23.41	8.85	565.08	608.38	561.50	626.50
Leaf Length - mm	Medium	Sawdust	3	38.28	1.3	.59	35.72	40.83	37.21	39.26
		Sawdust+ Amendment	3	37.60	9.29E-02	5.36E-02	37.37	37.83	37.49	37.66
		Amendment	1	37.25	.	.	.	.	37.25	37.25
		Total	7	37.84	.73	.28	37.16	38.52	37.21	39.26
Stem Diameter - mm	Medium	Sawdust	3	9.26	.56	.32	7.88	10.65	8.62	9.61
		Sawdust+ Amendment	3	9.41	.14	8.21E-02	9.06	9.77	9.25	9.51
		Amendment	1	8.73	.	.	.	.	8.73	8.73
		Total	7	9.25	.41	.16	8.87	9.63	8.62	9.61

Correlations

		Cumulative Growth	Leaf Length - mm	Stem Diameter - mm	Adjusted Marketable Yield - kg	Medium
Pearson Correlation	Cumulative Growth	1.00	.40	.29	.14	-.35
	Leaf Length - mm	.41	1.00	.81(**)	.44	-.08
	Stem Diameter - mm	.29	.81(**)	1.00	.28	-.10
	Adjusted Marketable Yield - kg	.14	.44	.28	1.00	-.41
	Medium	-.35	-.08	-.10	-.41	1.00
Sig. (2-tailed)	Cumulative Growth	.	.15	.31	.64	.21
	Leaf Length - mm	.15	.	.00	.12	.78
	Stem Diameter - mm	.31	.00	.	.33	.73
	Adjusted Marketable Yield - kg	.64	.12	.33	.	.14
	Medium	.21	.78	.73	.14	.
N	Cumulative Growth	14	14	14	14	14
	Leaf Length - mm	14	14	14	14	14
	Stem Diameter - mm	14	14	14	14	14
	Adjusted Marketable Yield - kg	14	14	14	14	14
	Medium	14	14	14	14	14

** Correlation is significant at the 0.01 level (2-tailed).

Plant Growth Data Summary by Row

			Cumulative Growth	Leaf Length - mm	Stem Diameter - mm
			Mean	Mean	Mean
Sawdust	Conventional	A	538.80	37.11	8.88
		B	587.80	37.39	9.36
		C	565.30	38.67	9.76
	Modified	A	568.50	37.21	8.62
		B	626.50	39.26	9.56
		C	609.00	38.36	9.61
Sawdust +Amendment	Conventional	A	555.00	37.94	9.33
		B	573.30	38.02	9.26
		C	576.50	39.80	11.14
	Modified	A	581.80	37.66	9.25
		B	587.80	37.49	9.48
		C	561.50	37.64	9.51
Amendment	Modified	A	572.00	37.25	8.73
	Modified 2	A	546.00	38.14	8.92

Plant Growth Summary by Group

		Cumulative Growth	Leaf Length - mm	Stem Diameter - mm
		Mean	Mean	Mean
Sawdust	Conventional	563.97	37.72	9.33
	Modified	601.33	38.28	9.26
Sawdust +Amendment	Conventional	568.27	38.59	9.91
	Modified	577.03	37.60	9.41
Amendment	Modified	572.00	37.25	8.73
	Modified 2	546.00	38.14	8.92

APPENDIX H

ANOVA – Test 3 (for Chapter VIII)

						Root Score			Height		
						Mean	Range	SD	Mean	Range	SD
Medium	Rockwool	Covering	Vermi-culite	Inocula-tion	FORL-	1.00	.00	.00	55.11	36.50	12.26
					FORL+	1.87	4.00	1.06	48.94	40.50	9.79
			Amend-ment P6	Inocula-tion	FORL-	1.00	.00	.00	51.55	30.50	9.56
					FORL+	1.40	2.00	.74	46.10	36.40	11.10
	Amend-ment P6	Covering	Vermi-culite	Inocula-tion	FORL-	1.00	.00	.00	49.68	45.60	14.02
					FORL+	1.13	1.00	.35	49.65	24.40	8.81

ANOVA - Root score, groups 1-6, last three dates

			Root Score	
Medium	Covering	Inoculation	Mean	N
Rockwool	Vermiculite	Total	1.43	30
	Amendment P6	Total	1.20	30
	Total	FORL-	1.00	30
		FORL+	1.63	30
		Total	1.32	60
Amendment P6	Vermiculite	Total	1.07	30
	Amendment P6	Total		0
	Total	FORL-	1.00	15
		FORL+	1.13	15
		Total	1.07	30
Total	Vermiculite	FORL-	1.00	30
		FORL+	1.50	30
		Total	1.25	60
	Amendment P6	FORL-	1.00	15
		FORL+	1.40	15
		Total	1.20	30
	Total	FORL-	1.00	45
		FORL+	1.47	45
		Total	1.23(a)	90

a Grand Mean

b Root Score by Medium, Covering, Inoculation

c 3-way and higher means are not computed due to the limit on maximum order interaction.

ANOVA(a,b)

			Experimental Method				
			Sum of Squares	df	Mean Square	F	Sig.
Root Score	Main Effects	(Combined)	6.97	3	2.32	7.36	.00
		Medium	2.02	1	2.02	6.39	.02
		Covering	.82	1	.82	2.59	.11
		Inoculation	4.90	1	4.90	15.53	.00
	Model		6.97	3	2.32	7.36	.00
	Residual		27.13	86	.32		
	Total		34.10	89	.38		

a Root Score by Medium, Covering, Inoculation

b Due to empty cells or a singular matrix, higher order interactions have been suppressed.

One way ANOVA - Root score, groups 1-6, last 3 dates, rockwool vs. amendment P6 medium

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Root Score	Medium	Rockwool	60	1.32	.72	9.36E-02	1.13	1.50	1.00	5.00
		Amend-ment P6	30	1.07	.25	4.63E-02	.97	1.16	1.00	2.00
		Total	90	1.23	.62	6.53E-02	1.10	1.36	1.00	5.00

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Root Score	Between Groups	1.25	1	1.25	3.35	.07
	Within Groups	32.85	88	.37		
	Total	34.10	89			

T-Test - root score, groups 1-6, rockwool vs. amendment P6

Group Statistics

	Medium	N	Mean	Std. Deviation	Std. Error Mean
Root Score	Rockwool	60	1.32	.72	9.36E-02
	Amendment P6	30	1.07	.25	4.63E-02

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Mean	
									Lower	Upper
Root Score	Equal variances assumed	13.80	.00	1.83	88	.07	.25	.14	-2.15E-02	.52
	Equal variances not assumed			2.40	81.51	.02	.25	.10	4.2E-02	.46

Oneway ANOVA - groups 1-6, last 3 dates, rockwool vs. amendment p6, F+

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Root Score	Medium	Rockwool	30	1.63	.93	.17	1.29	1.98	1.00	5.00
		Amendment P6	15	1.13	.35	9.09E-02	.94	1.33	1.00	2.00
		Total	45	1.47	.81	.12	1.22	1.71	1.00	5.00

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Root Score	Between Groups	2.50	1	2.50	4.03	.05
	Within Groups	26.70	43	.62		
	Total	29.20	44			

SPAD (leaf colour) groups 1-6 all dates

						Spad (colour)		
						Mean	Range	Std Deviation
Medium	Rockwool	Covering	Vermiculite	Inoculation	FORL-	38.86	36.40	10.65
					FORL+	36.46	30.00	8.55
			Amendment P6	Inoculation	FORL-	39.56	39.40	9.21
					FORL+	39.55	31.70	8.45
	Amendment P6	Covering	Vermiculite	Inoculation	FORL-	40.58	31.80	7.76
					FORL+	41.11	30.70	9.46

APPENDIX I

ANOVA – Test 4 (for Chapter VIII)

Test 4 First Scoring Summary

			Root Score		Shoot Height - cm		Leaf Colour SPAD	
			Mean	Range	Mean	Range	Mean	Range
Rock Wool	Vermiculite	FORL (-)	1.62	4	47.55	55.80	37.19	47.70
		FORL (+)	2.07	3	51.23	17.00	44.94	31.10
	Amendment P6	FORL (+)	1.00	0	56.49	39.10	40.27	30.30
Amendment P6	Vermiculite	FORL (+)	1.00	0	44.82	25.70	36.44	22.20
Amendment P7	Vermiculite	FORL (+)	1.00	0	49.24	39.70	39.08	32.30

Test 4 Second Scoring Summary

			Root Score		Shoot Height - cm		Leaf Colour SPAD	
			Mean	Range	Mean	Range	Mean	Range
Rock Wool	Vermiculite	FORL (-)	1.07	1	59.56	12.80	44.63	17.70
		FORL (+)	2.21	4	56.13	46.50	38.96	52.60
	Amendment P6	FORL (+)	1.72	2	61.57	30.10	45.68	18.50
Amendment P6	Vermiculite	FORL (+)	1.00	0	48.40	32.00	37.85	26.30
Amendment P7	Vermiculite	FORL (+)	1.00	0	44.39	50.00	38.45	30.70

Test 4 Summary

			Root Score		Shoot Height - cm		Leaf Colour SPAD	
			Mean	Range	Mean	Range	Mean	Range
Rock Wool	Vermiculite	FORL (-)	1.33	4	53.8	62.1	41.05	56.50
		FORL (+)	2.14	4	53.7	46.5	41.95	55.50
	Amendment P6	FORL (+)	1.35	2	59.0	47.7	42.90	35.00
Amendment P6	Vermiculite	FORL (+)	1.00	0	46.5	32.0	37.12	26.30
Amendment P7	Vermiculite	FORL (+)	1.00	0	46.8	51.2	38.77	32.50

ANOVA - Overall

Case Processing Summary(a)

Cases					
Included		Excluded		Total	
N	Percent	N	Percent	N	Percent
153	100.0%	0	.0%	153	100.0%

a Root Score by Medium, Covering, Inoculation

Cell Means(b,c)

			Root Score	
Medium	Covering	Inoculation	Mean	N
Rock Wool	Vermiculite	Total	1.75	55
	Amendment P6	Total	1.35	37
	Total	FORL (-)	1.33	27
		FORL (+)	1.69	65
		Total	1.59	92
Amendment P6	Vermiculite	Total	1.00	27
	Amendment P6	Total		0
	Total	FORL (-)		0
		FORL (+)	1.00	27
		Total	1.00	27
Amendment P7	Vermiculite	Total	1.00	34
	Amendment P6	Total		0
	Total	FORL (-)		0
		FORL (+)	1.00	34
		Total	1.00	34
Total	Vermiculite	FORL (-)	1.33	27
		FORL (+)	1.36	89
		Total	1.35	116
	Amendment P6	FORL (-)		0
		FORL (+)	1.35	37
		Total	1.35	37
	Total	FORL (-)	1.33	27
		FORL (+)	1.36	126
		Total	1.35(a)	153

a Grand Mean

b Root Score by Medium, Covering, Inoculation

c 3-way and higher means are not computed due to the limit on maximum order interaction.

ANOVA(a,b)

			Experimental Method				
			Sum of Squares	df	Mean Square	F	Sig.
Root Score	Main Effects	(Combined)	25.08	4	6.27	12.91	.00000
		Medium	25.07	2	12.53	25.81	.00000
		Covering	9.99	1	9.99	20.57	.00001
		Inoculation	9.01	1	9.01	18.55	.00003
	Model		25.08	4	6.27	12.91	.00000
	Residual		71.86	148	.49		
	Total		96.94	152	.64		

a Root Score by Medium, Covering, Inoculation

b Due to empty cells or a singular matrix, higher order interactions have been suppressed.

ANOVA - Controls

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Root Score	Inocul-ation	FORL (-)	27	1.33	.96	.18	.95	1.71	1	5
		FORL (+)	28	2.14	1.11	.21	1.71	2.57	1	5
		Total	55	1.75	1.11	.15	1.45	2.05	1	5
Shoot Height - cm	Inocul-ation	FORL (-)	27	53.78	13.79	2.65	48.33	59.24	4.40	66.50
		FORL (+)	28	53.68	9.34	1.77	50.06	57.30	27.00	73.50
		Total	55	53.73	11.63	1.57	50.59	56.87	4.40	73.50
Leaf Colour SPAD	Inocul-ation	FORL (-)	27	41.05	10.80	2.08	36.77	45.32	.00	56.50
		FORL (+)	28	41.95	11.65	2.20	37.43	46.47	.00	55.50
		Total	55	41.51	11.15	1.50	38.49	44.52	.00	56.50

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Root Score	Between Groups	9.01	1	9.01	8.31	.006
	Within Groups	57.43	53	1.08		
	Total	66.44	54			
Shoot Height - cm	Between Groups	.15	1	.15	.001	.97
	Within Groups	7300.25	53	137.74		
	Total	7300.39	54			
Leaf Colour SPAD	Between Groups	11.18	1	11.18	.09	.77
	Within Groups	6702.08	53	126.45		
	Total	6713.26	54			

ANOVA - Rockwool+ vs Rockwool P6 Covering+

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Root Score	Covering	Vermiculite	28	2.14	1.11	.21	1.71	2.57	1	5
		Amendment P6	37	1.35	.63	.10	1.14	1.56	1	3
		Total	65	1.69	.95	.12	1.46	1.93	1	5
Shoot Height - cm	Covering	Vermiculite	28	53.68	9.34	1.77	50.06	57.30	27.00	73.50
		Amendment P6	37	58.96	8.32	1.37	56.19	61.74	27.40	75.10
		Total	65	56.69	9.10	1.13	54.43	58.94	27.00	75.10
Leaf Colour SPAD	Covering	Vermiculite	28	41.95	11.65	2.20	37.43	46.47	.00	55.50
		Amendment P6	37	42.90	7.34	1.21	40.45	45.35	18.50	53.50
		Total	65	42.49	9.37	1.16	40.17	44.81	.00	55.50

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Root Score	Between Groups	9.99	1	9.99	13.14	.001
	Within Groups	47.86	63	.76		
	Total	57.85	64			
Shoot Height - cm	Between Groups	444.94	1	444.94	5.78	.020
	Within Groups	4849.11	63	76.97		
	Total	5294.06	64			
Leaf Colour SPAD	Between Groups	14.38	1	14.38	.16	.69
	Within Groups	5605.47	63	88.98		
	Total	5619.85	64			

ANOVA - Rockwool+ vs Amendment P6+

Descriptives

			N	Mean	Std. Dev.	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Root Score	Medium	Rock Wool	28	2.14	1.11	.21	1.71	2.57	1	5
		Amend-ment P6	27	1.00	.00	.00	1.00	1.00	1	1
		Total	55	1.58	.98	.13	1.32	1.85	1	5
Shoot Height - cm	Medium	Rock Wool	28	53.68	9.34	1.77	50.06	57.30	27.00	73.50
		Amend-ment P6	27	46.54	8.80	1.69	43.06	50.03	30.00	62.00
		Total	55	50.18	9.69	1.31	47.56	52.80	27.00	73.50
Leaf Colour SPAD	Medium	Rock Wool	28	41.95	11.65	2.20	37.43	46.47	.00	55.50
		Amend-ment P6	27	37.12	7.33	1.41	34.22	40.02	24.10	50.40
		Total	55	39.58	9.99	1.35	36.88	42.28	.00	55.50

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Root Score	Between Groups	17.95	1	17.95	28.46	.000
	Within Groups	33.43	53	.63		
	Total	51.39	54			
Shoot Height - cm	Between Groups	699.59	1	699.59	8.48	.005
	Within Groups	4370.91	53	82.47		
	Total	5070.50	54			
Leaf Colour SPAD	Between Groups	320.86	1	320.86	3.36	.073
	Within Groups	5065.19	53	95.57		
	Total	5386.05	54			

ANOVA - Rockwool+ vs Amendment P7+

Descriptives

			N	Mean	Std. Dev.	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Root Score	Medium	Rock Wool	28	2.14	1.11	.21	1.71	2.57	1	5
		Amend-ment P7	34	1.00	.00	.00	1.00	1.00	1	1
		Total	62	1.52	.94	.12	1.28	1.75	1	5
Shoot Height - cm	Medium	Rock Wool	28	53.68	9.34	1.77	50.06	57.30	27.00	73.50
		Amend-ment P7	34	46.81	13.11	2.25	42.24	51.39	14.50	65.70
		Total	62	49.91	11.98	1.52	46.87	52.96	14.50	73.50
Leaf Colour SPAD	Medium	Rock Wool	28	41.95	11.65	2.20	37.43	46.47	.00	55.50
		Amend-ment P7	34	38.77	9.41	1.61	35.49	42.05	21.40	53.90
		Total	62	40.20	10.51	1.34	37.53	42.87	.00	55.50

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Root Score	Between Groups	20.06	1	20.06	36.00	.000
	Within Groups	33.43	60	.56		
	Total	53.48	61			
Shoot Height - cm	Between Groups	724.03	1	724.03	5.41	.02
	Within Groups	8030.90	60	133.85		
	Total	8754.93	61			
Leaf Colour SPAD	Between Groups	155.50	1	155.50	1.42	.24
	Within Groups	6586.98	60	109.78		
	Total	6742.49	61			

APPENDIX J

ANOVA – Test 6 (for Chapter VIII)

Correlations

Descriptive Statistics

	Mean	Std. Deviation	N
Root Score	1.27	.67	168
Root Health	1.27	.52	168
Stem Diameter - mm	6.01	.65	168
Shoot Height - cm	50.45	8.86	168

Correlations

		Root Score	Root Health	Stem Diameter - mm	Shoot Height - cm
Pearson Correlation	**Root Score**	1.00	.25(**)	-.12	.07
	Root Health	.25(**)	1.00	-.35(**)	-.20(**)
	Stem Diameter - mm	-.12	-.35(**)	1.00	-.03
	Shoot Height - cm	.07	-.20(**)	-.03	1.00
Sig. (2-tailed)	**Root Score**	.	.001	.14	.38
	Root Health	.001	.	.00	.01
	Stem Diameter - mm	.14	.000	.	.73
	Shoot Height - cm	.37	.01	.73	.
N	**Root Score**	168	168	17	168
	Root Health	168	168	168	168
	Stem Diameter - mm	168	168	168	168
	Shoot Height - cm	168	168	168	168

** Correlation is significant at the 0.01 level (2-tailed).

Test 6 Summary

			Root Health		Root Score		Shoot Height - cm		Stem Diameter - mm		Leaf Colour SPAD		Root Index	
			Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Rock Wool	Vermi-culite	FORL (-)	1.18	2	1.00	0	49.7	33.50	6.3	1.70	45.55	26.80	1.18	2
		FORL (+)	1.50	2	2.18	3	55.1	36.00	5.8	3.30	42.77	32.53	3.36	8
	Amend-ment P6	FORL (+)	1.14	1	1.25	2	52.5	35.50	6.0	2.00	42.71	25.10	1.50	5
	Amend-ment 5A	FORL (+)	1.11	1	1.00	0	46.9	21.50	6.3	2.10	45.97	21.80	1.11	1
	Amend-ment 5C	FORL (+)	1.36	2	1.11	2	52.4	33.00	5.9	3.30	43.19	30.87	1.57	5

ANOVA - Controls

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Root Health	Inoculation	FORL (-)	28	1.18	.48	8.99E-02	.99	1.36	1	3
		FORL (+)	28	1.50	.64	.12	1.25	1.75	1	3
		Total	56	1.34	.58	7.76E-02	1.18	1.49	1	3
Root Score	Inoculation	FORL (-)	28	1.00	.00	.00	1.00	1.00	1	1
		FORL (+)	28	2.18	1.02	.19	1.78	2.57	1	4
		Total	56	1.59	.93	.12	1.34	1.84	1	4
Root Index	Inoculation	FORL (-)	28	1.18	.48	8.99E-02	.99	1.36	1	3
		FORL (+)	28	3.36	2.34	.44	2.45	4.27	1	9
		Total	56	2.27	2.00	.27	1.73	2.80	1	9
Shoot Height - cm	Inoculation	FORL (-)	28	49.70	7.41	1.40	46.83	52.57	35.50	69.00
		FORL (+)	28	55.09	8.57	1.62	51.76	58.41	33.50	69.50
		Total	56	52.39	8.39	1.12	50.15	54.64	33.50	69.50
Stem Diameter - mm	Inoculation	FORL (-)	28	6.29	.43	8.09E-02	6.12	6.46	5.30	7.00
		FORL (+)	28	5.78	.58	.11	5.55	6.00	3.90	7.20
		Total	56	6.03	.57	7.57E-02	5.88	6.18	3.90	7.20
Leaf Colour SPAD	Inoculation	FORL (-)	28	45.55	6.52	1.23	43.02	48.08	30.27	57.07
		FORL (+)	28	42.77	8.89	1.68	39.33	46.22	23.40	55.93
		Total	56	44.16	7.85	1.05	42.06	46.27	23.40	57.07

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Root Health	Between Groups	1.45	1	1.45	4.57	.037
	Within Groups	17.11	54	.32		
	Total	18.55	55			
Root Score	Between Groups	19.45	1	19.45	37.36	.000
	Within Groups	28.11	54	.52		
	Total	47.55	55			
Root Index	Between Groups	66.45	1	66.45	23.22	.000
	Within Groups	154.54	54	2.86		
	Total	220.98	55			
Shoot Height - cm	Between Groups	406.08	1	406.08	6.33	.015
	Within Groups	3464.19	54	64.15		
	Total	3870.28	55			
Stem Diameter - mm	Between Groups	3.70	1	3.70	14.35	.000
	Within Groups	13.94	54	.26		
	Total	17.64	55			
Leaf Colour SPAD	Between Groups	108.00	1	108.003	1.778	.19
	Within Groups	3279.85	54	60.738		
	Total	3387.86	55			

ANOVA - Ctrl+ vs P6+

Descriptives

			N	Mean	Std. Dev.	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Root Health	Covering	Vermiculite	28	1.50	.64	.12	1.25	1.75	1	3
		Amendment P6	28	1.14	.36	6.73E-02	1.00	1.28	1	2
		Total	56	1.32	.54	7.26E-02	1.18	1.47	1	3
Root Score	Covering	Vermiculite	28	2.18	1.02	.19	1.78	2.57	1	4
		Amendment P6	28	1.25	.59	.11	1.02	1.48	1	3
		Total	56	1.71	.95	.13	1.46	1.97	1	4
Root Index	Covering	Vermiculite	28	3.36	2.34	.44	2.45	4.27	1	9
		Amendment P6	28	1.50	1.14	.22	1.06	1.94	1	6
		Total	56	2.43	2.05	.27	1.88	2.98	1	9
Shoot Height - cm	Covering	Vermiculite	28	55.09	8.57	1.62	51.76	58.41	33.50	69.50
		Amendment P6	28	52.48	7.94	1.50	49.40	55.55	34.00	69.50
		Total	56	53.78	8.29	1.11	51.56	56.00	33.50	69.50
Stem Diameter - mm	Covering	Vermiculite	28	5.78	.58	.11	5.55	6.00	3.90	7.20
		Amendment P6	28	6.00	.52	9.78E-02	5.80	6.20	4.80	6.80
		Total	56	5.89	.56	7.42E-02	5.74	6.04	3.90	7.20
Leaf Colour SPAD	Covering	Vermiculite	28	42.77	8.89	1.68	39.33	46.22	23.40	55.93
		Amendment P6	28	42.71	6.58	1.24	40.16	45.25	28.37	53.47
		Total	56	42.74	7.75	1.04	40.67	44.81	23.40	55.93

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Root Health	Between Groups	1.79	1	1.79	6.68	.01
	Within Groups	14.44	54	.27		
	Total	16.21	55			
Root Score	Between Groups	12.07	1	12.07	17.45	.00
	Within Groups	37.36	54	.69		
	Total	49.43	55			
Root Index	Between Groups	48.29	1	48.29	14.22	.00
	Within Groups	183.43	54	3.40		
	Total	231.71	55			
Shoot Height - cm	Between Groups	95.42	1	95.42	1.40	.24
	Within Groups	3684.19	54	68.23		
	Total	3779.61	55			
Stem Diameter - mm	Between Groups	.73	1	.73	2.44	.13
	Within Groups	16.22	54	.30		
	Total	16.95	55			
Leaf Colour SPAD	Between Groups	6.79E-02	1	6.790E-02	.001	.974
	Within Groups	3300.35	54	61.118		
	Total	3300.41	55			

ANOVA - Amendments+

Case Processing Summary(a)

Cases					
Included		Excluded		Total	
N	Percent	N	Percent	N	Percent
112	66.7%	56	33.3%	168	100.0%

a Root Index by Covering

Cell Means(b)

	Root Index	
Covering	Mean	N
Amendment P6	1.50	28
Amendment L5A	1.11	28
Amendment L5C	1.57	28
Total	1.42(a)	112

a Grand Mean

b Root Index by Covering

ANOVA(a)

			Experimental Method				
			Sum of Squares	df	Mean Square	F	Sig.
Root Index	Main Effects	Covering	3.74	3	1.25	1.30	.28
	Model		3.74	3	1.25	1.30	.28
	Residual		103.54	108	.96		
	Total		107.28	111	.97		

a Root Index by Covering

ANOVA - P6+ vs 5A+

Descriptives

			N	Mean	Std. Dev.	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Root Health	Covering	Amendment P6	28	1.14	.36	6.73E-02	1.00	1.28	1	2
		Amendment L5A	28	1.11	.31	5.95E-02	.99	1.23	1	2
		Total	56	1.13	.33	4.46E-02	1.04	1.21	1	2
Root Score	Covering	Amendment P6	28	1.25	.59	.11	1.02	1.48	1	3
		Amendment L5A	28	1.00	.00	.00	1.00	1.00	1	1
		Total	56	1.13	.43	5.73E-02	1.01	1.24	1	3
Root Index	Covering	Amendment P6	28	1.50	1.14	.22	1.06	1.94	1	6
		Amendment L5A	28	1.11	.31	5.95E-02	.99	1.23	1	2
		Total	56	1.30	.85	.11	1.08	1.53	1	6
Shoot Height - cm	Covering	Amendment P6	28	52.47	7.94	1.50	49.40	55.55	34.00	69.50
		Amendment -5A	28	46.87	5.03	.95	44.92	48.83	35.50	57.00
		Total	56	49.67	7.17	.96	47.76	51.59	34.00	69.50
Stem Diameter - mm	Covering	Amendment P6	28	6.00	.52	9.78E-02	5.80	6.20	4.80	6.80
		Amendment L5A	28	6.33	.55	.10	6.12	6.54	5.20	7.30
		Total	56	6.17	.55	7.39E-02	6.02	6.32	4.80	7.30
Leaf Colour SPAD	Covering	Amendment P6	28	42.70	6.58	1.24	40.16	45.26	28.37	53.47
		Amendment L5A	28	45.97	4.87	.92	44.09	47.86	31.27	53.07
		Total	56	44.33	5.96	.80	42.74	45.94	28.37	53.47

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Root Health	Between Groups	1.79E-02	1	1.79E-02	.16	.69
	Within Groups	6.10	54	.11		
	Total	6.13	55			
Root Score	Between Groups	.88	1	.88	5.11	.03
	Within Groups	9.25	54	.17		
	Total	10.13	55			
Root Index	Between Groups	2.16	1	2.16	3.10	.084
	Within Groups	37.68	54	.70		
	Total	39.84	55			
Shoot Height - cm	Between Groups	439.04	1	439.04	9.93	.003
	Within Groups	2387.05	54	44.21		
	Total	2826.09	55			
Stem Diameter - mm	Between Groups	1.51	1	1.51	5.34	.025
	Within Groups	15.29	54	.28		
	Total	16.80	55			
Leaf Colour SPAD	Between Groups	149.54	1	149.54	4.47	.039
	Within Groups	1806.66	54	33.46		
	Total	1956.19	55			

ANOVA - L5A+ vs L5C+

Descriptives

			N	Mean	Std. Dev.	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Root Health	Covering	Amendment L5A	28	1.11	.31	5.95E-02	.99	1.23	1	2
		Amendment L5C	28	1.36	.56	.11	1.14	1.57	1	3
		Total	56	1.23	.47	6.24E-02	1.11	1.36	1	3
Root Score	Covering	Amendment L5A	28	1.00	.00	.00	1.00	1.00	1	1
		Amendment L5C	28	1.11	.42	7.87E-02	.95	1.27	1	3
		Total	56	1.05	.30	3.96E-02	.97	1.13	1	3
Root Index	Covering	Amendment L5A	28	1.11	.31	5.95E-02	.99	1.23	1	2
		Amendment L5C	28	1.57	1.14	.21	1.13	2.01	1	6
		Total	56	1.34	.86	.11	1.11	1.57	1	6
Shoot Height - cm	Covering	Amendment L5A	28	46.88	5.03	.95	44.92	48.83	35.50	57.00
		Amendment L5C	28	52.36	7.20	1.36	49.57	55.16	27.50	60.50
		Total	56	49.62	6.75	.90	47.81	51.43	27.50	60.50
Stem Diameter - mm	Covering	Amendment L5A	28	6.33	.55	.10	6.12	6.54	5.20	7.30
		Amendment L5C	28	5.94	.69	.13	5.68	6.21	3.80	7.10
		Total	56	6.14	.64	8.62E-02	5.96	6.31	3.80	7.30
Leaf Colour SPAD	Covering	Amendment L5A	28	45.97	4.87	.92	44.09	47.86	31.27	53.07
		Amendment L5C	28	43.19	7.95	1.50	40.10	46.27	22.73	53.60
		Total	56	44.58	6.68	.89	42.79	46.37	22.73	53.60

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Root Health	Between Groups	.88	1	.88	4.25	.04
	Within Groups	11.11	54	.21		
	Total	11.98	55			
Root Score	Between Groups	.16	1	.16	1.86	.18
	Within Groups	4.68	54	8.66E-02		
	Total	4.84	55			
Root Index	Between Groups	3.02	1	3.02	4.34	.04
	Within Groups	37.54	54	.70		
	Total	40.55	55			
Shoot Height - cm	Between Groups	421.85	1	421.85	10.93	.002
	Within Groups	2085.04	54	38.61		
	Total	2506.89	55			
Stem Diameter - mm	Between Groups	2.12	1	2.12	5.52	.02
	Within Groups	20.75	54	.38		
	Total	22.87	55			
Leaf Colour SPAD	Between Groups	108.64	1	108.64	2.50	.12
	Within Groups	2347.00	54	43.46		
	Total	2455.65	55			

APPENDIX K

ANOVA – Disease suppression yield test (for Chapter VIII)

UBC disease suppression yield ANOVA - FORL-

Descriptives

			N	Mean	Std. Dev.	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Yield - kg	Medium	Sawdust	9	10.69	1.23	.4088	9.75	11.64	8.43	11.89
		Sawdust/Amend-ment Mix	9	9.79	1.74	.5787	8.45	11.12	7.05	13.23
		Total	18	10.23	1.53	.3609	9.48	11.00	7.05	13.23
Average Fruit Size	Medium	Sawdust	9	.15	1.67E-02	5.565E-03	.14	.16	.13	.18
		Sawdust/Amend-ment Mix	9	.16	1.69E-02	5.633E-03	.15	.17	.14	.19
		Total	18	.15	1.66E-02	3.918E-03	.15	.16	.13	.19

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Yield - kg	Between Groups	3.70	1	3.70	1.64	.22
	Within Groups	36.15	16	2.26		
	Total	39.85	17			
Average Fruit Size	Between Groups	1.84E-04	1	1.84E-04	.65	.43
	Within Groups	4.51E-03	16	2.82E-04		
	Total	4.70E-03	17			

Yield ANOVA - FORL+

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Yield - kg	Medium	Sawdust	9	5.39	5.36	1.79	1.27	9.50	.00	11.64
		Sawdust/Amend-ment Mix	9	8.34	3.32	1.11	5.78	10.89	.00	10.95
		Total	18	6.86	4.58	1.08	4.58	9.14	.00	11.64
Average Fruit Size	Medium	Sawdust	5	.15	5.70E-03	2.55E-03	.14	.15	.14	.15
		Sawdust/Amend-ment Mix	8	.16	1.22E-02	4.31E-03	.15	.17	.14	.17
		Total	13	.15	1.09E-02	3.02E-03	.15	.16	.14	.17

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Yield - kg	Between Groups	39.22	1	39.22	1.97	.18
	Within Groups	317.89	16	19.87		
	Total	357.11	17			
Average Fruit Size	Between Groups	2.58E-04	1	2.58E-04	2.43	.15
	Within Groups	1.17E-03	11	1.06E-04		
	Total	1.43E-03	12			

Yield ANOVA - FORL+ without plant 4A-1

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Yield - kg	Medium	Sawdust	9	5.39	5.36	1.79	1.27	9.50	.00	11.64
		Sawdust/Amend-ment Mix	8	9.38	1.20	.43	8.37	10.39	7.49	10.95
		Total	17	7.27	4.38	1.06	5.01	9.52	.00	11.64
Average Fruit Size	Medium	Sawdust	5	.15	5.69E-03	2.55E-03	.14	.15	.14	.15
		Sawdust/Amend-ment Mix	8	.16	1.22E-02	4.31E-03	.15	.17	.14	.17
		Total	13	.15	1.09E-02	3.02E-03	.15	.16	.14	.17

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Yield - kg	Between Groups	67.58	1	67.58	4.23	.06
	Within Groups	239.66	15	15.98		
	Total	307.24	16			
Average Fruit Size	Between Groups	2.58E-04	1	2.58E-04	2.43	.15
	Within Groups	1.17E-03	11	1.06E-04		
	Total	1.43E-03	12			

UBC disease suppression yield ANOVA - overall

Case Processing Summary(a)

Cases					
Included		Excluded		Total	
N	Percent	N	Percent	N	Percent
36	100.0%	0	.0%	36	100.0%

a Yield - kg by Medium, Inoculation

Cell Means(b)

		Yield - kg	
Medium	Inoculation	Mean	N
Sawdust	FORL (-)	10.69	9
	FORL (+)	5.39	9
	Total	8.04	18
Sawdust/Amendment Mix	FORL (-)	9.79	9
	FORL (+)	8.34	9
	Total	9.06	18
Total	FORL (-)	10.24	18
	FORL (+)	6.86	18
	Total	8.55(a)	36

a Grand Mean

b Yield - kg by Medium, Inoculation

ANOVA(a)

			Experimental Method				
			Sum of Squares	df	Mean Square	F	Sig.
Yield - kg	Main Effects	(Combined)	112.00	2	56.00	5.06	.012
		Medium	9.42	1	9.42	.85	.36
		Inoculation	102.58	1	102.58	9.27	.005
	2-Way Interactions	Medium * Inoculation	33.51	1	33.51	3.03	.09
	Model		145.50	3	48.50	4.38	.01
	Residual		354.04	32	11.06		
	Total		499.54	35	14.27		

a Yield - kg by Medium, Inoculation