

**THE EFFECTS OF WINDROW COMPOSTING CONDITIONS  
ON PHYSICAL, CHEMICAL, AND BIOLOGICAL  
CHARACTERISTICS OF SEWAGE SLUDGE  
MIXED WITH GRASS CLIPPINGS**

**TANINPORN TIPPAYAMONGKONKUN**

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR  
THE DEGREE OF MASTER OF SCIENCE  
(ENVIRONMENTAL SANITATION)  
FACULTY OF GRADUATE STUDIES  
MAHIDOL UNIVERSITY  
2011**

**COPYRIGHT OF MAHIDOL UNIVERSITY**

Thesis  
entitled

**THE EFFECTS OF WINDROW COMPOSTING CONDITIONS  
ON PHYSICAL, CHEMICAL, AND BIOLOGICAL  
CHARACTERISTICS OF SEWAGE SLUDGE  
MIXED WITH GRASS CLIPPINGS**

.....  
Miss Taninporn Tippayamongkonkun  
Candidate

.....  
Asst. Prof. Siranee Sreesai,  
D.Tech.Sci  
Major advisor

.....  
Assoc. Prof. Pratana Satitvipawee,  
Ph.D.  
Co-advisor

.....  
Assoc. Prof. Pipat Luksamijarulkul,  
M.Sc.  
Co-advisor

.....  
Prof. Banchong Mahaisavariya,  
M.D. Dip Thai Board of Orthopedics  
Dean  
Faculty of Graduate Studies  
Mahidol University

.....  
Assoc. Prof. Pisit Vatanasomboon,  
M.Sc.  
Program Director  
Master of Science Program in  
Environmental Sanitation  
Faculty of Public Health,  
Mahidol University

Thesis  
entitled  
**THE EFFECTS OF WINDROW COMPOSTING CONDITIONS  
ON PHYSICAL, CHEMICAL, AND BIOLOGICAL  
CHARACTERISTICS OF SEWAGE SLUDGE  
MIXED WITH GRASS CLIPPINGS**

was submitted to the Faculty of Graduate Studies, Mahidol University  
for the degree of Master of Science (Environmental Sanitation)

on  
April 1, 2011

.....  
Miss Taninporn Tippayamongkonkun  
Candidate

.....  
Assoc. Prof. Pisit Vatanasomboon,  
M.Sc.  
Chair

.....  
Miss Kate-rachada Klankrong,  
D. Eng.  
Member

.....  
Asst. Prof. Siranee Sreesai,  
D.Tech.Sci.  
Member

.....  
Assoc. Prof. Pratana Satitvipawee  
Ph.D.  
Member

.....  
Assoc. Prof. Pipat Luksamijarulkul,  
M.Sc.  
Member

.....  
Prof. Banchong Mahaisavariya,  
M.D. Dip Thai Board of Orthopedics  
Dean  
Faculty of Graduate Studies  
Mahidol University

.....  
Assoc. Prof. Phitaya Charupoonphol,  
M.D., Dip Thai Board of Epidemiology  
Dean  
Faculty of Public Health  
Mahidol University

## ACKNOWLEDGEMENTS

I would like to express my appreciation and sincere gratefulness thank to my major advisor, Assistant professor Dr.Siranee Sreesai, for her attention, invaluable advice, precious guidance, suggestions, continuous encouragement and constructive comment, which carry out my thesis successfully.

I would like grateful for my co-advisor, Assoc.Prof. Pratana Satitvipawee, for his valuable suggestion in part of statistical analysis and all constructive comment of this thesis. I also thank Assoc. Prof. Pipat Luksamijarulkul kindly, co-advisor for his helpful guidance in “Discussion Chapter” which great important in this thesis.

I am equally appreciation and thank to Dr.Kate-rachada Klankrong, Department of Drainage and Sewerage, for constructive comments and kindly serving as the external examiner. I am very grateful to Mrs.Chumsin Siriaut and all staff of Department of Parasitology and Entomology, Mahidol University for assistance in training technique to identify parasite eggs, protozoa and permitting equipment used in my studies.

I wish to thank Graduate studies of Mahidol University Alumni Association for invaluable scholarship fund to support my thesis.

Sincere thanks to staffs in Nongkhem composting site for their spirit and kindness throughout this experiment. I would like to thank to my friends and staff in Department of Environmental Health Sciences, Faculty of Public Health and the Center of Excellence on Environmental Health, Toxicology and Management of Chemicals, Toxicology, Faculty of Science, Mahidol University for their kindness, guidance, valuable assistance and supporting the equipments for analysis in this study.

Finally, I am greatly indebted to my beloved family for their love, good attitude, good care and encouragement throughout my study and I extend my deep sense of gratitude to my beloved family.

Taninporn Tippayamongkonkun

**THE EFFECTS OF WINDROW COMPOSTING CONDITIONS ON PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF SEWAGE SLUDGE MIXED WITH GRASS CLIPPINGS**

TANINPORN TIPPAYAMONGKONKUN 4936341 PHES/M

M.Sc. (ENVIRONMENTAL SANITATION)

THESIS ADVISORY COMMITTEE: SIRANEE SREESAI, D.TECH. SCI. (NATURAL RESOURCE MANAGEMENT), PIPAT LUKSAMIJARUNKUL, M.Sc. (PUBLIC HEALTH), PRATANA SATITVIPAWEE, Ph.D. (PUBLIC HEALTH)

**ABSTRACT**

The effects of windrow composting conditions of sewage sludge mixed with grass clipping at various composting conditions; mixing ratio of sewage sludge and grass clippings (1:0, 1:1, 3:1, and 6:1 v/v), composting times (0, 2, 4, 6, and 8 weeks), and steam sterilization conditions (with black plastic cover, without black plastic cover) were studied. The field experiment was factorial with multiple independent variables. Compost materials were collected and determined by their characteristics including total solids (TS), volatile solids (VS), temperature, pH, total heavy metals, available heavy metals, fecal coliform bacteria, and parasitic contamination every two weeks. The descriptive and analytical statistics were used to describe parameter relationship and determine mean significant differences.

The results showed that the composting time was significant treatment at  $p < 0.05$  for TS, VS, temperature, all heavy metals, and fecal coliform bacteria. The mixing ratio was significant treatment at  $p < 0.05$  for temperature, TS, VS, pH, some total heavy metals (Cu and Ni), some available heavy metals (Cd and Cu), and fecal coliform bacteria. The steam sterilization condition was significant treatment at  $p < 0.05$  for TS, VS, pH, some total heavy metals (Cd and Cu), and some available heavy metals (Cd, Cu, and Zn). The end product of all treatments had an amount of total heavy metal that concentrations that met the acceptable limit for the agricultural application that was set by the U.S Environmental Protection Agency (US.EPA). In case of total Cu, it was over the acceptable limit for the Bangkok Metropolitan Administrative recommendation and the standard of organic compost of Department of Agricultural, Thailand. The fecal coliform bacteria and parasitic contamination were lower than the amount of class A of biosolids established by US.EPA.

The findings suggested that the end product could be used as a soil conditioner provided the risk of Cu is considered. The suitable time for the composting process base on the criterion of safety application from heavy metals, fecal coliform bacteria, and parasitic contamination is eight weeks and over. The pre-treatment of heavy metals in wastewater is highly recommended. Whereas, the monitoring of heavy metal concentrations and parasitic contamination should be done until the end of the composting process to assure safe application and to protect the environment from contamination.

**KEY WORDS:** WINDROW COMPOSTING / SEWAGE SLUDGE /  
FECAL COLIFORM /HEAVY METAL / PARASITE

208 pages

ผลจากสภาวะการหมักแบบกองแถวต่อลักษณะสมบัติทางกายภาพ ทางเคมี และทางชีวภาพ เมื่อหมักกากตะกอนน้ำเสีย ผสมกับเศษหญ้า

THE EFFECTS OF WINDROW COMPOSTING CONDITIONS ON PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF SEWAGE SLUDGE MIXED WITH GRASS CLIPPINGS

ธนิพนธ์ ทิพยมงคลกุล 4936341 PHE/M

วท.ม. (สาขาภิบาลสิ่งแวดล้อม)

คณะกรรมการที่ปรึกษาวิทยานิพนธ์ : ศิราณี ศรีใส, D.Tech.Sci. (NATURAL RESOURCE MANAGEMENT),  
พิพัฒน์ ลักขมิจรรกุล, วท.ม. (สาขารณสุขศาสตร์), ประรดา สติติชัยวิภาวี, Ph.D (PUBLIC HEALTH)

#### บทคัดย่อ

ศึกษาผลจากการหมักแบบกองแถวของกากตะกอนน้ำเสียผสมกับเศษหญ้าที่สภาวะการหมักต่างกัน คือ อัตราส่วนผสมของกากตะกอนน้ำเสียและเศษหญ้า (1:0 1:1 3:1 และ 6:1 โดยปริมาตร), ระยะเวลาการหมัก (0 2 4 6 และ 8 สัปดาห์), และสภาพการสตริมสเตอร์ไรเซชัน (คลุมและไม่คลุมด้วยพลาสติกสีดำ) ทดลองภาคสนาม แบบแฟคทอเรียลที่มีตัวแปรต้นหลายตัว เก็บรวบรวมวัสดุหมักทุก 2 สัปดาห์และศึกษาลักษณะสมบัติ ได้แก่ ปริมาณของแข็งทั้งหมด ปริมาณของแข็งระเหยได้ อุณหภูมิ พีเอช โลหะหนักทั้งหมด โลหะหนักที่พืชนำไปใช้ได้ ฟอสฟอรัส โคลิฟอร์มแบคทีเรีย และการปนเปื้อนปรสิติ ใช้สถิติเชิงพรรณนาและสถิติเชิงวิเคราะห์ในการอธิบายถึงความสัมพันธ์ และศึกษาค่าความแตกต่างกันอย่างมีนัยสำคัญของตัวแปร

การศึกษาพบว่า ระยะเวลาหมักส่งผลต่อ ปริมาณของแข็งทั้งหมด ปริมาณของแข็งระเหยได้ อุณหภูมิ พีเอช โลหะหนักทั้งหมด โลหะหนักที่พืชนำไปใช้ได้ และฟอสฟอรัสแบคทีเรีย อย่างมีนัยสำคัญทางสถิติที่  $P < 0.05$  อัตราส่วนผสมส่งผลต่อ ปริมาณของแข็งทั้งหมด ปริมาณของแข็งระเหยได้ พีเอช โลหะหนักทั้งหมดบางชนิด (ทองแดง นิกเกิล) โลหะหนักในรูปที่พืชนำไปใช้ได้บางชนิด (แคดเมียม ทองแดง) อย่างมีนัยสำคัญทางสถิติที่  $P < 0.05$  สภาวะ สตริมสเตอร์ไรเซชันส่งผลต่อปริมาณของแข็งทั้งหมด ปริมาณของแข็งระเหยได้ พีเอช โลหะหนักทั้งหมดบางชนิด (แคดเมียม, ทองแดง) โลหะหนักที่พืชนำไปใช้ได้บางชนิด (แคดเมียม ทองแดง และสังกะสี) อย่างมีนัยสำคัญทางสถิติที่  $P < 0.05$  ทุกตัวรับทดลองมีปริมาณโลหะหนักทั้งหมดอยู่ในเกณฑ์การนำไปใช้ทางการเกษตรของ US.EPA ในกรณีของทองแดงพบปริมาณทั้งหมดสูงกว่าเกณฑ์ยอมรับได้ของกรุงเทพมหานคร และมาตรฐานปุ๋ยอินทรีย์ของกรมวิชาการ เกษตร ฟอสฟอรัสแบคทีเรียและการปนเปื้อนปรสิติมีค่าต่ำกว่ามาตรฐาน Biosolids ประเภท A ของ US.EPA

การศึกษาเสนอแนะว่า ผลผลิตสุดท้ายของการหมักสามารถนำไปใช้เป็นสารปรับปรุงบำรุงดินได้ แต่ต้องระวังความเสี่ยงจากทองแดง ระยะเวลาหมักที่เหมาะสมเพื่อความปลอดภัย ซึ่งพิจารณาจากการปนเปื้อนของโลหะหนัก ฟอสฟอรัสแบคทีเรีย และการปนเปื้อนปรสิติ เท่ากับ 8 สัปดาห์ หรือมากกว่า การบำบัดโลหะหนักในน้ำเสียเบื้องต้นเป็นสิ่งที่แนะนำอย่างยิ่ง ควรติดตามตรวจสอบปริมาณโลหะหนักและการปนเปื้อนปรสิติ จนเสร็จสิ้นการหมัก เพื่อความปลอดภัยของการใช้กากตะกอนและป้องกันการปนเปื้อนสิ่งแวดล้อม

## CONTENTS

	<b>Page</b>
<b>ACKNOWLEDGEMENTS</b>	<b>iii</b>
<b>ABSTRACT (ENGLISH)</b>	<b>iv</b>
<b>ABSTRACT (THAI)</b>	<b>v</b>
<b>LIST OF TABLES</b>	<b>x</b>
<b>LIST OF FIGURES</b>	<b>xiii</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xix</b>
<b>CHAPTER I INTRODUCTION</b>	
1.1 Statement of problems	1
1.2 Objective of study	3
1.3 Hypotheses of study	3
1.4 Variables of study	4
1.5 Definition of terms	4
1.6 Scope of the study	5
1.7 Limitation of study	6
1.8 Expected outcome	6
1.9 Conceptual framework	6
<b>CHAPTER II LITERATURE REVIEWS</b>	
2.1 Bangkok central wastewater treatment plants	7
2.2 Sewage sludge characteristics	8
2.3 Agricultural utilization of sewage sludge	11
2.4 Steam sterilization	18
2.5 Composting	18
2.6 Guideline and regulation for Agricultural utilization of sewage sludge	25
2.7 Related Studied	27

## CONTENTS (cont.)

	<b>Page</b>
<b>CHAPTER III MATERIALS AND METHODS</b>	
3.1 Research design	29
3.2 Place of experiment	30
3.3 Research instruments and equipments	30
3.4 Chemical reagent and media	32
3.5 Research methodology	33
3.6 Research diagram	35
3.7 Statistic analysis	36
<b>CHAPTER IV RESULTS</b>	
4.1 Characteristics of sewage sludge and grass clippings	37
4.1.1 Characteristics of sewage sludge	37
4.1.2 Characteristics of grass clippings	38
4.2 Change of sewage sludge mixed with grass clippings	39
physical characteristics in composting process	
4.2.1 Temperature	39
4.2.2 Total solids	48
4.2.3 Volatile solids	57
4.3 Change of sewage sludge mixed with grass clippings	66
chemical characteristics in composting process	
4.3.1 pH	66
4.3.2 Heavy metal concentrations	76
4.4 Change of sewage sludge mixed with grass clippings	135
biological characteristics in composting process	
4.4.1 Fecal coliform bacteria	135
4.4.2 Parasitic contamination	141

## **CONTENTS (cont.)**

		<b>Page</b>
<b>CHAPTER IV</b>	<b>RESULTS</b>	
	4.5 Quality of end product from sewage sludge mixed with grass clippings	143
<b>CHAPTER V</b>	<b>DISCUSSION</b>	
	5.1 Characteristics of sewage sludge and glass clippings	146
	5.1.1 Characteristics of sewage sludge	146
	5.1.2 Characteristics of glass clippings	147
	5.2 Change of sewage sludge mixed with grass clippings physical characteristics in composting process	148
	5.2.1 Temperature	148
	5.2.2 Total solids	149
	5.2.3 Volatile solids	150
	5.3 Change of sewage sludge mixed with grass clippings chemical characteristics in composting process	151
	5.3.1 pH	151
	5.3.2 Heavy metal concentrations	152
	5.4 Change of sewage sludge mixed with grass clippings biological characteristics in composting process	153
	5.4.1 Fecal coliform bacteria	153
	5.4.2 Parasitic contamination	155
	5.5 Selected treatment for application	156
<b>CHAPTER VI</b>	<b>CONCLUSION AND RECOMMENDATION</b>	
	6.1 Conclusion	157
	6.2 Recommendation	160

**CONTENTS (cont.)**

	<b>Page</b>
<b>REFERENCES</b>	161
<b>APPENDICES</b>	167
<b>BIOGRAPHY</b>	208

## LIST OF TABLES

<b>Table</b>	<b>Page</b>
2.1 Treatment process and capacity of central wastewater treatment plant in Bangkok.	7
2.2 General characteristics of sewage sludge.	8
2.3 Characteristic of sewage sludge from Nongkhem central wastewater treatment plant.	9
2.4 Comparison of nutrient levels in commercial fertilizer and sewage sludge.	11
2.5 Major pathogenic microorganisms of concern in sewage sludge.	15
2.6 The comparison of pathogenic organism characteristics of class A and B biosolids.	16
2.7 Processes to reduce pathogenic microorganisms in sewage sludge.	17
2.8 Comparison four composting technology.	22
2.9 Characteristics for the composting process.	24
2.10 Guidelines for good quality organic composts.	25
2.11 BMA guideline for sewage sludge and soil application to agricultural.	26
2.12 The ceiling concentration of heavy metal content in sewage sludge use for land application.	26
3.1 Treatment combination of mixed sewage sludge and grass clippings composting.	29
3.2 Analytical method of sewage sludge and glass clipping characterization.	34
4.1 Physical and Chemical Characteristics of sewage sludge and grass clippings.	38
4.2 Biological Characteristics of sewage sludge and grass clippings.	39
4.3 The average temperature (°c) of each experimental treatment in composting process.	40

## LIST OF TABLES (cont.)

<b>Table</b>	<b>Page</b>
4.4 The analysis of variance of temperature.	41
4.5 The average total solids (%) of each experimental treatment in composting	49
4.6 The analysis of variance of total solids	50
4.7 Average amount of volatile solids (%) of each treatment in composting process.	58
4.8 The analysis of variance of volatile solids.	59
4.9 The average amount of pH value change of each experimental treatment in composting process.	67
4.10 The analysis of variance of pH.	68
4.11 The average of total cadmium concentrations (mg/kg DS) of each experimental treatment in composting process.	80
4.12 The analysis of variance of total cadmium.	81
4.13 The average available cadmium concentrations (mg/kg DS) of each experimental treatment in composting process.	85
4.14 The analysis of variance of available cadmium.	86
4.15 The average total copper concentrations (mg/kg DS) of each experimental treatment in composting process.	93
4.16 The statistic results of the total copper concentration.	94
4.17 The average amount available copper concentrations (mg/kg DS) of each experimental treatment in composting process.	98
4.18 The analysis of variance of the available copper.	99
4.19 The average amount total nickel concentrations (mg/kg DS) of each experimental treatment in composting process.	101
4.20 The statistic results of the total nickel concentration.	102
4.21 The average amount available nickel concentrations (mg/kg DS) of each experimental treatment in composting process	108

**LIST OF TABLES (cont.)**

<b>Table</b>		<b>Page</b>
4.22	The analysis of variance of available nickel.	109
4.23	The average amount total lead concentrations (mg/kg DS) of each experimental treatment in composting process.	112
4.24	The analysis of variance of the total lead.	113
4.25	The average amount total zinc concentrations (mg/kg DS) of each experimental treatment in composting process.	119
4.26	The analysis of variance of total zinc.	120
4.27	The average amount available zinc concentrations (mg/kg DS) of each experimental treatment in composting process.	127
4.28	The analysis of variance of available zinc.	128
4.29	The average number of fecal coliform bacteria (MPN/g DS) of each experimental treatment in composting process.	136
4.30	The analysis of variance of fecal coliform bacteria.	137
4.31	The parasitic contamination during composting process.	142
4.32	The parasitic contamination during composting process (cont.)	143
4.33	The comparison end product physical and chemical characteristics	144
4.34	The comparison end product biological characteristics with guideline and standard.	145

## LIST OF FIGURES

<b>Figure</b>	<b>Page</b>
2.1 The scheme of anaerobic digestion process at sewage sludge treatment center (Nongkhem WWTP).	10
3.1 Research diagram	35
4.1 Change of average temperature at each composting time.	40
4.2 The average temperature of with PC treatments	42
4.3 The average temperature of without PC treatments	43
4.4 The average temperature of mixing ratio 1:0 in with PC and without PC treatments.	44
4.5 The average temperature of mixing ratio 1:1 in with PC and without PC treatments.	44
4.6 The average temperature of mixing ratio 3:1 in with PC and without PC treatments.	45
4.7 The average temperature of mixing ratio 6:1 in with PC and without PC treatments.	46
4.8 The total solid contents of all treatments at the initial and final stage in composting process.	48
4.9 Change of average total solids at each composting process.	49
4.10 The average total solids of with PC treatments.	51
4.11 The average total solids of without PC treatments.	52
4.12 The average total solids of mixing ratio 1:0 in with PC and without PC treatments.	53
4.13 The average total solids of mixing ratio 1:1 in with PC and without PC treatments.	54
4.14 The average total solids of mixing ratio 3:1 in with PC and without PC treatments.	54

## LIST OF FIGURES (cont.)

<b>Figure</b>	<b>Page</b>
4.15 The average total solids of mixing ratio 6:1 in with PC and without PC treatment	55
4.16 The average volatile solids contents of all treatments at initial and final stage in composting process.	57
4.17 Change of volatile solids content at each composting time.	58
4.18 The average volatile solids of with PC treatments.	60
4.19 The average volatile solids of without PC treatments.	61
4.20 The average volatile solids of mixing ratio 1:0 in with PC and without PC treatments.	62
4.21 The average volatile solids of mixing ratio 1:1 in with PC and without PC treatments.	63
4.22 The average volatile solids of mixing ratio 3:1 in with PC and without PC treatments.	63
4.23 The average volatile solids of mixing ratio 6:1 in with PC and without PC treatments.	64
4.24 The average pH values of all treatments at the initial and final stage in composting process.	66
4.25 Change of pH at each composting time.	67
4.26 The average pH values at each mixing ratio of with PC treatments.	70
4.27 The average pH values at each mixing ratio of without PC treatments.	71
4.28 The average pH values of mixing ratio 1:0 in with PC and without PC treatments.	72
4.29 The average pH values of mixing ratio 1:1 in with PC and without PC treatments.	73

**LIST OF FIGURES (cont.)**

<b>Figure</b>		<b>Page</b>
4.30	The average pH values of mixing ratio 3:1 in with PC and without treatment	73
4.31	The average pH values of mixing ratio 6:1 in with PC and without PC treatments.	74
4.32	Total heavy metal concentration at the initial and final stage in composting process.	77
4.33	Available heavy metal concentration at the initial and final stage in composting process	78
4.34	Change of total cadmium concentration at each composting time.	79
4.35	The average total cadmium at each mixing ratio of with PC treatments.	81
4.36	The average total cadmium at each mixing ratio of without PC treatments.	82
4.37	Change of available cadmium concentration of all treatment at each composting time.	84
4.38	The average available cadmium of with PC treatments.	87
4.39	The average available cadmium of without PC treatments.	88
4.40	The average available cadmium of mixing ratio 1:0 in with PC and without PC treatments.	89
4.41	The average available cadmium of mixing ratio 1:1 in with PC and without PC treatments.	89
4.42	The average available cadmium of mixing ratio 3:1 in with PC and without PC treatments.	90
4.43	The average available cadmium of mixing ratio 6:1 in with PC and without PC treatments.	91

## LIST OF FIGURES (cont.)

<b>Figure</b>	<b>Page</b>
4.44 Change of total copper concentration at each composting time.	93
4.45 The average total copper at each mixing ratio of with PC treatments.	95
4.46 The average total copper at each mixing ratio of without PC treatments.	96
4.47 Change of available copper concentration at each composting time.	97
4.48 Change of total nickel concentration at each composting time.	100
4.49 The average total nickel of with PC treatments.	103
4.50 The average total nickel of without PC treatments.	103
4.51 The average total nickel of mixing ratio 1:0 in with PC and without PC treatments.	104
4.52 The average total nickel of mixing ratio 1:1 in with PC and without PC treatments.	105
4.53 The average total nickel of mixing ratio 3:1 in with PC and without PC treatments.	105
4.54 The average total nickel of mixing ratio 6:1 in with PC and without PC treatments.	106
4.55 Change of available nickel concentration at each composting time	107
4.56 The average available nickel of mixing ratio 1:0 in with PC and without PC treatments.	109
4.57 The average available nickel of mixing ratio 1:1 in with PC and without PC treatments.	110
4.58 The average available nickel of mixing ratio 3:1 in with PC and without PC treatments.	110
4.59 The average available nickel of mixing ratio 6:1 in with PC and without PC treatments.	111

## LIST OF FIGURES (cont.)

<b>Figure</b>	<b>Page</b>
4.60 Change of total lead at each composting time.	112
4.61 The average total lead of with PC treatments.	114
4.62 The average total lead of without PC treatments.	115
4.63 The average total lead of mixing ratio 1:0 in with PC and without PC treatments.	115
4.64 The average total lead of mixing ratio 1:1 in with PC and without PC treatments.	116
4.65 The average total lead of mixing ratio 3:1 in with PC and without PC treatments.	117
4.66 The average total lead of mixing ratio 6:1 in with PC and without PC treatments.	117
4.67 Change of total zinc concentration at each composting time.	119
4.68 The average total zinc of with PC treatments.	121
4.69 The average total zinc of without PC treatments.	122
4.70 The average total zinc of mixing ratio 1:0 in with PC and without PC treatments.	123
4.71 The average total zinc of mixing ratio 1:1 in with PC and without PC treatments.	124
4.72 The average total zinc of mixing ratio 3:1 in with PC and without PC treatments.	124
4.73 The average total zinc of mixing ratio 6:1 in with PC and without PC treatments.	125
4.74 Change of available zinc at each composting time	126
4.75 The average available zinc of with PC treatments.	129
4.76 The average available zinc of without PC treatments.	130

**LIST OF FIGURES (cont.)**

<b>Figure</b>		<b>Page</b>
4.77	The average available zinc of mixing ratio 1:0 in with PC and without PC treatments.	131
4.78	The average available zinc of mixing ratio 1:1 in with PC and without PC treatments.	131
4.79	The average available zinc of mixing ratio 3:1 in with PC and without PC treatments.	132
4.80	The average available zinc of mixing ratio 6:1 in with PC and without PC treatments.	133
4.81	Fecal coliform bacteria at the initial and final stage in composting process	135
4.82	Change of fecal coliform bacteria at each composting time	136
4.83	The average fecal coliform bacteria of with PC treatments.	138
4.84	The average fecal coliform bacteria of without PC treatments.	139

## LIST OF ABBREVIATIONS

BMA	Bangkok Metropolitan Administration
WWTP	Wastewater treatment plant
DDS	Department of Drainage and Sewerage
DOA	Department of Agricultural
US. EPA	United stated Environmental Protection Agency
v / v	volume by volume
%	percentage by weight
DS	Dry solid
g	grams
mL	milliliters
L	liter
m	meter
mg/L	milligram per liters
mg/kg	miligram per kilograms
Cd	Cadmium
Cu	Copper
Ni	Nickel
Zn	Zinc
Pb	Lead
With PC	With plastic cover
Without PC	Without plastic cover

## **CHAPTER I**

### **INTRODUCTION**

#### **1.1 Statement of problems**

Thailand has changed from agricultural to newly industrialized country on the expense of environmental resources. Because of this, the accumulation of environmental pollution is rapidly increasing to the point that the nature is unable to cope with the pollution loading which the environmental problems are occurred. Water pollution is one of the major environmental urban problems.

Bangkok Metropolitan Administration (BMA) has allocated budget more than 600 million U.S. dollar for construction the central wastewater treatment plants which resulted in a production of large amounts of wastewater treatment sludge (1). At 2011, the seven central wastewater treatment plants have been constructed and operated. The amount of sewage sludge production was approximately 187.85 tons DS per day in 2007 (2). Moreover, BMA are going to construct three central wastewater treatment plants in near futures. The estimate volume of sewage sludge will increase to 302 tons DS per day in 2020 (3). An increasing amount of sewage sludge resulted from those established wastewater treatment plants have been concerned as a serious environmental problem regarding to its human health and quality of life effects.

Basically, sewage sludge disposal could be managed by various alternative options which have different advantages and disadvantages depending on selected disposal technique and management. The decision making on disposal routes can be determined base on factors such as present and future sludge amounts, available capacities for disposal requirement, and reasonable economy.

When compared to other sewage sludge management options, using land treatment of sewage sludge especially for the agriculture utilization is being increasingly considered by many big cities throughout the world as the best alternative option for sludge disposal because it is a practical option that requires low operational cost and also causes less environmental problems (4, 5). Composting is a cost-effective

and environmental friendly way for stabilization of sewage sludge. Composted sewage sludge can be used as fertilizer or soil conditioner in agricultural or horticultural applications (6, 7) due to it contain organic matters and nutrients which can increase soil fertility and also can improve soil properties.

The utilization of sludge has also included the potential risks to public health from contamination of heavy metals, hazard organic chemicals, and pathogens. Heavy metals in sewage sludge can accumulate in soils, plants, animals, and the human food chain due to metals are non biodegradable and difficult to remove from the environment (8). At the same time, pathogen contamination is also as a serious problem because it increases the potential of disease transmission to human and animals (9). Therefore, the reduction of heavy metals and pathogenic levels in sewage sludge to acceptable levels is an essential concern before application of sewage sludge to the agricultural area.

Most data on sludge management are not readily available because a lack of information on sludge management options and example of a successful case study on sewage sludge application is not available even though there are a number of researches assessing the possibility of using sewage sludge for agriculture. Hence, a little amount of sewage sludge is recycled on agricultural purpose.

The objective of this experiment is to study a feasibility of using sewage sludge as a soil conditioner. The sewage sludge will be firstly mixed with grass clipping and then composted by turning windrow process at different conditions. Furthermore, the existence and change of heavy metals (Cd, Cu, Pb, Ni, and Zn) and the survival of fecal coliform bacteria and parasitic contamination (Helminthes eggs, Protozoa cysts) during the composting process will be investigated. The results will be used as the supportive information to set up a guideline for land application for sewage sludge as well as the helpful solution for sewage sludge and yard waste management problems.

## **1.2 Objectives of study**

### **1.2.1 General Objective**

1) To study the change and existence of heavy metals, fecal coliform bacteria and parasitic contamination in sewage sludge mixed with grass clippings through the windrow composting technique.

### **1.2.2 Specific objectives**

- 1) To determine sewage sludge and grass clippings characteristics.
- 2) To compare the change of physical, chemical, and biological characteristics in compost material under various mixing ratios.
- 3) To compare the change of physical, chemical, and biological characteristics in compost material under different composting times.
- 4) To compare the change of physical, chemical, and biological characteristics in compost material under various steam sterilization conditions.
- 5) To compare the change of physical, chemical, and biological characteristics in compost material under various composting conditions (mixing ratios, composting times, and steam sterilization conditions).
- 6) To compare the characteristic of end composted product with guideline and regulation for agricultural utilization of sewage sludge.

## **1.3 Hypotheses of study**

1.3.1 The different mixing ratio would have affect to different change of physical, chemical and biological characteristics in compost material.

1.3.2 The different composting time would have affect to different change of physical, chemical and biological characteristics in compost material.

1.3.3 The different steam sterilization condition would have affect to different change of physical, chemical, and biological characteristics in compost material.

## 1.4 Variables of study

### 1.4.1 Independent variables

- 1) Composting times
- 2) Mixing ratio
- 3) Steam sterilization conditions

### 1.4.2 Dependent variables

- 1) Physical characteristics
- 2) Chemical characteristics
- 3) Biological characteristics

### 1.4.3 Control variables

- 1) Type of sewage sludge (digested anaerobic sludge)
- 2) Type of composting process (windrow technique)
- 3) Size of grass clippings (2-5 cm)
- 4) Field moisture capacity (40-60%)

## 1.5 Definition of Terms

**1.5.1 Sewage sludge:** refer to sewage sludge which treated by anaerobic digester, dewatered by filter press and collected from Nongkhem central wastewater treatment plant by grab sampling method.

**1.5.2 Grass clippings:** refer to grass clipping that selected from yard waste at Bangkok area by random sampling method, shredded by a lawn mower and air dried.

**1.5.3 Steam sterilization condition:** is a condition which composted heap was covered with black plastic sheet from 10.00 am to 4.00 pm.

**1.5.4 Composting condition:** is a composting process under various factors (mixing ratios, composting times and steam sterilization conditions) by windrow method and mechanical turning every 1 week. The composted heaps had 6m long, 5m wide and 1.2m high.

**1.5.5 Composting time:** is the duration in which sewage sludge was mixed with grass clippings and composted for 8 weeks. During composting time (weeks 0, 2, 4, 6, and 8) the sewage sludge were collected for determination of physical, chemical, and biological characteristics.

**1.5.6 Effects of the windrow composting conditions:** refer to the change and existence of sewage sludge mixed with grass clippings characteristics during the compost process included change of physical characteristic (temperature, total solids, volatile solids), chemical characteristic (pH, total heavy metals, available heavy metals), biological characteristics (fecal coliform bacteria and parasitic contamination (helminthes egg, larva or protozoan cyst)).

## **1.6 Scope of study**

Sewage sludge was collected from Nongkhem wastewater treatment plant and grass clipping will be collected from yard waste from Bangkok public green area. Both sewage sludge and grass clipping was collected by random sampling method during November 2009. The sewage sludge and grass clipping were mixed at different mixing ratios (1:0, 1:1, 3:1, 6:1) under various composting conditions (composting times and steam sterilization conditions). The mixture will be mechanically homogenized. The composting process was started during November -December 2009.

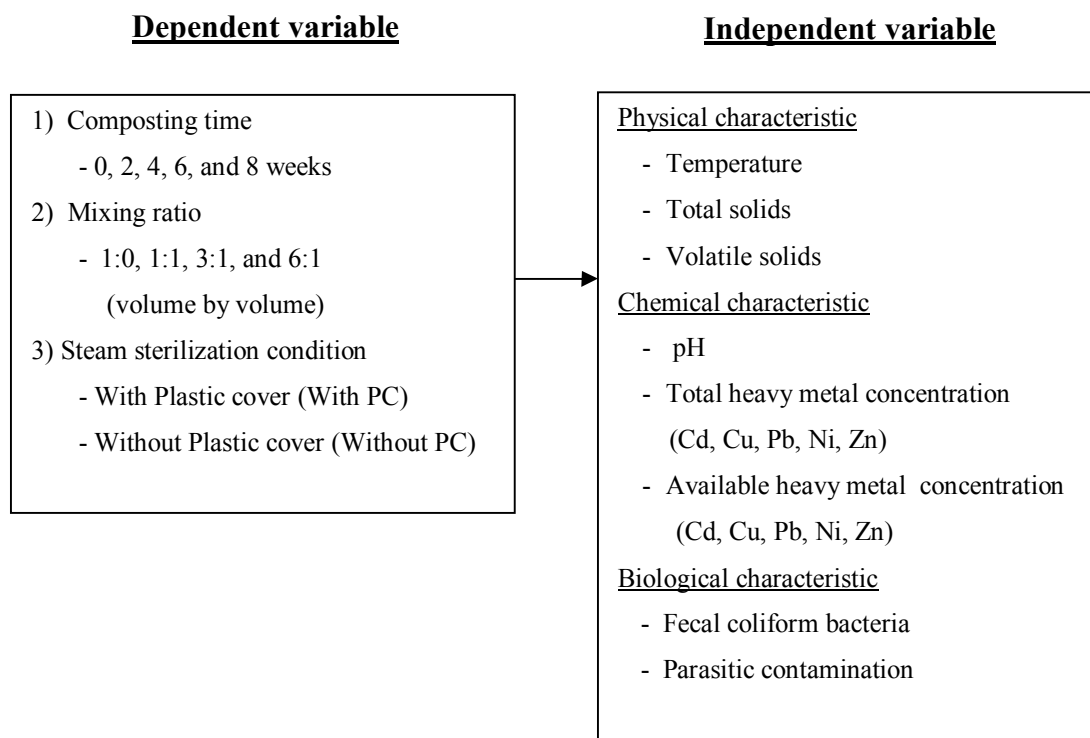
## 1.7 Limitation of study

1.7.1 The composting in this experiment represent only composted sewage sludge by windrow composting technique. They may not represent the composting from all composting techniques.

## 1.8 Expected outcome

1.8.1 The results of this study as basic information for set up a guideline of land application for sewage sludge as well as give a helpful solution for sewage sludge and yard waste management problems.

## 1.9 Conceptual framework



## CHAPTER II

### LITERATURE REVIEW

#### 2.1 Bangkok central wastewater treatment plants

The Department of Drainage and Sewerage (DDS), Bangkok Metropolitan Administration (BMA) has full authority to administer wastewater treatment plants in the Bangkok metropolitan area. At 2011, seven central wastewater treatment plants have been undertaken and operated. These will provide a total area of over than 191.7 km<sup>2</sup> with a total capacity of 992,000 m<sup>3</sup>/day. The amount of sewage sludge production was approximately 187.85 tons DS per day in 2007 (2) and estimate volume of sewage sludge will increase to 302 tons DS per day in 2020 (3). The central wastewater treatment process and capita of six plants are show in Table 2.1.

**Table 2.1** Treatment process and capacity of central wastewater treatment plant in Bangkok

<b>Central wastewater treatment plant</b>	<b>Treatment process</b>	<b>Capacity (m<sup>3</sup>/d)</b>
1. Sri praya	Contact stabilization Activated sludge system	30,000
2. Rattanakosin	Two stage Activated sludge system	40,000
3. Chongnosi	Cyclic Activated sludge system	200,000
4. Nongkhaem	Vertical loop reactor Activated sludge system	157,000
5. Chatuchak	Cyclic Activated sludge system	150,000
6. Thung kru	Vertical loop reactor Activated sludge system	65,000
7. Din daeng	Activated sludge with Nutrients removal	350,000

Source: BMA, 2011 (10)

## 2.2 Sewage sludge Characteristics

Sewage sludge is by product from biological wastewater treatment process that will change waste materials into microorganism cell and separate from the effluent. Physical characteristics of sewage sludge semi-solid, brown to black color. It may have unpleasant odor, gaseous, heated release if it as unstable form. Sewage sludge composition can vary considerably depending on wastewater characteristic, wastewater and sludge treatment process and quality of influent. The general sewage sludge characteristics are show in Table 2.2.

**Table 2.2** General characteristics of sewage sludge

Parameter	Value
pH	6.6-7.8
Total solid (%)	13-24
Volatile solid (%)	26-60
Moisture (%)	79-87
Total kjedahl's nitrogen (g/kg DS)	5-46
Total phosphorus (g/kg DS)	5-12
Total Heavy metals (mg/kg DS)	
- Cd	0.25-1.35
- Cu	1,216.64-1,637.64
- Pb	104.59-171.72
- Ni	92.36-151.35
- Zn	1,611.11-1,727.02
Parasitic contamination	Entamoeba histyloctica cyst., Hook worm, Teania egg, Hymenolepsis duminuta egg, Amoeba spp. cyst, Strongyloides stercolaris larva
Fecal Coliform (number/g dry wt)	$3 \times 10^3$ – $3 \times 10^6$

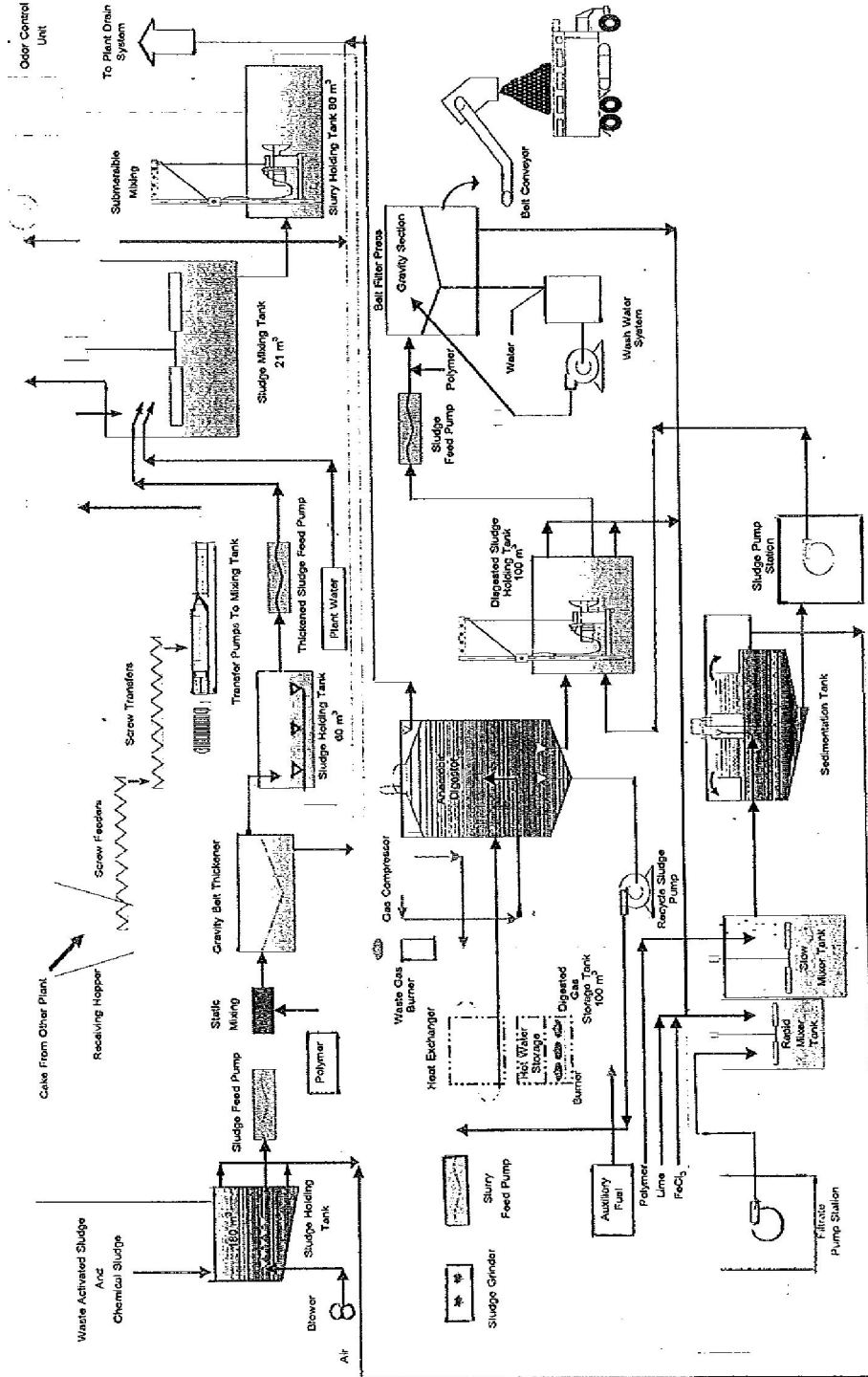
Source: adapt from AIT, 1995(11)

Sewage sludge from each wastewater treatment plant is collected and delivered to the sewage sludge treatment center located at Nongkhem WWTP. The sewage sludge are mixed and stabilized by an anaerobic digestion. Afterward, the treated sewage sludge is dewatered by belt press dewatering system. The results from digestion process, the organic solid in sewage sludge are converted to liquid and gases and volatile solids reduced about 45-50%. Chemicals and biological characteristics of digested sewage sludge from sewage sludge treatment center, Nongkhem WWTP are showed in Table 2.3.

**Table 2.3** Characteristic of sewage sludge from Nongkhem central wastewater treatment plant.

Parameter	Value
pH	7.61
Total solid (%)	23.52
Volatile solid (%)	41.40
Total kjedahl's nitrogen (mg/kg DS)	25,713.20
Total phosphorus (mg/kg DS)	17,258
Total potassium (mg/kg DS)	1,880.67
Total Heavy metals (mg/kg DS)	
- Cd	4.00
- Cu	2,737.83
- Pb	161.52
- Ni	244.39
- Zn	1,432.63
Parasites	<i>Entamoeba histolytica</i> cyst., Hook worm, <i>Taenia</i> spp. egg <i>Hymenolepis duminuta</i> egg, Amoeba spp. Cyst <i>Strongyloides stercolaris</i> larva, Ascaris spp. egg
- <i>Salmonella</i> spp.	Group B, C, E
- Faecal Coliform (MPN/g)	>11,000

Source: Department of drainage of sewerage, BMA, 2006 (12)



**Figure 2.1** Flow diagram of anaerobic sewage sludge digestion process at Nongkhem central wastewater treatment plant.  
 Source: Department of drainage of sewerage, BMA, 2006 (12)

## 2.3 Agricultural utilization of sewage sludge

Agricultural utilization of sewage sludge is one of the basic disposal options of sewage sludge. When compared to landfilling, lagooning, ocean dumping and incineration, agricultural utilization seems to be a practically feasible option because of its low operational cost and less related environmental problems. Additionally, valuable nutrients, organic matter, and essential trace metals represented in sewage sludge can also be recycled (13). An ocean dumping is an unacceptable alternative because it causes more environmental effects. Meanwhile, landfilling and an incineration are prohibited in both Europe and America (14). According to the Bangkok master plan, composted sewage sludge has been selected as an alternative of sewage sludge disposal. Composting Sewage sludge with municipal solid wastes is considered as a feasible disposal option for both wastes. However, further investigation on this method of disposal are required particularly in terms of the regulation of using sewage sludge for agriculture, identification of an application area, and the benefits and risks of using sewage sludge as a soil amendment or a fertilizer.

### 2.3.1 Advantages of using sewage sludge

Sewage sludge is a source of plant nutrients such as organic matter, nitrogen, phosphorus, potassium which are of agricultural value. An addition of sewage sludge to soil is able to improve soil structure. Reduction of soil bulk density, increment of soil porosity, soil density and water retention capacity are the examples of above advantages (15). Moreover, sewage sludge also can neutralize the soil pH. In coarse textured sandy soil, sewage sludge can increase water holding capacity. Table 2.4 shows the nutrient levels in both commercial fertilizer and sewage sludge.

**Table 2.4** Comparison of nutrient levels in commercial fertilizer and sewage sludge.

Source	Nutrient (%)		
	Nitrogen	Phosphorus	Potassium
Fertilizer for typical agricultural use	5	10	10
Typical values for stabilized wastewater sewage sludge	3.3	2.3	0.3

Source: Mclalf and Eddy, 1991 (16)

### **2.3.2 Risks of agricultural utilization of sewage sludge**

Sewage sludge not only contains valuable nutrients, organic matter, and essential trace metals but it also contaminated with toxic heavy metals, organic pollutants, and pathogens. Thus, an application of sewage sludge on land that comprises these contaminants is an environmental concern. Toxic constituents and pathogenic organisms presented in sewage sludge might cause the harmful effects to human health and the environment. For example, toxic contaminants can be leached and transported to surface water and subsurface environment due to the soil erosion and runoff losses.

#### 2.3.2.1 Heavy metals

Heavy metals are non-biodegradable substances that present in nearly all kind of waste materials. The heavy metals contaminated soil can cause permanently damage to plants greater than those organic pesticides. Heavy metals may contaminate to the surface and subsurface environment and enter to the living organisms via the food chain. The small amounts of heavy metals can cause severe physiological health effect, a metabolic disorder, and chronic diseases. Sewage sludge contains large amount of toxic elements for instance, cadmium, lead, zinc, copper and nickel (17). Cadmium, lead, and nickel are toxic substances to both human and other living organisms (animals). While, zinc and copper are essential micronutrients to plant growth.

- Toxicity of heavy metals

The effect of heavy metals contamination from sewage sludge application to agricultural soil depends on type of sewage sludge, amount of sewage sludge application and soil properties. They could not be metabolized by the body. The toxicity of heavy metals will present after the heavy metals accumulation in the soft tissues has reached particular level. In long term, the sewage sludge application can cause a significant accumulation of Cd, Cu, Pb, Ni and Zn in soil and plant (18).

- Cadmium (Cd) in sewage sludge can pollute surface waters as well as soil. In acidic soils enhance the cadmium uptake by plant. Moreover, cadmium is accumulated in the animal bodies such as fish, shrimps and will be accumulate in other organisms and ecosystem. Cadmium is toxic to animal and humans at extremely low levels. In humans, long-term exposure to lower levels leads to a buildup in the kidneys and possible kidney disease, lung damage, and fragile bones and higher level leads to obstructive lung disease, cadmium pneumonitis. At high level also produce health effect on respiratory system and has been associated with bone disease. Severe exposure may result in pulmonary edema and death. The chronic poisoning of cadmium is known as itai-itai. In plants, the most general of Cd effect are stunting, chlorosis, reduction in Photosynthesis, wilting and necrosis. At high level of exposure show to inhibit seed germination (19). Cadmium uptake by plants is affected by several soil factors such as pH, organic matter, soil particle size, chloride concentration.

- Copper (Cu) is an essential element for plants and animals. At long-time exposures lead to liver and kidney damage, cirrhosis and pink disease. At short- term exposure to irritation of mouth and throat, headaches, dizziness, nausea, diarrhea, gastric ulcers, jaundice, renal damage and death. The dermal exposure may induce allergic responses in sensitive individuals. Cu is toxic to man but poisoning is rare. Under normal conditions, Cu dose not cause toxicity to any organism except fish (20). Cu was very immobile micronutrient in soil and reaction in soil similar to the other. The copper solubility and availability more increased when pH of soil was decreased. A concentration above 25 mg/kg will produce toxicity in plants.

- Lead (Pb) is the most significant toxic of the heavy metals. An inorganic form can absorbed through ingestion of food and water and inhalation (21). High Pb levels cause severe damage to the brain, kidneys and ultimately cause of death. In men can damage the organs responsible for sperm production whereas pregnant women, lead can pass the placental barrier resulting in miscarriage, abortion, and still births. Pb does not readily move through the soil profile. The potential for contamination of ground water resources and drinking water was very low. However, the remaining at the surface, potential exposure to children by ingestion of soils or by dust is much greater. In plant, the toxicity inhibition of seed germination (19, 22).

- Nickel (Ni) has been reported as a cause of acute nickel carbonyl poisoning including frontal headache, vertigo, nausea, vomiting, insomnia, and irritability, followed by pulmonary symptoms similar to those of a viral pneumonia. In plant the toxicity are necrosis of the leaves, stunting of the roots, deformation of various plant organs, and wilting (23).

- Zinc (Zn) toxicity in human have been reported as vomiting, diarrhea, bloody urine, icterus (yellow musus membrane), liver failure, kidney failure and anemia. Chronic effect damage of immune system, and interferes with the body's ability to take in and use other essential elements such as copper and iron. In plant, the zinc deficiency effect greater than zinc excessive effect. The symptoms of Zn toxicity are chlorosis in young leaves, and change in periodic movement (light/dark) of leaves of soybean (24).

#### 2.3.2.2 Pathogenic organisms

Sewage sludge contains a wide variety of human pathogens including viruses, protozoa, helminthes and fungi (25). The various pathogens found in a particular source of sewage sludge reflect the incidence of disease in the community from which sewage sludge are derived (26). Both human and animals can expose to pathogens through either direct contact from a sewage sludge application or an indirect contact by consuming drinking water and food that has been contaminated by sewage sludge (27). Major pathogenic microorganisms of concern are including *Escherichia coli*, salmonella spp., Protozoa and Helminthes egg, etc (28). Table 2.6 show the diseases and symptom of pathogenic microorganisms that present municipal wastewater and sewage sludge.

Fecal coliform bacteria as indicator of the potential presence of pathogens in sewage sludge. They are abundant in human feces and therefore are always present in untreated sewage sludge. Fecal coliform bacteria can easily and inexpensive measure. Fecal coliform bacteria may also regrow in water, wastewater, and sewage sludge under appropriate condition.

Protozoan cyst and Helminthes egg can be infected to human and animal through various pathways. However, an oral route is the most important pathway in terms of an epidemiology. Protozoan and helminthes infection can be divided into 2 categories. First, a direct infection through an ingestion or handling of contaminated soil or vegetables with helminthes egg. Secondly, indirect infection via the consumption of drinking and raw vegetables cultivated with helminthes egg or protozoan contaminated sewage sludge.

**Table 2.5** Major pathogenic microorganisms of concern in sewage sludge

Organisms	Diseases and symptoms
<b>Bacteria</b>	
<i>Salmonella</i> spp.	Salmonellosis (food poisoning), typhoid fever
<i>Shigella</i> spp.	Bacillary dysentery
<i>Yersinia</i> spp.	Acute gastroenteritis (diarrhea, abdominal pain)
<i>Vibrio cholera</i>	Cholera
<i>Campholobacter jejuni</i>	Gastroenteritis
<i>Escherichia coli</i> (pathogen strain)	Gastroenteritis
<b>Viruses</b>	
Poliovirus	
Coxsackievirus	Poliomyelitis
Echovirus	Meningitis, pneumonia, hepatitis, fever, and common colds
Hepatitis A virus	Meningitis, paralysis, encephalitis, common colds
<b>Protozoa and helminthes</b>	
<i>Cyptosporidium</i>	Infectious hepatitis
<i>Entamoeba histolytica</i>	Gastroenteritis, cryptosporidiosis
<i>Giardia lamblia</i>	Amoebiasis,
<i>Balantidium coli</i>	Giardiasis (diarrhea, abdominal cramps)
<i>Ascaris lumbricoides</i>	Diarrhea and dysentery
<i>Ascaris suum</i>	Digestive and nutritional disturbances, abdominal plain, vomiting restlessness
<i>Trichuris trichiura</i>	May produce symptoms such as coughing, chest pain and fever
<i>Taenia</i> spp.	Abdominal pain, diarrhea, anemia, weight loss
<i>Necator americanus</i>	Nervousness, insomnia, anorexia, abdominal pain, digestive disturbances, Hookworm disease
<b>Fungi</b>	
<i>Aspergillus fumigatus</i>	Pulmonary disease

Source: US.EPA 2000 (28)

### 2.3.3 Control the numbering of pathogenic organisms in sewage sludge

The pathogenic microorganism in sewage sludge can be achieved by treated sewage sludge prior to use or disposal and through environmental attention. A regulation on the sewage sludge disposal was established by USEPA in 1993. It has included the pollutant limits for the land application of sewage sludge which can be further divided into 2 classes; class A and class B biosolids.

Class A biosolids is a treated sewage sludge in which the number of pathogens is well below the detectable level. It can be used without any pathogen-related restriction at the application site because the pathogens destruction must be completed before an application to land. Class A biosolids is required for application onto public use sites and certain crops such as turf, vegetable crops, root crops and home garden.

Class B biosolids is a treated sewage sludge that the pathogens are reduced before applying to land. However, number of pathogens may be detected. Thus, public access and harvest of crops are restricted for a period of time after application of class B biosolids to allow for pathogens destruction. These classes of sewage sludge are applied on grain and forage crops, pastures, grassland and timberland.

Prior to an application of treated sewage sludge to land, both class A and B biosolids should meet the USEPA regulation on the land application of sewage sludge in terms of trace element levels and vector attraction reduction. Pathogenic organism characteristics of class A and B biosolids are indicated below;

**Table 2.6** The comparison of pathogenic organism characteristics of class A and B biosolids.

	Class A	Class B
Fecal coliform bacteria	<1000 MPN / g of total dry weight solid	<2,000,000 MPN/g total solid (dry weight) or <2,000,000 CFU
Salmonella	<3 MPN/4g of total dry weight solid	Not applicable
Enteric viruses	<1 PFU/ 4 g total solid	Not applicable
Viable helminth ova	<1 viable helminth ova / 4 g total solids	Not applicable
Additional requirements for land application	Vector attraction reduction plus site restrictions after application	Vector attraction reduction

Source: US.EPA, 1999 (29)

**Table 2.7** Processes to reduce pathogenic microorganisms in sewage sludge

Approach	Effectiveness	Process sample
Application of high temperature by generated by chemical, biological, physical process	- Depends on time and temperature. - Sufficiently long time periods can reduce bacteria, viruses, protozoan cysts and helminthes ova to below detectable levels. Helminthes ova are the most resistant to high temperatures.	- Composting (using biological process to generate heat) - Heat drying and heat treatment (use physical process to generate heat eg. hot gasses, heat exchangers) - Pasteurization (physical heat, e.g. hot gases, heat exchanger) - Aerobic digestion (biological heat) - Anaerobic digestion (physical heat)
Application of radiation	- Depends on does. - Sufficient does can bacteria, virus, protozoan cysts, and helminthes ova to below detectable levels. Viruses are most resistant to radiation	- Gamma and high-energy electron beam radition
Using chemical disinfectants	- Substantially reduces bacteria and viruses and vector attraction. Probably reduces protozoan cysts. Dose not effectively reduces helminthes ova unless combined with heat	- Lime stabilization
Reducing the volatile organic content in sewage sludge	- Reduces bacteria. Reduces vector attraction.	- Aerobic digestion - Anaerobic digesting - Composting
Removal of moisture from sewage sludge	- Reduces viruses and bacteria. Reduces vector attractions as	- Air or heat drying

Source: US.EPA, 1999 (29)

## **2.4 Steam sterilization**

Steam sterilization is a technique that sterilizes soil with steam in open fields or greenhouses. Steam treatments of larger areas typically require 4 to 8 hours to complete at 60°C to 70°C for 30 minutes. Pests of plant cultures such as weeds, bacteria, fungi, nematode (larvae and eggs) and viruses are destroyed through hot steam which causes their cell structure to physically degenerate. Presently, this technique can be applied to horticulture for sterilization of substrates and top soil, mushroom cultivation for pasteurization of growing rooms, sterilization of top soil and combined application as heating.

## **2.5 Composting**

Composting is a biological process in which organic waste is converted into stabilized humus by the activity of complex organisms naturally present in the waste under anaerobic and aerobic conditions. Mostly, municipal sewage sludge is composted under aerobic conditions. Materials composted in aerobic conditions can decompose more rapidly and result in a higher rise in temperature necessary for pathogen destruction and also minimize the potential for nuisance odors. The advantages of composting are the oxidation of organic material to a stable state resistant to odor production, destruction of many human pathogens when composting temperature exceeds 60 °C, production of soil conditioner that can be stored and easily spread on the land. Mixing the sewage sludge with dry materials such as sawdust, vegetal remains, rice straw which act as bulking agents, providing structural support and increasing the porosity of the mixture for effective aeration (30). Moreover, these bulking agents can be a source of carbon to increase the low C/N ratio of the sewage sludge.

### **2.5.1 Composting process**

1) Raw materials preparation – This stage consists of the preparation of material by delivery from source, grinding and screening out undesirable material, and mixing bulking agents or other amendments. Pathogeneses level in sewage sludge are highest with little or no destruction occurred.

2) Composting This stage has often been termed as an “active composting”. This is the period when microbiological activity is greatest. During the composting process, the temperature increases from an initial mesophilic phase (ambient temperature) to mesophilic phase (45°C (104°F)), finally to the thermophilic phase when the composting temperature is over 45°C (104°F) (6). During this phase, the percentage of mesophilic organism organisms decreases as temperature rise, leading to thermophilic bacteria and fungi growth. These organisms have high activity and reproduction capacity, causing a further temperature rises, thus inactivating the pathogenic organisms. Pathogeneses are destroyed during this stage as a result of the high temperature. The active composting period essentially ends when temperatures descend to the mesophilic range and the compost becomes maturity.

3) Curing – Curing is an extension of the composting process but occurs at lower microbial activity. During this stage, microbiological activity decreases since the food supply has diminished. The temperatures are lower and the oxygen demand decreases. Toward the latter part of curing, the compost should be very stable, inducting very low microbial activity (i.e., low carbon dioxide evolution and little heat production).

4) Storage – The compost product should be stable. Prior to distribution of the final product, some storage may be needed. Unless contamination occurs, pathogenesis should be non – detectable.

### **2.5.2 Composting technology**

The compost technology chosen for aerobic composting will depend on the location of the facility, the capital available, and the amount and type of waste delivered to the site. Aerobic composting involves the activity of aerobic microbes, and hence the provision of oxygen during the composting process. Aerobic composting generally is characterized by high temperatures, the absence of foul odors, and is more rapid than

anaerobic composting. Two main types of systems are generally characterized which as: 1) open systems such as windrows and static piles and 2) closed "in-vessel" systems. In-vessel or "reactor" systems can be static or movable closed structures where aeration and moisture is controlled by mechanical means and often requires an external energy supply. Such systems are usually investment intensive and also more expensive to operate and maintain. Open systems are the ones most frequently used in developing countries. Four common methods for composting are aerated static pile, passive windrow, turned windrow and in-vessel composting. The comparison four composting techniques as shown in Table 2.8.

#### 1) Aerated static pile

The aerated static pile system used a grid of aeration or exhaust piping over which a mixture of dewatering sludge and bulking agent is placed. The bulking agents such as wood chip, corn cobs, crop residues, bark and leaves can be used for suit the texture and moisture of the compost. As the pile not turned the material must be given to mixing and blending by a pug-mill type or rotating-drum mixer or by movable equipment such as a front-end loader. Typical pile is generally about 2-2.5 m high and 3-5 m wide. Pile length should be around 21- 27m (depends on the aeration system). Material is composted for 21 to 28 days and is typically followed by curing period of 30 day or longer. A layer of screen compost is often placed on top of the pile for an insulation. Disposable corrugated plastic drainage pipe is commonly use for air supply and each individual pipe is recommended to have an individual blower for more effective aeration control. Screening of the cured compost usually is done to reduce the quantity of the end product requiring ultimate disposal ant to recovery the bulking agent. To improved process and odor control, many facilities should be covered or significant portions of system should be enclosed.

#### 2) Passive windrows systems

Passive windrow systems is a very low-cost approach requiring more land, but less labor and capital than other composting methods. The windrow is simply an elongated pile of material with more or less triangular cross section. A windrow is simply an elongated pile of material with a more or less triangular cross-section. The pile size is about 3 m wide, 1.8 m high and its length will vary depending upon the amount of materials used. This method can not mechanical for aeration, the aeration occur naturally. The coverings compost pile with layer can be prevent moisture loss, reduce unpleasant odor and

produce more uniform compost. Passive windrow composting takes a long time to be complete. The compost normally will require six months to two years. The center of large passive windrow can be quickly become anaerobic condition that will produce unpleasant odor.

### 3) Turned windrow systems

In turned windrow systems, the material is arranged in long narrow piles with 3-6m wide and 1-3.6m high. The width of pile is largely determined by the size of the machine used to turn the pile. The size of windrow for the maintenance of aerobic conditions is determined by porosity of composted material. Large windrow will quickly become anaerobic condition in the core, require constant turning, while small windrow will not attain the required temperature for efficient composting and the destruction of weed seeds and pathogen. The turning could be done manually However, it is impractical with the volume larger than one or two cubic meters. Turning frequency depends on the rate of the composting reaction. Temperature, oxygen concentration and odors are goods indicator for turning. In heavy rainfall area, windrow is necessary to be covered to prevent the wet composted material. Additionally, the dome or triangular shaped of windrow is effective for shedding excess rain.

### 4) In- vessel Composting

In-vessel composting is achieved inside an enclosed container or vessel. These systems are designed to minimize odors and process time by controlling environmental conditions such as air flow, temperature and oxygen concentration .The advantages of in-vessel composting system are better process and odor control, faster throughput lower labor costs and smaller area requirements. In-vessel composting system can be divided into two major categories which are plug flow and dynamic (agitated bed). In plug- flow system, the relationship between particles in the composting mass stays the same throughout the process, and the system operated on the basis of a first-in, first-out principle. In dynamic system, the compost material is mechanically mixed during the processing. In-vessel systems can be further categorized based on the geometric shape of the vessel or containers used.

**Table 2.8** Comparison four composting technology

	<b>Aerated static pile</b>	<b>Passive windrow</b>	<b>Turned windrow</b>	<b>In-vessel</b>
<b>General</b>	Effective for farm and municipal use	Low technology Quality problems	Active systems most common on farms	High technology
<b>Labor</b>	System design and planning important. Monitoring needed	Low labor required	Increases with aeration frequency and poor planning	Requires consistent level of management/product flow to be cost efficient.
<b>Site</b>	Less land required given faster rates and effective pile volumes	Requires large land areas	Can require large land area	Very limited land, due to rapid rates and continuous operations
<b>Bulking agent</b>	Less flexible, Must be porous	Less flexible, Must be porous	Flexible	Flexible
<b>Active period</b>	Range: 21-40 days	Range: 6-24 months	Range: 21-40 days	Range: 21-40 days
<b>Curing time</b>	30+ days	Not applicable	30+ days	30+ days
<b>Size:</b>				
- <b>Height</b>	3-4.5 m	1-4 m	1-2.8 m	Dependent on bay design
- <b>Width</b>	Variable	3-7 m	3-6 m	Variable
- <b>Length</b>	Variable	Variable	Variable	Variable
<b>Aeration system</b>	Forced positive/negative air flow through pile	Natural convection only	Mechanical turning and natural convection	Extensive mechanical turning and aeration
<b>Process control</b>	Initial mix. Aeration temperature and/or time control.	Initial mix only	Initial mix turning	Initial mix. Aeration temperature and/or time control.
<b>Odor factors</b>	Odor can occur, but controls can be used, such as pile insulation and filters on air system.	Odor from the windrow will occur. The larger the windrow the greater the odors.	From surface area of windrow. Turning can create odors during initial weeks.	Odor can occur. Often due to equipment failure or system design limitations.

Source: Ministry of agriculture, Food and fisheries, British Columbia, 1996 (31)

### 2.5.3 Factors affecting composting process

The factors that have affect to quality of compost are C:N ratio, moisture content, aeration, pH, surface area, temperature and retention time.

#### 1) C:N ratio

Carbon and nitrogen are both the most important and the most commonly limiting elements for microbial indicator growth. The ideal ratio for C/N is 25:1 to 30:1 for active composting. However, good results can be achieved with C:N ratios from 20:1 to 40:1. Carbon supplies energy and growth while nitrogen is used for protein synthesis and reproduction of microorganisms in the composting process.

#### 2) Moisture content

Maintaining adequate moisture content in the composting heap is important for microorganism degradation. Moisture content between 40 to 60 percent by weight is recommended for most materials. Moisture content less than 40 percent may cause the microorganisms to slow their activities and become inactive or die whereas exceeding moisture level will lead to anaerobic degradation, odors, and slower decomposition. Moisture in composting can be added during turning by sprinkling water. The covering compost heap by a roofed structure is a great idea for the control of moisture in heap. In open-air system, the covering pile by a tarpaulin, plastic sheeting or gunny-bags is used to reduce water infiltration. At the same time covering can prevent evaporation (33).

#### 3) Aeration

Aeration is one key factor affecting composting process. Aeration must provide the oxygen required by the microorganisms used in breaking down the waste. An oxygen content of 16 to 18.5 percent is ideal. Oxygen consumption during composting is directly proportional to microbial activity. There is a direct relationship between oxygen consumption, temperature and aeration. The common way for aerating compost heap by turning has low cost in the developing country (32).

#### 4) pH

Composting can work effectively between the pH levels of 5.5 to 9. However, the process is most effective between pH level 6.5 to 8. In the initial stage of composting process, pH was decreased around 5 as organic acids are formed

and then pH rise up into 8-8.5 because of ammonification. During maturation stage, pH sink below 8 due to the change of ammonium compound from nitrified to nitrate. Thus, a high pH is generally the sign of immature compost.

#### 5) Surface area

The surface area of organic material exposed to microorganisms is another factor in determining the rate of composting. Smaller particles of raw materials have more surface area which makes nutrients and energy more available to microorganisms. However, smaller particles can reduce the porosity of the heap and possible air circulation. The optimum particle size ranging from 1/8 to 2 inches in diameter generally produces good results. The physical state and size of compost materials affect the moisture content and composting process.

#### 6) Temperature

The temperature is important for composting because the higher operating temperature of thermophilic bacteria can sterilize the waste of pathogenic bacteria. The internal pile temperature must be maintained at 50-55°C. Temperature is a good indicator of the composting process because microorganisms release heat while they work.

#### 7) Retention time

The length of time required to convert raw materials to compost depends on the other factors described in Table 2.8. The shortest composting period results from proper moisture content and C:N ratio, plus frequent aeration. Active composting usually takes two weeks to nine months, depending on the method and materials. Curing generally requires another one to four months. The intended use of the compost ultimately determines the required composting period.

**Table 2.9** Characteristics for the composting process

Characteristics	Reasonable range	Preferred range
C/N ratio	20:1-40:1	25:1-30:1
Moisture content	40-65%	50-60%
Oxygen content	>6%	~16-18.5
Bulk density	5.5-9.0	6.5-8.5
Temperature	110-140° F	130-140°F
Particle size	1/8 – 2 inches diameter	Varies*

\* Depend on raw material, pile size, and/or weather condition

## 2.6 Guidelines and Regulations for Agricultural utilization of sewage sludge.

### 2.6.1 Guidelines for good organic compost.

**Table 2.10** Guidelines for good quality organic composts.

Parameter	Department of Agriculture standard	Department of Land development criteria
Compost Characteristic	No contamination object (ex .plastic, glass and steel)  Crush stone and gravel size (< 5mm and ≤ 5% by weight)	Non toxic substances Dark-brown or black color Odorless Temperature stable or equal to ambient temperature. Like an earthlike mass or softer than the initial material characteristics.
Sizing	≤ 12.5 x 12.5 mm.	Not include
Moisture	≤ 35%	≤ 35-40 %
C:N ratio	≤ 20:1	20:1 or < 20:1
EC	≤ 5 dM/M	Not include
Nutrients	Nitrogen (N) ≥ 1 % by weight, Available phosphorus ≥ 0.5 % by weight, Available potassium ≥ 0.5 % by weight.	Nitrogen (N) ≥ 1 % by weight, Available phosphorus ≥ 0.5 % by weight, Available potassium ≥ 0.5 % by weight.
Heavy metal	As ≤ 50 mg/kg, Cd ≤ 5 mg/kg, Cr ≤ 300 mg/kg, Cu ≤ 500 mg/kg, Pb ≤ 500 mg/kg, Hg ≤ 2mg/kg	Not include
Organic matter	>30% by weight	25-50%
pH	5.5-8.5	6.0-7.5

Source: Department of Agriculture (33), Department of Land development (34)

### 2.6.2 BMA guideline for sewage sludge and night soil application to agricultural.

The following standards and regulations are suggested with respect to the agricultural application of sludge in Bangkok Metropolitan Administration and its surrounding.

**Table 2.11** BMA guideline for sewage sludge and soil application to agricultural

Parameter	Department of Agriculture standard
Sewage sludge application	Must be applied to the soil before plantation or seeding.
Soil and crop monitoring	Monitoring of soil and crop parameters such as pH, CEC, N, P, K and the heavy metals of concern must be done following every 5 years application.
Heavy metal	$Cd \leq 20$ mg/kg, $Cr \leq 1,000$ mg/kg, $Cu \leq 900$ mg/kg, $Hg \leq 10$ mg/kg, $Ni \leq 400$ mg/kg, $Pb \leq 1,000$ mg/kg, $Zn \leq 3,000$ mg/kg.
Pathogen	For the crops, which are in direct contact to the customers, the sludge to be applied must be a pathogens free product (for example composted or lime treated)
pH	Should not be applied normally to soil having a pH < 5, however, extensive monitoring is essential for soil having a pH < 5.

Source: AIT, 1995 (11)

### 2.6.3 The ceiling concentration of heavy metals in Biosolids and Biosolids products.

This is the maximum concentration in mg/kg of heavy metal in biosolids compost that is allowed for land application.

**Table 2.12** The ceiling concentration limits for all biosolids applied to land.

	Concentration limits of heavy metal (mg/kg dry solid)				
	Cd	Cu	Pb	Ni	Zn
US.EPA	85	4300	840	420	7500

Source; USEPA, 1996 (35)

## 2.6 Related Studied

Pasda N. *et al.* (36) studied the characteristics of sewage sludge from three central wastewater treatment plants in Bangkok. The objectives of this study were to study the variability in sewage sludge characteristics and to assess the possibility of using sewage sludge for agricultural purposes. They concluded that the composition of sewage sludge varied according to the area of collection and period of sampling. Plant nutrient were high (total N 38 g/kg DM, total P 14.0 g/kg DM, total K 6.0 g/kg DM) Fecal coliforms were present in the sludge, C/N ratio low (around 6). The authors suggested that this sewage sludge should improve quality before an application by mix with high organic carbon content materials, heat to kill fecal coliforms and identify source of contamination.

Uyasatian .U *et al.* (37) studied on the chemical characteristics and phototoxic effect from sewage sludge on agriculture utilization. And sewage sludge in this studied were namely non digested sludge, digested sludge and “Nongkhem” composted sludge. The results showed that some heavy metal was such as K was lower than standards of organic fertilizer and Cu and Ni were higher the above the allowable level of sewage sludge for agriculture. For seed germination test with Pak-choi and Chinese cabbage seeds found that composted sludge might be used as soil conditioner, however the high concentrations of Cr and Cu will be monitored level when application on agricultural land.

Gantzer C. *et al.*(9) studied impact of various sludge treatment from four sampling campaigns and 10 treatment type process on pathogenic organisms (salmonella and viable pathogenic nematode eggs) and assessed levels of fecal contamination indicator (E.coli, Enterococci, sulfite-reducing anaerobic spores). They found that the treatment had more than 45°C pathogenic microorganisms were can be destroy.

Iranzo M. *et al.* (30) studied the characteristics of rice straw and sewage sludge as composting material and temperature effect over some pathogenic organisms. They found that a temperature at 62°C, 48 hr, the pathogen organisms removed from rice straw and sewage sludge mixture and C/N ratios suitable for a rapid increased in microbial activity were the lowest (16–24). The results show that; the time and temperature conditions that are reached during thermophilic phase can be highly effective in eliminating the pathogenic microorganism present in compost.

Trabdee T. (38) studied on survival of *Ascaris* eggs in soil applied with fecal sludge, sewage sludge, and fecal sludge after through drying process. The studied results suggest that the parasite egg in sewage sludge should treated before applied to land and the monitoring risk of parasitic from soil with sewage sludge at before and after plantation time.

## CHAPTER III

### MATERIALS AND METHODS

#### 3.1 Research design

The purpose is to study the condition of sewage sludge composting for using as soil conditioner by turned windrow process. This experiment was three-factor experiments with repeated measures on one factor design. The study factors are composting times, mixing ratios, and steam sterilization conditions. The study was consisted of 8 experimental of the mixing ratio 1:0, 1:1, 3:1, and 6:1 volume by volume and 2 steam sterilization conditions (with and with out plastic cover) as shown in Table 3.1.

Three replicate samples were randomly performed for each heaps. Total studied samples were 24 units (4 mixing ratios x 2 steam sterilization condition x 3 replicate) at each composting times. The compost material samples were taken and determined characteristics including temperature, pH, total solid, volatile solid, total heavy metal, available heavy metal, fecal coliform bacteria, and parasitic contamination.

**Table 3.1** Treatment combination of mixed sewage sludge and grass clippings composting at different composting time and replications.

Mixing ratio (SS: GC)	Steam sterilization condition	Composting time (weeks)	Replications
1:0	With PC	0,2,4,6 and 8 wk	3
1:0	Without PC	0,2,4,6 and 8 wk	3
1:1	With PC	0,2,4,6 and 8 wk	3
1:1	Without PC	0,2,4,6 and 8 wk	3
3:1	With PC	0,2,4,6 and 8 wk	3
3:1	Without PC	0,2,4,6 and 8 wk	3
6:1	With PC	0,2,4,6 and 8 wk	3
6:1	Without PC	0,2,4,6 and 8 wk	3

Note; PC= plastic cover

## **3.2 Place of experiment**

3.2.1 Analysis of total solids, volatile solids, moisture content, pH, fecal coliform bacteria was analyzed at Department of Environmental Health science, Faculty of Public Health, Mahidol University.

3.2.3 Analysis of total and available heavy metal by using the Flame Atomic Absorption Spectrophotometer (FAAS) was analyzed at Center of excellence on Environmental Health Toxicology and management of Chemicals, Faculty of science, Mahidol University.

3.2.3 Analysis of Helminthes egg and protozoan cysts was analyzed at Department of Parasitology and Entomology, Faculty of public Health, Mahidol University.

3.2.4 Field experiment was conducted at Nong-khame sludge composting site Phudthamonthon sai 3 Road, Nongkhem district, Bangkok.

## **3.3 Research instruments and equipments**

### **3.3.1 Instruments and equipments for field experiment**

- Plastic sheet, size 30 m<sup>2</sup>
- A plastic pail, 10L
- Sterile zip log plastic bag
- Dial thermometer, Tel-tru
- pH meter; Eutech model teastr 30
- A shovel
- Balance 2 decimal

### **3.3.2 Instruments and equipments for moisture, total solids, volatile solids total and available heavy metals analysis**

- Hot- air oven; Memmert model UNE 400
- Hot plate; Stuart model CB 302
- Analytical balance; Mettler model AB204-S
- Desiccators; Patron model GH-51
- Atomic absorption spectrophotometer;  
Varian, model spectrAA-220 FS
- Rotary shaker
- Filter paper ;No.42, diameter 11 cm, Whatman
- Volumetric flask size 25, 50mL, 100mL ,200mL
- Erlenmeyer flask size 50 mL, 150 mL
- Micropipette, Lio pette size 1 mL, 5mL, 10mL
- Beaker size 150mL, 250 mL,500mL
- Cylinder size 100 ml
- Funnels
- Plastic bottles

### **3.3.3 Instrument and equipments for fecal coliform bacteria analysis**

- Autoclave; Sanyo model MLS-3020
- Analytical balance; Mettler model AB204-s
- Incubator, Thelco model 6
- pH meter, Eutech model teastr 30
- Stomacher, Seward model 400 Circulation
- Micro pipette, Lio pette size 1 mL, 5mL, 10mL
- Water bath
- Glass Petri dish
- Screw cap tubes
- Durham's tubes
- Stomacher bag
- Cylinder size 100 ml
- Wire loops

### **3.3.4 Instrument and equipments for parasites analysis**

- Centrifuge; Hettich universal II
- Microscope; Olympus model
- Stirred rods
- Forceps
- Gauze
- Beaker size 50 mL, 100 mL, 250 mL, 500 mL
- Centrifuge tube size 15 mL
- Erlenmeyer flask size 1000 mL
- Glass microscope slide
- Cover glass 22x40 mm

## **3.4 Chemical reagents and media**

### **3.4.1 Reagents for analyzing total and available heavy metals according to the standard methods of Soil Analysis (39)**

- Total heavy metals (Cd, Pb, Ni, Cu, Zn)
  - Perchloric acid (HClO<sub>4</sub>) 70-72 %, Merck
  - Nitric acid 65%, Merck
  - Deionization water
  - Standard calibration solution 1,000 ppm (Cd, Pb, Ni, Cu, Zn), Ajeck
- Available heavy metals (Cd, Pb, Ni, Cu, Zn)
  - Diethytriaminepentaacetic acid (DTPA)
  - Triethanolamine (TEA) 0.1M, Ajeck
  - Calcium chloride (CaCl) 0.01M, Ajeck
  - Deionization water
  - Standard calibration solution 1,000 ppm (Cd, Pb, Ni, Cu, Zn), Ajeck

### **3.4.2 Reagents for analyzing Fecal coliform bacteria according to the US Food and Drug Administration 2006 (40)**

- Sterile sodium chloride 0.85%
- Lactose broth, Merck
- EC broth, Merck

### **3.4.3 Reagents for analyzing parasite according to Faust et al. (41)**

The helminthes eggs, larva and protozoa cyst were identified on the basis of the shape and size and compared with standard eggs, larva, and protozoa cyst.

- Sodium hypochlorite 2%
- Iodine
- Distillation water

## **3.5 Research methodology**

### **3.5.1 Preparation of composting heap**

Sewage sludge used in this study was digested sewage sludge from Nongkhem WWTP. Grass clippings were selected from yard waste at Bangkok area. Sewage sludge and grass clippings were mixed at four mixing ratios 1:0, 1:1, 3:1 and 6:1 volume by volume. The mixture were laid as a windrow over concrete floor and turned thoroughly with mechanical. The composting heap was set up 6 m long, 5 m wide, and 1.2 m high, triangular shape, and used open-air system. The with PC treatments were covered by plastic sheet and without PC treatments were not covered by plastic sheet (see appendix B).

### **3.5.2 Experimental method**

Sewage sludge and grass clippings were analyzed the physical, chemical, and biological characteristics before composting. Parameters in this experiment were analyzed pH, moisture, total solids, volatile solids, total and available heavy metals (Cd, Pb, Ni, Cu, and Zn), fecal coliform bacteria and parasitic contamination.

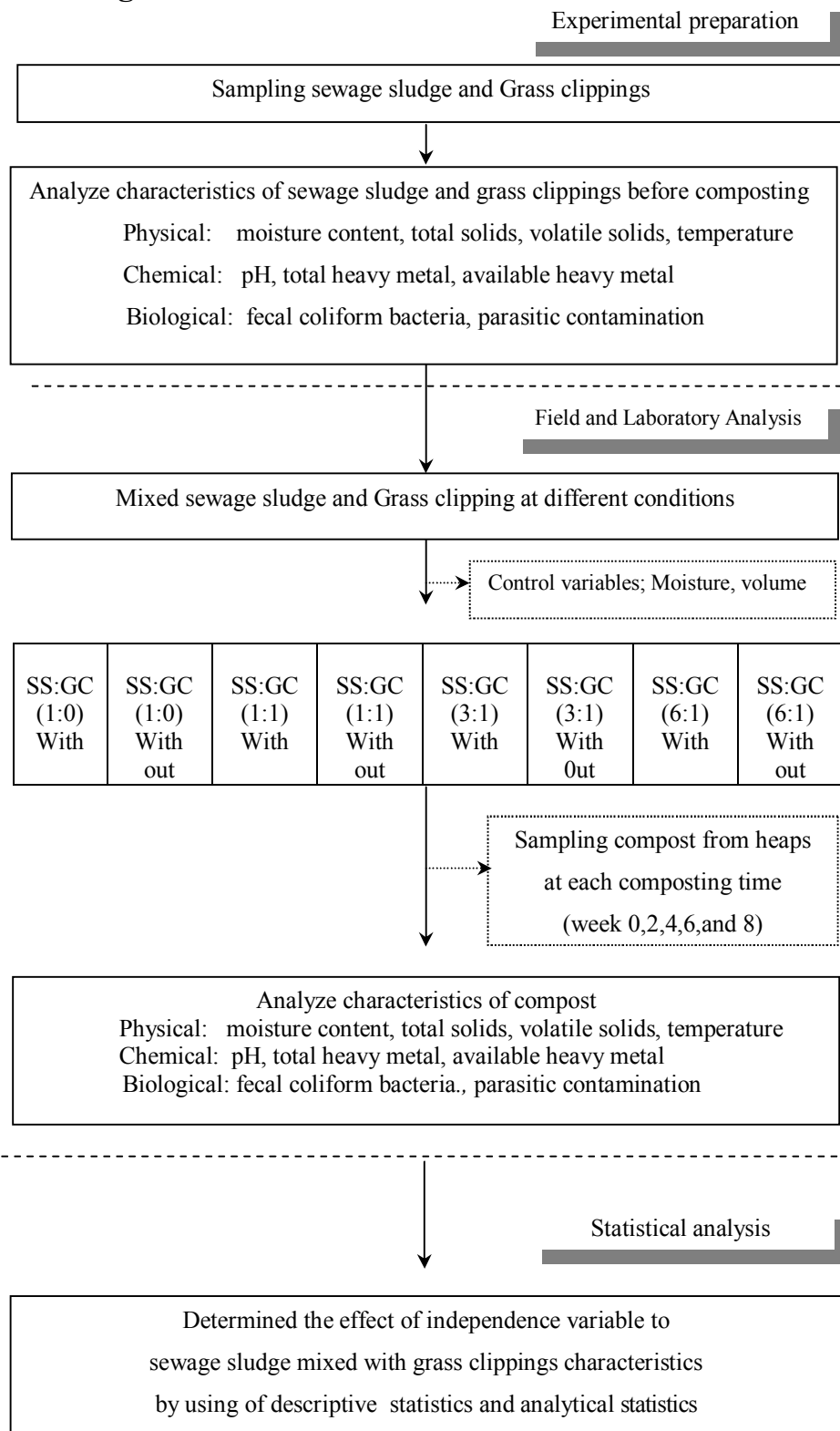
Sewage sludge and grass clippings were mixed at different conditions; mixing ratios (1:0, 1:1, 3:1, and 6:1 volume by volume) and steam sterilization conditions (with PC, with out PC treatment) in each composting site. Moisture content of the heaps was maintained around 40-60% field capacity throughout the composting time. At each composting time pH, total solids, volatile solids, total and available heavy metals, fecal coliform bacteria, and parasitic contamination were monitored as parameter. The temperature was daily monitored parameter.

The 2 kg mixture sample was collected at each heap after turning heap from 5 different positions (60 cm depth below piles surface) at each incubation times (0, 2, 4, 6, and 8 weeks). The compost material samples were homogenized in plastic pail. Compost sample for biological analysis were kept in sterile zip log plastic bag and stored at 4°C. Compost sample for physical and chemical characterization were kept in plastic bag, air-dried at ambient temperature 25-30°C, crushed and sieved through a 2 mm stainless steel screen. The compost samples were characterized in three replicates.

**Table 3.2** Analytical method of sewage sludge and glass clipping characterization

Parameter	Method and Instruments
<b>Physical Characteristics</b>	
Temperature	Dial thermometer, Tel tru model
Moisture content	Oven- dried at 105 °C for 24hr, Memmert, model UNE 400
Volatile solid	Ignition at 550 °C by oven, memmert, model UNE 400
<b>Chemical Characteristics</b>	
pH	1:2.5 water/soil, measurement by pH meter, Eutech, model pH teastr 30
Total Heavy metals (Cd, Pb, Ni, Zn, Cu)	HNO <sub>3</sub> – HClO <sub>4</sub> digestion and quantity by Atomic absorption spectrophotometer, Varian, model Spectr AA-202FS
Available Heavy metal (Cd, Pb, Ni, Zn, Cu)	0.005 M DTPA extract, pH 7.3 extraction and quantity by Atomic absorption spectrophotometer, Varian, model Spectr AA-202FS
<b>Biological characteristics</b>	
Fecal coliform bacteria	Multiple-Tube Enrichment Technique
Helminthes egg, larva or protozoa cysts	Modified simple smear technique

### 3.6 Research diagram



**Note:** SS = Sewage sludge, GC= Glass clippings

**Figure 3.1** Research diagram

## **3.7 Statistical analysis**

### **3.7.1 Descriptive statistics**

The characteristics including total solid, volatile solid, pH, temperature, total metal and available heavy metal concentration, fecal coliform bacteria were described as mean, minimum, maximum, and standard deviation (SD).

Except the parasitic contamination as qualitative study, identified type and observed morphological change in helminthes egg, larva or protozoa cysts.

### **3.7.2 Analytical statistics**

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization conditions, and composting time.

When interaction exists among these factors each composting time and classified each level of steam sterilization conditions.

1) In case of a triple interaction, F-test of ANOVA was used to test a simple main effect of an impendent variable (e.g. mixing ratio) classified by each level of another independent variable (e.g. steam sterilization condition) at each time period.

2) In case of double interaction, the F-test was used to test the simple main effect of mixing ratio at each time periods. Then Bonferroni adjustment was used to test the difference in each pair of the main effect. The significant level was set at P-value <0.05.

## **CHAPTER IV**

### **RESULTS**

The results emphasized the change of physical, chemical, and biological characteristics in sewage sludge mixed with grass clippings under various composting conditions (mixing ratios, composting times, and steam sterilization conditions). The main effect and interaction effect of the treatment on physical, chemical, and biological characteristics in composted sewage sludge on the were analyzed by the three way analysis of variance with one repeated factor was used to analyze main effect and their interaction effect.

#### **4.1 Characteristics of sewage sludge and glass clippings**

This study is aim to determine sewage sludge and grass clippings characteristics. The determined physical characteristics were moisture content, total solids, and volatile solids. The studied chemical characteristics were pH, total heavy metal content, available heavy metal content. Biological characteristics were fecal coliform bacteria, and parasitic contamination (helminthes egg, larvae or protozoa cysts).

##### **4.1.1 Characteristics of sewage sludge**

The characterizations of sewage sludge are described in Table 4.1. The moisture content was 78.09%. Total solids and volatile solids were 21.91% and 40.11%. pH was 6.66. The total heavy metals were Cd 1.96 mg/kg DS, Cu 2,084.37 mg/kg DS, Ni 258.25 mg/kg DS, Pb 62.20 mg/kg DS, and Zn 1,026.12 mg/kg DS. The available heavy metals were Cd 0.85 mg/kg DS, Cu 544.51 mg/kg DS, Ni 45.93 mg/kg DS, and Zn 130.49 mg/kg DS. The fecal coliform was  $1.09 \times 10^4$  MPN /g DS. It was found active form of *Entamoeba histolytica* cysts, and viable hookworm eggs.

#### 4.1.2 Characteristics of grass clippings

The characterizations of grass clippings are also described in Table 4.1 and 4.2. The moisture content was 2.64%. Total solids and volatile solids were 97.36% and 79.39%. pH was 5.70. The total heavy metals were Cu 35.31 mg/kg DS, Ni 10.92 mg/kg DS, Pb 3.52 mg/kg DS, and Zn 76.91 mg/kg DS. The available heavy metals were Cu 4.29 mg/kg DS, Ni 2.39 mg/kg DS, Zn 15.59 mg/kg DS. Cadmium concentration was not found in both total form and available form but lead was found only total form. The faecal coliform was  $1.99 \times 10^4$  MPN/ g DS. It was also found active form of *Entamoeba histolytica* cysts., viable *Trichostrongylus* spp. eggs, and viable *Strongyloides stercoralis* larvae.

**Table 4.1** Physical and Chemical characteristics of sewage sludge and grass clippings.

Parameter	Sewage sludge	Grass clippings
<b>Physical characteristics</b>		
Moisture content (%)	78.09 (0.63)	2.64 (0.38)
Total solids (%)	21.91 (0.63)	97.36 (0.38)
Volatile solid (%)	40.11 (0.33)	79.39 (0.09)
<b>Chemical characteristics</b>		
pH	6.66 (0.00)	5.70 (0.01)
Total heavy metal concentration		
- Total cadmium (mg/kg DS)	1.96 (0.37)	ND
- Total copper (mg/kg DS)	2084.37 (61.60)	35.31 (17.42)
- Total nickel (mg/kg DS)	258.25 (34.48)	10.92 (2.01)
- Total lead (mg/kg DS)	62.20 (5.83)	3.52 (0.96)
- Total zinc (mg/kg DS)	1,026.12 (24.43)	76.91 (7.0)
Available heavy metal concentration		
- Available cadmium (mg/kg DS)	0.85 (0.06)	ND
- Available copper (mg/kg DS)	544.51 (30.95)	4.29 (0.07)
- Available nickel (mg/kg DS)	45.93 (2.76)	2.39 (0.10)
- Available lead (mg/kg DS)	ND	ND
- Available zinc (mg/kg DS)	130.49 (6.40)	15.59 (0.32)

Note: ND = nondetectable, values in parentheses are standard deviation (SD) of three replications

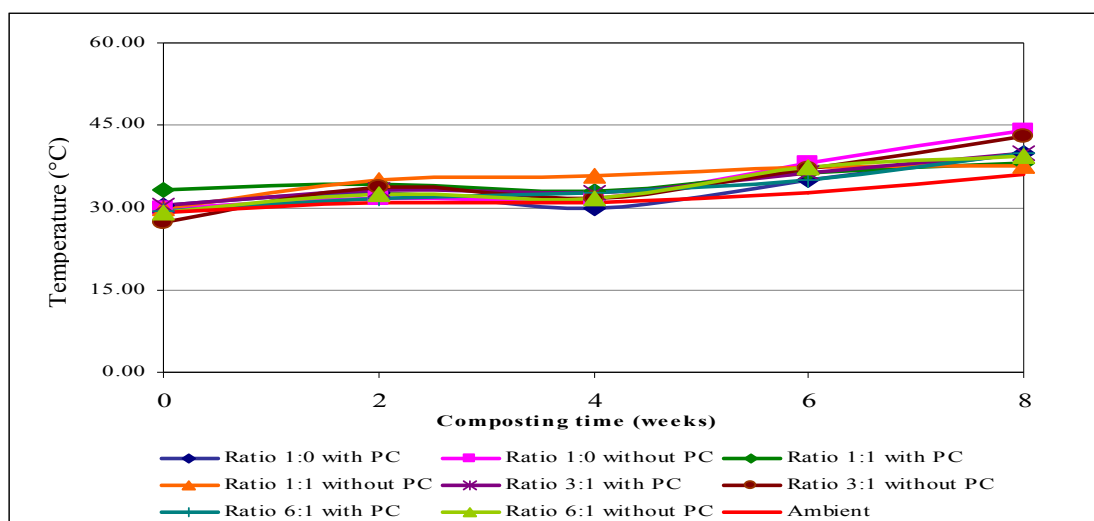
**Table 4.2** Biological characteristics of sewage sludge and grass clippings.

Parameter	Sewage sludge	Grass clippings
<b>Biological characteristics</b>		
Fecal coliform bacteria (MPN/g DS)	1.09 x 10 <sup>4</sup>	1.99 x 10 <sup>4</sup>
Pathogenic parasites contamination	<i>Entamoeba histolytica</i> cyst (Active form)	<i>Entamoeba histolytica</i> cyst (Active form)
	Hook worm egg (Viable egg)	<i>Trichostrongylous</i> spp. egg (Viable egg)
		<i>Strongyloides stercoralis</i> larva (Viable larva)

## 4.2 Change of sewage sludge mixed with grass clipping physical characteristics in composting process.

### 4.2.1 Temperature

The average temperature range within the compost heap during week 0 to week 8 was 27.33 to 44.0°C. The changes of averages temperature of all treatment in each composting time are showed in Figure 4.1 and Table 4.3. Figure 4.1 showed that during week 0 to week 8, all treatments had slightly increasing of average temperature in week 0 to week 2 and then they were continuously clearly increasing in week 4 to week 8. When comparing the average temperature within compost heap in week 0 to week 8 with the ambient temperature, they were quite near to the ambient temperature range. However, the peak of temperature within compost heap which been observed was 47.4 °C at the 2<sup>nd</sup> day of composting process (see appendix A). Moreover, at week 0 to week 2, the composting process was effected by rainfall. The ambient temperature was the varied from 29 to 36°C.



**Figure 4.1** Change of average temperature at each composting time.

**Table 4.3** The average temperature (°C) of each experimental treatment in composting process.

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	30.33 (0.57)	32.67 (0.58)	30.0 (0.00)	35.00 (1.00)	40.0 (1.00)
	Without PC	30.00 (0.00)	31.67 (0.58)	31.67 (0.58)	38.00 (1.0)	44.00 (0.00)
1:1	With PC	33.33 (0.57)	34.33 (1.15)	33.00 (0.00)	37.33 (0.58)	38.00 (1.0)
	Without PC	30.0 (0.00)	35.00 (1.0)	35.74 (1.15)	37.33 (0.58)	37.67 (0.58)
3:1	With PC	30.33 (0.57)	33.33 (0.58)	32.67 (0.58)	36.33 (1.0)	40.0 (1.0)
	Without PC	27.33 (0.57)	33.67 (0.58)	31.67 (0.58)	37.00 (0.00)	43.0 (1.0)
6:1	With PC	29.33 (1.15)	31.67 (0.58)	32.67 (0.58)	35.00 (0.00)	40.0 (0.00)
	Without PC	29.00 (2.30)	32.33 (0.58)	31.67 (1.15)	37.33 (0.58)	39.33 (1.53)
Ambient		29	31	31	32.60	36

Note: Values in parentheses are standard deviation of three replications, PC = plastic cover

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their triple interaction effect (mixing ratio, steam sterilization conditions, and composting time) of temperature.

The main effect of mixing ratio and composting time of all treatments were significantly different ( $P=0.005$ ) and ( $P<0.001$ ), respectively. The main effect of composting time of all treatments was significantly different ( $P<0.001$ ). However, the main effect of steam sterilization conditions of all treatments was not significantly different ( $P = 1.121$ ).

The interaction among mixing ratio, steam sterilization conditions, and composting time was significantly different ( $P<0.001$ ) in within subject effect. There were also had an interaction between mixing ratios and steam sterilization conditions ( $P=0.006$ ), composting time and mixing ratio ( $P<0.001$ ), composting time and steam sterilization condition ( $P<0.001$ ). The results are showed in Table 4.4.

**Table 4.4** The analysis of variance of temperature.

Source	SS	Df	MS	F	P-value
<b>Between - subject effects</b>					
Intercept	141110.208	1	141110.208	156789.120	< 0.001
Steam sterilization	16.758	3	5.586	6.207	0.121
Mixing ratio	2.408	1	2.408	2.676	0.005
Steam sterilization *Mixing ratio	16.425	3	5.475	6.083	0.006
Error	0.002	16	<0.001		
<b>Within-subject effects</b>					
Composting time	1653.667	4	413.417	668.148	< 0.001
Composting time * Steam sterilization	25.467	4	6.367	10.290	< 0.001
Composting time * Mixing ratio	126.533	12	10.544	17.042	< 0.001
Composting time * Steam sterilization * Mixing ratio	59.533	12	4.961	8.018	< 0.001
Error	39.600	64	0.619		

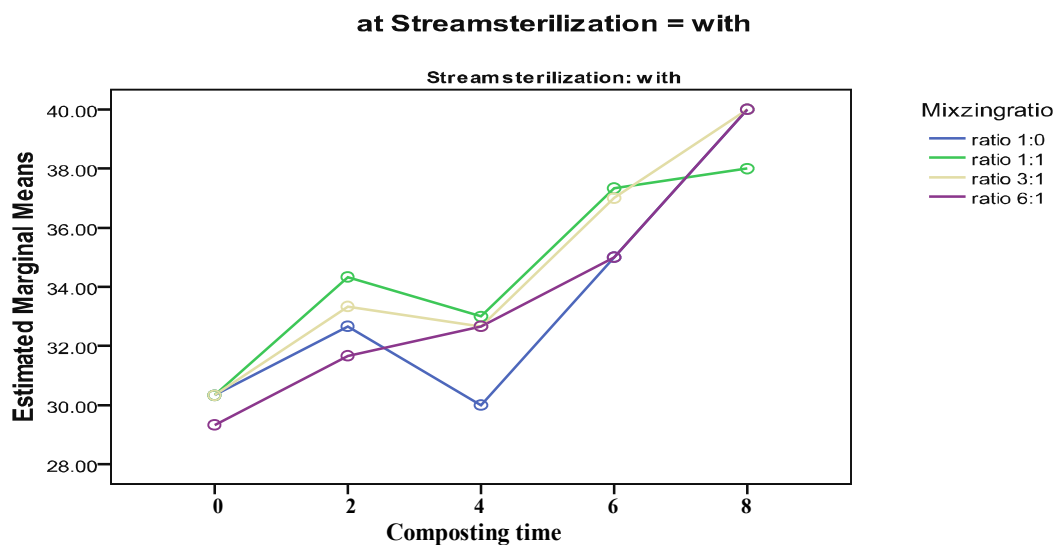
- When interactions exist among the three factor, F-test of ANOVA is used to test the simple main effect of mixing ratio at each time period classified by each level of steam sterilization conditions (with PC / without PC treatment). To test the difference between groups Bonferroni adjustment was used to compare.

- With PC treatment, temperature was found significant difference in 3 periods as show in Figure 4.2.

At week 2, the temperature of mixing ratio 1:1 was significantly different from mixing ratio 6:1.

At week 4, the temperature of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1.

At week 6, the temperature of mixing ratio 1:1 was significantly different from mixing ratio 1:0 and 6:1.



**Figure 4.2** The average temperature of with PC treatments

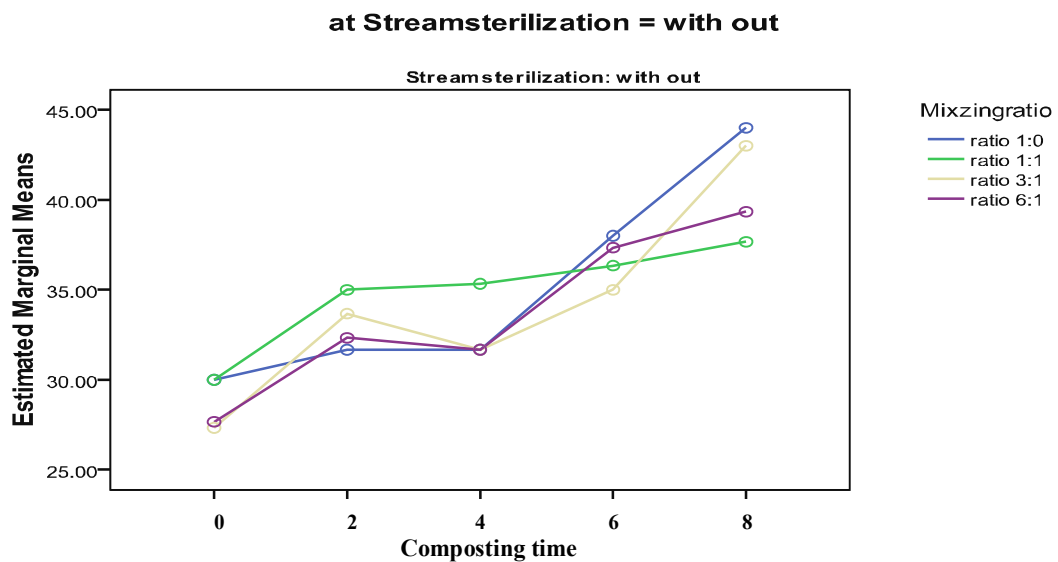
- With out PC treatment, the temperature was found significant difference at almost period, except week 0 as show in Figure 4.3.

At week 2, the temperature of mixing ratio 1:1 was significantly different from mixing ratio 1:0 and 6:1.

At week 4, the temperature of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.

At week 6, the temperature of mixing ratio 3:1 was significantly different from mixing ratio 1:0 and 6:1.

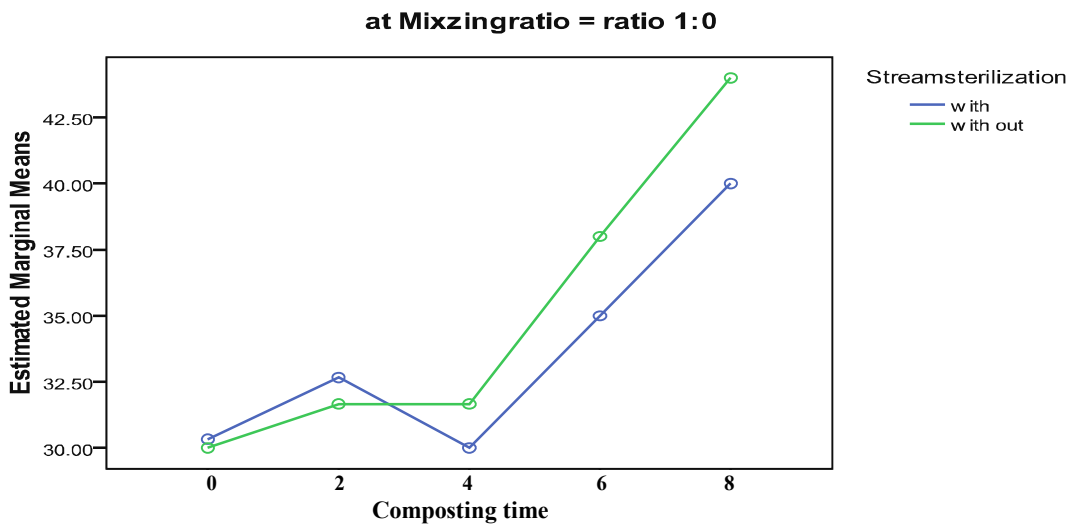
At week 8, the temperature of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 1:1 and 6:1.



**Figure 4.3** The average temperature of without PC treatments.

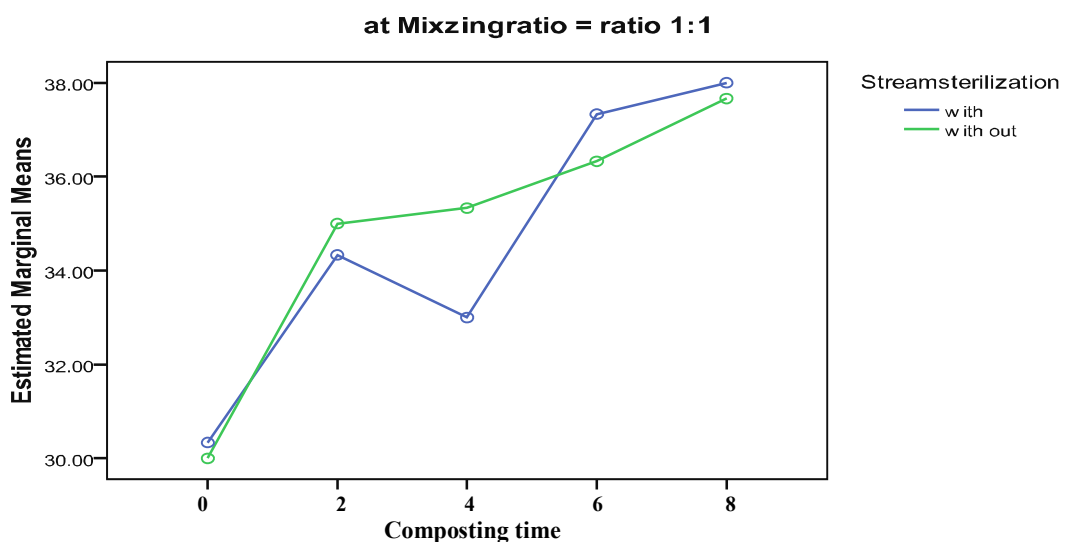
- To test the simple main effect of steam sterilization condition classified by each level of mixing ratio at each level of time period. For testing of difference Bonferroni adjustment was used to compare.

For mixing ratio 1:0, temperature was found significance in 3 periods. At week 2, 4, and 8, temperature of with PC treatment was significantly different from without PC treatment as show in Figure 4.4.



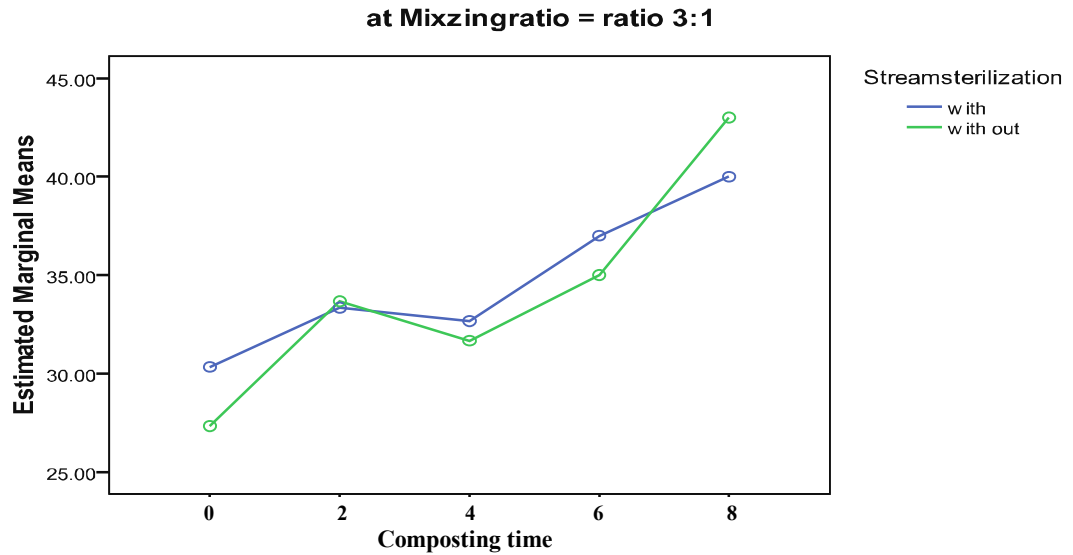
**Figure 4.4** The average temperature of mixing ratio 1:0 in with PC and without PC treatments.

For mixing ratio 1:1, temperature was no significant differences of interaction of steam sterilization condition and mixing ratio in all periods as show in Figure 4.5.



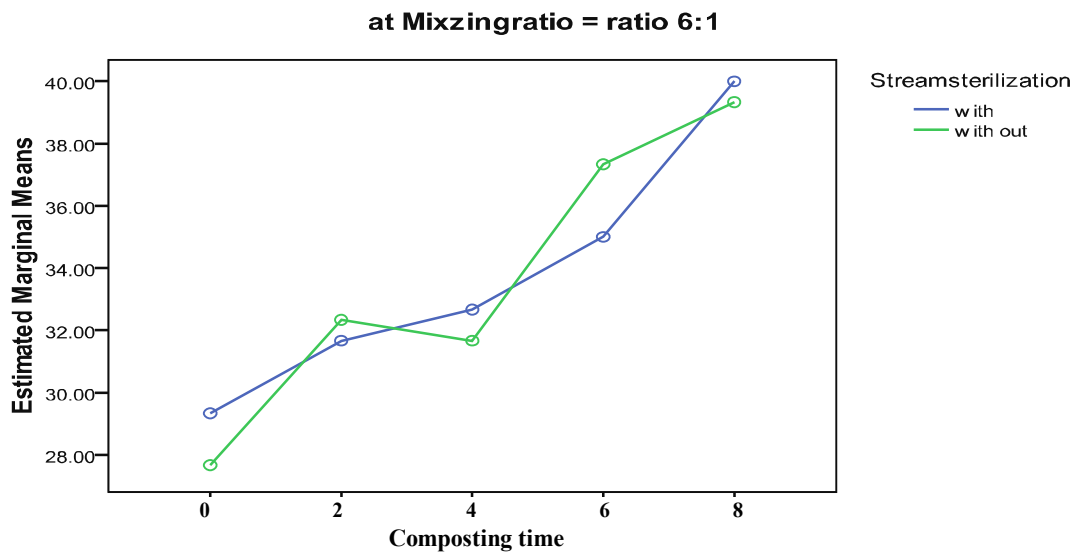
**Figure 4.5** The average temperature of mixing ratio 1:1 in with PC and without PC treatments.

For mixing ratio 3:1, temperature was found significant in 3 periods. At week 0, 6, and 8, temperature of with PC treatment was significantly different from without PC treatment as show in Figure 4.6.



**Figure 4.6** The average temperature of mixing ratio 3:1 in with PC and without PC treatments.

For mixing ratio 6:1, temperature was found significant only at week 6. At week 6 of with PC treatment was significantly different from without PC treatment as show in Figure 4.7.



**Figure 4.7** The average temperature of mixing ratio 6:1 in with PC and without PC treatments.

- To test the simple main effect of composting time at each interaction level of steam sterilization conditions and mixing ratio. Then, to test difference between groups, Bonferroni adjustment was used to compare.

For mixing ratio 1:0 with PC treatment, the temperature of composting time at week 0 was significantly different from week 2, 6, and 8. The temperature at week 2 was significantly different from week 4, 6, and 8. The temperature at week 4 was significantly different from week 6, 8. The temperature at week 6 was significantly different from week 8.

For mixing ratio 1:1 with PC treatment, the temperature at week 0 was significantly different from week 2, 4, 6, and 8. The temperature at week 2 was significantly different from week 6 and 8. The temperature at week 4 was significantly different from week 6 and 8.

For mixing ratio 3:1 with PC treatment, the temperature at week 0 was significantly different from week 2, 4, 6, and 8. The temperature at week 2 was significantly different from week 6 and 8. The temperature at week 4 was significantly different from week 6, and 8. The temperature at week 6 was significantly different from week 8 and 2.

For mixing ratio 6:1 with PC treatment, the temperature at week 0 was significantly different from week 6 and 8. the temperature at week 2 was significantly different from week 6 and 8. The temperature at week 4 was significantly different from week 6, and 8. The temperature at week 6 was significantly different from week 8.

For mixing ratio 1:0 without PC treatment, the temperature at week 0 was significantly different from week 2, 4, 6, and 8. The temperature at week 2 was significantly different from week 6 and 8. The temperature at week 4 was significantly different from week 6, and 8. The temperature at week 6 was significantly different from week 8.

For mixing ratio 1:1 without PC treatment, the temperature at week 0 was significantly different from week 2, 4, 6, and 8. The temperature at week 2 was significantly different from week 8. The temperature at week 4 was significantly different from week 8.

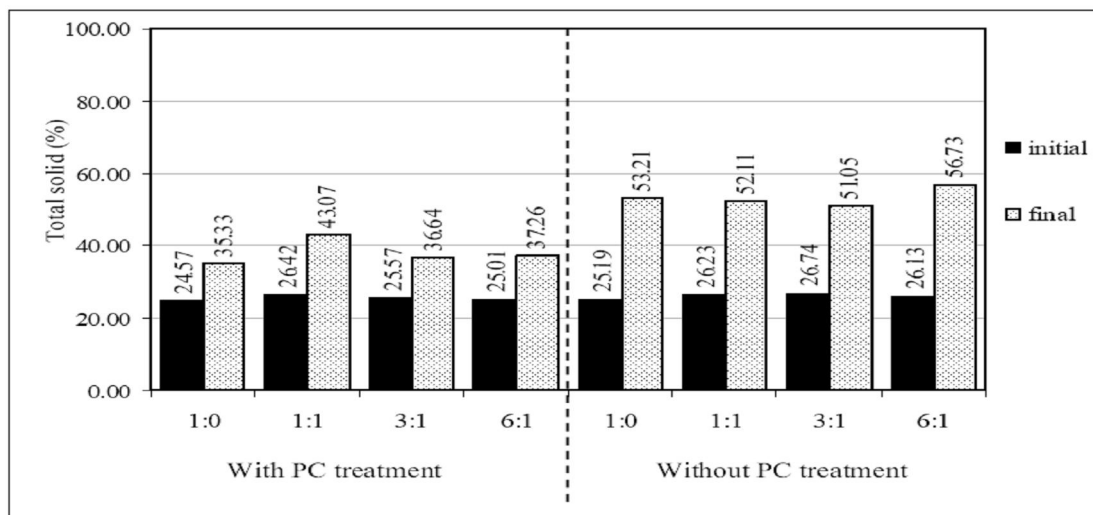
For mixing ratio 3:1 without PC treatment, the temperature at week 0 was significantly different from week 2, 4, 6, and 8. The temperature at week 2 was significantly different from week 4 and week 8. The temperature at week 4 was significantly different from week 6 and 8. The temperature at week 6 was significantly different from week 8.

For mixing ratio 6:1 without PC treatment, the temperature at week 0 was significantly different from week 2, 6, and 8. The temperature at week 2 was significantly different from week 6 and week 8. The temperature at week 4 was significantly different from week 6 and 8.

#### 4.2.2 Total solids

The results of average total solids contents at the initial stage of all treatments for both treatments with PC and without PC were more than the average total solids at the final stage of composting time. The without PC treatment in all mixing ratios had more changes of total solids when compared with PC treatment. The 6:1 without PC had total solids changed more than the other treatments.

The average total solids at the initial and final stage in composting process are showed in Figure 4.8. The average total solids range at initial stage found in the treatment with PC was 24.57-26.42 % while total solids of the treatment without PC was 25.19-26.74%. The total solids range at final stage was found that the treatment with PC 35.33-43.07% while the total solids of the treatment without PC 51.0-56.73%.



**Figure 4.8** The total solids contents of all treatments at the initial and final stage in composting process.

The average total solids at each composting time are showed in Figure 4.9 and Table 4.5. The average total solids were slightly increasing at week 0 to week 4 and then they were continuously rapid increasing in week 4 to week 8. The average total solids of without PC treatments had rapidly increasing than the without PC treatments at week 4 to week 8. The maximum and minimum values of the average volatile solids in all treatments were found in week 0 and week 8.

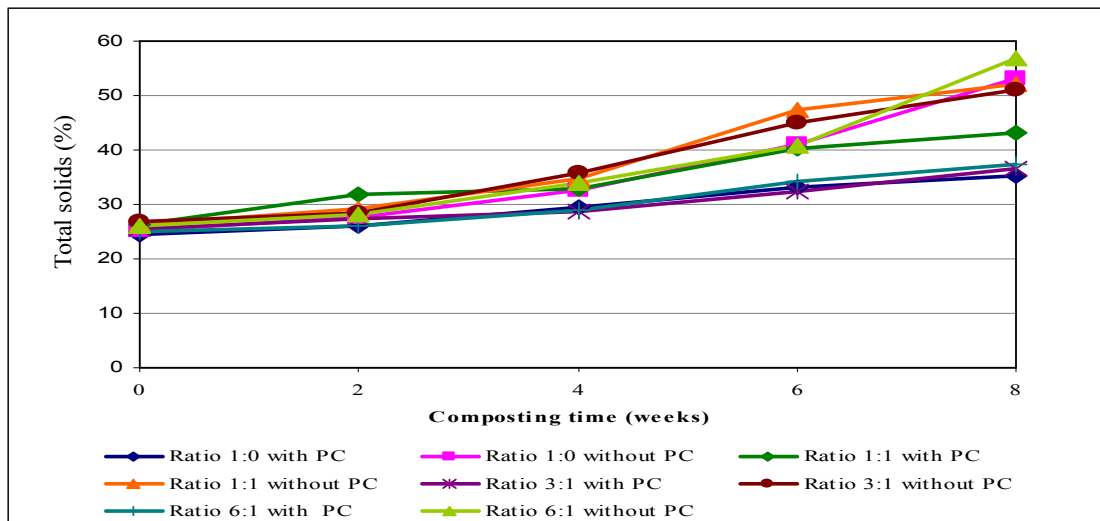


Figure 4.9 Change of average total solids at each composting process.

Table 4.5 The average total solids (%) of each experimental treatment in composting process.

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	24.57 (0.24)	26.05 (0.26)	29.53 (0.25)	33.04 (0.63)	35.33 (0.01)
	Without PC	25.19 (0.63)	27.56 (0.4)	32.57 (0.51)	40.96 (0.13)	53.21 (1.83)
1:1	With PC	26.42 (0.36)	31.72 (4.84)	32.83 (0.43)	40.23 (0.54)	43.07 (1.68)
	Without PC	26.23 (0.24)	29.31 (3.58)	34.74 (1.59)	47.4 (1.09)	52.11 (0.66)
3:1	With PC	25.57 (0.2)	27.38 (0.15)	28.56 (0.44)	32.45 (0.1)	36.64 (0.59)
	Without PC	26.74 (0.2)	28.31 (0.26)	35.86 (1.71)	45.12 (0.86)	51.05 (1.18)
6:1	With PC	25.01 (0.21)	26.16 (0.36)	28.84 (0.45)	34.26 (0.70)	37.26 (0.47)
	Without PC	26.13 (0.48)	28.20 (0.26)	33.93 (1.16)	40.68 (0.63)	56.73 (3.08)

Note: Values in parentheses are standard deviation (SD) of three replications, PC = plastic cover

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their triple interaction effect (mixing ratio, steam sterilization conditions, and composting time) of total solids.

The main effect of mixing ratio and composting time of all treatments were significantly different ( $P < 0.001$ ). The main effect of composting time of all treatments was significant different ( $P < 0.001$ ).

The interaction among mixing ratio, steam sterilization conditions, and composting time was significantly different ( $P = 0.001$ ) in within subject effect, the results of analytical statistics as show in Table 4.6

**Table 4.6** The analysis of variance of total solids.

Source	SS	Df	MS	F	p-value
<b>Between - subject effects</b>					
Intercept	140133.905	1	140133.905	6.108E4	<0.001
Steam sterilization	217.304	3	72.435	31.573	<0.001
Mixing ratio	1027.611	1	1027.611	447.914	<0.001
Steam sterilization *Mixing ratio	80.176	3	26.725	11.649	<0.001
Error	36.707	16	2.294		
<b>Within-subject effects</b>					
Composting time	6502.248	1.906	3410.767	1.068E3	<0.001
Composting time * Steam sterilization	913.132	1.906	478.985	149.926	<0.001
Composting time * Mixing ratio	107.943	5.719	18.874	5.908	<0.001
Composting time * Steam sterilization * Mixing ratio	96.588	5.719	16.888	5.286	0.001
Error	97.449	30.502	3.195		

- When interactions exist among the three factor, F-test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilization conditions (with PC / without PC treatment) at each time period. To test the difference between groups Bonferroni adjustment was used to compare.

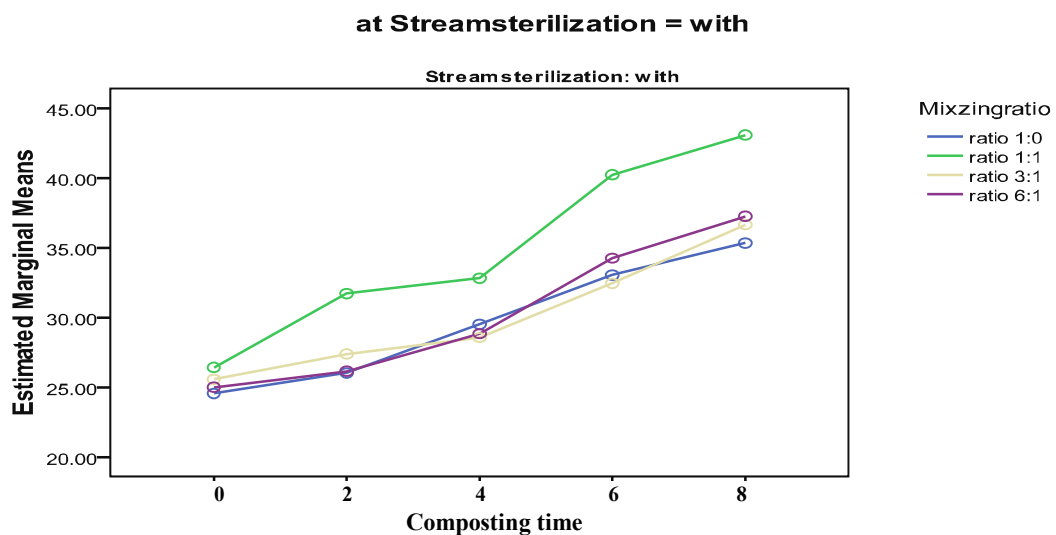
- With PC treatment, total solids were found significant difference in 4 periods, except at week 2 as shown in Figure 4.10.

At week 0, the total solids of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1. And mixing ratio 1:1 was significantly different from mixing ratio 3:1, 6:1.

At week 4, the total solids of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.

At week 6, the total solids of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1. And mixing ratio 6:1 was significantly different from mixing ratio 3:1.

At week 8, the total solids mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1, and 6:1.



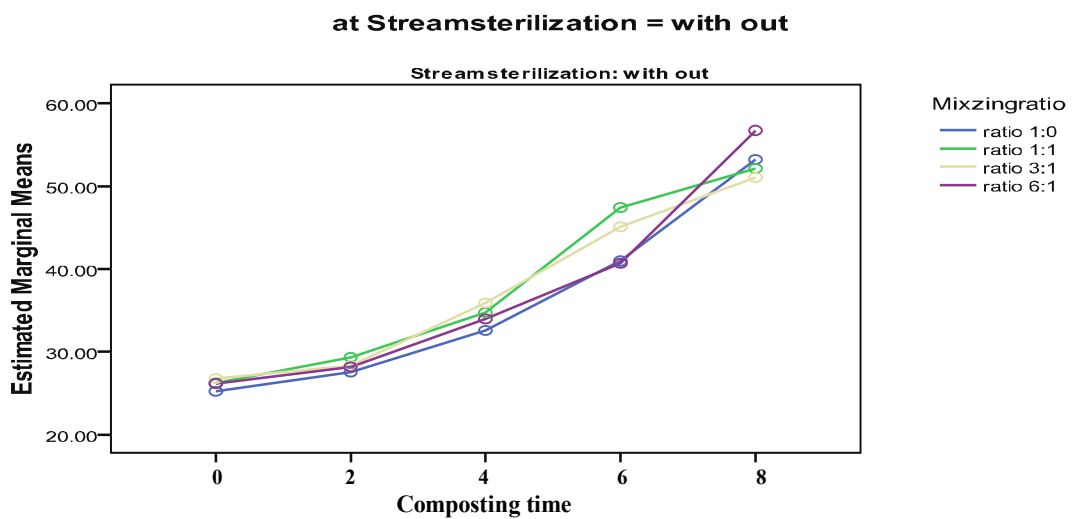
**Figure 4.10** The average total solids of with PC treatments.

- With out PC treatment, total solids were found significant difference in week 0, 6 and 8 of composting time as show in Figure 4.11.

At week 0, the total solids of mixing ratio 1:0 was significantly different from mixing ratio 3:1.

At week 6, the total solids of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 1:0 and 6:1.

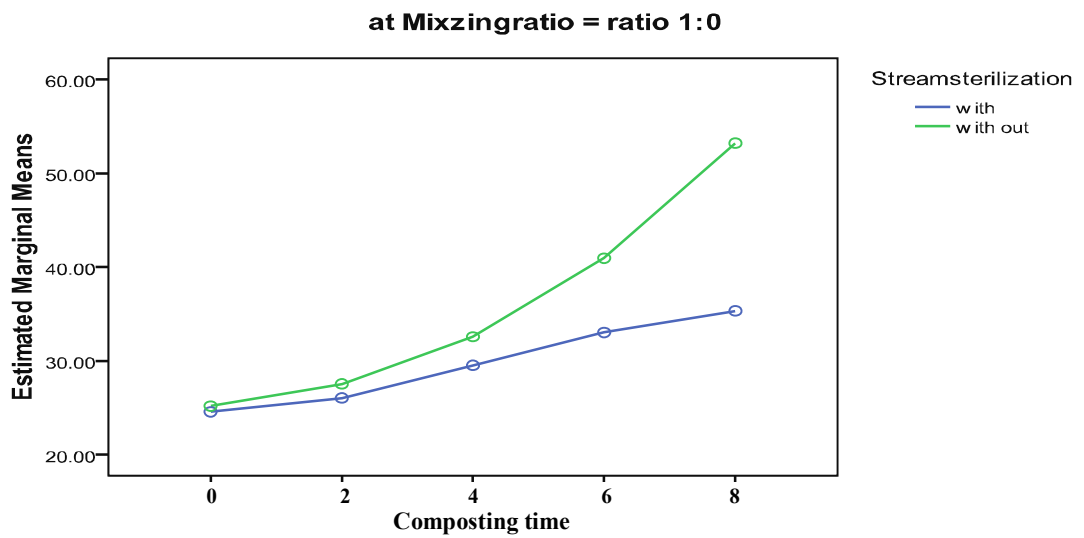
At week 8, the total solids of mixing ratio 3:1 was significantly different from mixing ratio 6:1.



**Figure 4.11** The average total solids of without PC treatments.

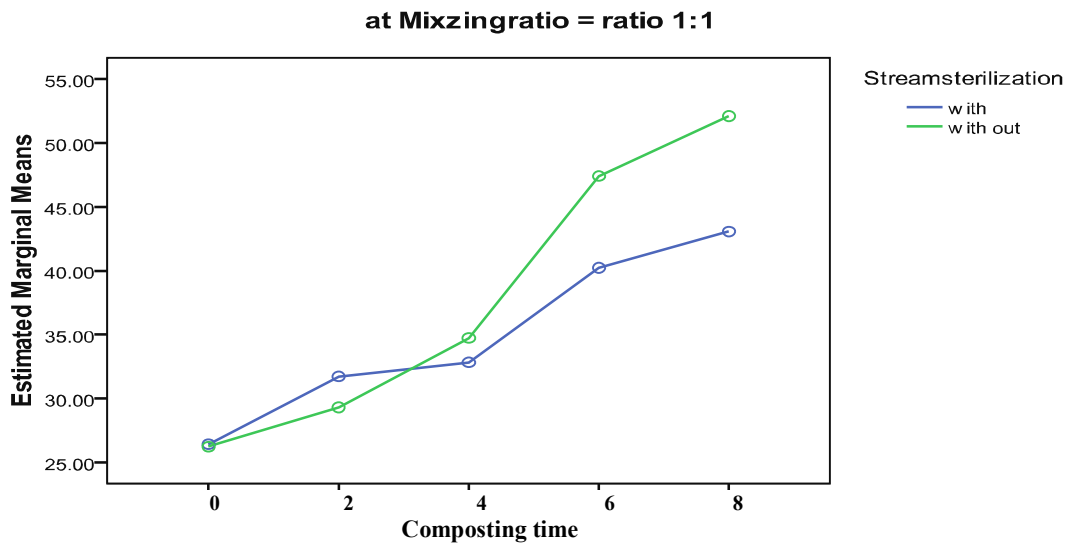
- To test the simple main effect of steam sterilization condition classified by each level of mixing ratio at each level of time period. For testing of difference Bonferroni adjustment was used to compare.

For mixing ratio 1:0, total solids were found significant in 4 periods, except 0 week. At week 2, 4, 6 and 8, the total solids of with PC treatment was significantly different from without PC treatment as show in Figure 4.12.



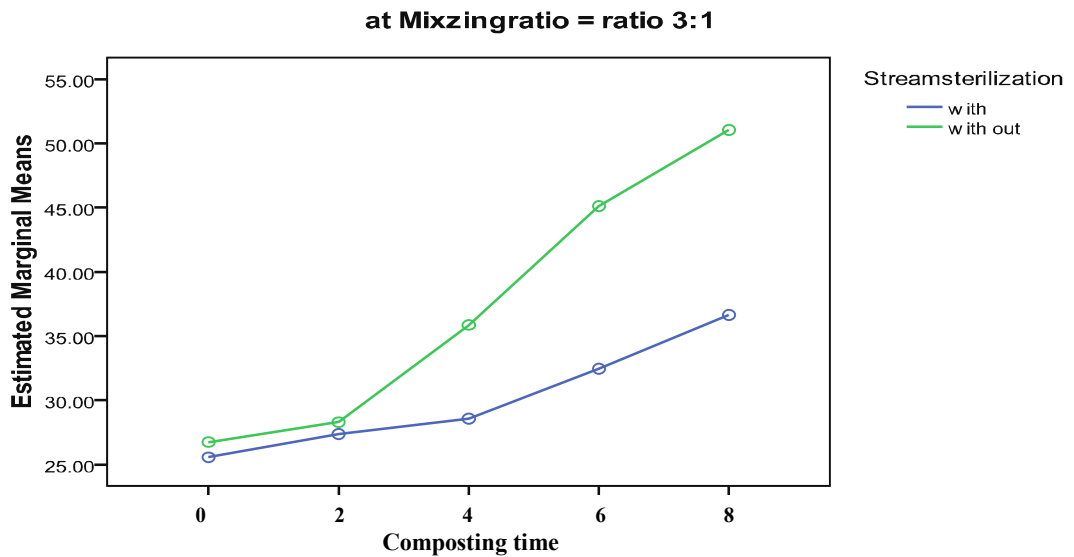
**Figure 4.12** The average total solids of mixing ratio 1:0 in with PC and without PC treatments.

For mixing ratio 1:1, total solids were found significant at week 6 and week 8 of composting time. At week 6 and 8, total solids of with PC treatment was significantly different from without PC treatment as show in Figure 4.13.



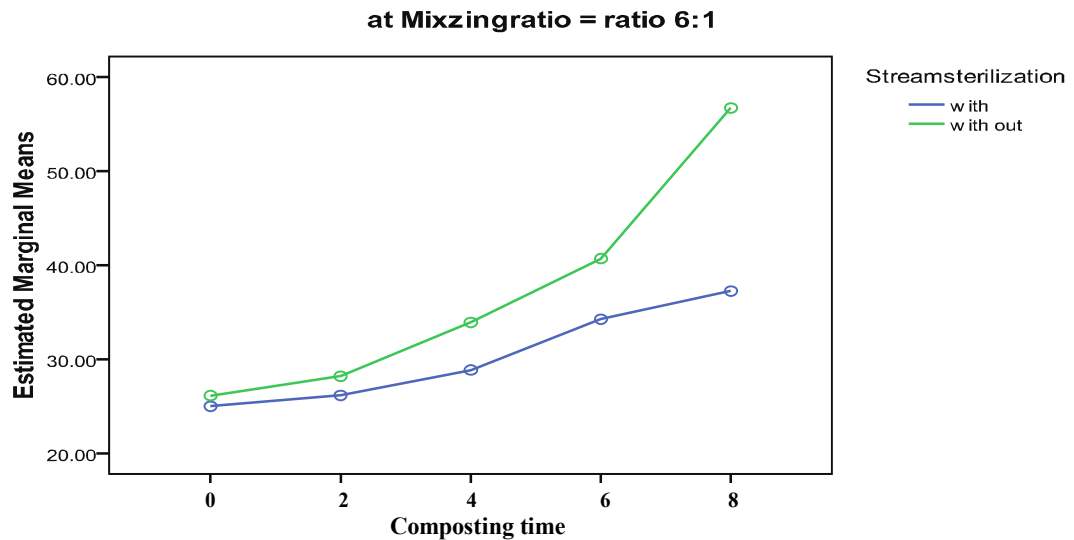
**Figure 4.13** The average total solids of mixing ratio 1:1 in with PC and without PC treatments.

For mixing ratio 3:1, total solids were found significant at all periods of composting time. The total solids at all periods time of with PC treatment was significantly different from without PC treatment as show in Figure 4.14.



**Figure 4.14** The average total solids of mixing ratio 3:1 in with PC and without PC treatments.

For mixing ratio 6:1, total solids were found significant at all periods of composting time. The total solids content at all periods time of with PC treatment was significantly different from without PC treatment as show in Figure 4.15.



**Figure 4.15** The average total solids of mixing ratio 6:1 in with PC and without PC treatments.

- To test the simple main effect of composting time at each interaction level of steam sterilization conditions and mixing ratio. Then, to test difference between groups, Bonferroni adjustment was used to compare.

For 1:0 with PC treatment, the total solids at week 0 was significantly different from composting time at week 2, 4, 6, and 8. The total solids at week 2 was significantly different from week 4, 6, and 8. The total solids at week 4 was significantly different from composting time at week 6, 8. The total solids at week 6, was significantly different from composting time at week 8.

For 1:1 with PC treatment, the total solids at week 0 was significantly different from week 6 and 8. The total solids at week 2 was significantly different from week 6 and 8. The total solids at week 4 was significantly different from week 6 and 8.

For 3:1 with PC treatment, the total solids at week 0 was significantly different from week 2, 4, 6, and 8. The total solids at week 2 was significantly different from week 4, 6 and 8. The total solids at week 4 was significantly different from week 6, and 8. The total solids at week 6 was significantly different from week 8.

For 6:1 with PC treatment, the total solids content at week 0 was significantly different from week 4, 6 and 8. The total solids at week 2 was significantly different from week 4, 6 and 8. The total solids at week 4 was significantly different from week 6, and 8. The total solids at week 6 was significantly different from week 8.

For 1:0 without PC treatment, the total solids content at week 0 was significantly different from week 4, 6, and 8. The total solids at week 2 was significantly different from week 6 and 8. The total solids at week 4 was significantly different from week 6, and 8. The total solids at week 6 was significantly different from week 8.

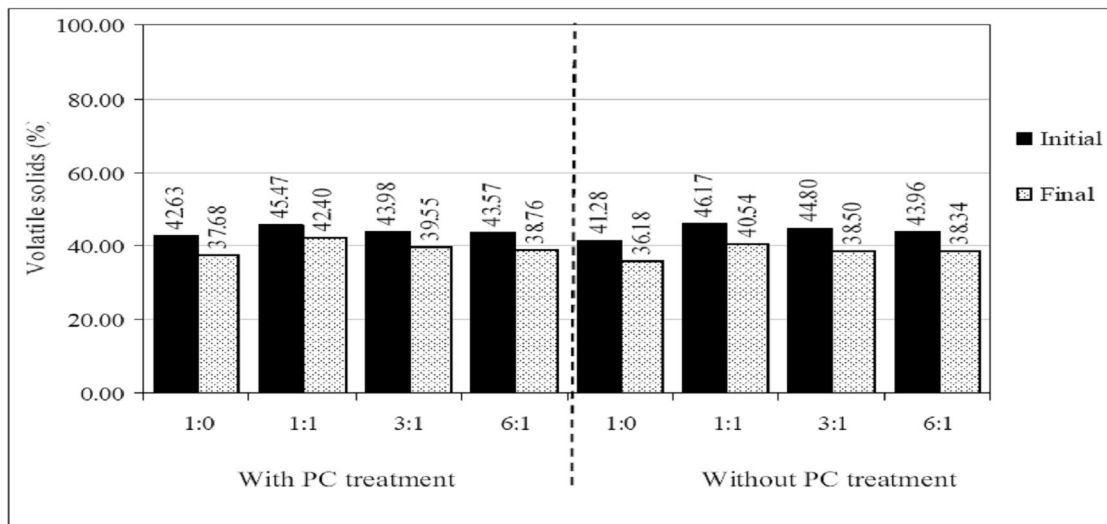
For 1:1 without PC treatment, the total solids at week 0 was significantly different from week 4, 6, and 8. The total solids at week 2 was significantly different from week 4, 6, 8. The total solids at week 4 was significantly different from week 6 and 8.

For 3:1 without PC treatment, the total solids at week 0 was significantly different from week 4, 6, and 8. The total solids at week 2 was significantly different from week 4, 6 and 8. The total solids at week 4 was significantly different from week 6 and 8. The total solids at week 6 was significantly different from week 8.

For 6:1 without PC treatment, the total solids at week 0 was significantly different from week 4, 6 and 8. The total solids at week 2 was significantly different from week 4, 6, and 8. The total solids at week 4 was significantly different from week 6 and 8. The total solids at week 6 was significantly different from week 8.

### 4.2.3 Volatile solids

The results of average volatile solids contents at the initial stage of all treatments were more than those volatile solids at the final stage of composting time. The change of volatile solid had a small value and all treatments had a similar trend. The average volatile solids at the initial and final stage are showed in Figure 4.16.



**Figure 4.16** The average volatile solids contents of all treatments at initial and final stage in composting process.

The volatile solids of all treatments at each composting time in composting process are showed in Figure 4.17 and Table 4.7 According to Figure 4.17, it showed that the average volatile solids of all treatments were slightly decreasing from week 0 to week 8. The maximum and minimum of the average volatile solids in all treatments were found at mixing ratio in week 0 and week 8 respectively. However, the volatile solids content in all treatments were not changed much according to the composting time.

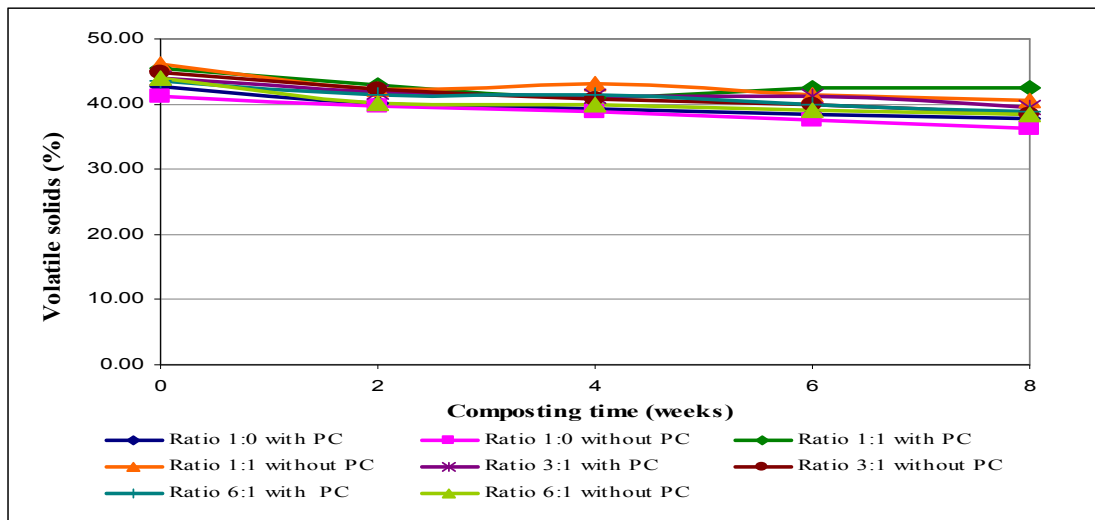


Figure 4.17 Change of volatile solids content at each composting time.

Table 4.7 Average amount of volatile solids (%) of each treatment in composting process.

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	42.63 (2.25)	40.19 (0.09)	39.37 (0.23)	38.43 (0.17)	37.68 (0.23)
	Without PC	41.28 (0.26)	39.65 (0.25)	38.81 (0.23)	37.51 (0.10)	36.18 (0.19)
1:1	With PC	45.47 (0.63)	42.96 (0.11)	40.89 (0.08)	42.41 (0.09)	42.40 (0.77)
	Without PC	46.17 (0.98)	42.28 (0.17)	43.05 (0.93)	41.34 (0.27)	40.54 (0.20)
3:1	With PC	43.98 (0.18)	41.84 (0.37)	41.31 (0.36)	41.29 (0.50)	39.55 (0.25)
	Without PC	44.80 (0.33)	42.22 (0.08)	40.69 (0.30)	39.90 (0.07)	38.50 (0.33)
6:1	With PC	43.57 (0.11)	41.36 (0.23)	41.45 (0.25)	39.93 (0.11)	38.76 (0.64)
	Without PC	43.96 (0.07)	40.14 (0.17)	40.0 (0.28)	38.96 (0.06)	38.34 (0.44)

Note: Values in parentheses are standard deviation (SD) of three replications, PC = plastic cover

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization conditions, and composting time) of volatile solids.

The main effect of mixing ratio of all treatments was significantly different ( $p < 0.001$ ). The main effect of steam sterilization conditions of all treatments was significantly different ( $p < 0.001$ ). The main effect of composting time of all treatments was significantly different ( $p\text{-value} = 0.011$ ).

The interaction among mixing ratio, steam sterilization conditions, and composting time were significantly different ( $P=0.001$ ) on within subject effect. It was also had an interaction between mixing ratios and steam sterilization conditions ( $P=0.036$ ). The results of analytical statistics are show in Table 4.8.

**Table 4.8** The analysis of variance of volatile solids.

Source	SS	Df	MS	F	p-value
<b>Between - subject effects</b>					
Intercept	201658.50	1	201658.50	721680.2	<0.001
Steam sterilization	200.992	3	66.997	239.765	<0.001
Mixing ratio	9.280	1	9.280	33.209	<0.001
Steam sterilization *Mixing ratio	3.029	3	1.010	3.613	0.036
Error	4.471	16	0.279		
<b>Within-subject effects</b>					
Composting time	340.193	1.645	206.853	340.456	<0.001
Composting time * Steam sterilization	8.293	1.645	5.042	8.299	<0.001
Composting time * Mixing ratio	11.349	4.934	2.300	3.786	<0.001
Composting time * Steam sterilization * Mixing ratio	16.589	4.934	3.362	5.534	0.001
Error	15.988	26.31	0.608		

- When interactions exist among the three factor, F-test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilization conditions (with PC / without PC treatment) at each time period. To test the difference between groups Bonferroni adjustment was used to compare.

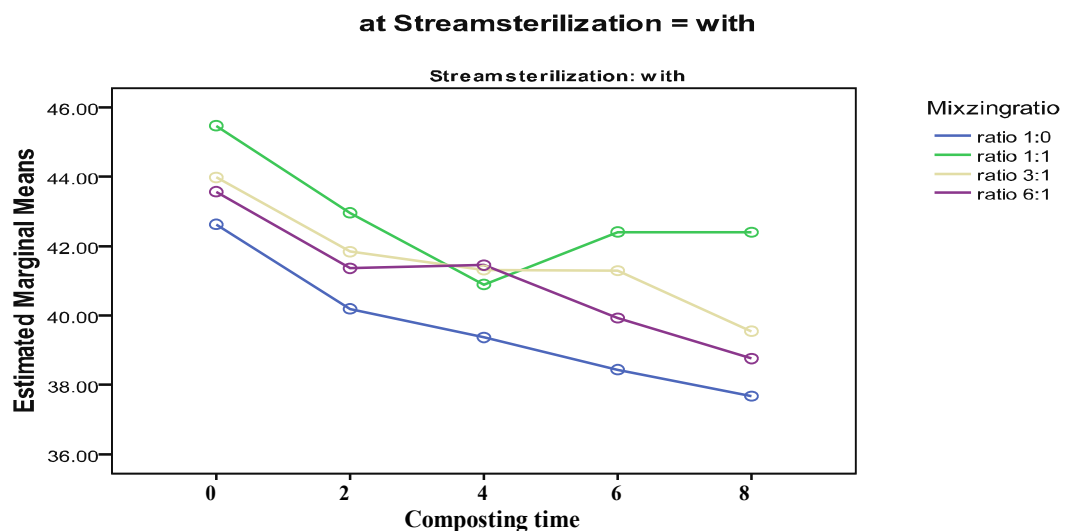
- With PC treatment, volatile solids were found significant difference in week 2, 4, 6, and 8 of composting time as shown in Figure 4.18.

At week 2, volatile solids contents of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1, 6:1. And mixing ratio 1:1 was significantly different from mixing ratio 3:1, and 6:1.

At week 4, the volatile solids of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1.

At week 6, the volatile solids of mixing ratio 1:1 was significantly different from mixing ratio 1:0 and 6:1.

At week 8, the volatile solids of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1. The mixing ratio 1:1 was significantly different from mixing ratio 3:1 and 6:1. And mixing ratio 6:1 was significantly different from mixing ratio 3:1.



**Figure 4.18** The average volatile solids of with PC treatments.

- With out PC treatment were found significant difference in all periods of composting time as show in Figure 4.19.

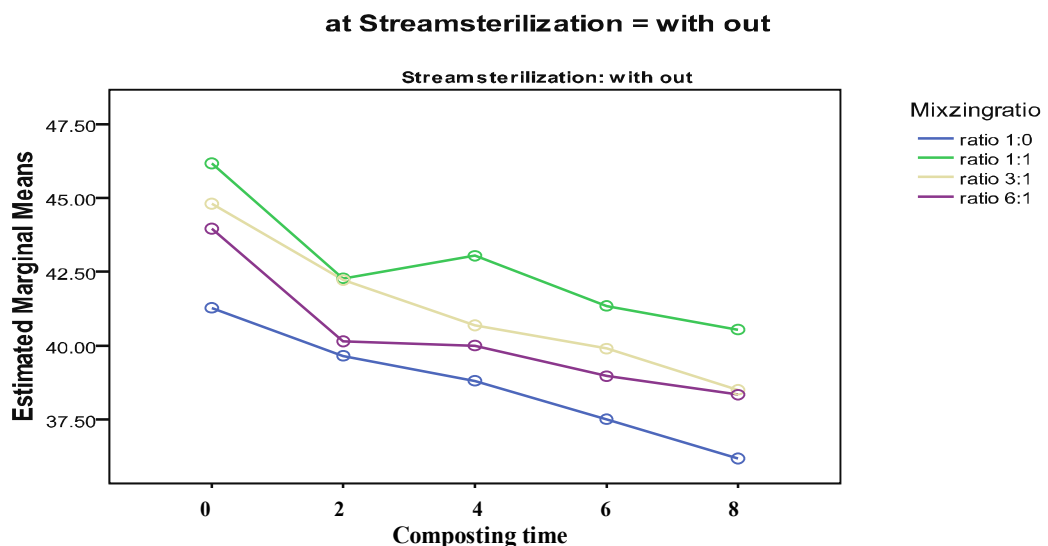
At week 0, volatile solids contents of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1, 6:1. And mixing ratio 1:1 was significantly different from mixing ratio 6:1.

At week 2, the volatile solids of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1. And mixing ratio 6:1 was significantly different from mixing ratio 1:1, 3:1.

At week 4, the volatile solids of mixing ratio 1:0 was significantly different from mixing ratio 1: 1 and 3:1. And mixing ratio 1:1 was significantly different from mixing ratio 3:1, 6:1.

At week 6, the volatile solids of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1. And mixing ratio 1:1 was significantly different from mixing ratio 3:1, 6:1.

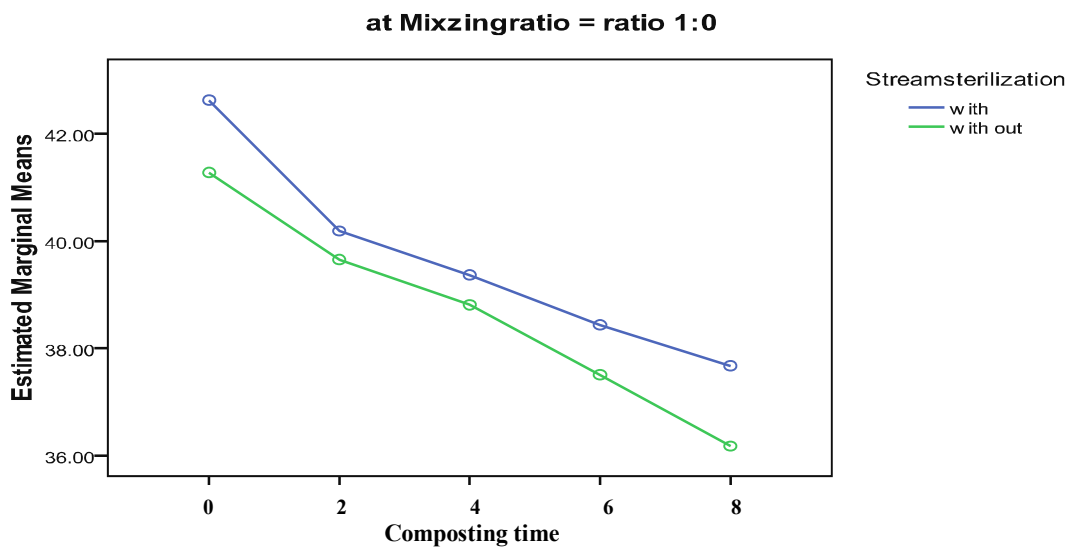
At week 8, the volatile solids of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1. The mixing ratio 1:1 was significantly different from mixing ratio 3:1, 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 1:1, 6:1.



**Figure 4.19** The average volatile solids of without PC treatments.

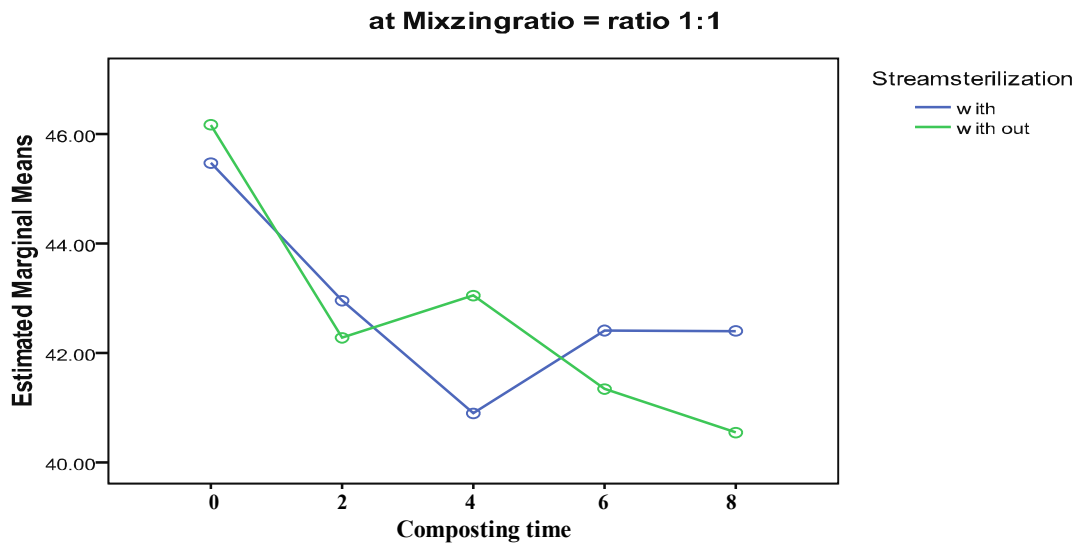
- To test the simple main effect of steam sterilization condition classified by each level of mixing ratio at each level of time period. For testing of difference Bonferroni adjustment was used to compare.

For mixing ratio 1:0 at week 2, 4, 6 and 8, the volatile solids content of with PC treatment was significantly different from without PC treatment as show in Figure 4.20.



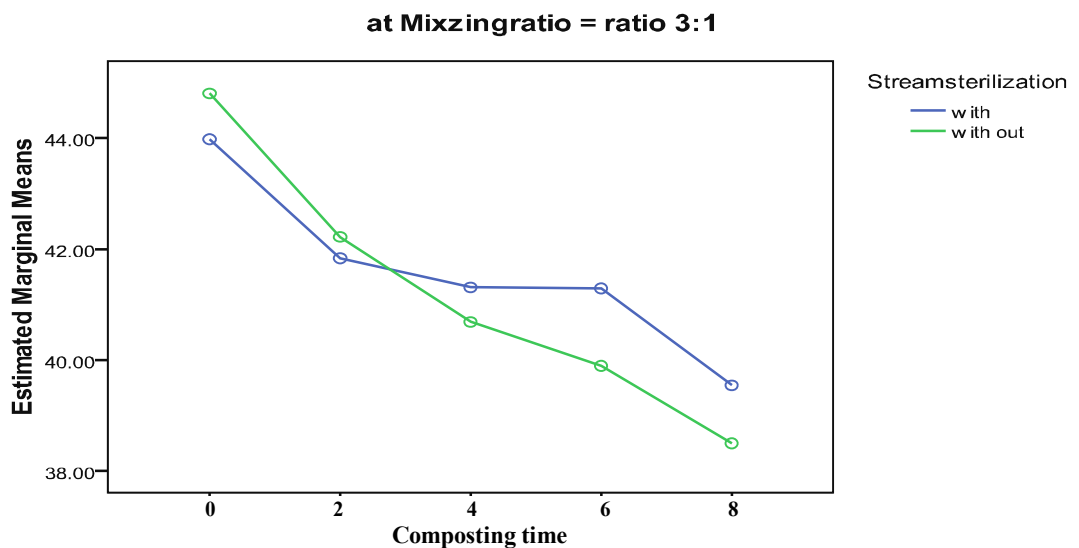
**Figure 4.20** The average volatile solids of mixing ratio 1:0 in with PC and without PC treatments.

For mixing ratio 1:1, volatile solids were found significant different at week 2, 4, 6, and 8. The volatile solids content of with PC treatment was significantly different from without PC treatment as showed in Figure 4.21



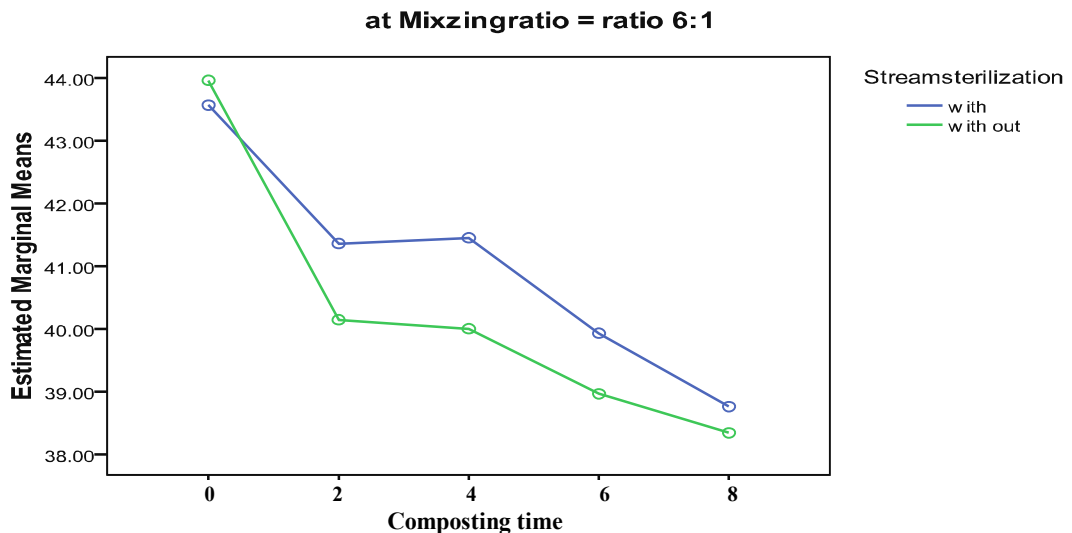
**Figure 4.21** The average volatile solids of mixing ratio 1:1 in with PC and without PC treatments.

For mixing ratio 3:1, the volatile solids were found significant different in 3 period, except week 2, and week 4. At week 0, the 6, 8 volatile solids contents of with PC treatment was significantly different from without PC treatment as shown in Figure 4.22.



**Figure 4.22** The average volatile solids of mixing ratio 3:1 in with PC and without PC treatments.

For mixing ratio 6:1, volatile solids were found significant different in 3 period, except week 2, and week 4. At week 0, the 6, 8 volatile solids contents of with PC treatment was significantly different from without PC treatment as shoe in Figure 4.23.



**Figure 4.23** The average volatile solids of mixing ratio 6:1 in with PC and without PC treatments.

- To test the simple main effect of composting time at each interaction level of steam sterilization conditions and mixing ratio. Then, to test difference between groups, Bonferroni adjustment was used to compare.

For 1:0 with PC treatment, the volatile solid at week 0 was significantly different from composting time at week 4, 6, and 8.

For 1:1 with PC treatment, the volatile solid at week 0 was significantly different from week 2, 4, 6, and 8. The volatile solids at week 4 was significantly different from week 2, 6 and 8.

For 3:1 with PC treatment, the volatile solid at week 0 was significantly different from week 2, 4, 6, and 8. The volatile solids at week 8 was significantly different from week 2, 4, and 6.

For 6:1 with PC treatment, the volatile solid at week 0 was significantly different from week 2, 4, 6, and 8. The volatile solids at week 2 was significantly different from week 6 and 8. The volatile solids at week 4 was significantly different from week 6, and 8. The volatile solids at week 6 was significantly different from week 8.

For 1:0 without PC treatment, the volatile solid at week 0 was significantly different from week 2, 4, 6, and 8. The volatile solids at week 2 was significantly different from week 6 and 8. The volatile solids at week 4 was significantly different from week 6, and 8. The volatile solids at week 6 was significantly different from week 8.

For 1:1 without PC treatment, the volatile solid at week 0 was significantly different from week 2, 4, 6, and 8. The volatile solids at week 2 was significantly different from week 8. The value at week 4 was significantly different from week 8.

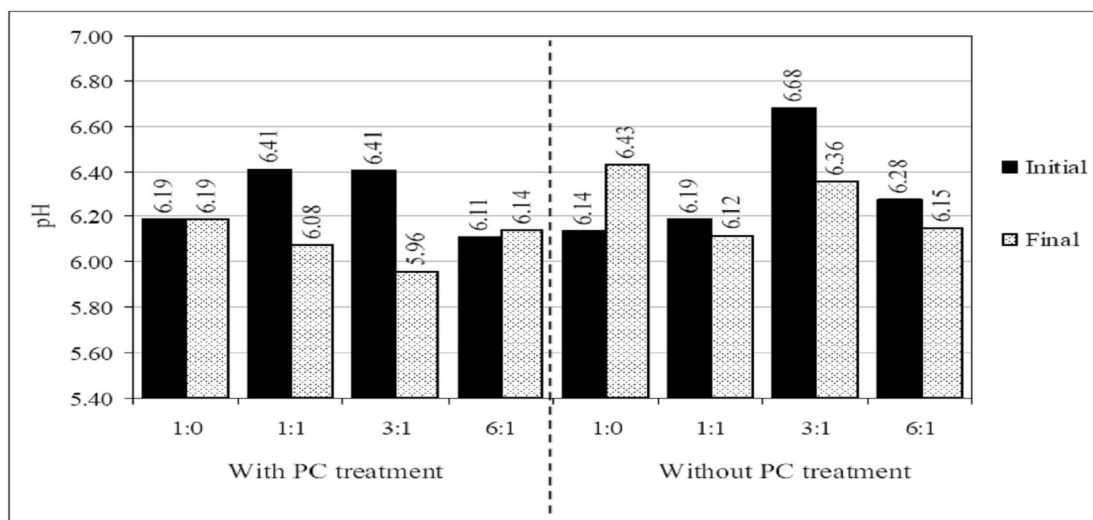
For 3:1 without PC treatment, the volatile solid at week 0 was significantly different from week 2, 4, 6, and 8. The value at week 4 was significantly different from week 6 and 8. The value at week 8 was significantly different from week 2, 4, and 6.

For 6:1 without PC treatment, the volatile solid at week 0 was significantly different from week 2, 4, 6, and 8. The value at week 2 was significantly different from week 6 and week 8. The value at week 4 was significantly different from week 6 and 8.

### 4.3 Change of sewage sludge mixed with grass clippings chemical characteristics in composting process.

#### 4.3.1 pH

The changes of pH at the initial and final stage are showed in Figure 4.24. The pH was change to a bit acid condition when compared values between initial stage and final stage of composting time. The pH range of treatment with PC at initial stage was slightly acid condition (pH 5.96 – 6.19) than that of the treatment without PC (pH 6.12-6.36). And final stage, the treatment with PC had pH 5.99-6.19 while the treatment without PC had pH 6.12-6.43. Moreover, the treatment 3:1 with PC had more change of pH value than the other treatments.



**Figure 4.24** The average pH values of all treatments at the initial and final stage in composting process.

The trends of pH of all treatments at each composting time are showed in Figure 4.25 and Table 4.9. At week 0 to week 2, pH values were near 7 and they were slowly decreasing until week 4. After that they had an upward trend to increasing at week 6 to week 8. The maximum of the average pH were found in 3:1 without PC treatment at week 0 (6.68). The minimum values were found in 3:1 with PC treatment at week 4 (5.24).

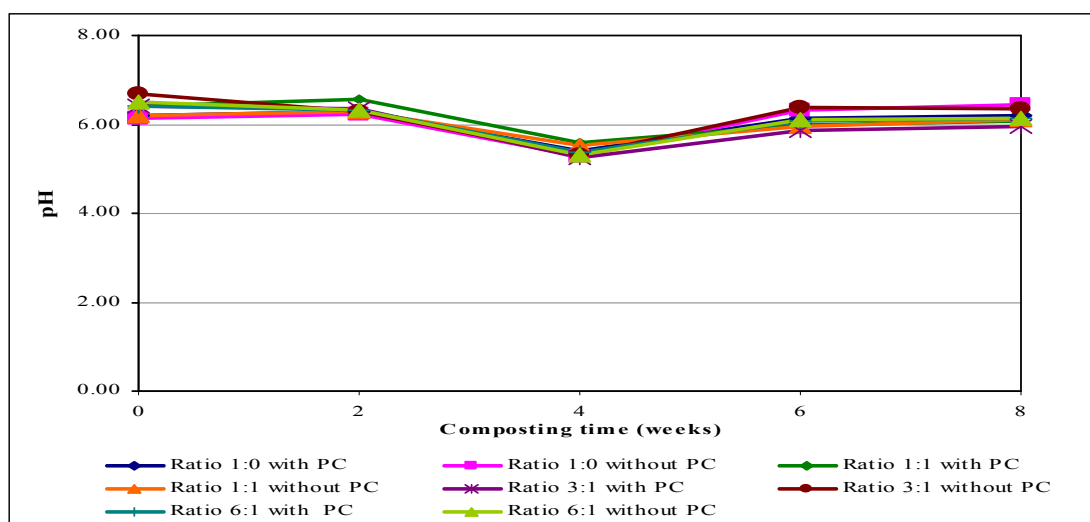


Figure 4.25 Change of pH at each composting time.

Table 4.9 The average amount of pH value change of each experimental treatment in composting process.

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
		1:0	With PC	6.19 (0.02)	6.28 (0.01)	5.39 (0.01)
	Without PC	6.14 (0.01)	6.24 (0.01)	5.29 (0.01)	6.32 (0.01)	6.43 (0.01)
1:1	With PC	6.41 (0.02)	6.56 (0.01)	5.59 (0.02)	5.98 (0.01)	6.08 (0.02)
	Without PC	6.19 (0.01)	6.30 (0.00)	5.52 (0.01)	5.95 (0.01)	6.12 (0.01)
3:1	With PC	6.14 (0.01)	6.35 (0.00)	5.24 (0.02)	5.87 (0.01)	5.96 (0.01)
	Without PC	6.68 (0.02)	6.29 (0.01)	5.32 (0.02)	6.40 (0.01)	6.36 (0.01)
6:1	With PC	6.11 (0.02)	6.33 (0.01)	5.28 (0.01)	6.09 (0.01)	6.01 (0.01)
	Without PC	6.28 (0.02)	6.32 (0.00)	5.25 (0.01)	6.02 (0.02)	6.16 (0.00)

Note: Values in parentheses are standard deviation (SD) of three replications

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their triple interaction effect (mixing ratio, steam sterilization conditions, and composting time) of pH value.

The main effect of mixing ratio of all treatments was significantly different ( $P < 0.001$ ). The main effect of steam sterilization conditions of all treatments was significantly different ( $P < 0.001$ ). The main effect of composting time of all treatments was significantly different ( $P < 0.001$ ).

The interaction among mixing ratio, steam sterilization conditions, and composting time were significantly different ( $P < 0.001$ ) on within subject effect. It was also had an interaction between mixing ratios and steam sterilization conditions ( $P < 0.001$ ). The results of analytical statistics are show in Table 4.10.

**Table 4.10** The analysis of variance of pH.

Source	SS	df	MS	F	p-value
<b>Between-Subjects Effects</b>					
Intercept	4392.421	1	4392.421	4.467E+07	<0.001
Mixing ratio	0.094	1	0.094	951.059	<0.001
Steam sterilization	0.183	3	0.061	619.715	<0.001
Mixing ratio * steam sterilization	0.465	3	0.155	1577.048	<0.001
Error	0.002	16	0.000		
<b>Within-Subjects Effects</b>					
Composting times	0.382	4	3.792	26494.475	<0.001
composting times * mixing ratio	1.169	12	0.097	680.493	<0.001
composting times * steam sterilization	0.284	12	0.024	165.590	<0.001
composting times * mixing ratio * steam sterilization	0.009	64	0.000		
Error					

- When interactions exist among the three factor, F-test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilization conditions (with PC / without PC treatment) at each time period. To test the difference between groups Bonferroni adjustment was used to compare.

- With PC treatment, pH values were found significant difference in all periods, as show in Figure 4.26.

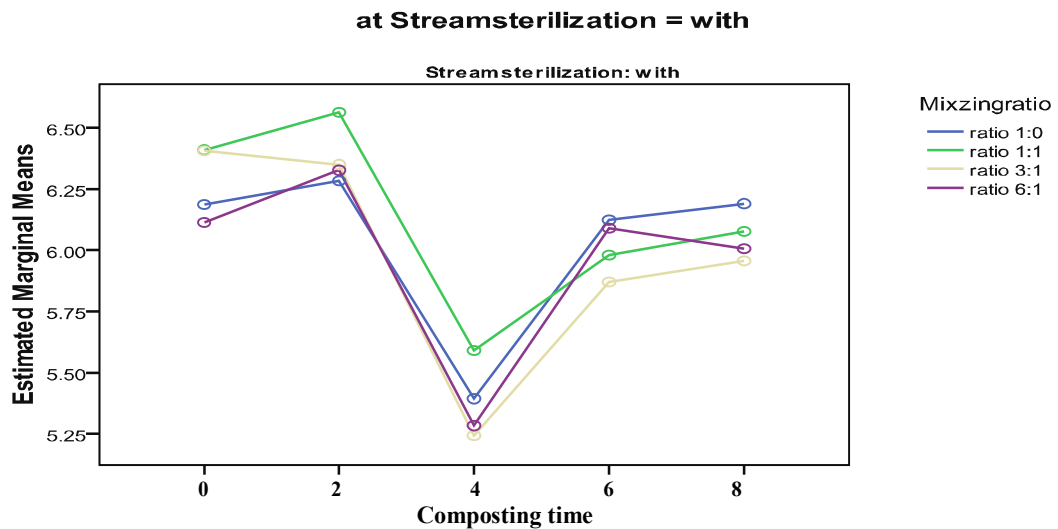
At week 0 pH of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1, and 6:1. The mixing ratio 1:1 was significantly different from mixing ratio 1:0 and 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 6:1.

At week 2, pH of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1. The mixing ratio 6:1 was significantly different from mixing ratio 1:1 and 3:1.

At week 4, the pH of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1, and 6:1. The mixing ratio 6:1 was significantly different from mixing ratio 1:1 and 3:1. And mixing ratio 1:1 was significantly different from mixing ratio 3:1.

At week 6, the pH of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1. The mixing ratio 1:1 was significantly different from mixing ratio 3:1 and 6:1. And mixing ratio 6:1 was significantly different from mixing ratio 3:1.

At week 8, the pH of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1. The mixing ratio 1:1 was significantly different from mixing ratio 3:1 and 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 6:1.



**Figure 4.26** The average pH values at each mixing ratio of with PC treatments.

- Without PC treatment, pH values were found significant difference in all periods.

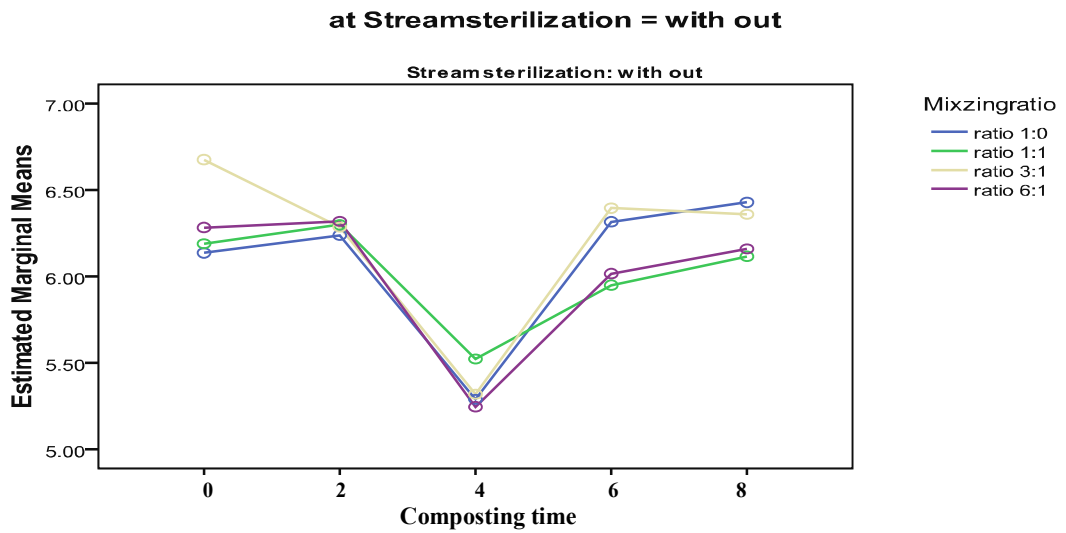
At week 0 pH value of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1, and 6:1. Mixing ratio 1:1 was significantly different from mixing ratio 3:1 and 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 6:1.

At week 2, pH value of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1, and 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 6:1.

At week 4, pH value of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1, and 6:1. Mixing ratio 1:1 was significantly different from mixing ratio 3:1 and 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 6:1.

At week 6, pH value of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1, and 6:1. Mixing ratio 1:1 was significantly different from mixing ratio 3:1 and 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 6:1.

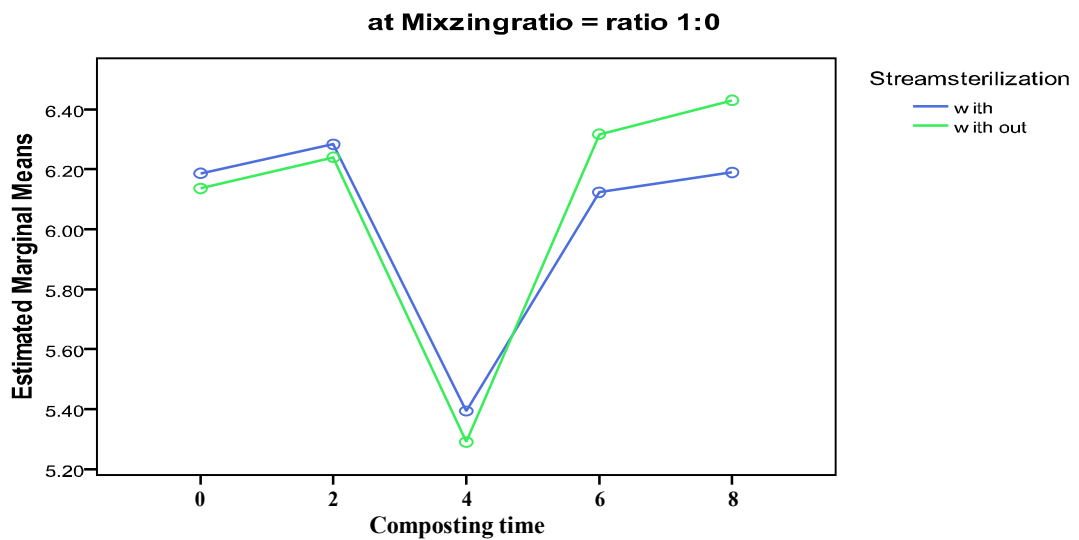
At week 8, the pH value of mixing ratio 1:0 was pH of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1, and 6:1. Mixing ratio 1:1 was significantly different from mixing ratio 3:1 and 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 6:1.



**Figure 4.27** The average pH values at each mixing ratio of without PC treatments.

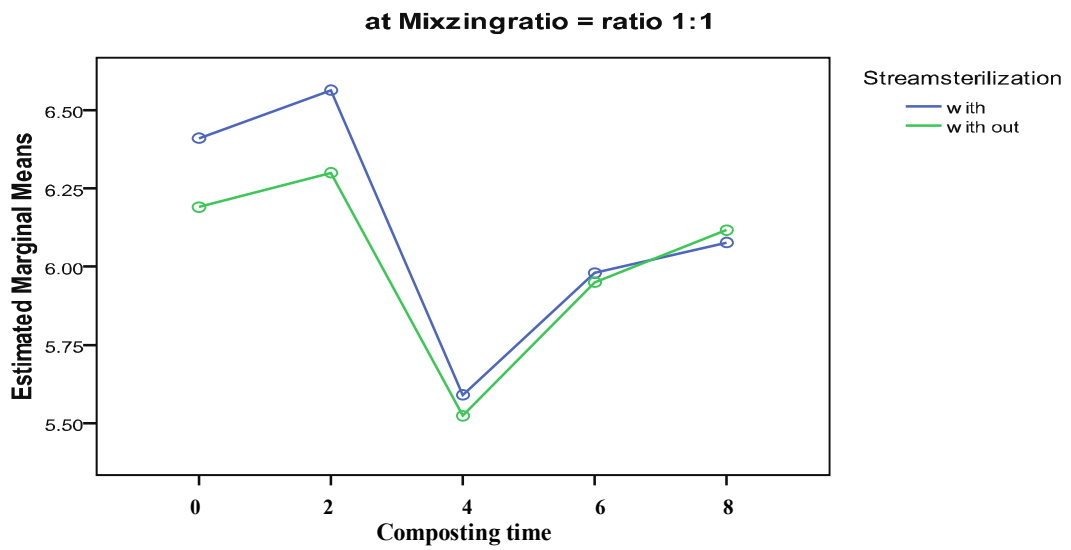
- To test the simple main effect of steam sterilization condition classified by each level of mixing ratio at each level of time period. For testing of difference Bonferroni adjustment was used to compare.

For mixing ratio 1:0, pH values were found significant difference in 5 periods. At week 0, 2, 4, 6, and 8 pH values of with PC treatment was significantly different from without treatment as show in Figure 4.28.



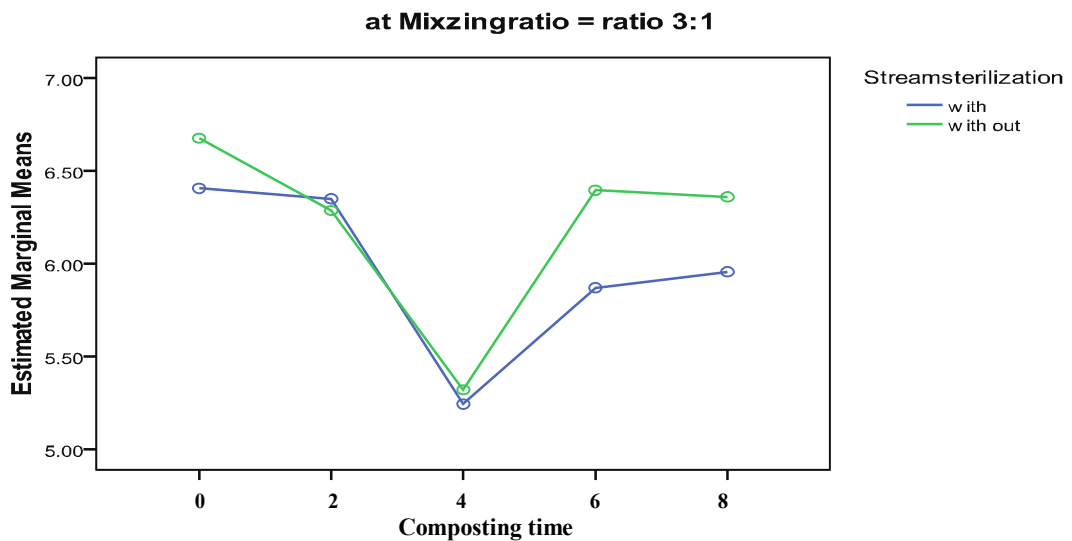
**Figure 4.28** The average pH values of mixing ratio 1:0 in with PC and without PC treatments

For mixing ratio 1:1, pH values were found significant difference in 5 periods. At week 0, 2, 4, 6, and 8, pH values of with PC treatment was significantly different from without PC treatment.



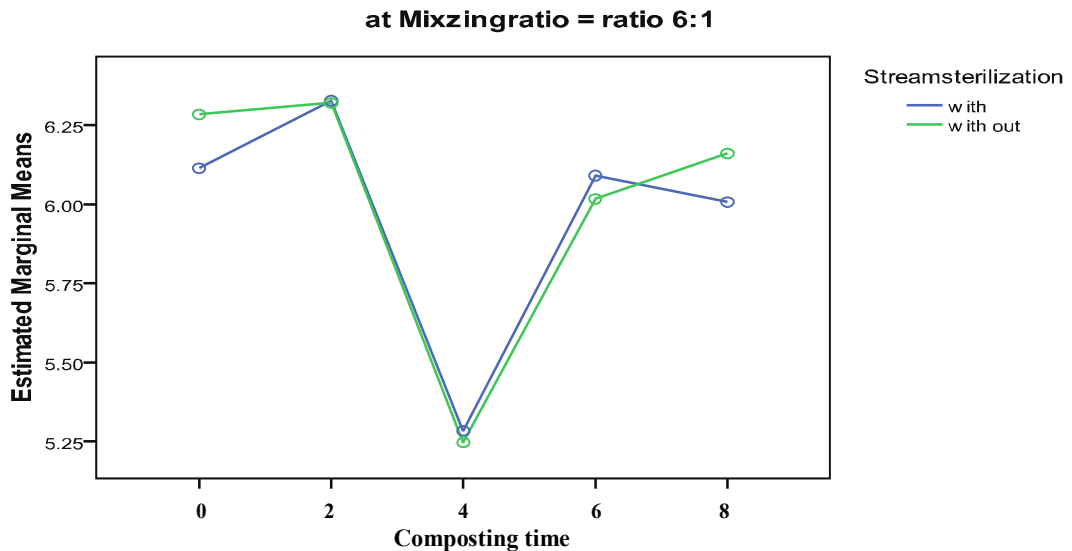
**Figure 4.29** The average pH values of mixing ratio 1:1 in with PC and without PC treatments.

For mixing ratio 3:1, pH values were found significant difference in 5 periods. At week 0, 2, 4, 6, and 8, pH values of with PC treatment was significantly different from without PC treatment as show on Figure 4.30.



**Figure 4.30** The average pH values of mixing ratio 3:1 in with PC and without PC treatments.

For mixing ratio 6: 1, pH were found significant difference in 4 periods, except week2. At week 0, 2, 4, 6, and 8, pH values of with PC treatment was significantly different from without PC treatment.



**Figure 4.31** The average pH values of mixing ratio 6:1 in with PC and without PC treatments.

- To test the simple main effect of composting time at each interaction level of steam sterilization conditions and mixing ratio. Then, to test difference between groups, Bonferroni adjustment was used to compare.

For 1:0 with PC treatment, the pH value at week 0 was significantly different from composting time at week 2, 4, and 6. The pH value at week 2 was significantly different from week 4, 6, and 8. The pH at week 4 was significantly different from composting time at week 6. The pH at week 6 was significantly different from composting time at week 8.

For 1:1 with PC treatment, the pH value at week 0 was significantly different from week 2, 4, 6, and 8. The pH at week 2 was significantly different from week 4, 6 and 8. The pH at week 4 was significantly different from week 6 and 8. The pH at week 6 was significantly different from week 8.

For 3:1 with PC treatment, the pH value at week 0 was significantly different from week 2, 4, 6, and 8. The pH at week 2 was significantly different from week 4, 6 and 8. The pH at week 4 was significantly different from week 6, and 8. The pH at week 6 was significantly different from week 8.

For 6:1 with PC treatment, the pH value at week 0 was significantly different from week 2, 4 and 8. The pH at week 2 was significantly different from week 4, 6 and 8. The pH at week 4 was significantly different from week 6, and 8. The pH at week 6 was significantly different from week 8.

For 1:0 without PC treatment, the pH value at week 0 was significantly different from week 2, 4, 6, and 8. The pH at week 2 was significantly different from week 4, 6 and 8. The pH at week 4 was significantly different from week 6, and 8. The pH at week 6 was significantly different from week 8.

For 1:1 without PC treatment, the pH value at week 0 was significantly different from week 2, 4, 6, and 8. The pH at week 2 was significantly different from week 4, 8. The pH at week 4 was significantly different from week 8.

For 3:1 without PC treatment, the pH value at week 0 was significantly different from week 2, 4, 6, and 8. The pH at week 2 was significantly different from week 4, 6 and 8. The pH at week 4 was significantly different from week 6 and 8. The pH at week 6 was significantly different from week 8.

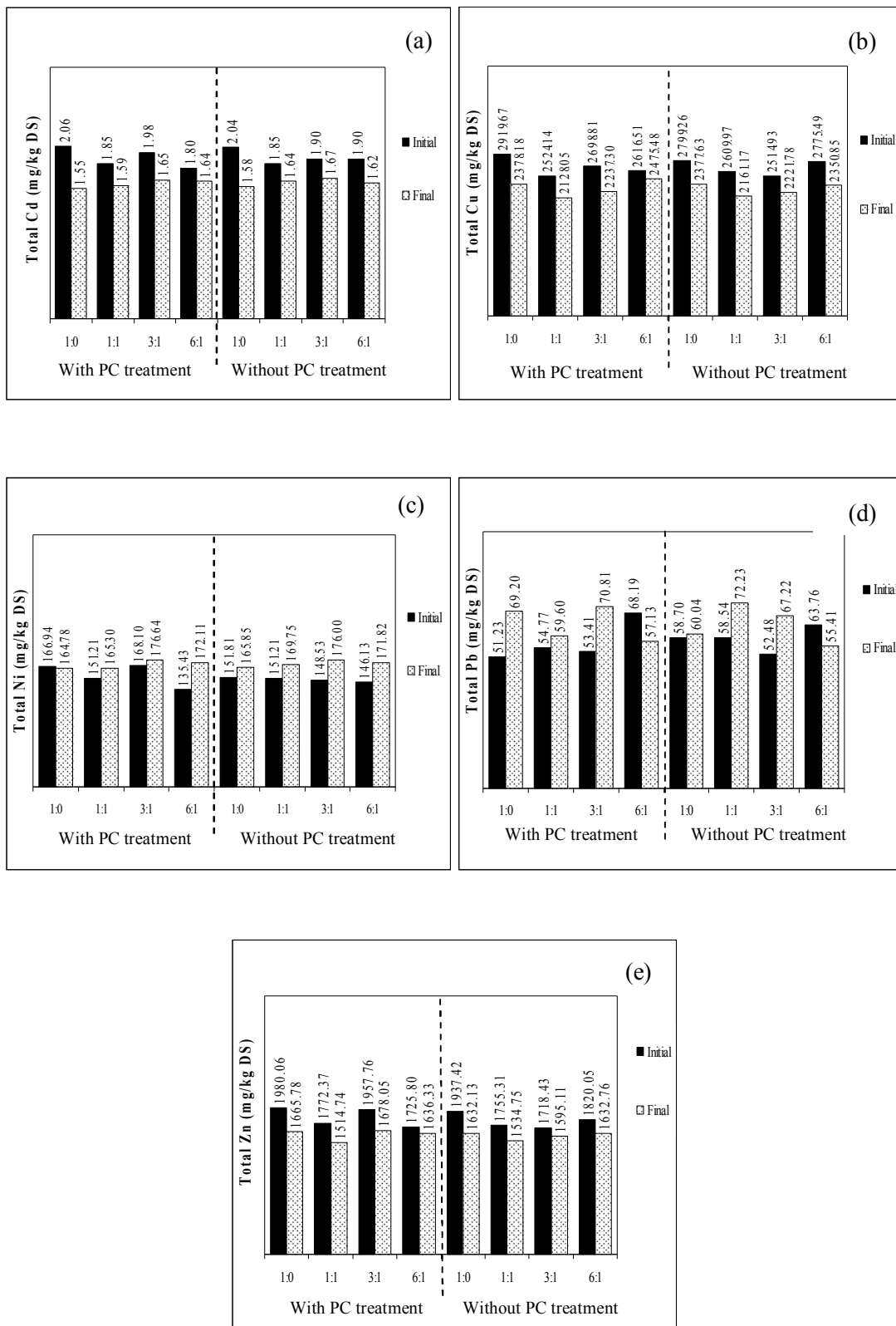
For 6:1 without PC treatment, the pH value at week 0 was significantly different from week 2, 4, 6, and 8. The pH at week 2 was significantly different from week 4, 6 and week 8. The pH at week 4 was significantly different from week 6 and 8.

### 4.3.2 Heavy metal concentrations

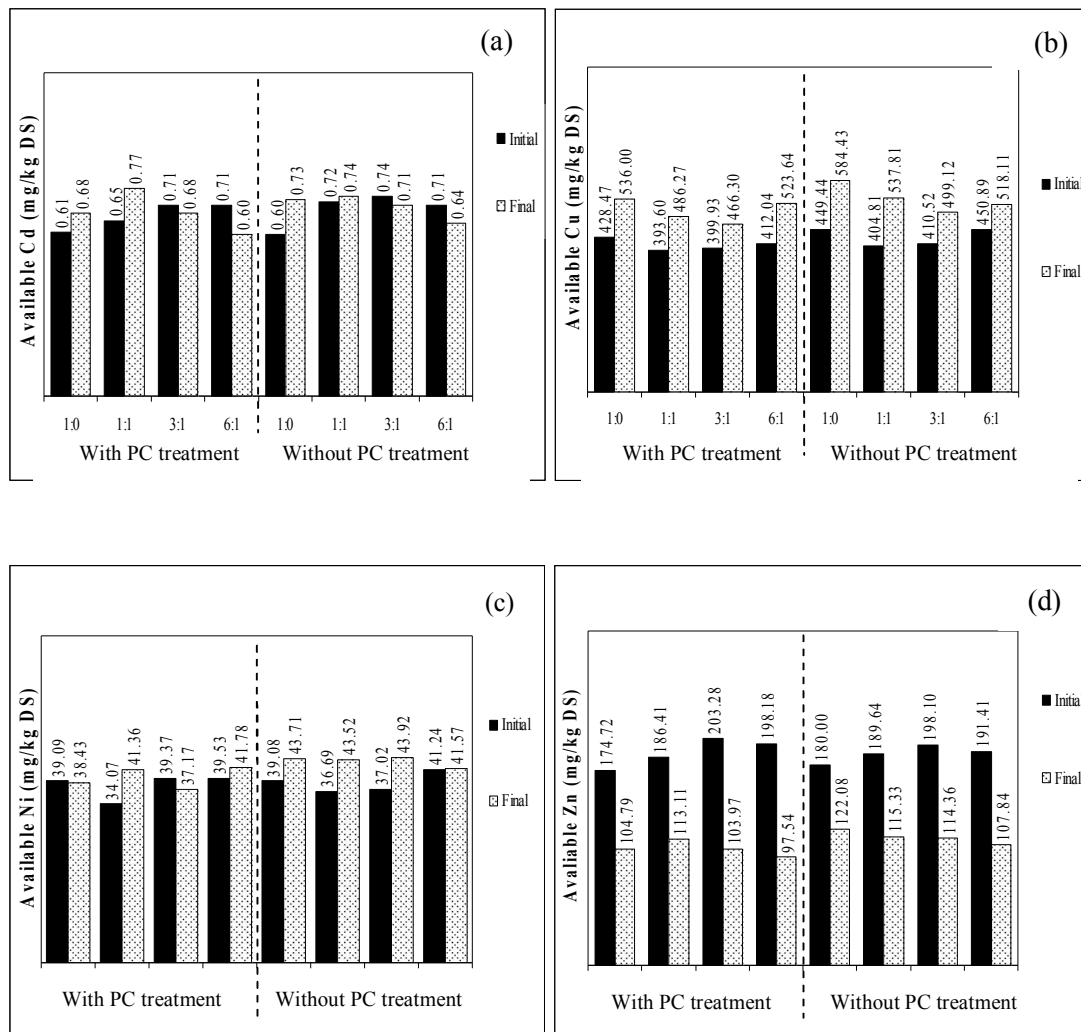
Figure 4.32 showed total heavy metal concentration at the initial and final stage in composting. The initial total Cd, Cu, and Zn concentration were higher than that of the final stage. On opposite, the initial total Ni concentration was rather lower than that of the final stage. And total Pb concentration had similar trend as total Ni except the treatment of mixing ratio 6:1 of both with and without PC. The total heavy metal concentration range at final stage were total cadmium 1.55-1.67 mg/kg DS, total copper 2161.71-2475.48 mg/kg DS, total zinc 1514.74 -1678.05 mg/kg DS, total nickel 164.78-176.64 mg/kg DS, and total lead 55.41-72.23 mg/kg DS.

Figure 4.33 show available heavy metal concentration at the initial and final stage in composting. The available Ni and Cd concentration had variable trend at initial stage. On the other hand, the available Cu and Zn had clearly trend. The initial available Cu concentrations were lower than that of the final stage while the initial available Zn concentrations were higher than the final Zn concentration. The available heavy metal concentration at final stage were available Cd 0.60-0.77 mg/kg DS, available Cu 466.30-584.43 mg/kg DS, available Zn 97.54-122.08 mg/kg DS, and available Ni 37.17- 43.92 mg/kg DS.

When comparing of the concentration of heavy metal in all treatments, it found that the total heavy metal were higher than the available form. In case of trace metal such Pb, it was found in only total form and absent in the available form. The change of studied heavy metals in each composting time is as below;



**Figure 4.32** Total heavy metal concentration at the initial and final stage in composting process; (a) total Cd, (b) total Cu, (c) total Ni, (d) total Pb, and (e) total Zn.

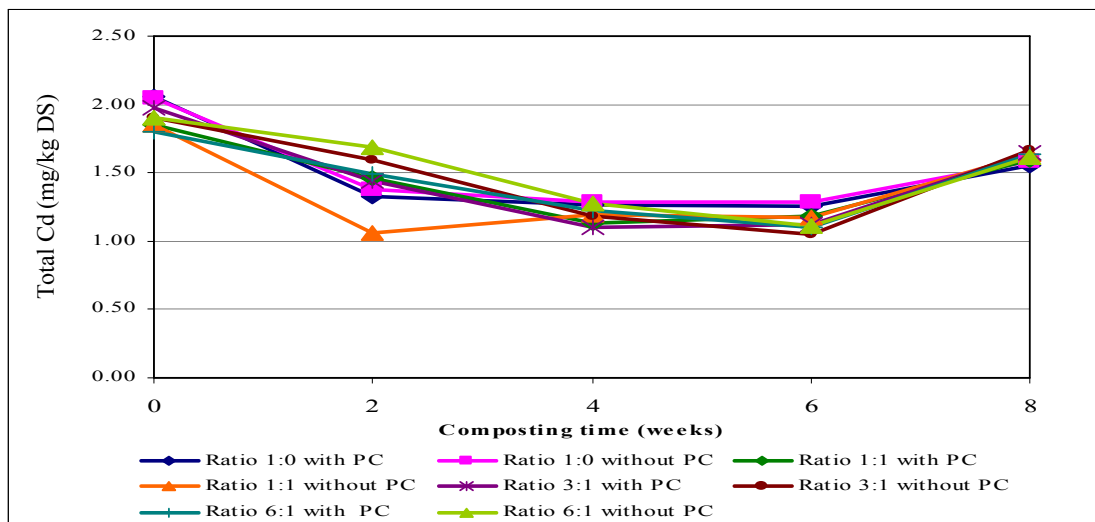


**Figure 4.33** Available heavy metal concentration at the initial and final stage in composting process; (a) available Cd, (b) available Cu, (c) available Ni, (d) available Zn.

### 4.3.2.1 Total cadmium

Total cadmium concentration change at each composting time are showed in Figure 4.34 and Table 4.11. According to Figure 4.34, it showed that total cadmium concentrations were continuously decreased in week 0 to week 4 and they were changed in small value at week 4 to week 6 and then they turned to slightly increasing in week 6 to week 8. However, total cadmium concentrations of all treatments increased at week 8 were not higher than that of the initial total cadmium concentrations.

The maximum of total cadmium in with PC treatments were found in 1:0 with PC treatment at week 0 (2.06 mg/kg DS) while the minimum were found in 3:1 with PC treatment at week 4 (1.10 mg/kg DS). The maximum of the averages total cadmium in without PC treatments were found in 1:0 without PC treatment at week 0 (2.04) while the minimum value were found in 3:1 without PC treatment at week 6 (1.05 mg/kg DS).



**Figure 4.34** Change of total cadmium concentration at each composting time.

**Table 4.11** The average of total cadmium concentrations (mg/kg DS) of each experimental treatment in composting process.

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	2.06 (0.13)	1.32 (0.13)	1.27 (0.04)	1.26 (0.07)	1.55 (0.04)
	Without PC	2.04 (0.08)	1.38 (0.25)	1.29 (0.03)	1.29 (0.07)	1.58 (0.08)
1:1	With PC	1.86 (0.11)	1.46 (0.12)	1.13 (0.05)	1.18 (0.08)	1.59 (0.05)
	Without PC	1.85 (0.06)	1.06 (0.02)	1.19 (0.09)	1.17 (0.03)	1.64 (0.10)
3:1	With PC	1.98 (0.12)	1.44 (0.12)	1.10 (0.06)	1.12 (0.05)	1.65 (0.05)
	Without PC	1.90 (0.08)	1.59 (0.05)	1.18 (0.01)	1.05 (0.02)	1.67 (0.06)
6:1	With PC	1.80 (0.06)	1.49 (0.23)	1.22 (0.04)	1.10 (0.10)	1.64 (0.14)
	Without PC	1.90 (0.04)	1.69 (0.21)	1.28 (0.09)	1.11 (0.10)	1.62 (0.06)

Note: Values in parentheses are standard deviation (SD) of three replications

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization conditions, and composting time) of total cadmium.

The main effect of mixing ratio of all treatments was not significantly different ( $P=0.448$ ). The main effect of steam sterilization conditions of all treatments was significantly different ( $P=0.034$ ). The main effect of composting time of all treatments was significantly different ( $P<0.001$ ).

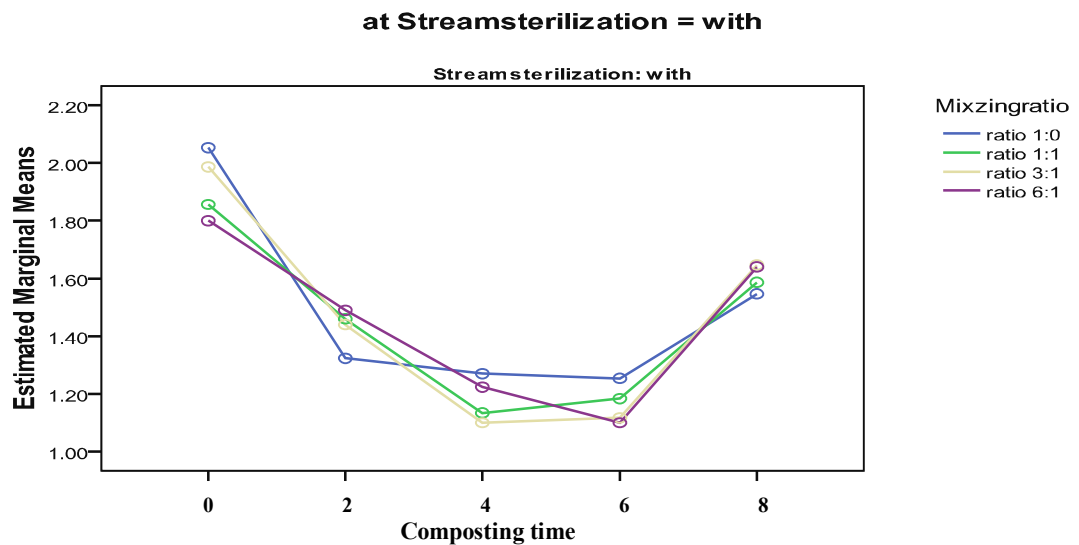
The interaction among mixing ratio, steam sterilization conditions, and composting time were significantly different ( $P=0.004$ ) on within subject effect. It was also had an interaction between composting time and mixing ratio ( $P<0.001$ ). The results of analytical statistics are show in Table 4.12

**Table 4.12** The analysis of variance of total cadmium.

Source	SS	Df	MS	F	p-value
<b>Between - subject effects</b>					
Intercept	258.574	1	258.574	23749.577	<0.001
Steam sterilization	0.121	3	0.040	3.707	0.034
Mixing ratio	0.007	1	0.007	0.606	0.448
Steam sterilization *Mixing ratio	0.058	3	0.019	1.776	0.192
Error	0.174	16	0.011		
<b>Within-subject effects</b>					
Composting time	9.496	4	2.374	249.750	<0.001
Composting time * Steam sterilization	0.015	4	0.004	0.383	0.820
Composting time * Mixing ratio	0.665	12	0.055	5.831	<0.001
Composting time * Steam sterilization * Mixing ratio	0.323	12	0.027	2.832	0.004
Error	0.608	64	0.010		

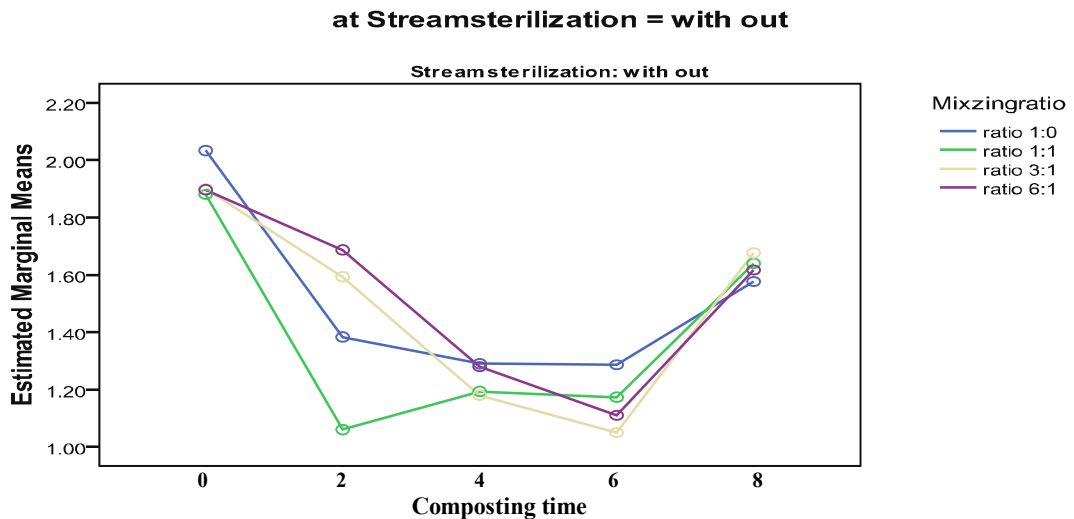
- When interactions exist among the three factor, F-test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilization conditions (with PC / without PC treatment)at each time period. To test the difference between groups Bonferroni adjustment was used to compare.

- With PC treatment, total cadmium were found significant difference only week 4. At week 4 total cadmium of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 3:1 as show in Figure 4.35.



**Figure 4.35** The average total cadmium at each mixing ratio of with PC treatments.

- Without PC treatment, total cadmium was found significant difference in week 2 and week 6. At week 2 total cadmium of mixing ratio 1:1 was significantly different from mixing ratio 3:1, 6:1. At week 6 total cadmium of mixing ratio 1:0 was significantly different from mixing ratio 3:1.



**Figure 4.36** The average total cadmium at each mixing ratio of without PC treatments.

- Because there were no significant differences of interaction of steam sterilization and mixing ratio. Mixing ratio 1:0, 1:1, 3:1, and 6:1, total cadmium were not significant different at all periods.

- To test the simple main effect of composting time at each interaction level of steam sterilization conditions and mixing ratio. Then, to test difference between groups, Bonferroni adjustment was used to compare.

For mixing 1:0 with PC treatment, the total cadmium at week 0 was significantly different from composting time at week 2, 4, 6 and 8. The total cadmium at week 8 was significantly different from week 4 and week 6.

For mixing 1:1 with PC treatment, the total cadmium at week 0 was significantly different from week 2, 4, 6, and 8. The total cadmium at week 2 was significantly different from week 4 and 6. At week 8, total cadmium was significantly different from week 4 and 6.

For mixing 3:1 with PC treatment, the total cadmium at week 0 was significantly different from week 2, 4, 6, and 8. The total cadmium at week 2 was significantly different from week 4 and 6. At week 8, total cadmium was significantly different from week 4, and 6.

For mixing 6:1 with PC treatment, the total cadmium at week 0 was significantly different from week 4 and 6. The total cadmium at week 2 was significantly different from week 6. At week 8, total cadmium was significantly different from week 4 and 6.

For mixing 1:0 without PC treatment, the total cadmium at week 0 was significantly different from week 2, 4, 6 and 8. The total cadmium at week 2 was significantly different from week 0.

For mixing 1:1 without PC treatment, the total cadmium at week 0 was significantly different from week 2, 4, 6, and 8. The total cadmium at week 8 was significantly different from week 2, 4, and 6.

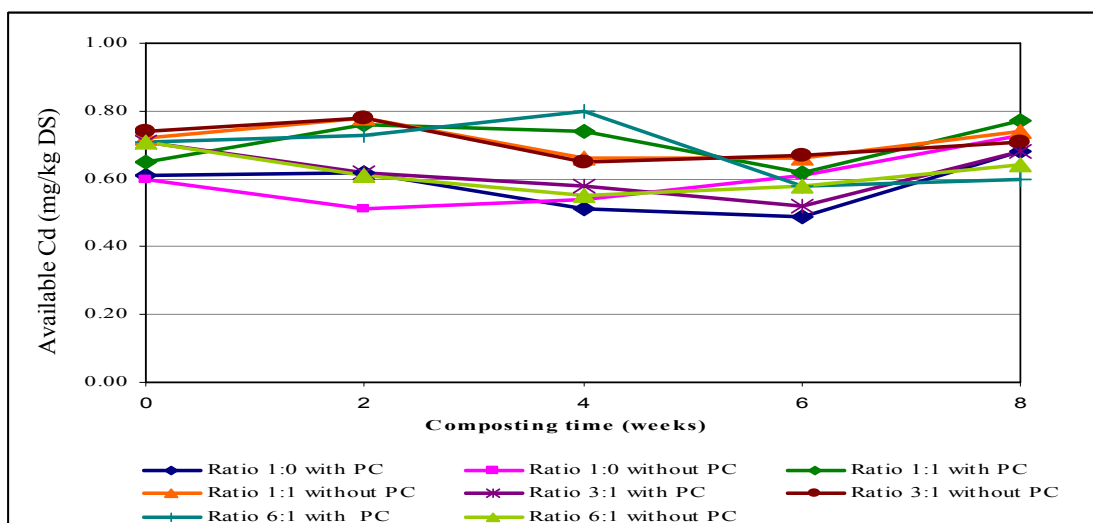
For mixing 3:1 without PC treatment, the total cadmium at week 0 was significantly different from week 2, 4, 6, and 8. The total cadmium at week 2 was significantly different from week 4 and 6. The total cadmium at week 8 was significantly different from week 4 and 6.

For mixing 6:1 without PC treatment, the total cadmium at week 0 was significantly different from week 0 and 4. The total cadmium at week 2 was significantly different from week 4 and 6. The total cadmium at week 8 was significantly different from week 6 and 4.

#### 4.3.2.2 Available cadmium

The available cadmium concentration of each composting time are showed in Figure 4.37 and Table 4.13. According to Figure 4.37, it showed that the available cadmium concentration all treatments had a slightly increasing trend during week 0 to week 2. At this period, the available cadmium concentration of with PC were decreased until week 6 and turned to increase in week 8 while the values in without PC were continuously increasing in week 4 to week 8.

The maximum and minimum of the averages available cadmium concentration in with PC treatments were found in 6:1 with PC treatment at week 4 (0.80 mg/kg DS), and 1:0 with PC treatment at week 4 (0.51 mg/kg DS) respectively. The maximum and minimum of the averages total solids in without PC treatments were found in 1:1 without PC treatment at week 0 (0.78 mg/kg DS), and 6:1 without PC treatment at week 4 (0.50 mg/kg DS) respectively.



**Figure 4.37** Change of available cadmium concentration of all treatments at each composting time.

**Table 4.13** The average available cadmium concentrations (mg/kg DS) of each experimental treatment in composting process.

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	0.61 (0.03)	0.62 (0.02)	0.51 (0.01)	0.49 (0.01)	0.68 (0.05)
	Without PC	0.60 (0.01)	0.51 (0.02)	0.54 (0.01)	0.61 (0.00)	0.73 (0.01)
1:1	With PC	0.65 (0.02)	0.76 (0.04)	0.74 (0.02)	0.62 (0.01)	0.77 (0.01)
	Without PC	0.72 (0.03)	0.78 (0.04)	0.66 (0.01)	0.66 (0.02)	0.74 (0.06)
3:1	With PC	0.71 (0.02)	0.62 (0.01)	0.58 (0.01)	0.52 (0.08)	0.68 (0.01)
	Without PC	0.74 (0.04)	0.78 (0.00)	0.65 (0.03)	0.67 (0.05)	0.71 (0.00)
6:1	With PC	0.71 (0.03)	0.73 (0.03)	0.80 (0.00)	0.58 (0.02)	0.60 (0.00)
	Without PC	0.71 (0.03)	0.61 (0.01)	0.55 (0.00)	0.58 (0.02)	0.64 (0.00)

Note: Values in parentheses are standard deviation (SD) of three replications, PC=plastic cover

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization conditions, and composting time) of available cadmium.

The main effect of mixing ratio of all treatments was significantly different ( $P < 0.001$ ). The main effect of steam sterilization conditions of all treatments was significantly different ( $P = 0.019$ ). The main effect of composting time of all treatments was significantly different ( $P < 0.001$ ).

The interaction among mixing ratio, steam sterilization conditions, and composting time were significantly different ( $P < 0.001$ ) on within subject effect. It was also had an interaction between mixing ratios and steam sterilization conditions ( $P = 0.006$ ). These results are show in Table 4.14.

**Table 4.14** The analysis of variance of available cadmium.

Source	SS	df	MS	F	p-value
<b>Between - subject effects</b>					
Intercept	51.104	1	51.104	63482.982	<0.001
Steam sterilization	0.005	1	0.005	6.792	0.019
Mixing ratio	0.205	3	0.068	85.061	<0.001
Steam sterilization *Mixing ratio	0.098	3	0.033	40.633	<0.001
Error	0.013	16	0.001		
<b>Within-subject effects</b>					
Composting time	0.182	4	0.046	63.071	<0.001
Composting time * Steam sterilization	0.055	4	0.014	19.191	<0.001
Composting time * Mixing ratio	0.152	12	0.013	17.565	<0.001
Composting time * Steam sterilization* Mixing ratio	0.116	12	0.010	13.423	<0.001
Error	0.046	64	0.001		

- When interactions exist among the three factor, F-test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilization conditions (with PC / without PC treatment)at each time period. To test the difference between groups Bonferroni adjustment was used to compare.

- With PC treatment, available cadmium was found significant difference in 5 periods of composting time as show in Figure 4.38.

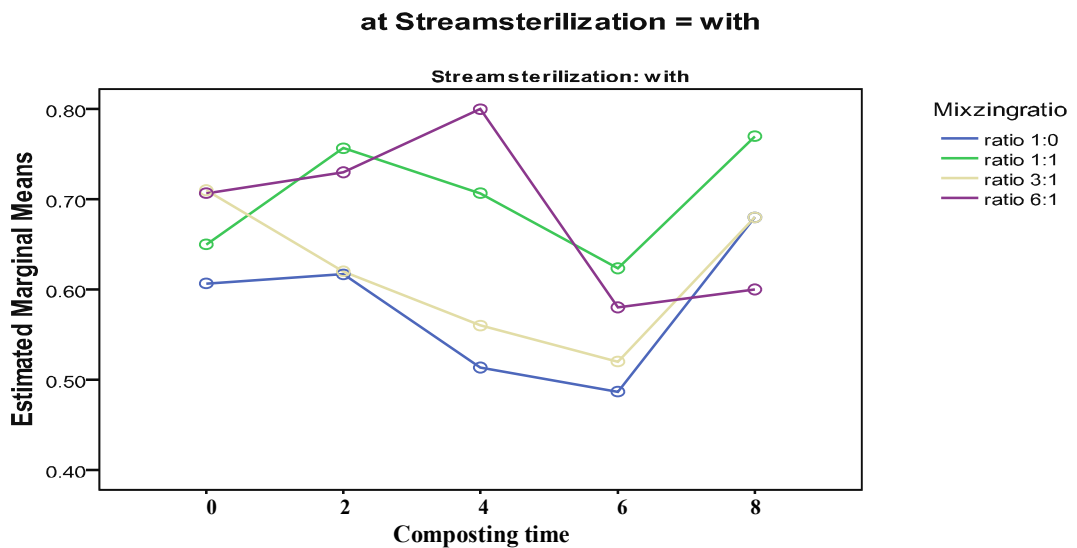
At week 0, available cadmium of mixing ratio 1:0 was significantly different from mixing ratio 3:1 and 6:1.

At week 2, available cadmium of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 6:1. And mixing ratio 3:1 was significantly different from 3:1 and 6:1.

At week 4, the available cadmium of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1. Mixing ratio 1:1 was significantly different from mixing ratio 3:1, 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 6:1.

At week 6, the available cadmium of mixing ratio 1:0 was significantly different from mixing ratio 1:1.

At week 8, the available cadmium of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 6:1. Mixing ratio 1:1 was significantly different from mixing ratio 3:1, 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 6:1.



**Figure 4.38** The average available cadmium of with PC treatments.

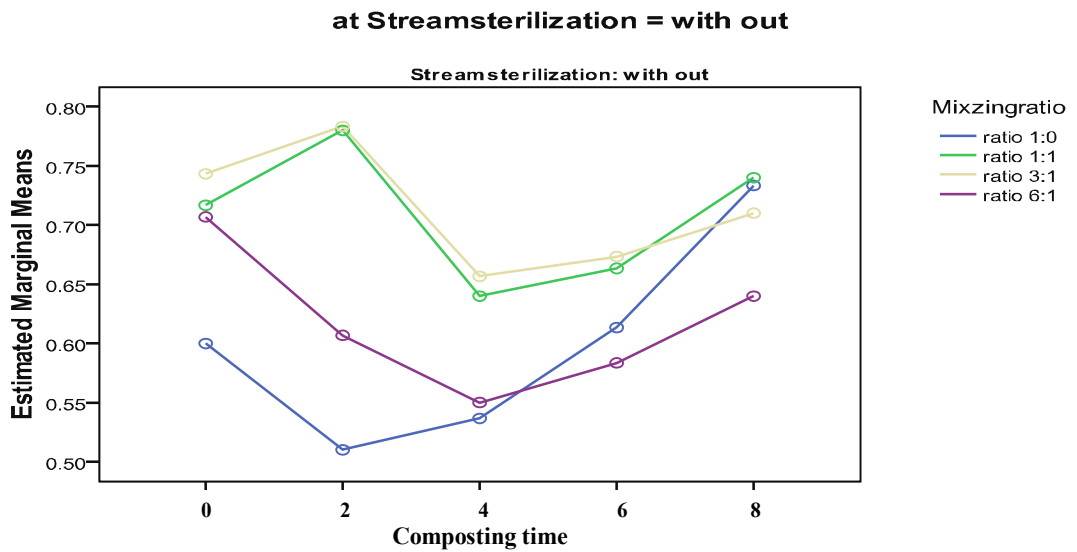
- Without PC treatment, available cadmium were found significant difference in 5 periods as show in Figure 4.39.

At week 0 available cadmium of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1, and 6:1.

At week 2, available cadmium of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1. And mixing ratio 6:1 was significantly different from 1:1 and 3:1.

At week 4, the available cadmium of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1. Mixing ratio 6:1 was significantly different from mixing ratio 1:1 and 3:1.

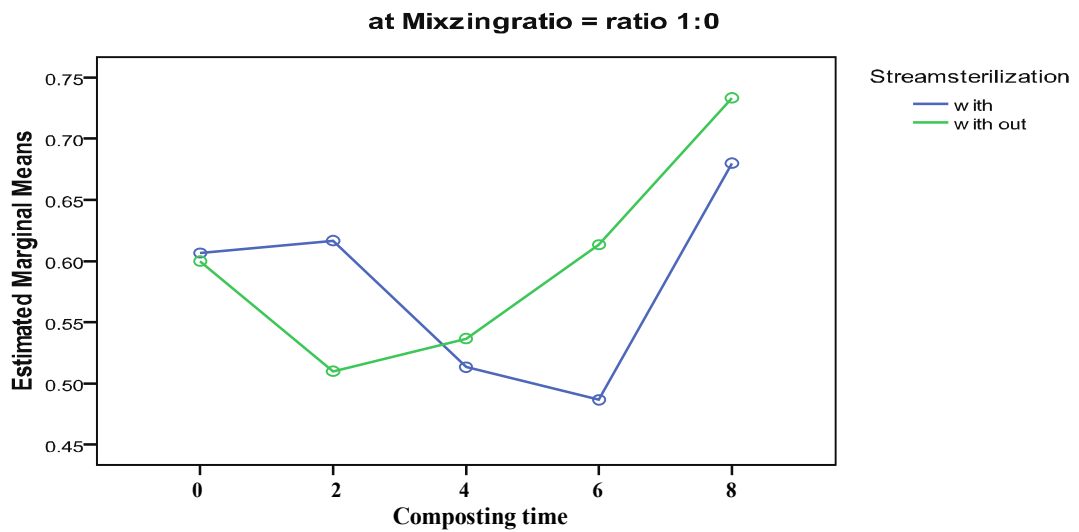
At week 8, the available cadmium of mixing ratio 6:1 was significantly different from mixing ratio 1:0 and 1:1.



**Figure 4.39** The average available cadmium of without PC treatments.

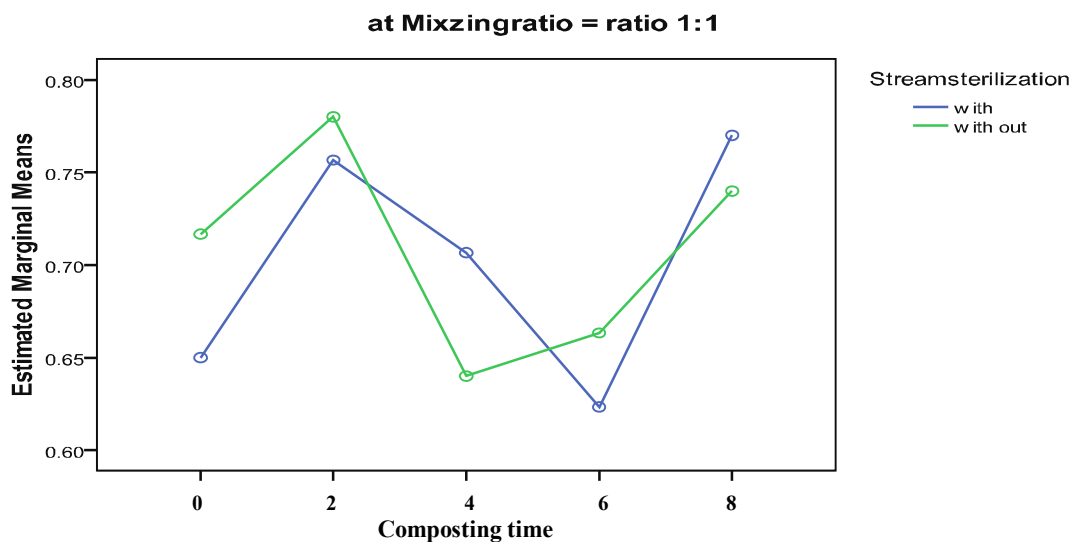
- To test the simple main effect of steam sterilization condition classified by each level of mixing ratio at each level of time period. For testing of difference Bonferroni adjustment was used to compare.

For mixing ratio 1:0, available cadmium were found significant difference in 2 periods, except week 0, 4, and 8. At week 2 and week 6, available cadmium of with PC treatment was significantly different from without PC treatment as show in Figure 4.40.



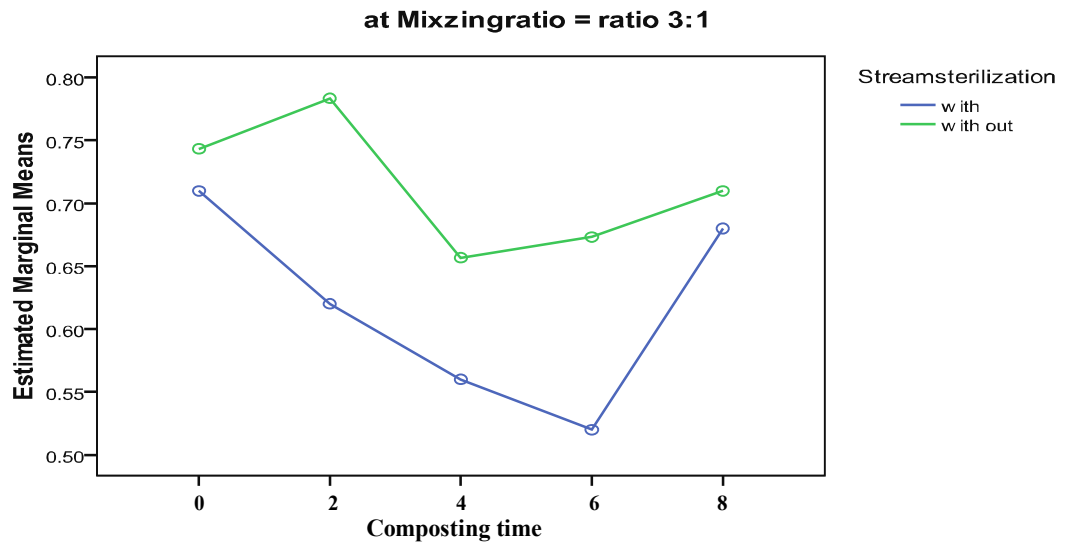
**Figure 4.40** The average available cadmium of mixing ratio 1:0 in with PC and without PC treatments.

For mixing ratio 1:1, available cadmium were found significant difference in 2 periods of composting time. At week 0 and week 4, available cadmium of with PC treatment was significantly different from without PC treatment as show in Figure 4.41.



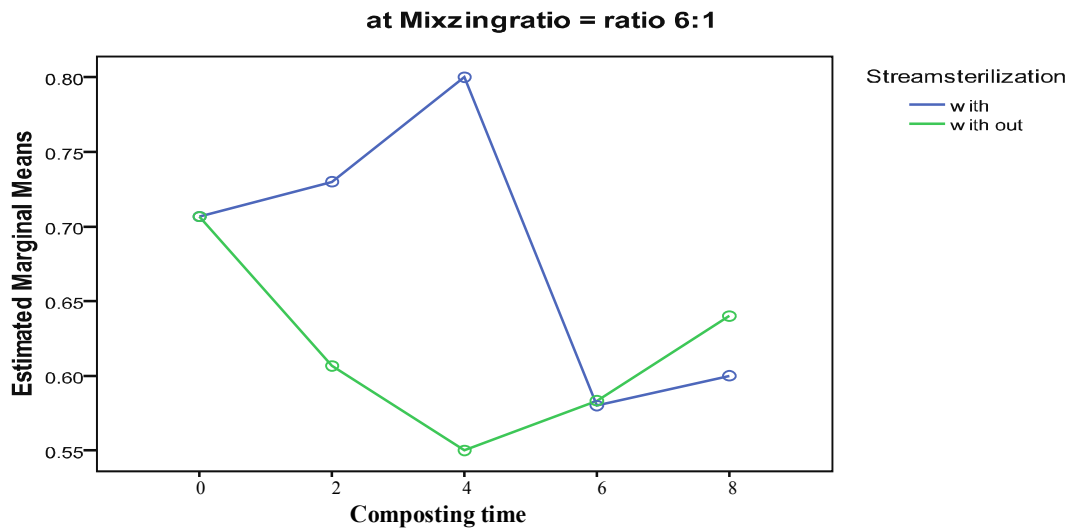
**Figure 4.41** The average available cadmium of mixing ratio 1:1 in with PC and without PC treatments.

For mixing ratio 3:1, available cadmium were found significant difference in 3 periods, except week 0 and week 6. The available cadmium of with PC treatment was significantly different from without PC treatment at week 2, 4 and week 8 as show in Figure 4.42.



**Figure 4.42** The average available cadmium of mixing ratio 3:1 in with PC and without PC treatments.

For mixing ratio 6:1, available cadmium were found significant difference at week 2. At week 2, available cadmium of with PC treatment was significantly different from without PC treatment as show in Figure 4.43.



**Figure 4.43** The average available cadmium of mixing ratio 6:1 in with PC and without PC treatments.

- To test the simple main effect of composting time at each interaction level of steam sterilization conditions and mixing ratio. Then, to test difference between groups, Bonferroni adjustment was used to compare.

For 1:0 with PC treatment, the available cadmium at week 0 was significantly different from composting time at week 4 and 6. The available cadmium at week 2 was significantly different from week 4 and week 6. The available cadmium at week 8 was significantly different from week 4 and 6.

For 1:1 with PC treatment, the available cadmium at week 0 was significantly different from week 2 and 8. The available cadmium at week 6 was significantly different from week 2 and 4. At week 6, available cadmium was significantly different from week 8.

For 3:1 with PC treatment, the available cadmium at week 0 was significantly different from week 4 and 6. The available cadmium at week 8 was significantly different from week 4 and 6.

For 6:1 with PC treatment, the available cadmium at week 0 was significantly different from week 4, 6 and 8. The available cadmium at week 2 was significantly different from week 4, 6, and 8. At week 4, available cadmium was significantly different from week 6 and 8. The available cadmium at week 6 was significantly different from week 8.

For 1:0 without PC treatment, the available cadmium at week 0 was significantly different from week 2, 4, and 8. The available cadmium at week 6 was significantly different from week 2 and 4. The available cadmium at week 8 was significantly different from week 2, 4 and 6.

For 1:1 without PC treatment, the available cadmium at week 2 was significantly different from week 4 and 6. At week 8, available cadmium was significantly different from week 4.

For 3:1 without PC treatment, the available cadmium at week 2 was significantly different from week 4 and 6.

For 6:1 without PC treatment, the available cadmium at week 0 was significantly different from week 2, 4, 6, and 8. The available cadmium at week 2 was significantly different from week 4. At week 8, available cadmium was significantly different from week 6 and 4.

#### 4.3.2.3 Total copper

Total copper concentrations changes at each composting time are showed in Figure 4.44 and Table 4.15 According to Figure 4.44, it showed that total copper concentrations of all treatments were decreasing in week 0 to week 2. And they were slightly decreasing in week 2 to week 4 expect the treatment 1:1 with PC, 1:1 without PC, and 3:1 with PC. Then the total copper concentration of all treatments were changed a small value in week 4 to week 8.

The maximum and minimum of the total copper concentration in with PC treatments were found in 1:0 with PC treatment at week 0 (2919.67 mg/kg DS) and 3:1 with PC treatment at week 4 (1885.05 mg/kg DS). The maximum and minimum of the total copper concentration in without PC treatments were found in 1:1 with PC treatment at week 0 (2799.26 mg/kg DS), and 1:1 with PC treatment at week 4 (2161.17 mg/kg DS), respectively.

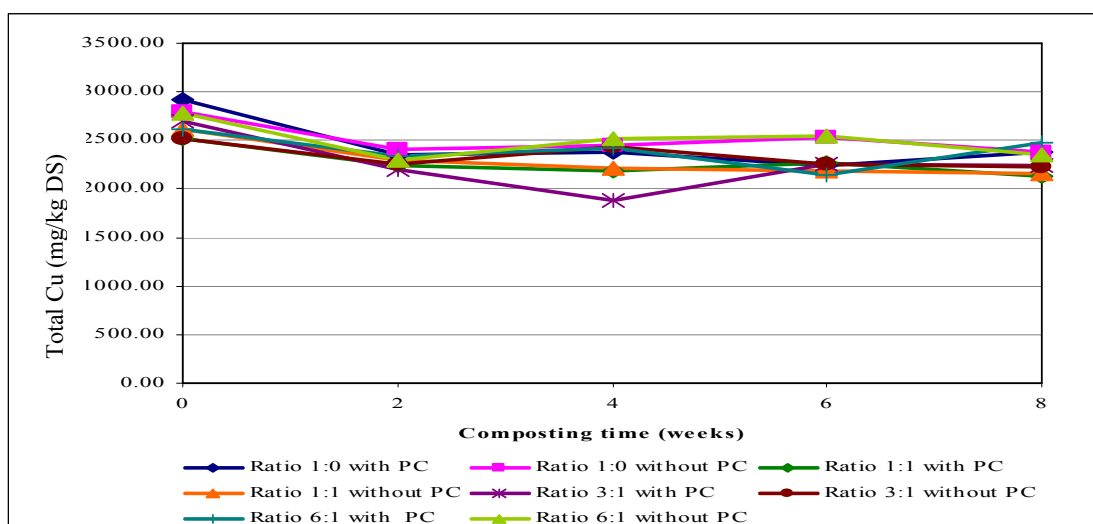


Figure 4.44 Change of total copper concentration at each composting time.

Table 4.15 The average total copper concentrations (mg/kg DS) of each experimental treatment in composting process

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	2919.67 (273.79)	2355.84 (68.79)	2378.06 (30.44)	2245.06 (183.90)	2378.18 (118.74)
	Without PC	2799.26 (161.74)	2412.73 (61.69)	2442.42 (77.83)	2535.76 89.41	2377.63 (128.11)
1:1	With PC	2524.14 (136.81)	2239.43 (97.05)	2191.02 (136.13)	2269.33 (273.28)	2128.05 (39.29)
	Without PC	2609.97 (146.54)	2302.82 (72.20)	2211.29 (77.53)	2179.17 (32.51)	2161.17 (3.02)
3:1	With PC	2698.81 (67.55)	2192.85 (42.68)	1885.05 (146.45)	2289.87 (57.24)	2237.30 (21.32)
	Without PC	2514.93 (66.62)	2261.27 (26.76)	2428.56 (97.51)	2256.40 (120.52)	2221.78 (46.23)
6:1	With PC	2616.51 (14.45)	2337.14 (25.86)	2415.67 (73.29)	2148.29 (32.60)	2475.48 (208.27)
	Without PC	2775.49 (93.43)	2296.53 (8.58)	2521.11 (31.10)	2541.03 (157.16)	2350.85 (48.51)

Note: Values in parentheses are standard deviation (SD) of three replications, PC is plastic cover

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization conditions, and composting time) of total copper.

The main effect of mixing ratio of all treatments was not significantly different at  $P < 0.001$ . The main effect of steam sterilization conditions of all treatments was significantly different at ( $P = 0.018$ ). The main effect of composting time of all treatments was significantly different at ( $p < 0.001$ ).

The interaction among mixing ratio, steam sterilization conditions, and composting time were significantly different ( $P < 0.001$ ) on within subject effect. It was also had an interaction between mixing ratios and steam sterilization conditions ( $P = 0.730$ ). The results of analytical statistics are show in Table 4.16.

**Table 4.16** The statistic results of the total copper concentration.

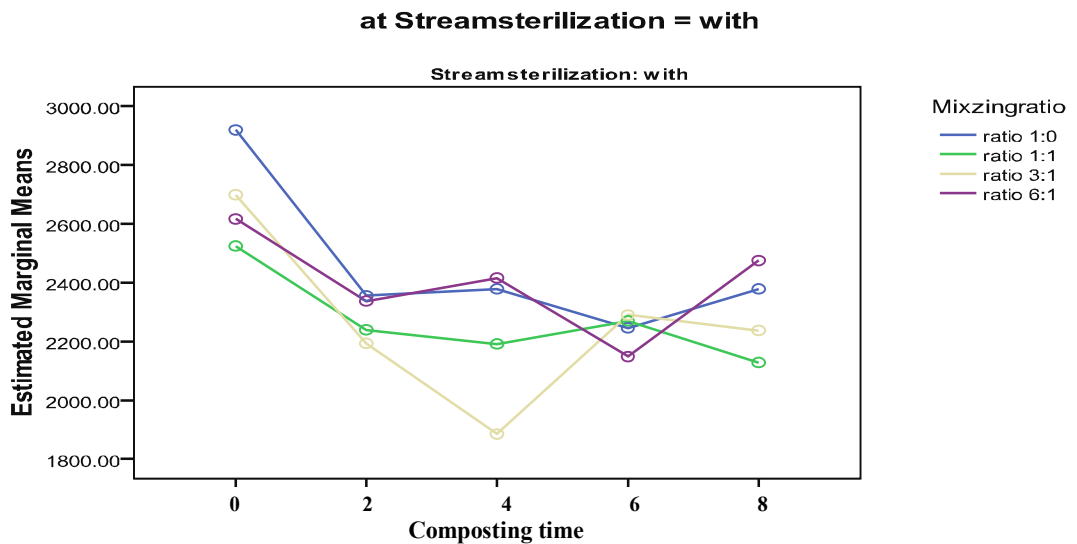
Source	SS	df	MS	F	p-value
<b>Between - subject effects</b>					
Intercept	6.787E+08	1	6.787E+08	38474.458	<0.001
Steamsterilization	121815.436	1	121815.436	6.906	0.018
Mixing ratio	953521.217	3	317840.406	18.019	<0.001
Steamsterilization *Mixing ratio	23085.148	3	7695.049	0.436	0.730
Error	282232.085	16	17639.505		
<b>Within-subject effects</b>					
Composting time	2781121.457	4	695280.364	62.515	<0.001
Composting time * Steamsterilization	211410.059	4	52852.515	4.752	0.002
Composting time * Mixing ratio	237987.917	12	19832.326	1.783	0.070
Composting time * Steamsterilization* Mixing ratio	649431.017	12	54119.251	4.866	<0.001
Error	711797.295	64	11121.833		

- When interactions exist among the three factor, F-test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilization conditions (with PC / without PC treatment)at each time period. To test the difference between groups Bonferroni adjustment was used to compare.

- With PC treatment, total copper were found significant difference 2 periods as show in Figure 4.44.

At week 4, total copper of mixing ratio 3:1 was significantly different from mixing ratio 1:0 and 1:1.

At week 8, total copper of mixing ratio 1:1 was significantly different from mixing ratio 6:1.



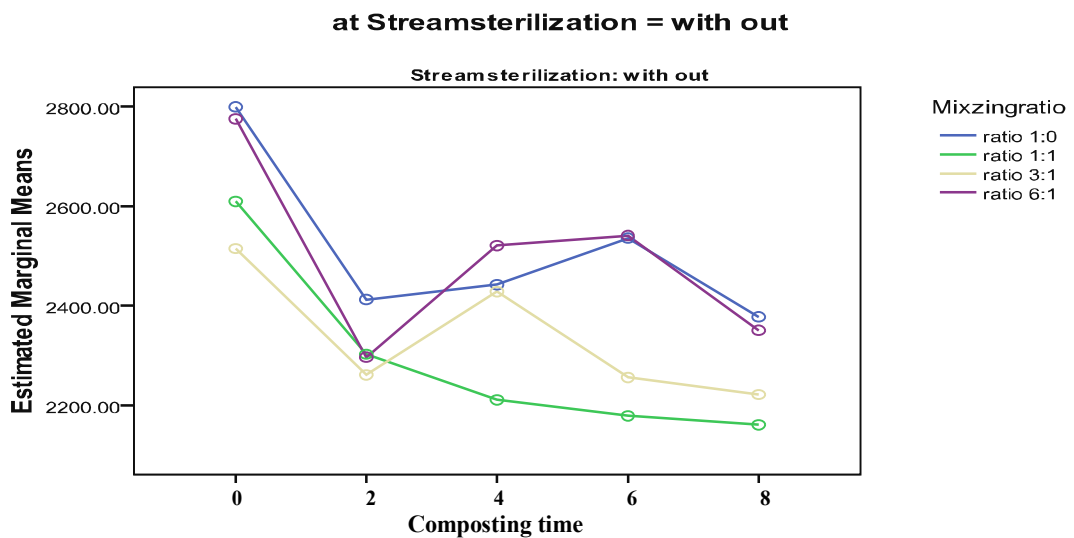
**Figure 4.45** The average total copper at each mixing ratio of with PC treatments.

- Without PC treatment, total copper were found significant difference in 4 periods, except week 0 as show in Figure 4.46.

At week 2, total copper of mixing ratio 1:0 was significantly different from mixing ratio 3:1. At week 4, total copper of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1, and 6:1.

At week 6, total copper of mixing ratio 1:1 was significantly different from mixing ratio 1:0 and 6:1.

At week 8, total copper of mixing ratio 1:0 was significantly different from mixing ratio 1:1.



**Figure 4.46** The average total copper at each mixing ratio of without PC treatments.

- Because there were no significant differences of interaction of steam sterilization and mixing ratio. The mixing ratios (1:0, 1:1, 3:1, and 6:1) were not significant different between steam sterilization conditions at each level of time.

- To test the simple main effect of composting time at each level of time classified each level of mixing ratio. Then, test difference between groups by Bonferroni adjustment used to compare.

For 1:0 with PC treatment, the total copper at week 0 was significantly different from composting time at week 2, 4, 6, and 8.

For 3:1 with PC treatment, the total copper at week 0 was significantly different from week 2, 4, 6, and 8. The total copper at week 4 was significantly different from week 2, 6, and 8.

For 6:1 with PC treatment, the total copper at week 0 was significantly different from week 6 and 8.

For 1:0 without PC treatment, the total copper at week 0 was significantly different from week 2, 4, and 8.

For 1:1 without PC treatment, the total copper at week 0 was significantly different from week 2, 4, 6, and 8.

For 3:1 without PC treatment, the total copper value at week 0 was significantly different from week 2, 6, and 8.

For 6:1 without PC treatment, the total copper value at week 0 was significantly different from week 2, 4, and 8.

#### 4.3.2.4 Available copper

Available copper concentrations change at each composting time are showed in Figure 4.47, and Table 4.17. According to Figure 4.47, it showed that available copper concentrations were increasing in week 0 to week 2 but that of 1:0 with PC treatment was decreased. And they were slightly decreasing in week 2 to week 4 (except 1:0 with PC treatment). Then they were slowly increasing in week 4 to week 6 (except 3:1 with PC treatment, and 1:0 with PC treatment). Finally, they were increasing in week 6 to week 8.

The maximum and minimum of the available copper concentration in with PC treatments were found in 1:0 with PC treatment at week 8 (536.0 mg/kg DS) and 1:1 with PC treatment at week 4 (345.72 mg/kg DS), respectively. The maximum and minimum of the averages total solids in without PC treatments were found in 1:1 without PC treatment at week 8 (537.81 mg/kg DS), and 1:1 without PC treatment at week 4 (394.88 mg/kg DS) respectively.

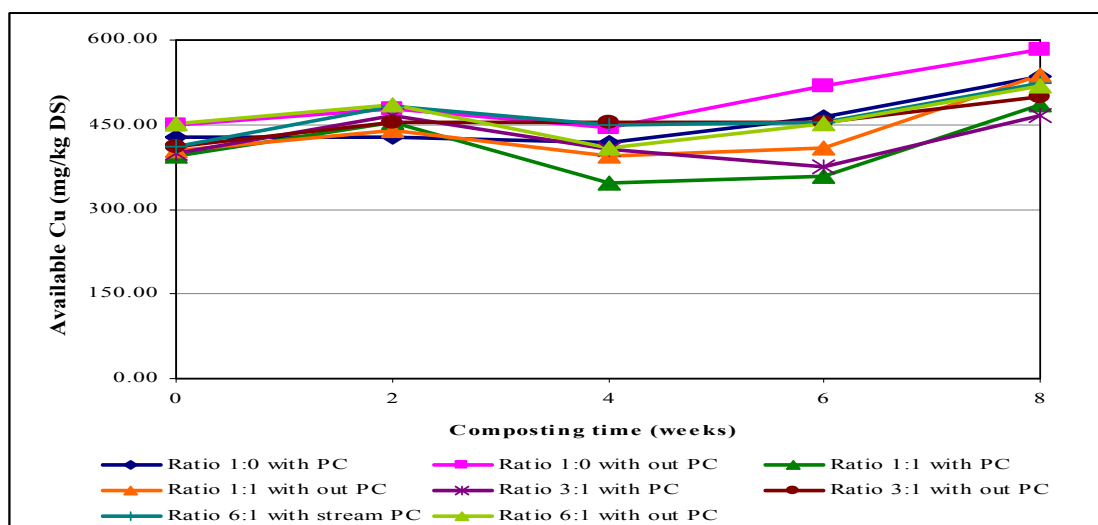


Figure 4.47 Change of available copper concentration at each composting time.

**Table 4.17** The average amount available copper concentrations (mg/kg DS) of each experimental treatment in composting process.

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	428.47 (34.74)	428.10 (10.69)	419.26 (6.95)	464.18 (9.54)	536.0 (37.01)
	Without PC	455.22 (14.74)	477.45 (15.51)	444.49 (20.50)	519.28 (11.02)	584.43 (13.03)
1:1	With PC	393.60 (12.74)	455.24 (44.85)	345.72 (11.76)	357.90 (11.79)	486.27 (18.18)
	Without PC	404.81 (71.24)	440.72 (23.76)	394.88 (11.10)	407.76 (17.16)	537.81 (36.35)
3:1	With PC	399.93 (23.20)	465.97 (12.14)	405.80 (3.46)	375.94 (65.51)	466.30 (9.74)
	Without PC	410.52 (24.70)	455.12 (18.22)	453.52 (17.24)	454.40 (11.70)	499.12 (7.98)
6:1	With PC	412.04 (14.09)	483.96 (6.82)	449.67 (7.67)	452.99 (4.51)	523.64 (12.01)
	Without PC	450.89 (30.68)	485.06 (53.0)	409.57 (6.53)	451.07 (11.1)	518.11 (5.63)

Note: Values in parentheses are standard deviation (SD) of three replications, PC is plastic cover

- Analytical statistics results

The Three -way Analyses of Variance with one Repeated Factors was used to analyze mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization conditions, and composting time) of available copper.

The main effect of mixing ratio of all treatments was significantly different at  $P < 0.001$ . The main effect of steam sterilization conditions of all treatments was significantly different at  $P < 0.001$ . The main effect of composting time of all treatments was significantly different at  $P < 0.001$ .

The interaction among steam sterilization conditions and mixing ratio ( $P = 0.111$ ), composting time and mixing ratio were significantly different ( $P < 0.001$ ) on within subject effect. The results of analytical statistics are show in Table 4.18.

**Table 4.18** The analysis of variance of the available copper.

Source	SS	df	MS	F	p-value
<b>Between - subject effects</b>					
Intercept	2.413E+07	1	2.413E+07	37518.804	<0.001
Steamsterilization	52015.026	3	17338.342	26.755	<0.001
Mixing ratio	18992.529	1	18992.529	29.307	<0.001
Steamsterilization *Mixing ratio	7676.358	3	2558.786	3.948	0.028
Error	10368.803	16	648.050		
<b>Within-subject effects</b>					
Composting time	173575.189	2.540	68339.579	70.467	<0.001
Composting time * Steamsterilization	5055.202	2.540	1990.321	2.052	0.130
Composting time * Mixing ratio	34675.072	7.620	4550.727	4.692	<0.001
Composting time * Steamsterilization * Mixing ratio	13212.318	7.620	1733.873	1.788	0.111
Error	39411.654	40.638	969.816		

- In case of available copper, the triple interaction was not significance. Thus, the double interaction of the simple main effect of mixing ratio at each time periods. Then, to test difference between groups by Bonferroni adjustment used to compare.

For 1:0 with PC treatment, the available copper at week 8 was significantly different from composting time at week 0, 2, 4, and 6.

For 1:1 with PC treatment, the available copper at week 2 was significantly different from week 4 and 6. The available copper at week 8 was significantly different from week 0, 4 and 6.

For 6:1 with PC treatment, the available copper at week 0 was significantly different from week 2, 4, 6, and 8. The available copper value at week 2 was significantly different from week 4, 6 and 8. The available copper at week 8 was significantly different from week 4, and 6.

For 1:0 without PC treatment, the available copper at week 6 was significantly different from week 0, 2, and 4. The available copper at week 8 was significantly different from week 0, 2 and 4.

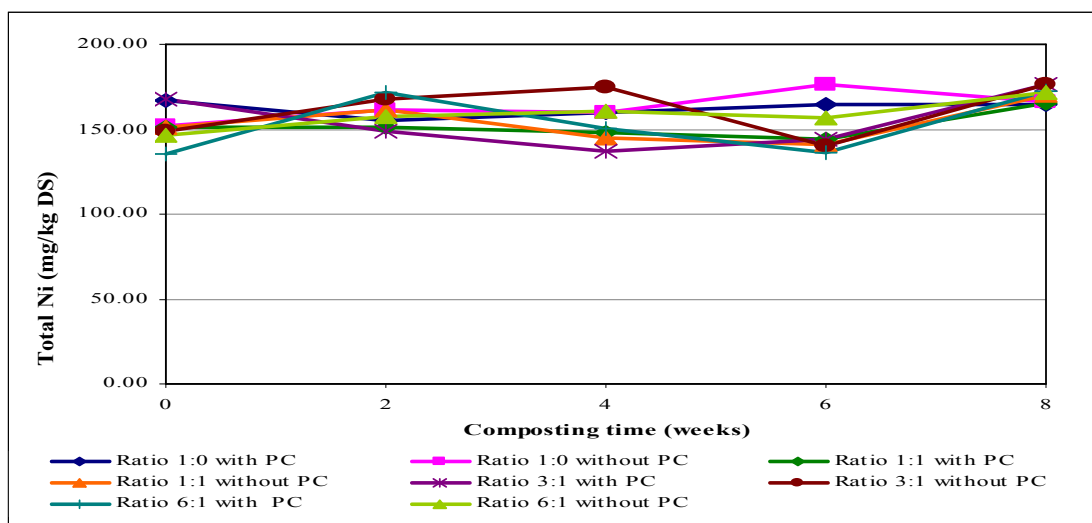
For 1:1 without PC treatment, the available copper at week 8 was significantly different from week 0, 4, and 6.

For 3:1 without PC treatment, the available copper at week 0 was significantly different from week 8.

For 6:1 without PC treatment, the available copper at week 4 was significantly different from week 8.

#### 4.3.2.5 Total Nickel

Total nickel concentrations change at each composting time are showed in Figure 4.48, and Table 4.19. According to Figure 4.48, it showed that total nickel concentration trends were changed a small value during week 0 to week 8. The average total nickel concentrations were slightly increasing in week 0 to week 2 (except the treatment of 1:0 with PC, 1:1 with PC, 3:1 with PC). And they were decreasing in week 2 to week 6 for treatment 1:1 with PC, 1:1 without PC, and 6:1 with PC. Then, the values were slightly increased in week 8 that of 1:0 without PC treatment decreased.



**Figure 4.48** Change of total nickel concentration at each composting time

**Table 4.19** The average amount total nickel concentrations (mg/kg DS) of each experimental treatment in composting process

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	166.94 (11.04)	155.08 (4.99)	160.05 (5.77)	164.50 (8.67)	164.78 (13.91)
	Without PC	151.81 (8.55)	161.27 (7.24)	159.67 (17.32)	176.02 (10.86)	165.85 (8.99)
1:1	With PC	151.21 (15.86)	151.0 (6.58)	147.89 (16.01)	143.87 (8.25)	165.30 (5.69)
	Without PC	151.25 (7.60)	161.17 (2.63)	144.62 (1.40)	141.20 (5.97)	169.75 (5.96)
3:1	With PC	168.10 (6.71)	148.89 (3.40)	136.89 (8.13)	143.95 (5.28)	176.64 (17.55)
	Without PC	148.53 (19.25)	167.97 (1.65)	174.68 (5.26)	140.31 (4.53)	176.0 (9.59)
6:1	With PC	135.43 (3.40)	171.85 (5.60)	150.43 (5.99)	136.23 (10.38)	172.11 (5.77)
	Without PC	146.13 (9.89)	157.47 (4.11)	160.84 (1.88)	156.92 (7.76)	171.82 (2.42)

Note: Values in parentheses are standard deviation (SD) of three replications, PC is Plastic cover

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization conditions, and composting time) of total nickel values.

The main effect of mixing ratio of all treatments was significantly different ( $P=0.012$ ). The main effect of steam sterilization conditions of all treatments was not significantly different ( $P=0.081$ ). The main effect of composting time of all treatments was significantly different ( $P<0.001$ ).

The interaction among mixing ratio, steam sterilization conditions, and composting time were significantly different ( $P<0.001$ ) on within subject effect. It was also had an interaction between mixing ratios and composting time ( $P < 0.001$ ) The results of analytical statistics are show in Table 4.20.

**Table 4.20** The statistic results of the total nickel concentration.

Source	SS	df	MS	F	p-value
<b>Between - subject effects</b>					
Intercept	2961800	1	2961800	35817.239	<0.001
Steam sterilization	287.123	1	287.123	3.472	0.081
Mixing ratio	1251.076	3	417.025	5.043	0.012
Steam sterilization *Mixing ratio	298.787	3	99.596	1.204	0.340
Error	1323.072	16	82.692		
<b>Within-subject effects</b>					
Composting time	6533.084	4	1633.271	20.557	<0.001
Composting time * Steam sterilization	937.682	4	234.42	2.951	0.027
Composting time * Mixing ratio	3471.768	12	289.314	3.642	<0.001
Composting time * Steam sterilization* Mixing ratio	3663.394	12	305.283	3.842	<0.001
Error	5084.739	64	79.449		

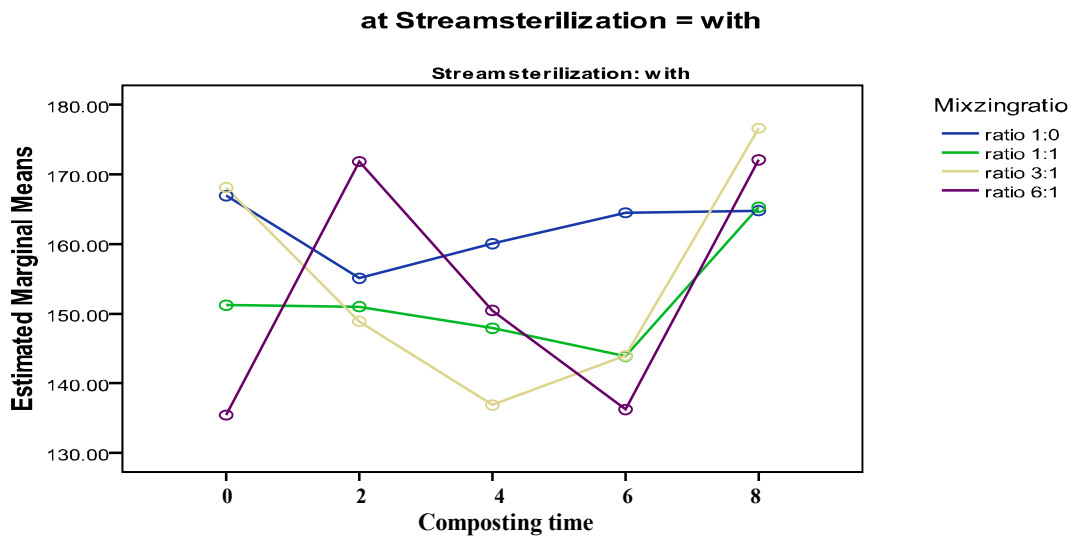
- When interactions exist among the three factor, F-test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilization conditions (with PC / without PC treatment) at each time period. To test the difference between groups Bonferroni adjustment was used to compare.

- With PC treatment, total nickel was found significant difference in 3 periods, except at week 4, week 8.

At week 0, total nickel of mixing ratio 6:1 was significantly different from mixing ratio 1:0 and 3:1.

At week 2, total nickel of mixing ratio 6:1 was significantly different from mixing ratio 1:0, 1:1 and 3:1.

At week 6, total nickel of mixing ratio 1:0 was significantly different from mixing ratio 6:1 as show in Figure 4.49.

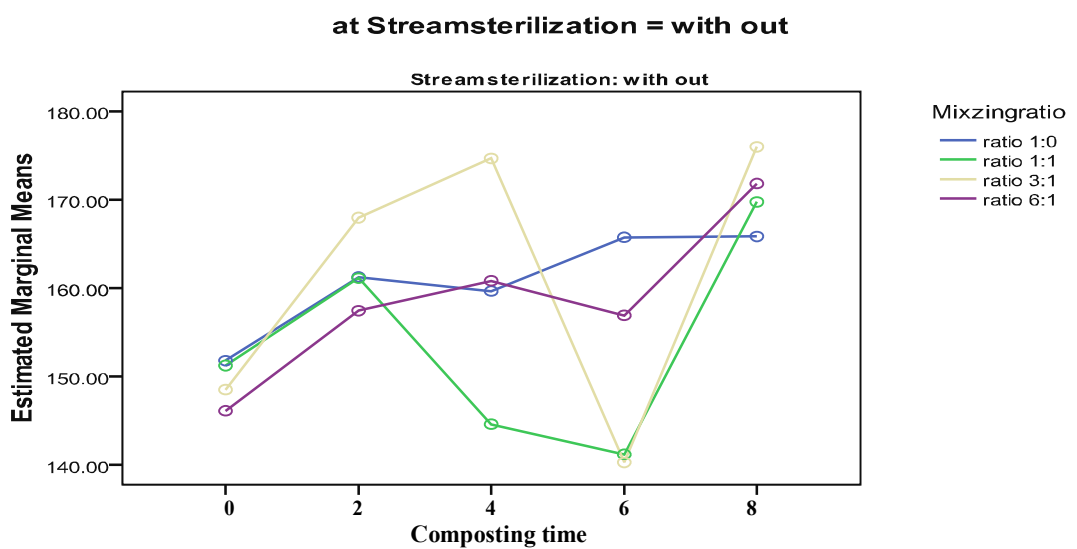


**Figure 4.49** The average total nickel of with PC treatments.

- With out PC treatment, total nickel was found significant difference in 2 periods, except at week 2, week 8.

At week 4, total nickel of mixing ratio 1:1 was significantly different from mixing ratio 3:1.

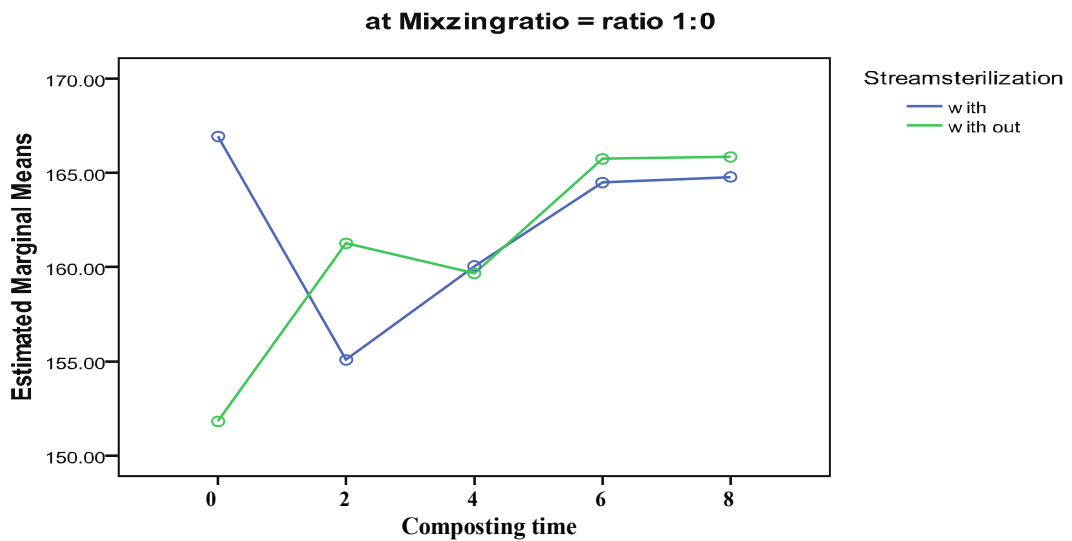
At week 6, total nickel of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 3:1 as show in Figure 4.50.



**Figure 4.50** The average total nickel of without PC treatments.

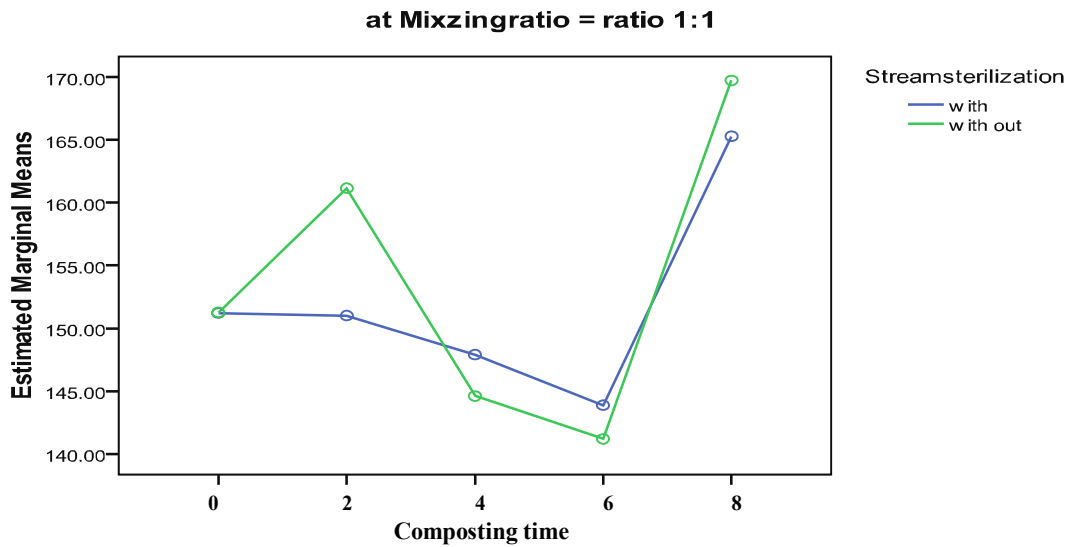
- To test the simple main effect of steam sterilization at each level of time classified each level of mixing ratio. And to test difference between groups by Bonferroni adjustment used to compare.

For mixing ratio 1:0, the total nickel of with PC treatment was not significant different from total nickel of without PC treatment at all periods as show in Figure 4.51.



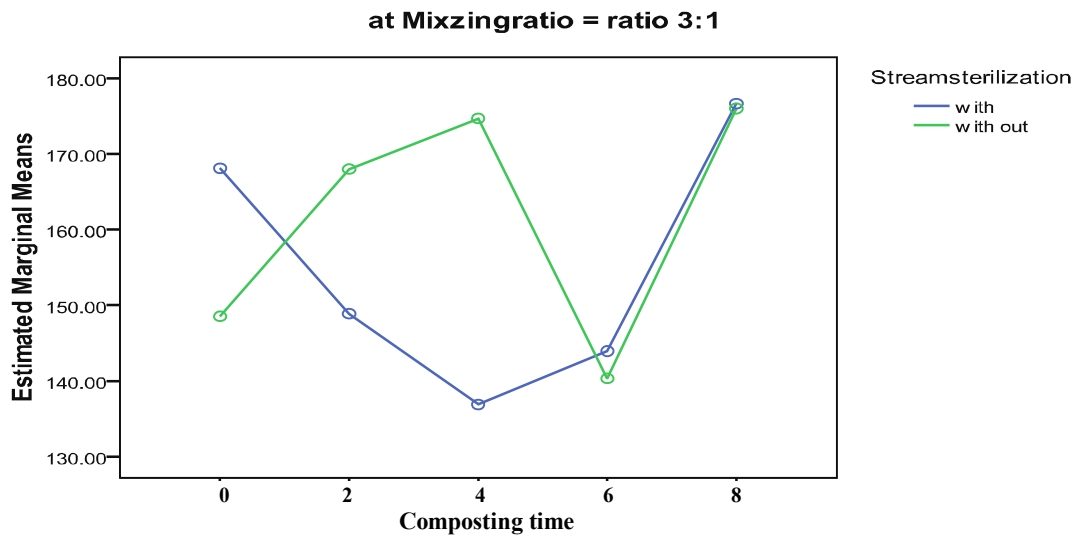
**Figure 4.51** The average total nickel of mixing ratio 1:0 in with PC and without PC treatments.

For mixing ratio 1:1, the total nickel of with PC treatment was not significant different from total nickel of without PC treatment at all periods as show in Figure 4.52.



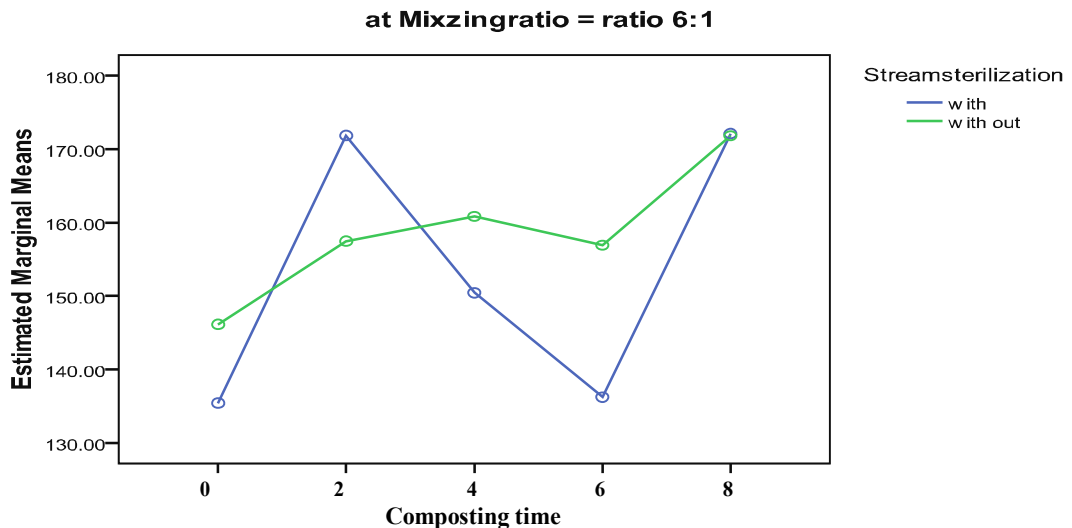
**Figure 4.52** The average total nickel of mixing ratio 1:1 in with PC and without PC treatments.

For mixing ratio 3:1, the total nickel were significant different in 2 periods. At week 4, total nickel of with PC treatment was significantly different from without PC treatment. At week 6, total nickel of with PC treatment was significantly different from without PC treatment as show in Figure 4.53.



**Figure 4.53** The average total nickel of mixing ratio 3:1 in with PC and without PC treatments.

For mixing ratio 6:1, total nickel were significant in 2 periods. At week 2, total nickel of with PC treatment was significantly different from without PC treatment. At week 4, total nickel of with PC treatment was significantly different from without PC treatment as show in Figure 4.54.



**Figure 4.54** The average total nickel of mixing ratio 6:1 in with PC and without PC treatments.

- To test the simple main effect of composting time classified by each level of mixing ratio at each period. For testing of different between groups Bonferroni adjustment.

For 3:1 with PC treatment, the total nickel at week 4 was significantly different from composting time at week 0 and week 8. The total nickel at week 8 was significantly different from week 6.

For 6:1 with PC treatment, the total nickel at week 0 was significantly different from week 2 and 8. The total nickel at week 2 was significantly different from week 4 and 6. The total nickel at week 4 was significantly different from week 8.

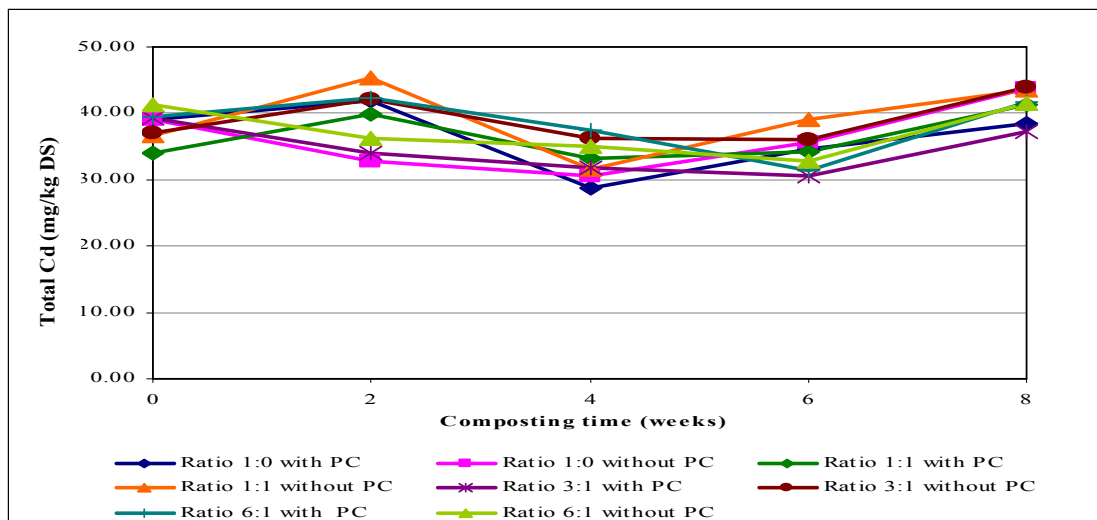
For 3:1 without PC treatment, the total nickel at week 6 was significantly different from week 4 and 8.

For 6:1 without PC treatment, the total nickel at week 0 was significantly different from week 8.

#### 4.3.2.6 Available nickel

The available nickel concentration changes of each composting time are showed in Figure 4.55 and Table 4.21. According to Figure 4.55, it showed that the available nickel concentrations trends were slightly increased in week 0 to week 2 (except the 1:0 with PC treatment, 3:1 with PC treatment, 6:1 without PC treatment). The average nickel concentrations of all treatments were slightly decreasing in week 4. At week 4 to week 8, the treatment 1:0 (both of with PC treatment and without PC treatment), 1:1 (both of with PC treatment and without PC treatment) were continuously increasing in week 4 to week 8. While the experimental treatment 3:1 (both of with PC treatment and without treatment), 6:1 (both of with PC treatment and without PC treatment) were decreased in week 6 and then they are turned to slightly increasing in week 6 to week 8.

Both of the maximum and minimum of the available nickel concentration in with PC treatment were found at mixing ratio 1:0 at week 2 (41.95 mg/kg DS) and at week 4 (28.69 mg/kg DS) respectively. The maximum and minimum in without PC experimental treatments were found in 3:1 without PC treatment at week 8 (43.92 mg/kg DS), and 1:0 without PC treatment at week 4 (30.48 mg/kg DS) respectively.



**Figure 4.55** Change of available nickel concentration at each composting time

**Table 4.21** The average amount available nickel concentrations (mg/kg DS) of each experimental treatment in composting process

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	39.09 (8.02)	41.95 (4.30)	28.69 (2.94)	34.63 (0.20)	38.43 (2.05)
	Without PC	39.08 (4.28)	32.74 (3.10)	30.48 (2.73)	35.71 (3.20)	43.77 (3.63)
1:1	With PC	34.01 (2.04)	39.93 (1.52)	33.24 (4.89)	34.27 (1.73)	41.36 (0.94)
	Without PC	36.69 (8.58)	45.29 (2.41)	31.54 (0.88)	38.98 (1.17)	43.52 (10.33)
3:1	With PC	39.31 (3.25)	34.01 (2.80)	31.71 (3.58)	30.65 (4.94)	37.17 (3.47)
	Without PC	37.02 (2.53)	42.04 (5.15)	36.19 (4.59)	36.02 (0.60)	43.92 (2.40)
6:1	With PC	39.53 (3.59)	42.36 (4.29)	37.45 (4.33)	31.31 (6.12)	41.78 (0.15)
	Without PC	41.24 (1.97)	36.24 (5.74)	34.94 (0.43)	32.72 (7.80)	41.57 (4.62)

Note: Values in parentheses are standard deviation (SD) of three replications, PC is plastic cover

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization conditions, and composting time) of available nickel values.

The main effect of mixing ratio of all treatments was significantly different ( $P < 0.001$ ). The main effect of steam sterilization conditions of all treatments was not significantly different ( $P = 0.060$ ). The main effect of composting time of all treatments was significantly different ( $P < 0.001$ ).

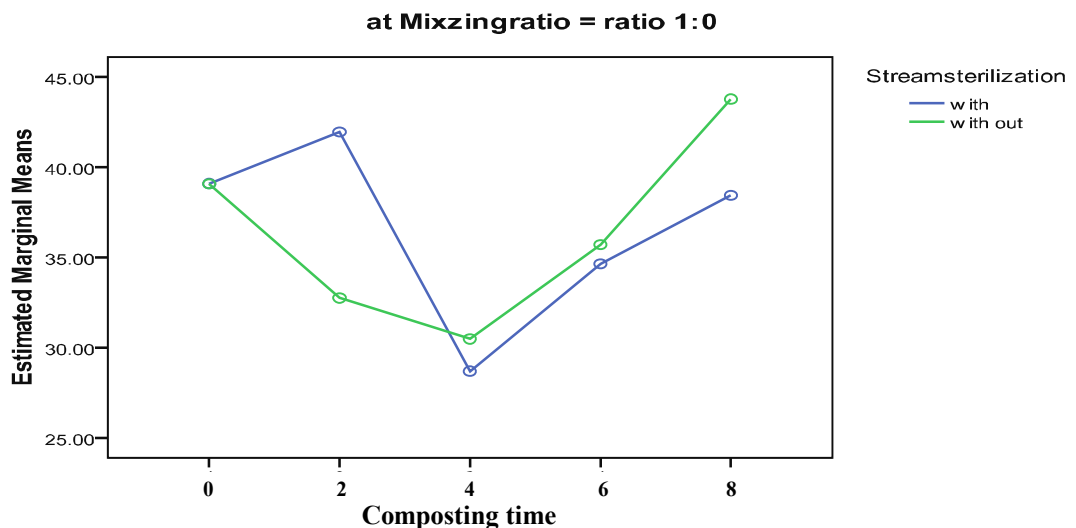
The interaction among mixing ratio, steam sterilization conditions, and composting time were not significantly different ( $P = 0.196$ ) on within subject effect. It was also had an interaction between mixing ratios and steam sterilization conditions ( $P = 0.046$ ). The results of analytical statistics are show in Table 4.22.

**Table 4.22** The analysis of variance of available nickel.

Source	SS	df	MS	F	p-value
<b>Between - subject effects</b>					
Intercept	166676.658	1	166676.658	11166.042	<0.001
Steam sterilization	61.276	1	61.276	4.105	0.060
Mixing ratio	49.819	3	16.606	1.112	0.373
Steam sterilization *Mixing ratio	148.875	3	49.625	3.324	0.046
Error	238.834	16	14.927		
<b>Within-subject effects</b>					
Composting time	1185.101	4	296.275	16.019	<0.001
Composting time * Steam sterilization	76.331	4	19.083	1.032	0.398
Composting time * Mixing ratio	354.473	12	29.539	1.597	0.115
Composting time * Steam sterilization* Mixing ratio	307.572	12	25.631	1.386	0.196
Error	1183.672	64	18.495		

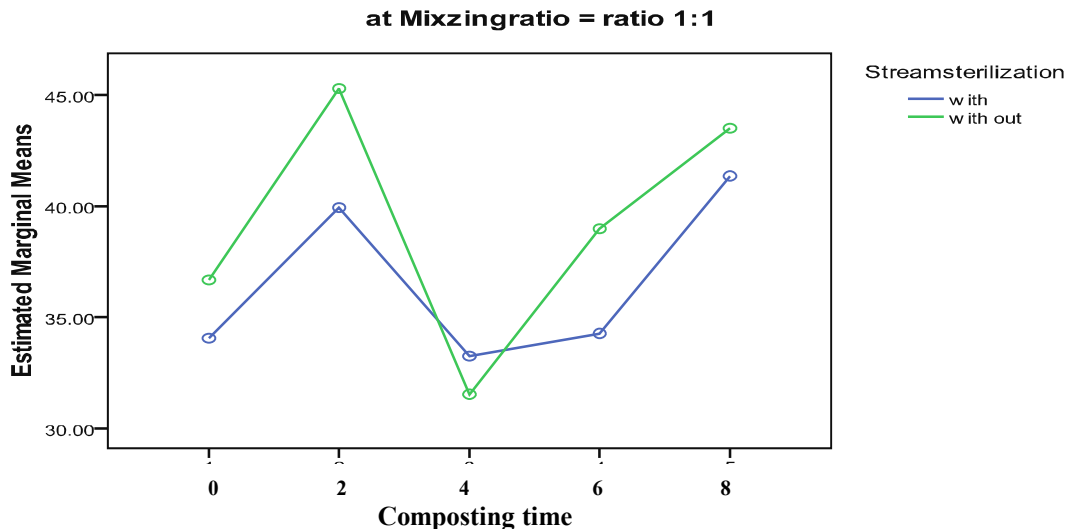
- In case of available nickel, the triple interaction Thus, the double interaction of the simple main effect of mixing ratio at each time periods. Then, to test difference between groups by Bonferroni adjustment used to compare.

For mixing ratio 1:0, the available nickel of with PC treatment was not significant different from available nickel of without PC treatment at all periods as show in Figure 4.56.



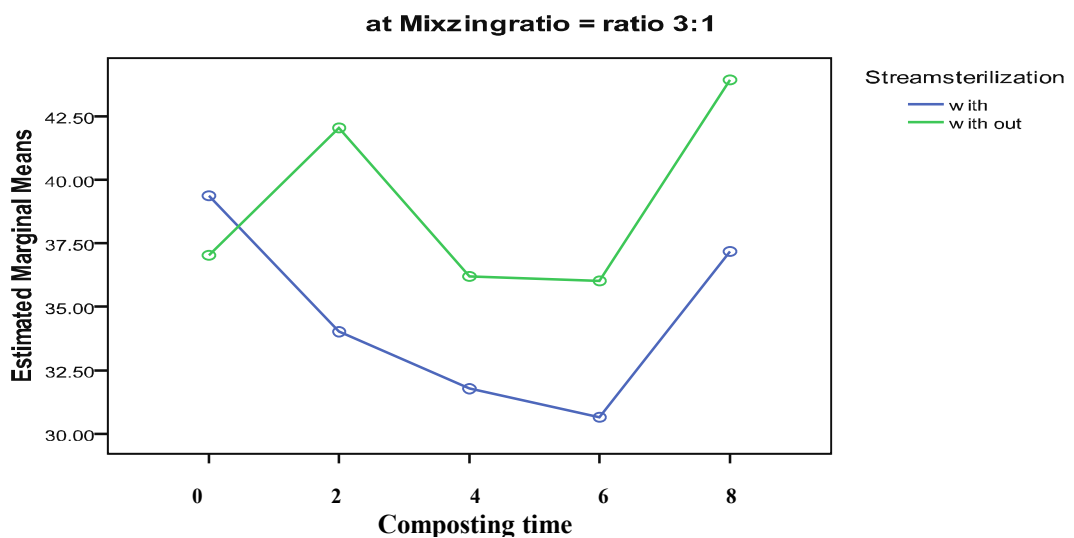
**Figure 4.56** The average available nickel of mixing ratio 1:0 in with PC and without PC treatments.

For mixing ratio 1:1, the available nickel of with PC treatment was not significant different from available nickel of without PC treatment at all periods as show in Figure 4.57.



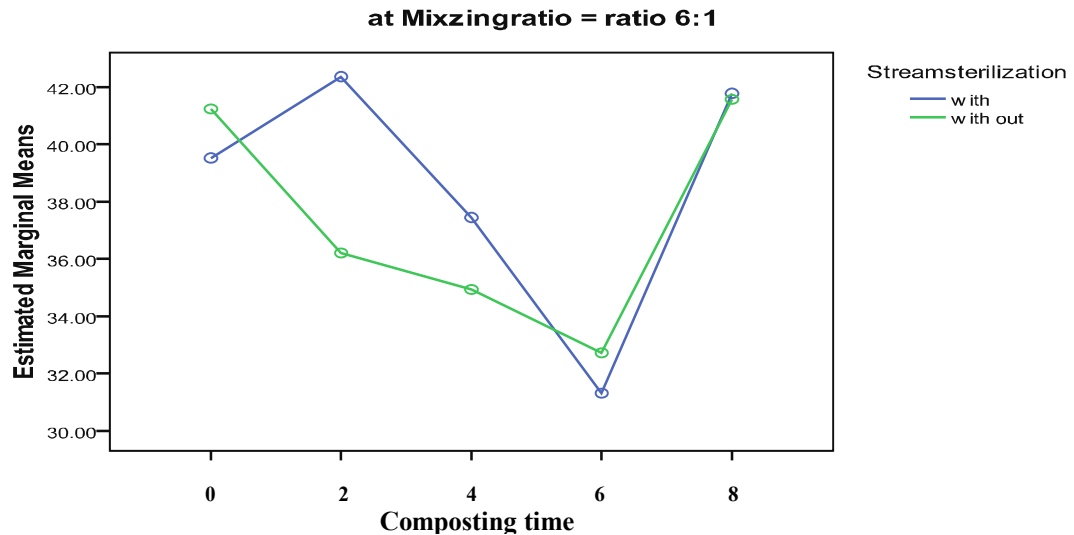
**Figure 4.57** The average available nickel of mixing ratio 1:1 in with PC and without PC treatments.

For mixing ratio 3:1, the available nickel of with PC treatment was not significant different from available nickel of without PC treatment at all periods as show in Figure 4.58.



**Figure 4.58** The average available nickel of mixing ratio 3:1 in with PC and without PC treatments.

For mixing ratio 6:1, the available nickel of with PC treatment was not significant different from available nickel of without PC treatment at all periods as show in Figure 4.59.

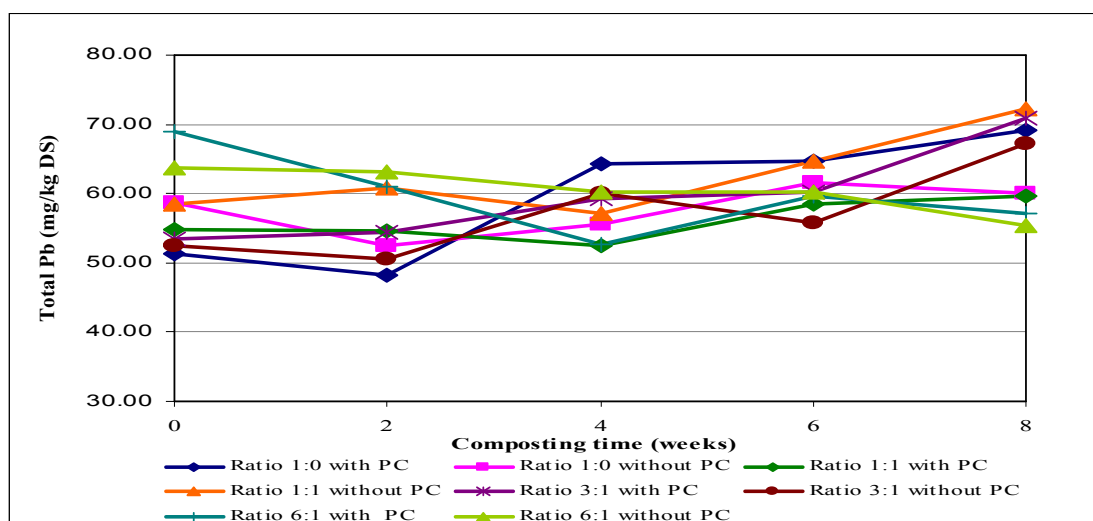


**Figure 4.59** The average available nickel of mixing ratio 6:1 in with PC and without PC treatments.

#### 4.3.2.7 Total lead

Total lead concentration changes of each composting time are showed in Figure 4.60 and Table 4.23. According to Figure 4.60, it showed that total lead concentration trends were slightly decreasing in week 0 to week 2. On the other hand, the average total lead concentration in experimental treatment 1:1 without PC and 3:1 with out PC were slightly increasing in week 0 to week 2. Then they were continuously increasing week 4 to week 8 for experimental treatment 1:1 with PC and 3:1 with PC but that of experimental treatment 6:1 with out PC were continuously decreasing during week 4 to week 8. The other experimental treatments had consistence average total lead in week 4 to week 8.

The maximum and minimum of the total lead concentration in with PC treatments were found treatment 3:1 at week 8 (70.81 mg/kg DS) and 1:0 at week 2 (48.25 mg/kg DS), respectively. Both of maximum and minimum value in without PC experimental treatments were found treatment 3:1 at week 8 (67.22 mg/kg DS), and week 2 (50.56 mg/kg DS), respectively.



**Figure 4.60** Change of total lead at each composting time.

**Table 4.23** The average amount total lead concentrations (mg/kg DS) of each experimental treatment in composting process.

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	51.23 (8.45)	48.25 (1.14)	64.27 (7.05)	64.74 (9.04)	69.20 (1.50)
	Without PC	58.70 (5.64)	52.47 (2.67)	55.63 (4.28)	61.55 (0.42)	60.04 (2.60)
1:1	With PC	54.77 (6.17)	54.60 (1.28)	52.52 (4.86)	58.48 (3.26)	59.60 (3.64)
	Without PC	58.54 (1.20)	60.73 (1.04)	57.10 (1.25)	64.61 (0.83)	72.23 (0.71)
3:1	With PC	53.41 (3.98)	54.49 (3.75)	59.22 (1.15)	60.21 (7.45)	70.81 (5.08)
	Without PC	52.48 (4.59)	50.56 (3.82)	59.97 (6.84)	55.86 (1.18)	67.22 (4.73)
6:1	With PC	68.89 (4.55)	61.08 (8.84)	52.66 (0.53)	59.59 (6.75)	57.13 (3.97)
	Without PC	63.76 (3.91)	63.08 (5.32)	60.27 (3.93)	60.22 (3.01)	55.41 (4.42)

Note: Values in parentheses are standard deviation (SD) of three replications

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization conditions, and composting time) of total lead concentration.

The main effect of mixing ratio of all treatments was not significantly different ( $P=0.272$ ). The main effect of steam sterilization conditions of all treatments was not significantly different at ( $P=0.247$ ). The main effect of composting time of all treatments was significantly different ( $P < 0.001$ ).

The interaction among mixing ratio, steam sterilization conditions, and composting time were significantly different ( $P = 0.034$ ) on within subject effect. It was also had an interaction between mixing ratios and steam sterilization conditions ( $P = 0.001$ ), composting time and steam sterilization conditions ( $P < 0.001$ ). The results of analytical statistics are show in Table 4.24.

**Table 4.24** The analysis of variance of the total lead.

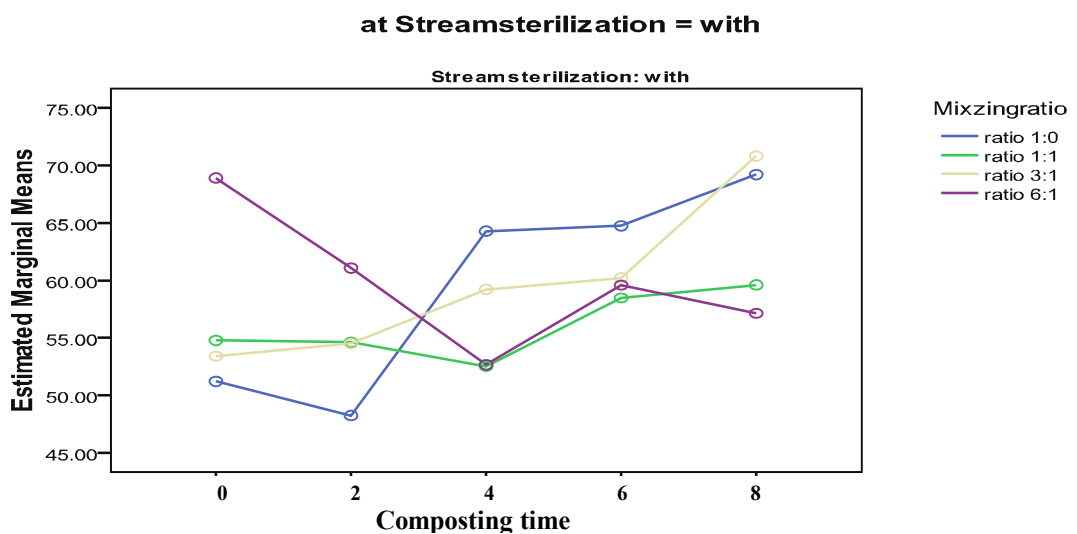
Source	SS	df	MS	F	p-value
<b>Between - subject effects</b>					
Intercept	420174.455	1	420174.455	29485.837	<0.001
Steam sterilization	20.543	1	20.543	1.442	0.247
Mixing ratio	60.994	3	20.331	1.427	0.272
Steam sterilization *Mixing ratio	410.082	3	136.694	9.593	0.001
Error	228.001	16	14.250		
<b>Within-subject effects</b>					
Composting time	1012.868	4	253.217	11.290	<0.001
Composting time * Steam sterilization	24.249	4	6.062	0.270	0.896
Composting time * Mixing ratio	1811.672	12	150.973	6.731	<0.001
Composting time * Steam sterilization* Mixing ratio	550.574	12	45.881	2.046	0.034
Error	1435.402	64	22.428		

- When interaction exist among the three factor, F-test of ANOVA is used to test main effect of mixing ratio classified by each level of steam sterilization conditions (with PC/without PC) at each composting time. And to test difference between group Bonferroni adjustment used to compare.

With PC treatment, total lead was found significant difference in 3 periods, except at week 2 and week 6 as show in Figure 4.61.

At week 0, total lead of mixing ratio 1:0 was significantly different from mixing ratio 6:1.

At week 8, total lead of mixing ratio 1:0 was significantly different from mixing ratio 6:1 and 3:1. And mixing ratio 1:1 was significantly different from mixing ratio 3:1.



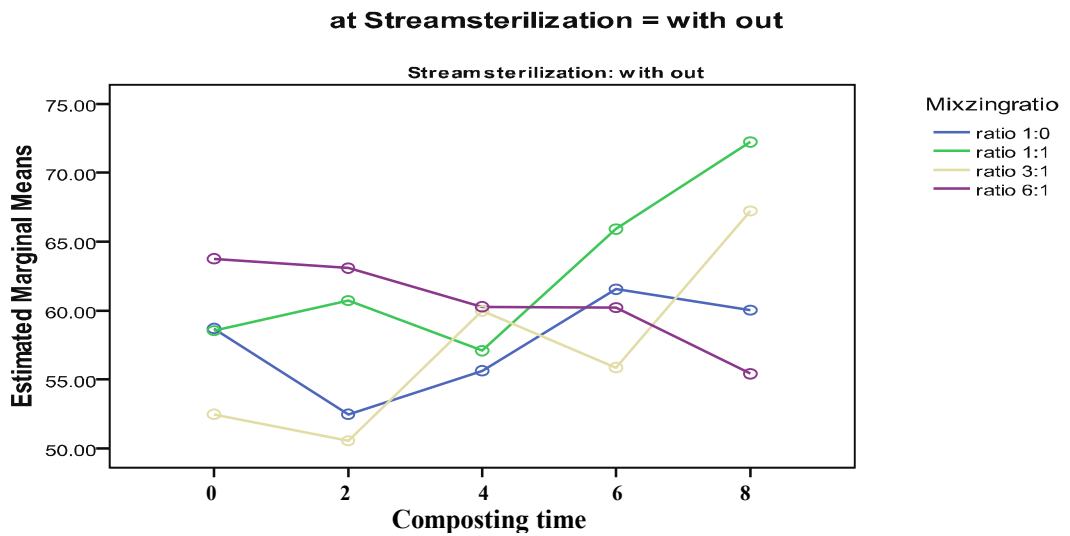
**Figure 4.61** The average total lead of with PC treatments.

- Without PC treatment, total lead were found significant difference in 3 periods, except at week 0 and week 4 as show in Figure 4.62.

At week 2, total lead of mixing ratio 1:1 was significantly different from mixing ratio 3:1.

At week 6, total lead of mixing ratio 1:1 was significantly different from mixing ratio 3:1 and 6:1. And mixing ratio 1:0 was significantly different from mixing ratio 3:1.

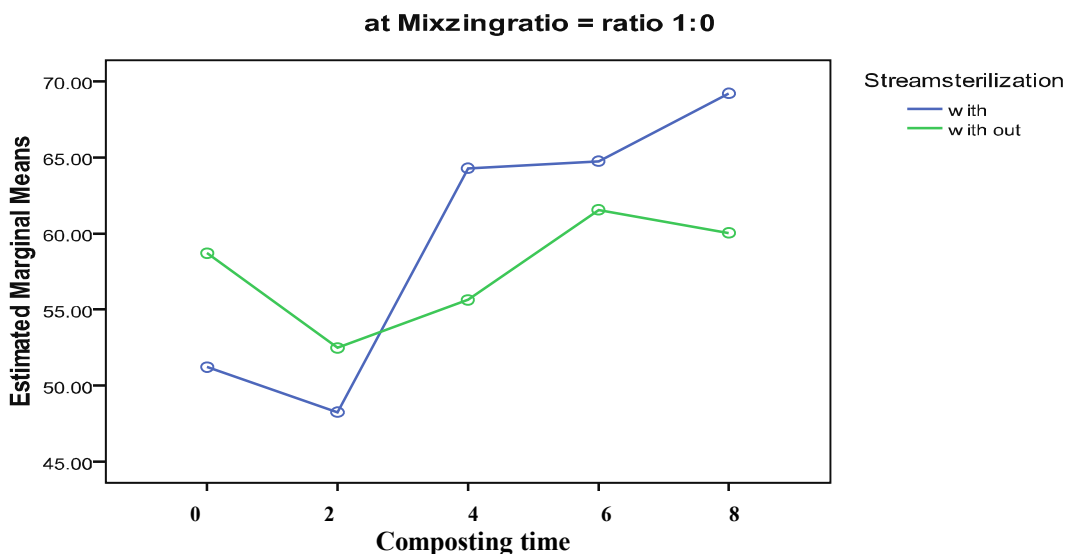
At week 8, total lead of mixing ratio 1:1 was significantly different from mixing ratio 1:0 and 6:1. And mixing ratio 3:1 was significantly different from mixing ratio 6:1.



**Figure 4.62** The average total lead of without PC treatments.

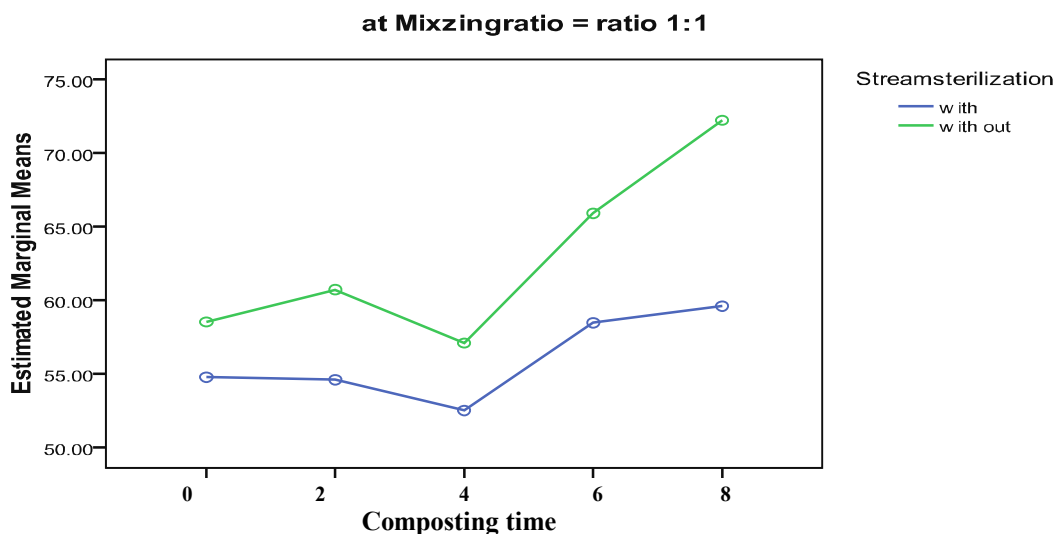
- To test the simple main effect of steam sterilization classified by each level of mixing ratio at each period. For testing of different between groups Bonferroni adjustment.

For mixing ratio 1:0, total lead of with PC treatment was not significant from total lead without PC treatment at all periods as show in Figure 4.63



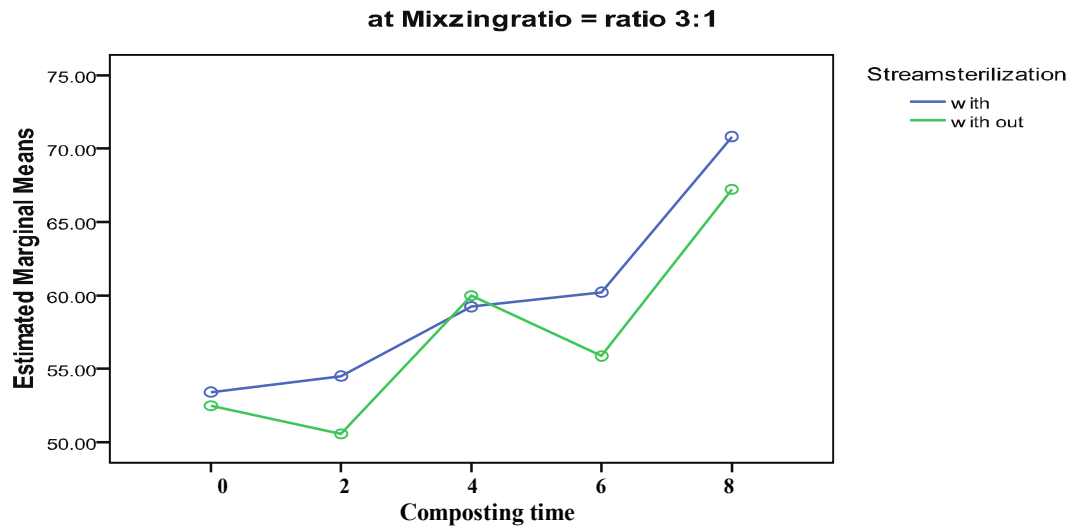
**Figure 4.63** The average total lead of mixing ratio 1:0 in with PC and without PC treatments.

For mixing ratio 1:1, total lead were found significant at 3 periods, except week 0, week 4. At week 2, total lead of with PC treatment was significantly different from without PC treatment. At week 6, total lead of with PC treatment was significantly different from without PC treatment. At week 8, total lead of with PC treatment was significantly different from without PC treatment as show in Figure 4.64



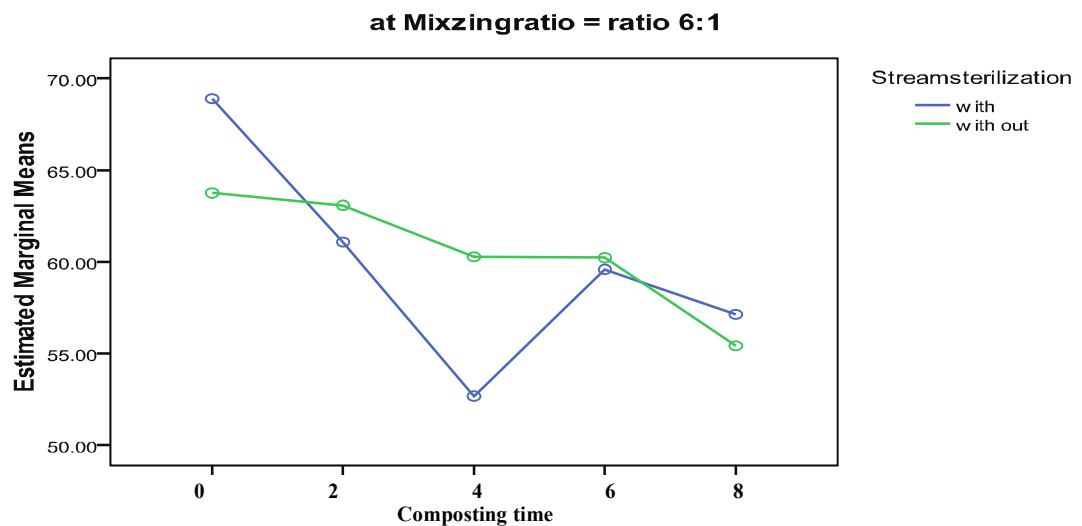
**Figure 4.64** The average total lead of mixing ratio 1:1 in with PC and without PC treatments.

For mixing ratio 3:1, total lead of with PC treatment was not significant from total lead without PC treatment at all periods as show in Figure 4.65



**Figure 4.65** The average total lead of mixing ratio 3:1 in with PC and without PC treatments.

For mixing ratio 6:1, total lead of with PC treatment was not significant from total lead without PC treatment at all periods as show in Figure 4.66.



**Figure 4.66** The average total lead of mixing ratio 6:1 in with PC and without PC treatments.

- To test the simple main effect of composting time at each level of time classified each level of mixing ratio. Then, test difference between groups by Bonferroni adjustment used to compare.

For 1:0 with PC treatment, the total lead at week 2 was significantly different from week 8.

For 1:1 and 6:1 with PC treatment, the total lead was not significantly different in all period time.

For 3:1 with PC treatment, the total lead at week 8 was significantly different from week 0 and week 2.

For 1:0, 3:1 and 6:1 without PC treatment, the total lead was not significantly different in all period time.

For 1:1 without PC treatment, the total lead at week 0 was significantly different from week 6 and 8. At week 2 was significantly different from week 4, 6, and 8. The total lead at week 8 was significantly different from week 6, 4.

#### 4.3.2.8 Total zinc

Total zinc concentration changes at each composting time are showed in Figure 4.67 and Table 4.25. According to Figure 4.67, it showed the average total zinc concentration trend and they were slightly decreasing in week 0 to week 2 except the treatment 1:1 with PC and 1:1 without PC. Then they were decreased until week 4. The average total zinc in treatment 3:1 with out PC, 6:1 with PC, and 6:1 without PC were increased. They were slightly increasing in week 4 to week 6 (except treatment 1:1 with PC, 6:1 with PC, and 6:1 without PC which had a decreasing value). The average total zinc concentrations of all treatments were decreased in week 8.

The maximum and minimum of the total zinc concentration in with PC were found in 1:0 with PC treatment at week 6 (1995.12 mg/kg DS) and 1:1 with PC at week 8 (1514.74 mg/kg DS), respectively. The maximum and minimum in without PC experimental treatments were found in 1:0 without PC treatment at week 0 (1941.92 mg/kg DS), and 1:1 without PC treatment at week 8 (1534.75 mg/kg DS), respectively.

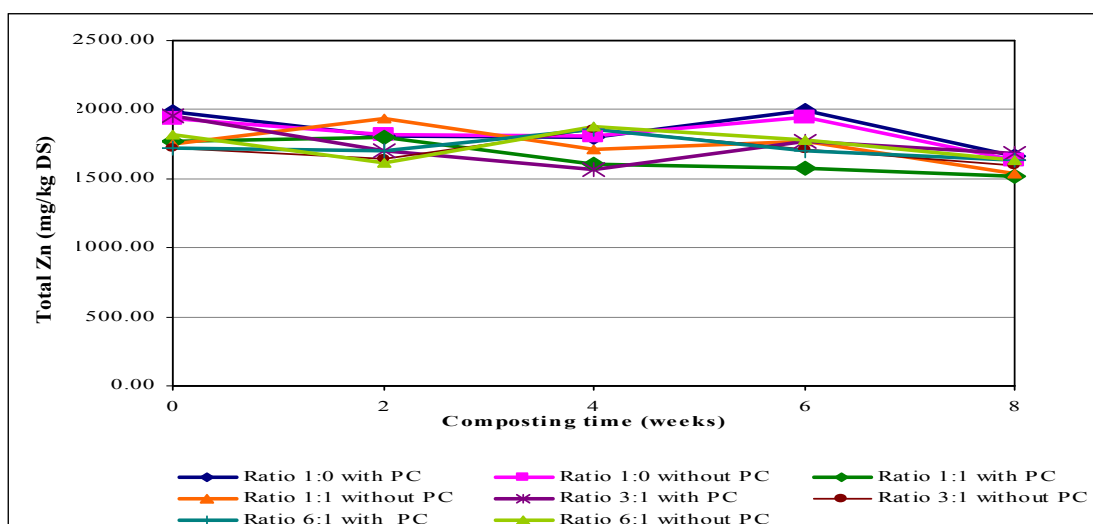


Figure 4.67 Change of total zinc concentration at each composting time.

Table 4.25 The average amount total zinc concentrations (mg/kg DS) of each experimental treatment in composting process.

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	1980.06 (42.03)	1811.44 (27.96)	1801.51 (19.76)	1995.12 (98.41)	1665.78 (62.66)
	Without PC	1937.42 (69.66)	1817.32 (13.74)	1810.54 (22.91)	1941.92 (94.62)	1632.13 (68.83)
1:1	With PC	1772.37 (150.01)	1796.69 (71.42)	1605.07 (91.21)	1571.39 (63.24)	1514.74 (44.11)
	Without PC	1755.31 (20.10)	1939.05 (120.86)	1712.61 (32.16)	1767.07 (26.10)	1534.75 (36.14)
3:1	With PC	1957.76 (66.61)	1706.62 (11.50)	1565.04 (53.50)	1774.40 (13.12)	1678.05 (159.49)
	Without PC	1718.43 (35.37)	1645.32 (53.69)	1860.71 (67.58)	1708.13 (49.61)	1595.11 (44.01)
6:1	With PC	1725.82 (24.28)	1706.55 (12.60)	1855.14 (80.09)	1705.73 (35.88)	1636.33 (52.73)
	Without PC	1820.05 (31.25)	1618.69 (11.58)	1872.59 (43.08)	1777.69 (114.11)	1632.76 (89.90)

Note: Values in parentheses are standard deviation (SD) of three replications

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization conditions, and composting time) of total zinc.

The main effect of mixing ratio of all treatments was significantly different ( $P < 0.001$ ). The main effect of steam sterilization conditions of all treatments was not significantly different at ( $P = 0.176$ ). The main effect of composting time of all treatments was significantly different at ( $P < 0.001$ ).

The interaction among mixing ratio, steam sterilization conditions, and composting time were significantly different ( $P < 0.001$ ) on within subject effect. It was also had an interaction between mixing ratios and steam sterilization conditions ( $P = 0.006$ ). The results of analytical statistics are show in Table 4.26.

**Table 4.26** The analysis of variance of total zinc.

Source	SS	df	MS	F	p-value
<b>Between - subject effects</b>					
Intercept	3.672E+08	1	3.672E+08	93694.655	<0.001
Steam sterilization	7845.684	1	7845.684	2.002	0.176
Mixing ratio	352022.214	3	117340.738	29.938	<0.001
Steam sterilization *Mixing ratio	69765.082	3	23255.027	5.933	0.006
Error	62711.549	16	3919.472		
<b>Within-subject effects</b>					
Composting time	612483.952	4	153120.988	33.606	<0.001
Composting time * Steam sterilization	86236.947	4	21559.237	4.732	0.002
Composting time * Mixing ratio	507128.973	12	42260.748	9.275	<0.001
Composting time * Steam sterilization* Mixing ratio	227357.466	12	18946.455	4.158	<0.001
Error	291607.425	64	4556.366		

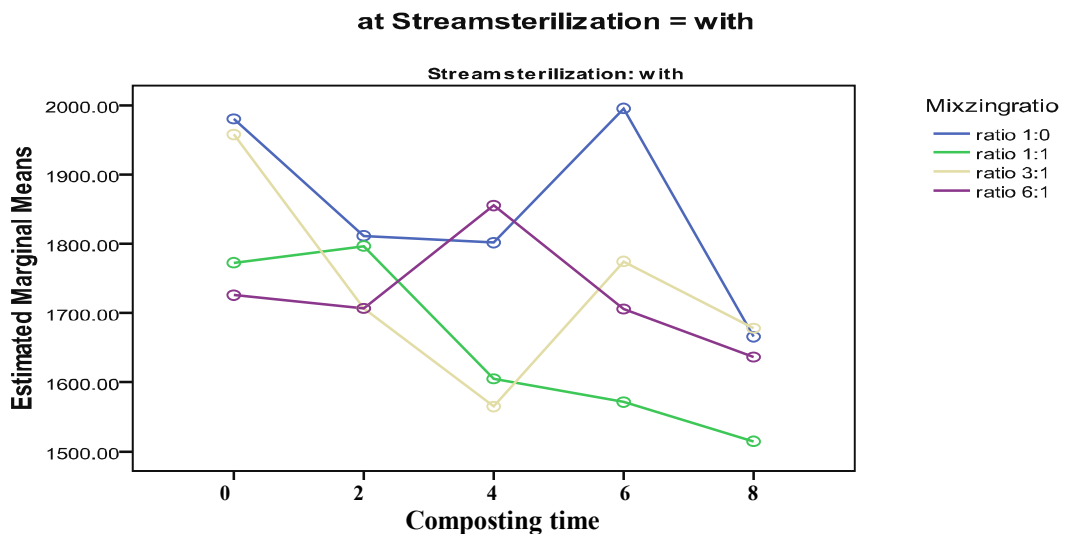
- When interaction exist among the three factor, F-test of ANOVA is used to test main effect of mixing ratio classified by each level of steam sterilization conditions (with PC/without PC) at each composting time. To test difference between groups by Bonferroni adjustment used to compare.

- With PC treatment, total zinc was found significant difference in 4 periods, except at week 8.

At week 0, the total zinc of mixing ratio 1:0 was significantly different from mixing ratio 6:1.

At week 4, the total zinc of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 3:1. And mixing ratio 6:1 was significantly different from mixing ratio 1:1, 3:1.

At week 6, the total zinc mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1, and 6:1. And mixing ratio 1:1 was significantly different from mixing ratio 3:1 as show in Figure 4.68.



**Figure 4.68** The average total zinc of with PC treatments.

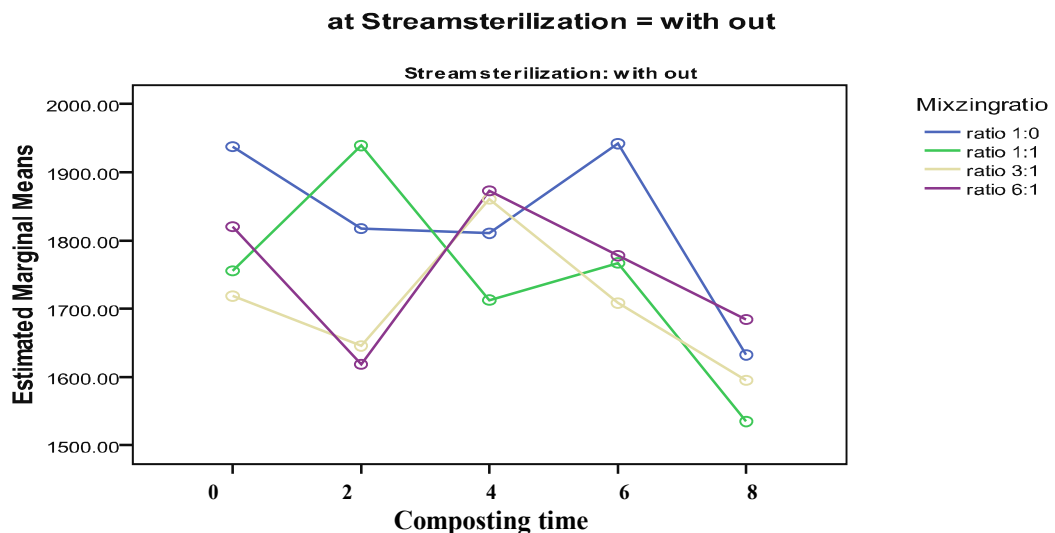
- Without PC treatment, total zinc were found significant difference in 4 periods, except at week 8. It was show in Figure 4.69.

At week 0, the total zinc of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 3:1.

At week 2, the total zinc of mixing ratio 1:0 was significantly different from mixing ratio 6:1. And mixing ratio 1:1 was significantly different from mixing ratio 1:1, 3:1, and 6:1.

At week 4, the total zinc mixing ratio 1:1 was significantly different from mixing ratio 3:1, and 6:1.

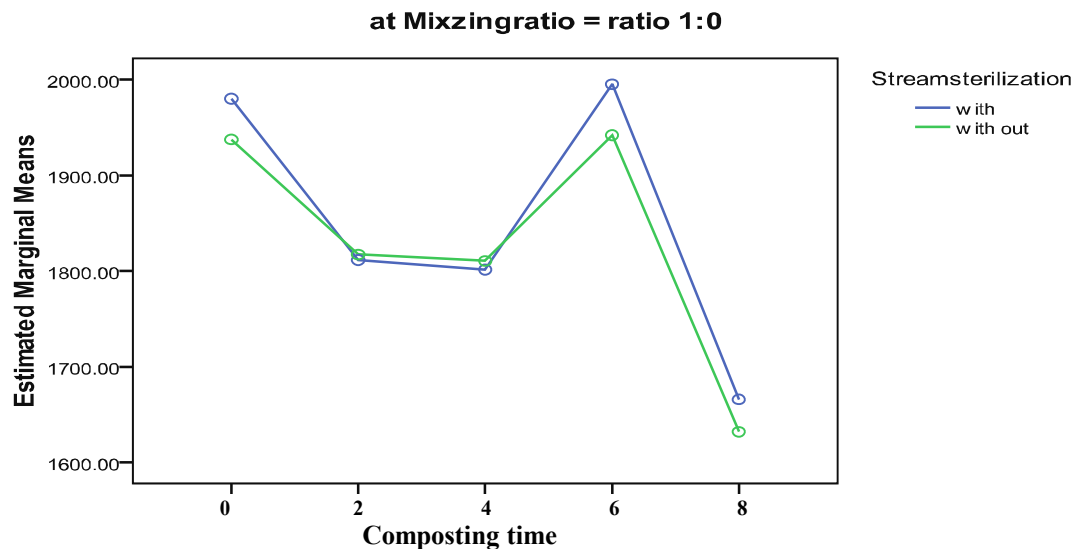
At week 6, the total zinc mixing ratio 1:0 was significantly different from mixing ratio 3:1.



**Figure 4.69** The average total zinc of without PC treatments.

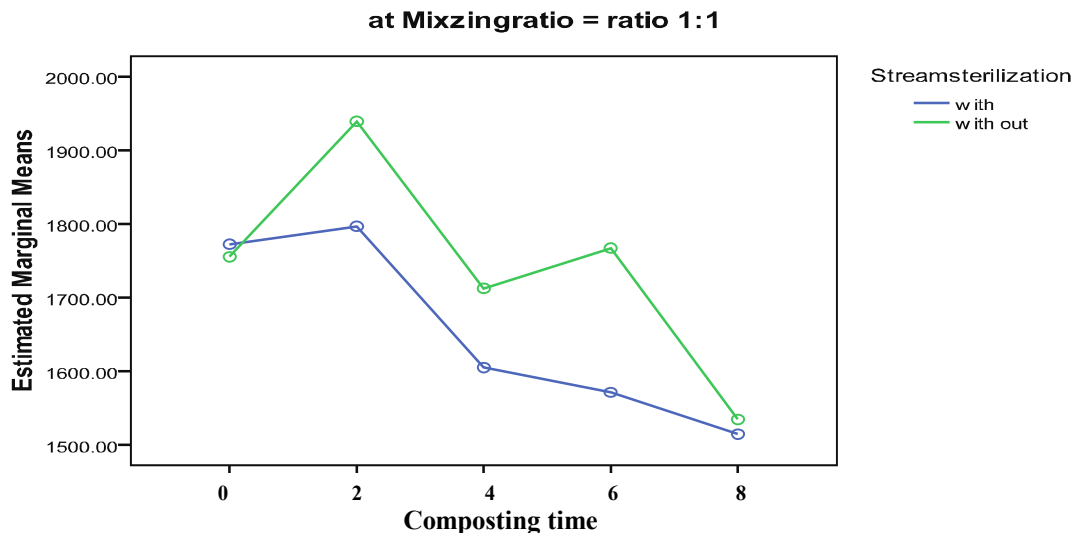
- To test the simple main effect of steam sterilization classified by each level of mixing ratio at each period. For testing of different between groups Bonferroni adjustment.

For mixing ratio 1:0, total zinc of with PC treatment were not significant from total zinc of without PC treatment in all periods as show in Figure 4.70.



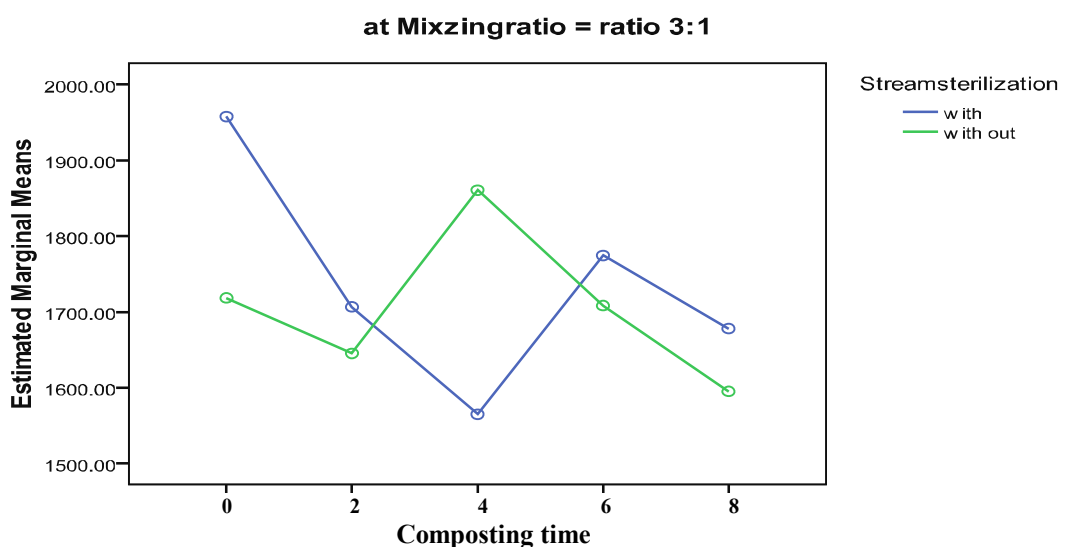
**Figure 4.70** The average total zinc of mixing ratio 1:0 in with PC and without PC treatments.

For mixing ratio 1:1, total zinc of with PC treatment were not significant from total zinc of without PC treatment in all periods.



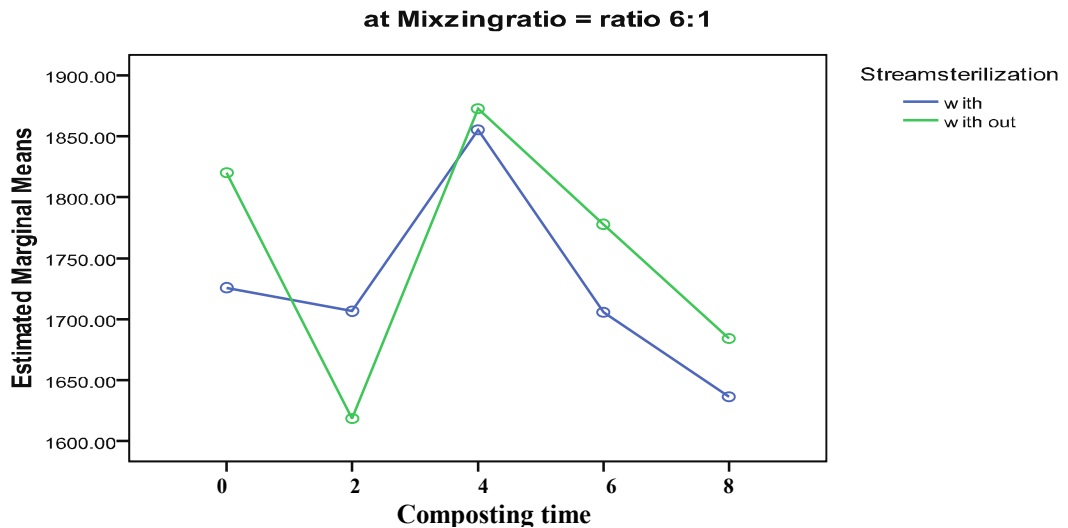
**Figure 4.71** The average total lead of mixing ratio 1:1 in with PC and without PC treatments.

For mixing ratio 3:1, total zinc were found significance in 2 periods, except week 2, week 6, and week 8. At week 0 and week 4, total zinc of with PC treatment was significantly different from without PC treatment.



**Figure 4.72** The average total zinc of mixing ratio 3:1 in with PC and without PC treatments.

For mixing ratio 6:1, the total zinc was found significance in 2 periods, except week 4, week 6, and week 8. At week 0, the total zinc of with PC treatment was significantly different from without PC treatment. At week 2, the total zinc of with PC treatment was significantly different from without PC treatment.



**Figure 4.73** The average total zinc of mixing ratio 6:1 in with PC and without PC treatments.

- To test the simple main effect of composting time at each level of time classified each level of mixing ratio. Then, test difference between groups by Bonferroni adjustment used to compare.

For 1:0 with PC treatment, the total zinc at week 0 was significantly different from composting time at week 2, 4, and 8. The total zinc at week 6 was significantly different from week 4 and 6.

For 1:1 with PC treatment, the total zinc at week 2 was significantly different from week 8.

For 3:1 with PC treatment, the total zinc at week 0 was significantly different from week 2, 4 and 8.

For 6:1 with PC treatment, the total zinc at week 4 was significantly different from week 2, 6, and 8.

For 1:0 without PC treatment, the total zinc at week 8 was significantly different from week 0, 2, and 6.

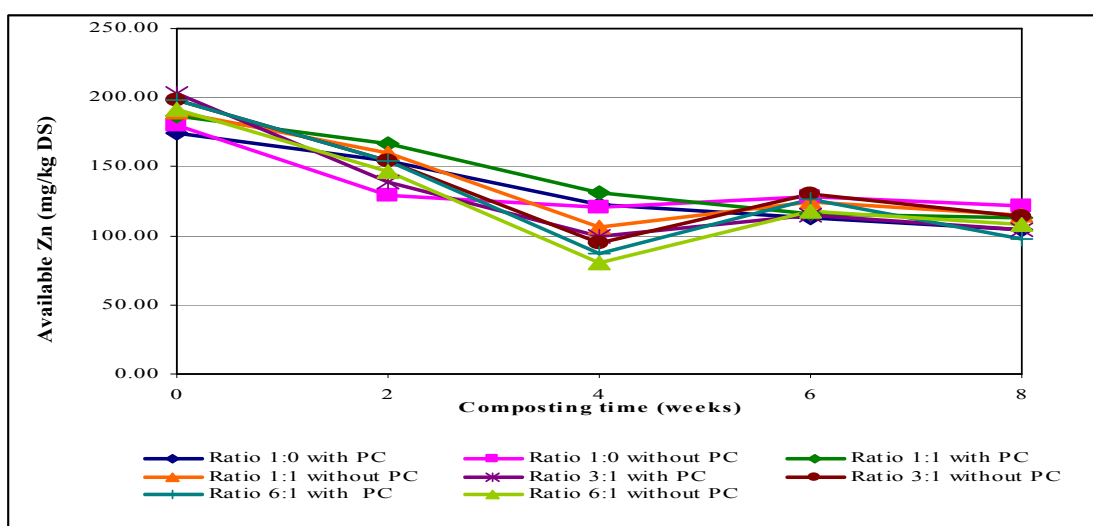
For 1:1 without PC treatment, the total zinc at week 2 was significantly different from week 0, 4, and 8. The total zinc at week 8 was significantly different from week 0, 4, and 6.

For 3:1 without PC treatment, the total zinc at week 4 was significantly different from week 2, 6, and 8.

For 6:1 without PC treatment, the total zinc at week 2 was significantly different from week 4.

#### 4.3.2.9 Available zinc

Available zinc concentration changes at each composting time in composting process shown in Figure 4.74 and Table 4.27. The available zinc concentration trends of all treatments had a similar trend. They had continuously decreasing values in week 0 to week 4. At week 4 the average available zinc concentrations were rapidly decreased and slightly increasing until week 6. Then, they were decreased in week 8. The maximum concentration was found at week 0 for 3:1 with PC treatment at week 0 (203.28 mg/kg DS). The maximum in without PC treatments was found in 6:1 without treatment at week 0 (198.18 mg/kg DS).



**Figure 4.74** Change of available zinc at each composting time

**Table 4.27** The average amount available zinc concentrations (mg/kg DS) of each experimental treatment in composting process.

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	174.72 (10.98)	154.18 (4.56)	122.23 (2.74)	112.75 (4.61)	104.19 (6.80)
	Without PC	180.0 (0.16)	129.10 (3.48)	121.15 (5.83)	128.71 (1.30)	122.08 (3.21)
1:1	With PC	186.41 (4.77)	166.68 (15.75)	130.80 (4.31)	115.89 (2.16)	113.11 (2.58)
	Without PC	189.64 (2.84)	160.34 (5.60)	106.19 (2.43)	124.08 (4.80)	115.33 (14.58)
3:1	With PC	203.28 (8.0)	139.07 (3.05)	99.22 (3.26)	115.25 (4.13)	103.97 (0.23)
	Without PC	198.10 (9.87)	154.07 (6.35)	95.30 (13.16)	130.0 (4.08)	114.36 (0.50)
6:1	With PC	198.18 (6.25)	153.74 (4.23)	87.59 (2.68)	97.54 (1.17)	132.67 (1.50)
	Without PC	191.41 (10.84)	146.64 (12.76)	80.25 (1.24)	107.84 (1.48)	128.75 (0.84)

Note: Values in parentheses are standard deviation (SD) of three replications

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization conditions, and composting time) of available zinc values.

The main effect of mixing ratio of all treatments was not significantly different ( $P=0.771$ ). The main effect of steam sterilization conditions of all treatments was significantly different ( $P<0.001$ ). The main effect of composting time of all treatments was significantly different ( $P< 0.001$ ).

The interaction among mixing ratio, steam sterilization conditions, and composting time were significantly different ( $P < 0.001$ ) on within subject effect. It was also had an interaction between mixing ratios and steam sterilization conditions ( $p = 0.023$ ), composting time and steam sterilization condition ( $P < 0.001$ ), composting time and mixing ratio ( $P < 0.001$ ). The results of analytical statistics are show in Table 4.28.

**Table 4.28** The analysis of variance of available zinc.

Source	SS	df	MS	F	p-value
<b>Between - subject effects</b>					
Intercept	2200997.526	1	2200997.526	51277.706	<0.001
Steam sterilization	1556.596	3	518.865	12.088	<0.001
Mixing ratio	3.767	1	3.767	0.088	0.771
Steam sterilization * Mixing ratio	541.135	3	180.378	4.202	0.023
Error	686.769	16	42.923		
<b>Within-subject effects</b>					
Composting time	119745.046	4	29936.261	740.370	<0.001
Composting time * Steam sterilization	1686.272	4	421.568	10.426	<0.001
Composting time * Mixing ratio	8129.974	12	677.498	16.756	<0.001
Composting time * Steam sterilization* Mixing ratio	2096.548	12	174.712	4.321	<0.001
Error	2587.789	64	40.434		

- When interaction exist among the three factor, F-test of ANOVA is used to test main effect of mixing ratio classified by each level of steam sterilization conditions (with PC/without PC) at each composting time. To test difference between groups by Bonferroni adjustment used to compare.

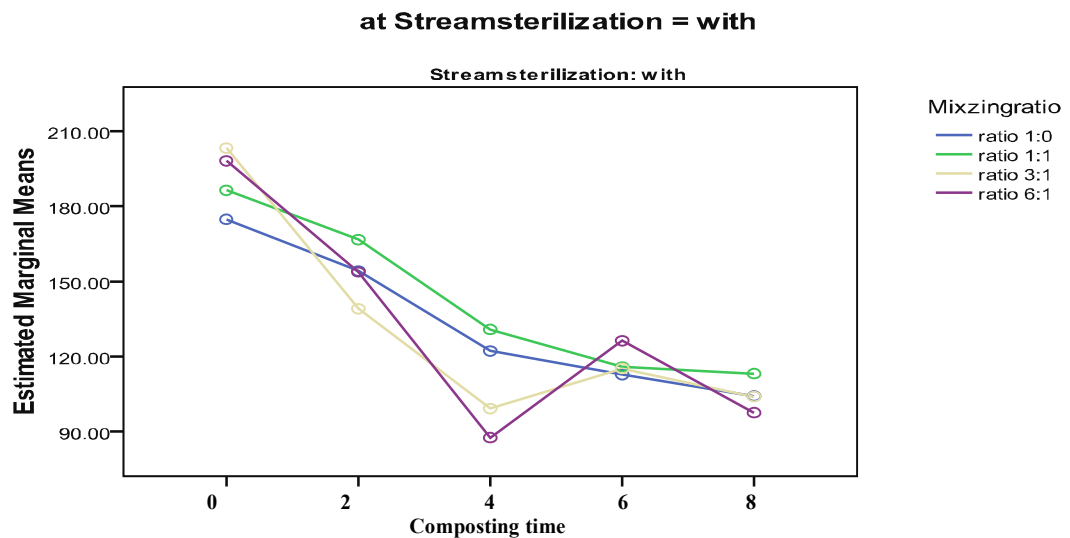
- With PC treatment, available zinc was found significant difference in all period as shoe in Figure 4.75.

At week 0, the available zinc of mixing ratio 1:0 was significantly different from mixing ratio 3:1 and 6:1.

At week 2, the available zinc of mixing ratio 1:1 was significantly different from mixing ratio 3:1.

At week 4, the available zinc of mixing ratio 1:0 was significantly different from mixing ratio 3:1 and 6:1. The available zinc of mixing ratio 1:1 was significantly different from mixing ratio 3:1 and 6:1. And the available zinc of mixing ratio 3:1 was significantly different from mixing ratio 6:1.

At week 6, the available zinc of mixing ratio 6:1 was significantly different from mixing ratio 1:0, 3:1, and 6:1.



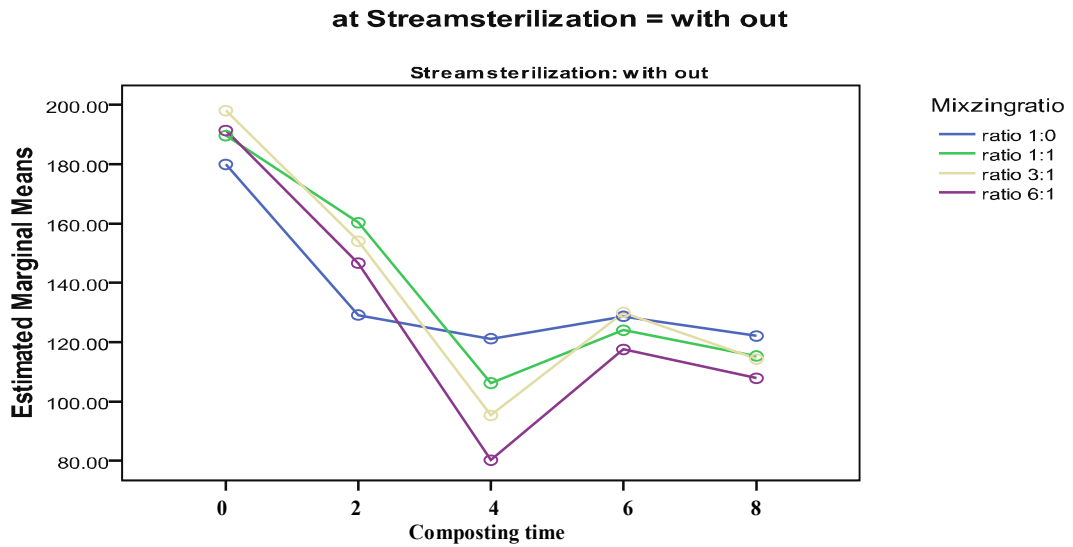
**Figure 4.75** The average available zinc of with PC treatments.

- Without PC treatment, available zinc was found significant difference in 2 periods, except week 0, week 8.

At week 2, the available zinc of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 3:1.

At week 4, the available zinc of mixing ratio 1:0 was significantly different from mixing ratio 3:1 and 6:1. The available zinc of mixing ratio 1:1 was significantly different from mixing ratio 6:1.

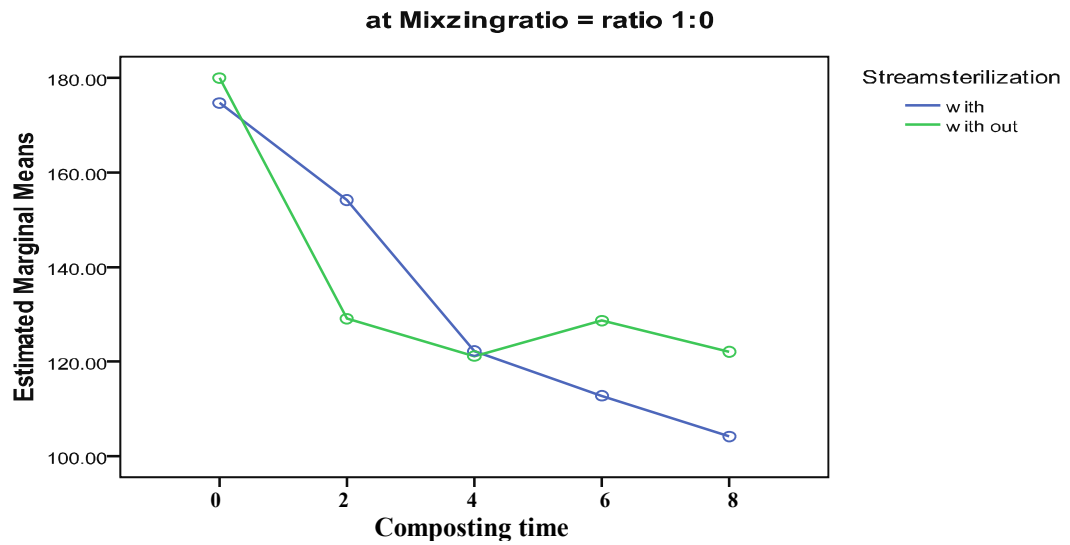
At week 6, the available zinc of mixing ratio 1:0 was significantly different from mixing ratio 3:1 and 6:1. The available zinc of mixing ratio 1:1 was significantly different from mixing ratio 3:1 and 6:1. And the available zinc of mixing ratio 3:1 was significantly different from mixing ratio 6:1.



**Figure 4.76** The average available zinc of without PC treatments.

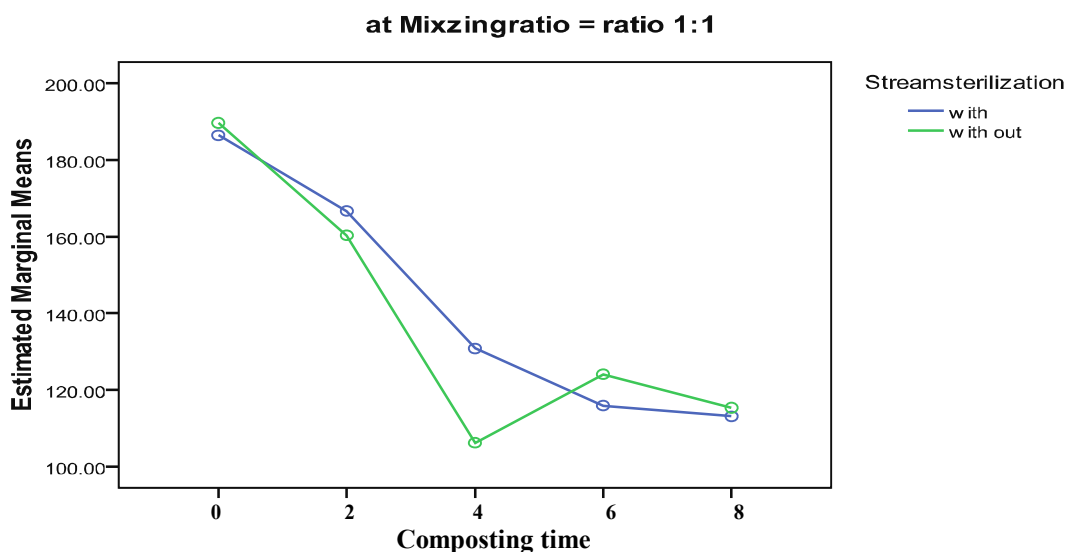
- To test the simple main effect of steam sterilization classified by each level of mixing ratio at each period. For testing of different between groups Bonferroni adjustment.

For mixing ratio 1:0, available zinc were found significant in periods, except week 0 and week 4 as show Figure 4.77. At week 2, available zinc of with PC treatment was significantly different from without PC treatment. At week 6, available zinc of with PC treatment was significantly different from without PC treatment. At week 8, available zinc of with PC treatment was significantly different from without PC treatment.



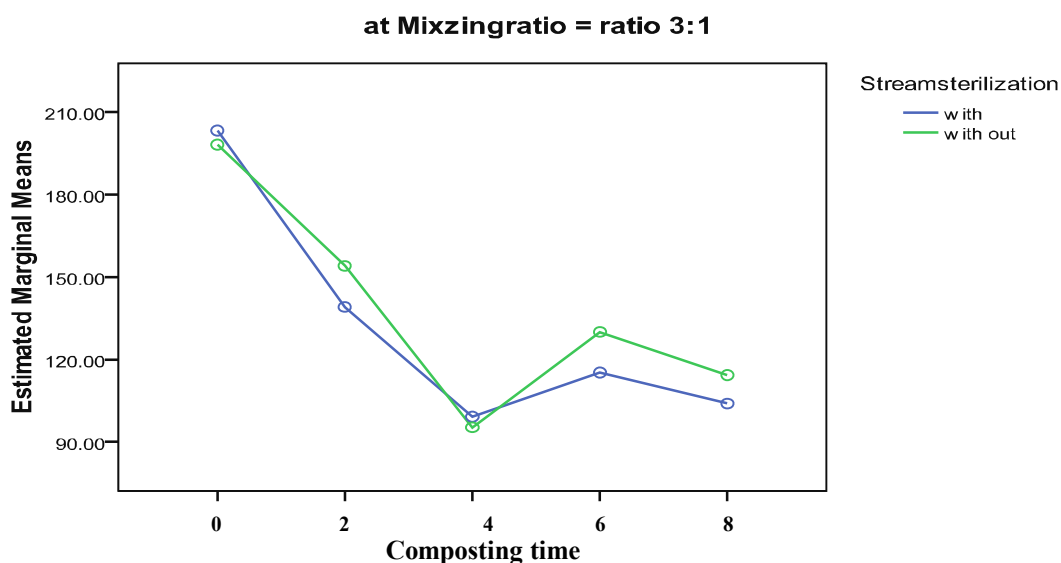
**Figure 4.77** The average available zinc of mixing ratio 1:0 in with PC and without PC treatments.

- To test the simple main effect of steam sterilization at each level of time classified each level of mixing ratio. And to test difference between groups by Bonferroni adjustment used to compare. In mixing ratio 1:0, 1:1, 3:1, and 6:1, the available zinc of with PC treatment were not significant from and without PC treatment at all periods.



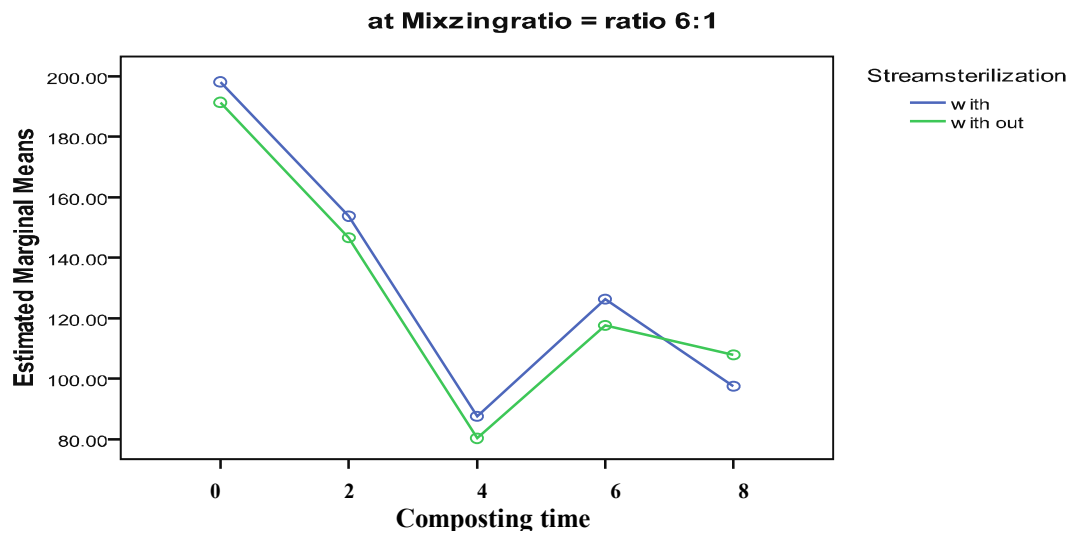
**Figure 4.78** The average available zinc of mixing ratio 1:1 in with PC and without PC treatments.

For mixing ratio 3:1, available zinc were significant in 3 periods, except week 0, week 4. At week 2, available zinc of with PC treatment was significantly different from without PC treatment. At week 6, available zinc of with PC treatment was significantly different from without PC treatment. At week 8, available zinc of with PC treatment was significantly different from without PC treatment.



**Figure 4.79** The average available zinc of mixing ratio 3:1 in with PC and without PC treatments.

For mixing ratio 6:1, available zinc were significant in 3 periods, except week 0, week 2. At week 4, available zinc of with PC treatment was significantly different from without PC treatment. At week 6, available zinc of with PC treatment was significantly different from without PC treatment. At week 8, available zinc of with PC treatment was significantly different from without PC treatment.



**Figure 4.80** The average available zinc of mixing ratio 6:1 in with PC and without PC treatments.

- To test the simple main effect of composting time at each level of time classified each level of mixing ratio. And to test difference between groups by Bonferroni adjustment used to compare.

For 1:0 with PC treatment, the available zinc of composting time week 0 was significantly different from composting time at week 2, 4, 6, and 8. The available zinc at week 2 was significantly different from composting time at week 4, 6, and 8. The available zinc at week 8 was significantly different from composting time at week 0 and 2.

For 1:1 with PC treatment, the available zinc of composting time at week 0 was significantly different from composting time at 2, 4, 6, and 8. The available zinc at week 2 was significantly different from composting time at week 4, 6, and 8. The available zinc at week 8 was significantly different from composting time at week 0 and 2.

For 3:1 with PC treatment, the available zinc of composting time at week 0 was significantly different from composting time at week 2, 4, 6, and 8. The available zinc at week 2 was significantly different from composting time at week 4, 6, and 8. The available zinc at week 6 was significantly different from composting time at week 4.

For 6:1 with PC treatment, the available zinc of composting time at week 0 was significantly different from composting time at week 2, 4, 6, and 8. The available zinc at week 2 was significantly different from composting time at week 4, 6, and 8. The available zinc at week 4 was significantly different from composting time at week 6 and 8. The available zinc at week 8 was significantly different from composting time at week 6.

For 1:0 without PC treatment, the available zinc of composting time week 0 was significantly different from composting time at week 2, 4, 6, and 8.

For 1:1 without PC treatment, the available zinc of composting time 0 was significantly different from composting time at 2, 4, 6, and 8. The available zinc at week 2 was significantly different from composting time at week 4, 6, and 8.

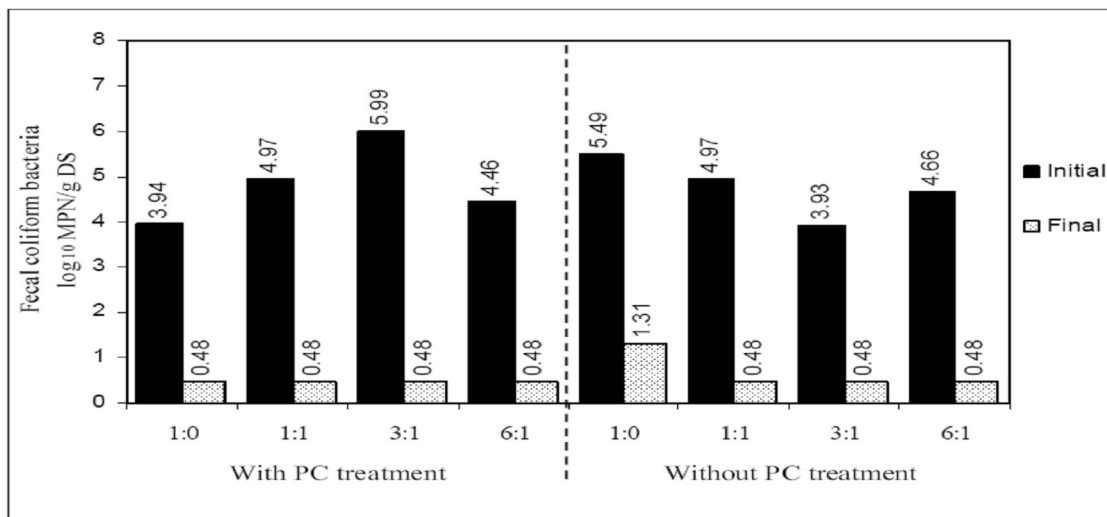
For 3:1 without PC treatment, the available zinc of composting time at week 0 was significantly different from composting time at week 2, 4, 6, and 8. The available zinc at week 2 was significantly different from composting time at week 4, 6, and 8. The available zinc at week 4 was significantly different from composting time at week 6.

For 6:1 without PC treatment, the available zinc of composting time at week 0 was significantly different from composting time at week 2, 4, 6, and 8. The available zinc at week 2 was significantly different from composting time at week 4, 6, and 8. The available zinc at week 4 was significantly different from composting time at week 6 and 8.

### 4.4 Change of sewage sludge mixed with grass clipping biological characteristics in composting process.

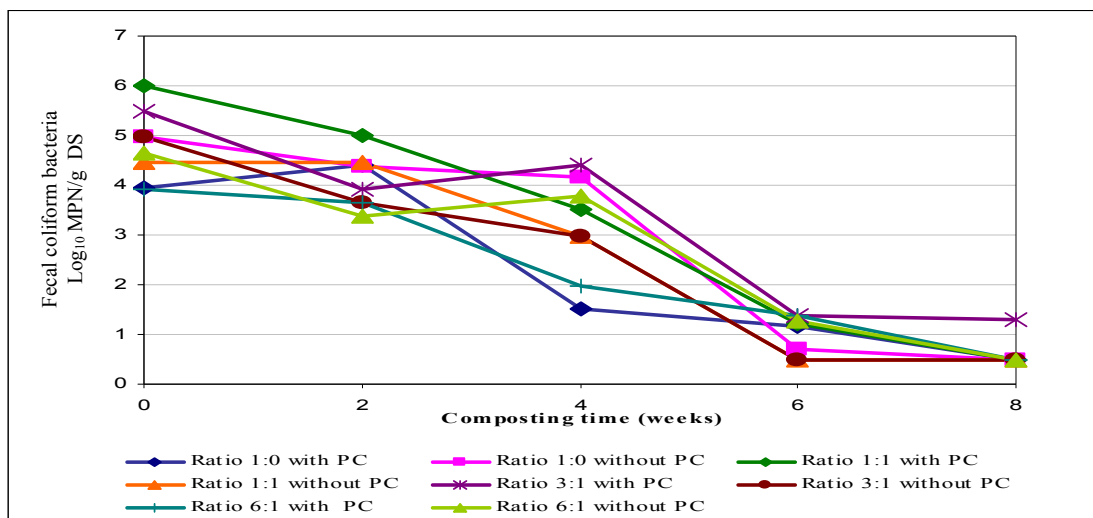
#### 4.4.1 Fecal coliform bacteria

The results of fecal coliform bacteria at the initial stage of all treatments for both with PC and without PC were higher than those fecal coliform bacteria at the final stage of composting time. Fecal coliform bacteria ranges at initial stage were found in treatment with PC were  $9.53 \times 10^3$  to  $1.6 \times 10^6$  MPN/g DS, and treatment without PC  $3 \times 10^4$  to  $1.72 \times 10^5$  MPN/g DS. Fecal coliform range at final stage were found in treatment with PC were  $\leq 3$  to  $2.61 \times 10^1$  MPN/g DS, and treatment without PC  $\leq 3$  MPN/g DS.



**Figure 4.81** Fecal coliform bacteria at the initial and final stage in composting process

The fecal coliform bacteria changes at each composting time in composting process are showed in Figure 4.82 and Table 4.29. Figure 4.82 showed that the number of faecal coliform bacteria were considerable decreased after 4 weeks of composting period. At week 8, the detected faecal coliform bacteria in all treatments were less than 3 MPN/g dry solid, except the treatment of a mixing ratio 3:1 with PC was found only  $2.61 \times 10^1$  MPN/g DS.



**Figure 4.82** Change of fecal coliform bacteria at each composting time.

**Table 4.29** The average of fecal coliform bacteria (MPN/g DS) of each experimental treatment in composting process.

Mixing ratio	Steam sterilization Condition	Composting time (weeks)				
		0 week	2 week	4 week	6 week	8 week
1:0	With PC	$1.09 \times 10^4$	$3.6 \times 10^4$	$3.2 \times 10^1$	$1.57 \times 10^1$	$\leq 3$
	Without PC	$2.73 \times 10^5$	$6.5 \times 10^4$	$1.49 \times 10^4$	5.47	$\leq 3$
1:1	With PC	$1.25 \times 10^6$	$3.32 \times 10^5$	$3.18 \times 10^3$	$3.7 \times 10^1$	$\leq 3$
	Without PC	$3.0 \times 10^4$	$3.77 \times 10^4$	$8.10 \times 10^2$	$\leq 3$	$\leq 3$
3:1	With PC	$1.60 \times 10^6$	$1.79 \times 10^4$	$2.61 \times 10^4$	$5.67 \times 10^1$	$2.61 \times 10^1$
	Without PC	$1.72 \times 10^5$	$6.57 \times 10^3$	$9.3 \times 10^2$	$\leq 3$	$\leq 3$
6:1	With PC	$9.53 \times 10^3$	$6.57 \times 10^3$	$9.2 \times 10^1$	$2.7 \times 10^1$	$\leq 3$
	Without PC	$5.33 \times 10^4$	$3.43 \times 10^3$	$6 \times 10^3$	$1.97 \times 10^1$	$\leq 3$

- Analytical statistics results

The three-way Analyses of Variance with one Repeated Factors was used to analyze main effects mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization conditions, and composting time) of available zinc values.

The main effect of mixing ratio of all treatments was not significantly different ( $P = 0.198$ ). The main effect of steam sterilization conditions of all treatments was significantly different ( $P=0.020$ ). The main effect of composting time of all treatments was significantly different ( $P < 0.001$ ).

The interaction among mixing ratio, steam sterilization conditions, and composting time were significantly different ( $P=0.002$ ) on within subject effect. It was also had an interaction between mixing ratios and steam sterilization conditions ( $P < 0.001$ ), composting time and steam sterilization condition ( $P=0.002$ ), composting time and mixing ratio ( $P = 0.001$ ). The results of analytical statistics are show in Table 4.30

**Table 4.30** The analysis of variance of fecal coliform bacteria.

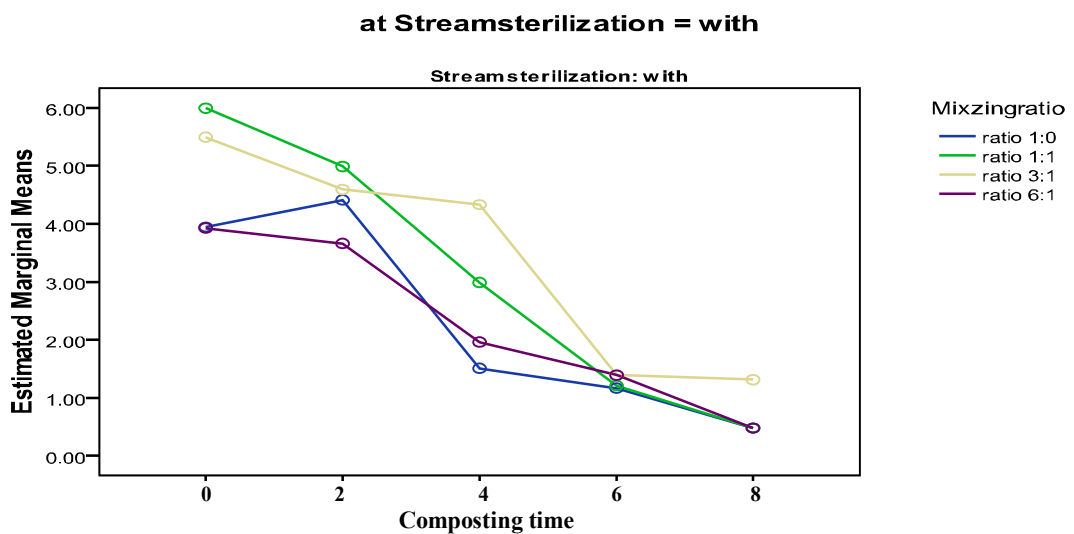
Source	SS	df	MS	F	p-value
<b>Between - subject effects</b>					
Intercept	882.702	1	882.702	2496.270	<0.001
Steam sterilization	4.632	3	1.544	4.366	0.020
Mixing ratio	0.637	1	0.637	1.800	0.198
Steam sterilization *Mixing ratio	11.422	3	3.807	10.767	<0.001
Error	5.658	16	0.354		
<b>Within-subject effects</b>					
Composting time	337.237	2.781	121.253	431.539	<0.001
Composting time * Steam sterilization	4.540	2.781	1.632	5.810	0.002
Composting time * Mixing ratio	10.016	8.344	1.200	4.272	0.001
Composting time * Steam sterilization* Mixing ratio	8.510	8.344	1.020	3.630	0.002
Error	12.504	44.500	0.281		

- When interaction exist among the three factor, F-test of ANOVA is used to test main effect of mixing ratio classified by each level of steam sterilization conditions (with PC/without PC) at each composting time. To test difference between groups by Bonferroni adjustment used to compare.

- With PC treatment, faecal coliform bacteria were found significant difference in week 0, week 4.

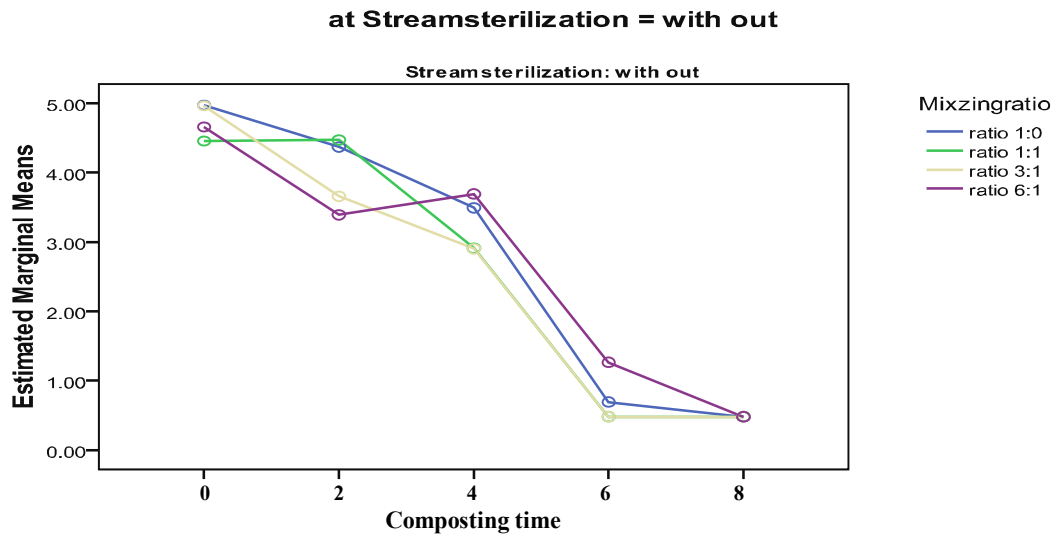
At week 0, the faecal coliform bacteria of mixing ratio 1:0 was significantly different from mixing ratio 1:1. Mixing ratio 6:1 was significantly different from mixing ratio 1:1.

At week 4, the faecal coliform of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 3:1. Mixing ratio 3:1 was significantly different from mixing ratio 1:1 and 6:1.



**Figure 4.83** The average faecal coliform bacteria of with PC treatments.

- Without PC treatment, fecal coliform were found significant difference at only week 6. At week 6, fecal coliform bacteria of mixing ratio 6:1 was significantly different from mixing ratio 1:0, 1:1, and 3:1.



**Figure 4.84** The average fecal coliform bacteria of without PC treatments.

- To test the simple main effect of steam sterilization at each level of time classified each level of mixing ratio. And to test difference between groups by Bonferroni adjustment used to compare. For mixing ratio 1:0, 1:1, 3:1, and 6:1, the fecal coliform of with PC treatment were not significant from and without PC treatment at all periods.

- To test the simple main effect of composting time at each level of time classified each level of mixing ratio. And to test difference between groups by Bonferroni adjustment used to compare.

For 1:0 with PC treatment, the fecal coliform of composting time week 0 was significantly different from composting time at week 4, 6, and 8. Composting time at week 2 was significantly different from composting time at week 4, 6, and 8. Composting time at week 4 was significantly different from composting time at week 8.

For 1:1 with PC treatment, the fecal coliform of composting time at week 0 was significantly different from composting time at 4, 6, and 8. And composting time at week 2 was significantly different from composting time at week 4, 6, and 8. Composting time at week 4 was significantly different from composting time at week 8.

For 3:1 with PC treatment, the fecal coliform of composting time at week 0 was significantly different from composting time at week 6 and 8. Composting time at week 2 was significantly different from composting time at week 6 and 8. Composting time at week 4 was significantly different from composting time at week 6 and week 8.

For 6:1 with PC treatment, the fecal coliform of composting time at week 0 was significantly different from composting time at week 4, 6 and 8. Composting time at week 2 was significantly different from composting time at week 4, 6, and 8. Composting time at week 4 was significantly different from composting time at week 8. Composting time at week 6 was significantly different from composting time at week 8.

For 1:0 with PC treatment, the fecal coliform of composting time week 0 was significantly different from composting time at week 6 and week 8. Composting time at week 2 was significantly different from composting time at week 6 and week 8. Composting time at week 4 was significantly different from composting time at week 6 and week 8.

For 1:1 with PC treatment, the fecal coliform of composting time 0 was significantly different from composting time at 4, 6, and 8. And composting time at week 2 was significantly different from composting time at week 4, 6, and 8. Composting time at week 4 was significantly different from composting time at week 6, and 8. Composting time at week 6 was significantly different from composting time at week 8.

For 3:1 without PC treatment, the fecal coliform of composting time at week 0 was significantly different from composting time at week 2, 4, 6, and 8. Composting time at week 2 was significantly different from composting time at week 0, 6, and 8. Composting time at week 4 was significantly different from composting time at week 0, 6, and 8.

For 6:1 without PC treatment, the fecal coliform of composting time at week 0 was significantly different from composting time at week 2, 4, 6, and 8. Composting time at week 2 was significantly different from composting time at week 6 and week 8. Composting time at week 4 was significantly different from composting time at week 6 and week 8.

#### 4.4.2 Parasitic contamination

The parasite contamination was found during composting time as show Table 4.31.

At week 0, the parasite contamination was found in many species of viable parasite egg, active form of protozoan cysts, and viable larva. The viable parasite egg was found Hook worm egg, *Taenia* spp. egg, *Ascaris* spp. egg. The active form protozoa cyst was found *Entamoeba histolytica* cyst.

At week 2, the parasite contamination was clearly decreasing when compare with week 0. The viable parasite egg was found only *Trichuris* spp. egg. This period, the viable larva of *strongyloides stercoralis* at first time. The active form of *Entamoeba histolytica* cyst. was found in almost treatments except 1:0 without PC treatment .

At week 4, the parasite contamination was found only active form of *Entamoeba histolytica* cyst and viable *strongyloides stercoralis* larva. The active form of *Entamoeba histolytica* cyst was found in almost treatments except 1:1 without PC treatment. The viable *strongyloides stercoralis* larva was found in almost treatments expect 1:0 with PC, 3:1 with PC, 6:1 with PC, and 6:1 without PC treatment.

At week 6, the contaminated parasite had changed the living phage in larva and protozoa cyst. The *Entamoeba histolytica* cyst was found in two form; active form and inactive form. The nonviable *strongyloides stercoralis* larva was found in 6:1 without PC treatment. This period was found viable *Toxocara* spp. egg in 6:1 without PC treatment.

At week 8, the parasite in almost treatments were not detectable. Only the 1:0 without PC treatment was found nonviable *strongyloides stercoralis* larva and nonhatch hook worm egg.

**Table 4.31** The parasitic contamination of during composting process.

Treatment	Composting time(weeks)				
	0 week	2 week	4 week	6 week	8 week
Ratio 1:0 With PC	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (inactive form)	ND
Ratio 1:0 Without PC	<i>Entamoeba histolytica</i> cyst (active form)  Hook worm egg (viable egg)	<i>Strongyloides stercoralis</i> larva (viable larva)	<i>Entamoeba histolytica</i> cyst (active form)  <i>Strongyloides stercoralis</i> larva (viable larva)	<i>Entamoeba histolytica</i> cyst (active form)	<i>Strongyloides stercoralis</i> larva (nonviable larva)  Hook worm egg ( non-hatch egg )
Ratio 1:1 With PC	<i>Entamoeba histolytica</i> cyst (active form)  <i>Taenia</i> spp. egg (viable egg)  <i>Strongyloides stercoralis</i> larva (viable larva)	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)  <i>Strongyloides Stercoralis</i> larva (viable larva)	<i>Entamoeba histolytica</i> cyst (active form)	ND <sup>1</sup>
Ratio 1:1 Without PC	<i>Entamoeba histolytica</i> cyst (active form)  <i>Strongyloides stercoralis</i> larva (viable larva)	<i>Entamoeba histolytica</i> cyst (active form)	<i>Strongyloides stercoralis</i> larva (viable larva)	<i>Entamoeba histolytica</i> cyst (active form)  <i>Strongyloides stercoralis</i> larva (viable larva)	ND <sup>1</sup>
Ratio 3:1 With PC	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)  <i>Strongyloides stercoralis</i> larva (viable larva)	<i>Entamoeba histolytica</i> cyst (inactive form)  <i>Strongyloides stercoralis</i> larva (viable larva)	ND <sup>1</sup>
Ratio 3:1 Without PC	<i>Entamoeba histolytica</i> cyst (active form)  <i>Ascaris</i> spp. egg (viable egg)	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)	ND <sup>1</sup>

Note: <sup>1</sup> ND = non-detectable

**Table 4.32** The parasitic contamination during composting process (Cont).

Treatment	Composting time(weeks)				
	0 week	2 week	4 week	6 week	8 week
Ratio 6:1 With PC	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)	ND <sup>1</sup>
	Hook worm egg (viable egg)	<i>Tricuris</i> spp. egg (viable egg)		Toxocara spp. egg (viable egg)	
Ratio 6:1 Without PC	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)	<i>Entamoeba histolytica</i> cyst (active form)	ND <sup>1</sup>
				<i>Strongyloides stercoralis</i> larva (nonviable larva)	ND <sup>1</sup>

Note: <sup>1</sup> ND = non-detectable

#### 4.5 Quality of end product form sewage sludge mixed with grass clippings

The consideration of total heavy metal was contained in end product of all treatments when compare the guideline and standard for sewage sludge for agricultural as below; the total heavy metal was in line the acceptable range of US.EPA. In case of total copper concentration was higher concentration than the standard for organic compost by and Department of Agricultural and guideline for sewage sludge and night soil application were established by Bangkok Metropolitan Administration (BMA).

The faecal coliform bacteria and parasitic contamination was lower than when comparing the guideline and standard for sewage sludge for agricultural of US.EPA. These results of all treatments met to biosolids class A.

**Table 4.33** The comparison end product physical and chemical characteristics with guidelines and standards.

Mixing ratio	Steam sterilization Condition	pH	Total Cd (mg/kg)	Total Cu (mg/kg)	Total Ni (mg/kg)	Total Pb (mg/kg)	Total Zn (mg/kg)
1:0	With PC	6.19	1.55	2378.18	164.78	69.20	1665.78
	without PC	6.43	1.58	2377.63	165.85	60.04	1632.13
1:1	With PC	6.08	1.59	2128.05	165.30	59.60	1514.74
	without PC	6.12	1.64	2161.17	169.75	72.23	1534.75
3:1	With PC	5.96	1.65	2237.30	176.64	70.81	1678.05
	without PC	6.36	1.67	2221.78	176.0	67.22	1595.11
6:1	With PC	6.01	1.64	2475.48	172.11	57.13	1636.33
	without PC	6.16	1.62	2350.85	171.82	55.41	1632.76
USEPA <sup>1</sup>		-	85	4300	420	840	7500
BMA <sup>2</sup>		< 5	≤ 20	≤ 900	≤ 400	≤ 1000	≤ 3000
DOA <sup>3</sup>		5.5 - 8.5	≤ 5	≤ 500	-	≤ 500	-

Note: <sup>1</sup> The ceiling concentration for heavy metals in biosolids for land application by United stated Environmental Protection Agency (US.EPA).

<sup>2</sup> The recommendation for sewage sludge and night soil application to agricultural by Bangkok Administration (BMA).

<sup>3</sup> The standard for organic compost by Department of Agricultural (DOA), Thailand.

**Table 4.34** The comparison end product biological characteristics with guideline and standard.

Mixing ratio	Steam sterilization Condition	Fecal coliform bacteria (MPN/g DS)	Parasite contamination
1:0	With PC	$\leq 3$	ND <sup>1</sup>
	Without PC	$\leq 3$	<i>Strongyloides stercoralis</i> larva (nonviable larva) Hook worm egg (nonhatch egg)
1:1	With PC	$\leq 3$	ND <sup>1</sup>
	Without PC	$\leq 3$	ND <sup>1</sup>
3:1	With PC	$2.61 \times 10^1$	ND <sup>1</sup>
	Without PC	$\leq 3$	ND <sup>1</sup>
6:1	With PC	$\leq 3$	ND <sup>1</sup>
	Without PC	$\leq 3$	ND <sup>1</sup>
Class A <sup>2</sup>		$< 1 \times 10^3$	$< 1$ viable helminthes ova
Class B <sup>3</sup>		$2 \times 10^6$	-

Note: <sup>1</sup> ND = non-detectable

<sup>2</sup> Class A = requirement for applied onto public use site and certain crop, pathogeneses destruction must be complete.

<sup>3</sup> Class B = requirement for applied on to grain and forage crop, pasture, grassland and timberland.

## CHAPTER V

### DISCUSSION

#### 5.1 Characteristics of sewage sludge and glass clippings

##### 5.1.1 Characteristics of sewage sludge

The studied sewage sludge was digested sewage sludge from anaerobic digester system of Nongkhem wastewater treatment plant. The results are showed high moisture content ( $78.09 \pm 0.63\%$ ). In addition, it had total solid  $21.90 \pm 0.63\%$  and volatile solid  $40.11 \pm 0.33\%$ . These were closed to the value the study of AIT (10) which had total solid 13-24%, volatile solid 26-60%, and moisture content 79-87%. The characteristic indicated high moisture content would leads to anaerobic conditions through water logging. It will prevent and halt the ongoing composting activities (42).

The total heavy metals in studied sewage sludge were lower than pollutant limit for land application of biosolids established by the US.EPA (36). Moreover, the available heavy metal was presented in low concentration and available lead was not found in the studied sewage sludge. The comparing of total heavy metal concentration in studied sewage sludge with total heavy metals in Dacera et al's study (43), who studied on the characteristic of Nongkhem sewage sludge, found that the previous study was higher than those of total heavy metal in this studied sewage sludge. Total Cd was 4.8 mg/kg DS, total Cu was 3043 mg/kg DS, total Ni was 298 mg/kg DS, total Pb was 175.2, and total Zn was 1908 mg/kg DS. The result indicated the metal concentration in sewage sludge was in a wide variation. Nuanjun. P *et al* (36) did a studied on sewage sludge characteristics from three central wastewater treatment plants in Bangkok. They found a variation of total heavy metals which according to sewage sludge source and sampling time. Thus, the heavy metal concentrations in sewage sludge should be considerate before application.

The fecal coliform bacteria in studied sewage sludge were counted  $1.09 \times 10^4$  MPN/g DS. It was similar to a study of AIT (11) which found that the number fecal coliform bacteria was  $1 \times 10^4$  to  $1 \times 10^6$  MPN/g DS. The number of fecal coliform bacteria in studied sewage sludge was exceeded the US.EPA regulation of class A sewage sludge (5). Moreover, the regulation for sewage sludge class A required absent the viable helminth ova. The parasite contamination in studied sewage sludge was found an active form of *Entamoeba histolytica* cyst and viable hook worm egg. Regarding to the number of fecal coliform bacteria and parasite found in studied sewage sludge, it showed that Nongkhem wastewater treatment systems might contaminated by feces of human as well as animal excreta (44, 45). The pathogens in studies sludge would contaminate to recreation waters and drinking water supplies. Thus; this sewage sludge is needed to treat before application.

### 5.1.2 Characteristics of grass clippings

The studied grass clippings were used as the bulking agents for support air ventilation within compost heap. The low moisture content  $2.64 \pm 0.38\%$  of grass clipping can absorb moisture in sewage sludge. The concentrations of total and available heavy metals found in grass clipping were very low when compared to that of the studied sewage sludge. The comparing of total heavy metal in grass clippings with the other organic material used as bulking agent in study of Alidadi H. (46) was similar. It was studied the heavy metal in three types of organic waste (leave, rice hull, saw dust) and found Cd 2.11- 4.16 mg/kg DS, Ni  $5.11 \pm 17.44$  mg/kg DS, Zn 8.99- 47.35 mg/kg DS.

The parasitic study in grass clippings was found active *Entamoeba histolytica* cyst, viable *Trichostrongylous* spp. egg, viable *strongyloides stercoralis* larva. The fecal coliform bacteria was  $1.99 \times 10^4$  MPN/g DS. When compare the fecal coliform bacteria and parasite contamination with the studied sewage sludge that in grass clippings was high contamination. The fecal coliform bacteria and parasite in grass clippings may be contaminated from animal or human fecal, municipal waste, and soil which had many species of the pathogenic bacteria, and parasitic eggs. Thus, the direct application of grass clippings would lead to the transmission of diseases which could solve by composting during decomposition.

## **5.2 Change of sewage sludge mixed with grass clippings physical characteristics in compost process**

### **5.2.1 Temperature**

The temperature changes are due to decomposition of organic matter by soil microbial. The temperature can be an indicator of the proper composting process. The temperature between 45 – 55°C ensures the best degradation rates of the compost materials. The temperature more than 55°C is effective for pathogen reduction (47). The efficiency of the composting depends to a large extent on temperature since microbial succession occurs. The average temperatures during the composting process were 27.33 to 44.0°C. This process is classified as mesophilic stage.

When consideration the changed temperature during 8 weeks of composting time, it was found the composting time had effect to the changed temperature at  $P < 0.001$ . From the result, the temperature was quite near ambient temperature. However, the peak of temperature within compost heap at 2<sup>nd</sup> day of composting process which reached to 47.4°C. In addition, during the studied field experimental period, the ambient temperature had a wide variation from 29 to 36°C. The temperature within heap was effected more from the climate change. Leslie R. (48) found that the ambient air temperature can effect microbial activity rate in composting heap. The microbial activity was fastest rate in spring and then, they slow down in winter. This result supporting the change of temperature which showed that at initial stage a peak of high temperature was occurred in a short period.

The result of field experiment was found compost material from outer layer of heap was more dry than the compost material in the center of heap. These occurrences cause the water vaporization which drying of the composting materials. Finstein. *et al* (49) found that the change of temperature influence microbial activity which degrades the organic matter in composting material and releases energy in form of heat. The released heat could effects to water vaporization rate in compost heap.

The statistical results were found the influence of mixing ratio and steam sterilization conditions. This interaction can explain the effect to degradation rate because mixing ratio effect to physical structure such as aeration and porosity. Which influence steam sterilization condition. The comparing of with out PC and with PC

treatments at same mixing ratio are showed temperature range of the without PC treatment had more increases. This occurrence may be cause without PC treatment had effective degradation rate more than the with PC treatment. It can assume that in without PC treatment would has a good aeration that important factor to soil microbial within the compost heap. The with PC treatment would has poor aeration rate due to the covering with plastic sheet. It may become anaerobic condition that slow rate of degradation.

### **5.2.2 Total solids**

The comparing of the average total solids at different composting times, found total solid increased according to composting time. The total solids were significantly difference at  $P < 0.001$ . The change of total solids were related with the organic matter degradation and mineralization during composting process. The organic matter in compost material was decomposed to total solids and volatile solids.

The total solids in without PC treatment was higher than that of with PC treatment. The results are supported by the statistical results which showed the steam sterilization condition could effect to the total solids at  $P < 0.001$ . It might due to the different degradation rates in with PC and without PC treatments. The total solids was increased according to the increased temperature. The treatment of without PC had rapid degradation rate more than the with PC treatment because a good ventilation and more oxygen supplying when compared with the with PC treatment.

The mixing ratios had effected to the total solids at  $P < 0.001$ . It was because of the difference of organic matter in compost which effected to total solids quantity and degradation rate in composting process.

### 5.2.3 Volatile solids

The statistical results are showed the volatile solids of all treatments were slightly decreasing according to composting time from week 0 to week 8. It can explain that form a causation of degradation during of the composting process. The volatile solids are related to the organic material stabilization that has relative with the volatile solids in compost material. Additional, the digested sewage sludge as compost material, volatile solids were low content. The anaerobic digestion was reduced the total mass of solid in sewage sludge that had low organic matter. Therefore, volatile solids reduced 40-50% through anaerobic digestion. The heat and temperature were increased and supported the degradation of volatile solids. The increased temperature cause decreased in moisture content and increased in the total solids (50).

The statistical results are showed the volatile solids at different mixing ratios were significantly difference at  $P < 0.05$ . The decreased volatile solids were due to organic matter degradation during composting process which the degradation rate depended on the organic matter in raw material. However, volatile solids were changed in a small value. The result indicated the degradation rate of volatile solid in this compost process had slowly rate due to the temperature within the heap which not enough to effective degradation (51).

## **5.3 Change of composting conditions on chemical characteristics of sewage sludge mixed with grass clippings**

### **5.3.1 pH**

pH is an important factor related to microorganism growth and change of biochemical reaction in composting process. The trends of pH of all treatments were decreasing until week 4 and upward trend to increasing at week 6 to week 8.

The statistical results are showed the composting time had effect to pH at  $P < 0.001$ . pH was in slightly acid condition at the final stage of composting time. Moreover, the pH change was declined and reached minimum level at week 4 (pH 5.24-5.59). The decreased pH at week 4 would causes from biodegradation by acid forming bacteria. In this stage, the organic matter was reduced to organic acid by acid forming bacteria and lowered pH (52). The pH decreasing at lowest value at week 4 that indicates the active phage of composting process

In addition, the pH would decrease from mineralization of organic acids and the large amount of carbon dioxide released during the composting process. pH value was the increasing at week 4 to week 6 that would from the effect of ammonium production from ammonification (53). At week 6 to week 8, pH was change a bit condition and steadily value that indicated the compost process started maturity phage. Thus the composting process can continue more than 8 week for completely curing stage.

The steam sterilization condition was significantly difference at  $P < 0.001$ . The final pH of without PC treatments was more in neutral condition (pH 6.12-6.43) than that of the final pH of with PC treatments (pH 5.96-6.19). It can explain the pH of without PC treatments more good decomposition, the organic acid more mineralization and more produce ammonium.

The final pH value of all treatments were approximately 5.96-6.43 which acceptable when comparing to the standard for organic compost by Department of Agricultural (DOA) (33).

### 5.3.2 Heavy metal concentration

The change of heavy metals in composting process was related with pH and degradation rate of composting materials. Heavy metals concentration was increased during composting time which was caused from the mineralization of nutrients and organic matter decomposition (54). On the other hand, the metal concentration would decrease through leaching and can affect the reduction in metal concentration (55). The previous study reported (12) heavy metal in total form are transform to loss available forms from soil pH value. Moreover, the study of Haroun M. *et al* (56) found relationship of most metals with temperature and acidity. The more acidity condition and high temperature could increase the mobility of heavy metals.

In this study, the total Cd, Cu, and Zn concentration were decreased according to composting time ( $P < 0.05$ ). The total Ni and total Pb were increase according to composting time ( $P < 0.05$ ). The percentage changing of total heavy metal concentrations were total Cd 23.70%, total Cu 11.37%, total Zn 4.65%, total Ni 3.64%, and total Pb 3.37%. The percentage available metal changing was available Cd 23.70%, Cu 11.37%, Zn 4.65%, and Ni 8.71%.

It was found the heavy metal concentration had change value during the composting time. At week 0 to week 4 of composting time, the metal was changed form in a clearly trend. The results are showed the composting time was significant treatment at  $P < 0.001$ . It can be assumed that it was a suitable condition for transform to more available form. This period the pH was decline and temperature was slightly increased which implied the good decomposition rate in composting process.

The total Zn had clearly tendency of change. The total Zn concentration was decreased at pH decreasing and then the total Zn transformed as the available form. It was due to high solubility of zinc complex that across a wide pH range. Therefore, zinc was much more available form when compare with other metals.

In case of Pb, it was not available form. They are more transform as other exchangeable form according composting time. Therefore, Pb had increasing trend according to the time.

This study was found the order of total heavy metal concentration in composting material at the end of study was Cu>Zn>Ni>Pb>Cd. Total metals can be grouped according to their concentration as follow; Cu and Zn >1,000 mg/kg DS, Ni and Pb 50-500 mg/kg DS, and Cd <5 mg/kg DS. The total heavy metals in compost material acceptable were in the acceptable range when comparing with the guideline and regulation for agricultural application of US.EPA. In case of total Cu, it was over the acceptable limit of Bangkok Metropolitan recommendation (BMA) and standard of organic compost of Department of Agricultural (Table 4.33). The end products of almost concentration were under the threshold of phototoxic concentration of plant growth. These was only available Cu had higher concentration.

Moreover, the high concentration of some heavy metal such as Cu and Zn were presented in compost material, pre-treatment of heavy metal in wastewater should be looked upon as an element within each of the sewage sludge management option.

## **5.4 Change of composting conditions on biological characteristics of sewage sludge mixed with grass clippings**

### **5.4.1 Fecal coliform bacteria**

Fecal coliform bacteria is as used the microbial indicator for fecal contamination and potential presence of pathogen in sewage sludge. The factor affecting the survival of faecal coliform bacteria in soil are moisture content, moistures-holding capacity, temperature, pH, sunlight, organic matter, microorganisms, and other factors (57).

From the study results, it was found the number of faecal coliform decreased after 4 weeks of composting period. At week 8, the faecal coliform bacteria in all treatments were less than 3 MPN/g dry solid, except the treatment of mixing ratio 3:1 with PC was found only  $2.61 \times 10^1$  MPN/g DS. The results were in similar trend of both with PC treatment and without PC treatments.

When considering the result, the composting time had effect to the faecal coliform bacteria at  $P < 0.05$ . It was because from the organic substances in composting heap undergo decomposition. The soil microbial produced acid at early stage that effect to survival of faecal coliform bacteria. However, the pH value range which suitable for the growth of pathogen and bacteria indicator is 6.5 to 8.5 (58). In this study, it was found at week 4, all treatments had minimum of pH value range of 5.24-5.59 and then pH was increased in the range of 5.96-6.36. It can explain, the pH value was increased at minimum level may effect to the survival of faecal coliform bacteria. Moreover, the number of faecal coliform bacteria at final stage (week 8) was found the faecal coliform bacteria of both with and without PC treatment less than 3 MPN/g dry solid. The study indicated the elimination of faecal coliform bacteria more than 80-90%.

The mixing ratio was not significance treatment at  $P > 0.05$ . It can explained that the elimination of faecal coliform bacteria was not related with the mixing ratio of compost material. The composting time and temperature may be more important to elimination more than mixing ratio. The result are agreed with the study of Young *et al.* (59) found that the temperature only 50°C is enough to kill the pathogen but it should maintain this temperature for 24 hours. Thus, at temperature of about 47.4°C may take nearly a week to kill the pathogens completely.

In addition, these were others factors which may destroyed pathogens during composting process. The other factors were competition for food from compost microorganisms, consumption by compost organisms, inhibition and antagonism by compost organisms as well as antibiotics produced by compost microorganisms (60).

### 5.4.1 Parasitic contamination

Parasitic contamination are problem of concern in the develop countries. The wide variety of parasitic contaminant was observed in wastewater that probably to be found in sewage sludge due to their high setting velocity (61). The study results were found different types of parasitic contamination in composting materials. The frequency of the parasite contamination was presence in compost heap during 8 week of composting process as follow; *Entamoeba histolytica* cyst > *Strongyloides stercoralis* larva > Hook worm egg. *Teania* spp. egg = *Ascaris* spp. egg = *Toxocara* spp. egg.= *Trichuris* spp. egg. The type of parasitic egg and protozoan cyst was classified as soil - transmitted group of nematode which causing human infection through contact with parasite eggs or larvae that increase in the warm and moist tropical and subtropical countries.

When consideration the parasite contamination during composting time from week 0 to week 8, it was found an active form of protozoa cyst and viable form of helminthes egg in week 0 to week 6. The inactive form and nonviable egg or larva was found in week 6 to week 8. The result indicated efficiency of parasite elimination in composting process.

*Entamoeba histolytica* cyst was found in all treatments. Fechem *et al.* (62) found that *Entamoeba histolytica* cyst can survival in the environmental more than the other protozoan cysts. Cysts of *Entamoeba histolytica* can survive in water, soil, or in food for long periods. The cysts stage of protozoa can growth to trophozoite as pathogenic stage in the digestive tract when exposure to the bodies. During composting process, it can be survival in long time until week 6. Then, it was non detectable in compost material.

The comparing of both with PC and without PC treatments found an elimination of parasite in compost heap were not difference. The parasites in almost treatments were not detectable. Only the 1:0 without PC treatment was found non viable *strongyloides stercoralis* larva and non-hatch Hook worm egg. These results indicated the parasite cannot survive in the compost heap was unsuitable to the survival of parasitic. However, the end compost of all treatments was not found the parasitic contamination which lower of biosolids established by US.EPA.

## 5.5 Selected treatments for application

Total heavy metals had more transformed to available heavy metal form during week 0 to week 4. The transform of total heavy metal was decreased at week 6 to week 8. The heavy metal concentration of all treatments was met the acceptable for sewage sludge for agricultural application of US.EPA.

The fecal coliform bacteria and parasitic contamination was lower than the allowable level (<1,000 MPN/g DS, absent viable helminthes ova) (29). The fecal coliform bacteria were considerable decreased after 4 weeks of composting periods. The faecal colioform almost treatments was met allowable level (29).

The parasitic contamination was found active form of *Entamoeba histolytica* cyst and viable *strongyloides stercolaris* larva at week 4. At week 8, they were detectable only nonviable *strongyloides stercolaris* larva and nonhatch Hook worm egg.

The result was determined the suitable composting time for composting process by selected from the change of heavy metal, fecal coliform bacteria and parasitic contamination. The suitable composting time was observed in all treatments must more than 8 weeks for safety application.

## **CHAPTER VI**

### **CONCLUSION AND RECOMMENDATION**

The study is to determine the effects of windrow composting conditions on the change of physical, chemical, and biological characteristics of sewage sludge mixed with grass clippings. The windrow composting conditions were composting time, steam sterilization condition, and mixing ratio.

#### **6.1 Conclusion**

##### **6.1.1 Sewage sludge and grass clippings characteristics.**

Sewage sludge and grass clippings were used as composting materials for this study. However, sewage sludge contained heavy metals and parasitic contaminations which had risk if direct application. On the other hand, the grass clipping contained low concentration of heavy metals but it had more contaminated with parasites. The windrow composting process was a challenging for application of sewage sludge and grass clippings because of the practical option and less environmental problems.

##### **6.1.2 Change of sewage sludge mixed with grass clippings characteristics in composting process.**

6.1.2.1 The composting time, mixing ratio, and steam sterilization conditions had effect on physical characteristics such as total solids and volatile solids. The steam sterilization did not give different effect to temperature.

The physical characteristic change of compost material could indicate the degradation rate of composting process. Temperature was increasing according to composting time. Mixing ratio 1:1 had highest temperature between week 2 to week 4. Mixing ratio 3:1 had highest temperature between week 6 to week 8.

Total solids had increasing trend according to composting time. At final stage, total solids of with PC treatment 51.05-56.73% which more than that of with PC treatment 35.33-37.26%. The mixing ratio 1:1 had highest total solid at all periods. Total solid of 1:1 with PC treatment was significance from total solids of 1:1 without PC treatment at week 6 to week 8.

Volatile solids had decreasing trend according to composting time. The volatile solids of without PC treatment 36.18-40.54% had lower than that of with PC treatment 37.68-42.40%. At week 4 to week 8, mixing ratio 1:1 had highest volatile solids than other mixing ratio. Volatile solids of 1:1 with PC treatment were significantly different from total solids of 1:1 without PC treatment at week 2, 6 and 8.

6.1.2.2 The chemical characteristic changes during the composting process as follow; pH was declined and reached minimum level between week 0 to week 4 and turned up increasing trend at week 6 to week 8. Total heavy metals had transformed to available heavy metal during week 0 to week 4.

At final stage, total Cd, Cu and Zn concentration were decreased than that of the final stage. The initial total Ni and total Pb concentration were lower than that of the final stage. The initial available Cu concentration were lower that that of the final stage. The initial available Zn concentration were higher than final stage.

6.1.2.3 The composting time and steam sterilization conditions had effect on change of faecal coliform bacteria. Fecal coliform bacteria were considerable decreased after 4 weeks of composting period. At week 8, the faecal coliform bacteria was decreased in all treatments and the with PC treatments and without PC treatments can eliminated more than 80-90% at the final stage.

6.1.2.4 The active form of protozoan cyst and viable form of helminthes egg were found in week 0 to week 4. In case of inactive form and non-viable egg or larva they were found in week 6 to week 8. The result indicated efficiency of parasite elimination by composting process. And the with PC treatments and without PC treatments had no difference in reducing the parasite contamination.

### **6.1.3 Quality of end product form sewage sludge mixed with grass clippings**

The qualities of end product were compared with the guideline and regulation for sewage sludge for agricultural application (see at Table 4-31 and Table 4-32). It showed that the qualities of compost in all treatments were in the range. The fecal coliform and parasitic contaminations were lower than the allowable level (<1000 MPN/g DS for fecal coliform, absent viable helminthes egg) for land application of class A biosolids established by U.S Environmental Protection Agency (US.EPA).

The result was determined the suitable composting time for composting process by selected from heavy metal, fecal coliform bacteria and parasitic contamination. The suitable composting time was observed in all treatments must more than 8 weeks for safety application.

## **6.2 Recommendation**

### **6.2.1 Recommendation for the application**

6.2.1.1 The application of sewage sludge had effect high concentration of heavy metal in wastewater. Therefore, pre-treatment of heavy metal in wastewater is highly recommended.

6.2.1.2. The end product can be used as soil conditioner for land agricultural. The application of the end product to acidic soil should be considered the proper application rate because Cu may be leaching to the soil.

6.2.1.3 The suitable composting time was recommended for application more than 8 weeks for assure without risk from application.

6.2.1.4 The windrow composting process with or without steam sterilization condition (with PC / without PC) is a significant treatment to eliminate both fecal coliform bacteria and parasite contamination. The with PC treatment would enhance the anaerobic condition if the ambient is not high enough to generate the steam sterilization condition in composting heap. Thus, the maintenance of aeration is necessary to in the composting process.

### **6.2.2 Recommendation for the further study**

6.2.2.1 The study of effect of heavy metal concentrations in the end product to the types of soil is recommended for further study. There might be many factors effecting different heavy metals leaching to various soils when apply to agricultural.

6.2.2.2 The heavy metals were changed form of them. Thus, further study should be studied on heavy metal risk at various form and toxicity when application the end product to land. It is recommended for a safety practice of product utilization.

6.2.2.3 The plastic cover sheet used for cover the compost heap had a high quality grade that which expensive. Thus, the further study should be studied on the effect of different covering materials on the compost material characteristics changing.

## REFERENCES

1. Bangkok Metropolitan Administration. Sipraya Wastewater Treatment Plant Project Report, Water quality control division, Drainage and sewerage department. Bangkok. 1995.
2. Water Quality Management office. Department of drainage and sewerage, Bangkok metropolitan administration. The annual report of sewage sludge and composting quantities. 2006.
3. Japan International cooperation agency .The study for the master plan on sewage sludge Treatment/disposal and Reclaimed wastewater reuse in Bangkok in the Kingdom of Thailand. Nippon Koei Co, Ltd. Tokyo, Japan. 1999.
4. Hall J. Ecological and Economical Balance for Sludge Management Options. Proceeding of Workshop on Problems Around Sludge; Italy. 1999. p.155-172.
5. United States Environmental Protection Agency. Biosolids Generation, Use, and Disposal in The United States, USA, 1999.
6. Epstein, E. The Science of Composting. Pennsylvania, USA: Technomic Publishing Co Inc. 1997.
7. Hornick, S. B, Sikora, L.J, Sterrett, S.B, Murray, J.J, Millner, p.D et al. Utilization of sewage sludge Compost as soil conditioner and Fertilizer for plant Growth. U.S. Department of agricultural, agriculture information Bulletin No.464. U.S. Government Printing Office, Washington, D.C. 1984.
8. Bogaert N, Du Laing G, Tack F, Verloo M.G, Hendrickx F, Maelfait J.P et al. Heavy metal transfer in terrestrial ecosystems. Nriagu, Jerome. 11 th Annual International Conference on Heavy Metals in the Environment. Contribution 1392. Ann Arbor, MI, University of Michigan, School of Public Health, 2000.
9. Gantzer C, Gaspard P, Huyard A, et al, Monitoring of bacterial and parasitological contamination during various treatment of sludge. Water research 2001 Nov;35(16):3763-3770.

10. Bangkok Metropolitan Administration. Water Quality Management and Remediation. [Online]. [cited 2011 April 6]. Available form: URL: <http://dds.bangkok.go.th/wqm/English/inplementation.html>
11. Master plan on treatment and disposal of domestic sewage sludge including nightsoil and oil grease residues for Bangkok metropolitan. Bangkok: Asian Institute of Technology;1995. Support by GTZ, P.P. center Co.Ltd, KHD-Humboldt wedag AG and Passavant Werke AG.
12. Water Quality Management office, Department of drainage and sewerage, Bangkok metropolitan administration. The annual report of sewage sludge characteristics (2005-2006).
13. Wang, X, Chen, T, Ge, Y, Jia, Y. 2008, Studies on land application of sewage sludge and its limiting factors. Hazardous materials, 160 (2-3), 554-558.
14. Smith SR. Agricultural recycling of sewage sludge and the environmental. Guilford:Biddies;1996.
15. Hue NV. Sewage sludge. In: Rechiogl JE, editor. Soil amendments: impact on biotic system. Boca raton (FL): CRC press; 1995; 199-247.
16. Metcalf and Eddy, Inc.(1991). Wastewater Engineering: Treatment, Disposal and Resue. New York: McGraw-hill International editions.
17. Schmidt Jp. Understanding phytotoxicity threshold for trace elements in land-applied sewage sludge. Environmental 1997; 26: 4-10.
18. Mulchi CL, Adamu CA, Bell PF, Chaney RL. Residual heavy metal concentrations in sludge amended coastal plain soils. Comparison of extractans. Communications in Soil Science and Plant Analysis 1991; 22(9/10):919-941.
19. Koeppe, DE. The uptake, distribution and effect of cadmium and lead in plants. Science of the Total Environmental 1977 Mar; 7(3):197-206.
20. Panichsakpatana S. Soil pollution from chemical Utilization. Text and J.Pub.Co.Ltd, Bangkok.1997;327.
21. Ferner, D.J. Toxicity of heavy metals. eMedicine 2001;2(5):1.

22. Yu, M.H. Effects of lead, copper, zinc and cadmium on growth and soluble sugars in germinating mug bean seed. Abstracts of the 12<sup>th</sup> Annual Meeting of the society of Environmental Toxicology and Chemistry. Seattle, WA, 169; 1991.
23. Prokipcak, B, and Ormrod, D.P. Visible injury and growth response of tomato and soybean to combination of nickel, copper and ozone. *Water Air soil pollution* 1986 27(3-4): 329-340.
24. Fontes, R.L.F and F.R,Cox. Iron deficiency and zinc toxicity in soybean grow in nutrient solution with different level of sulfur. *Plant nutrition* 1998 21(8):1715-1722.
25. World health organization, 1981, the risk to health of microbes in sewage sludge applied to land. Euro reports and studies 54, world health organization, Copenhagen.
26. Pepper, I. L, Brooks, J.P, and Gerba, C.P. Pathogens in biosolids. *Advances in Agronomy* 2006 .90:1-41.
27. United States. Environmental Protection Agency. Environmental regulation and technology: control of pathogens in municipal wastewater sludge. Cincinnati (OH):U.S.EPA. Center for environmental Research Information; .EPA/625/10-89/006; 1989.
28. United States. Environmental Protection Agency. Guide to field storage of biosolids and other organic by-product used in agriculture and for soil resource management. [Online] 2000 [cited 2000 August 1] United States Environmental Protection Agency; 2000. Available from:  
URL: <http://www.epa.gov/owm/bio/fsguide/index.html>.
29. Environmental Regulations and Technology. Control of pathogen and vectors Attraction in Sewage sludge EPA1625/R-921013.[Online] October 1999 [cited 2009 January 20] Available from:  
URL: <http://www.epa.gov/IORD/NRMRL>.
30. Iranzo, M, Cañizares. J, Roca-Perez L, Sainz-Pardo, I, Mormeneo, S, Boluda, R. Characteristics of rice straw and sewage sludge as composting materials in Valencia (Spain). *Bioresource technology*.2004 March 95:107-112.

31. Ministry of Agriculture, Food and fisheries. Composting Fact sheet. British Columbia; 1996.
32. Swiss Federal institute of Environmental Science & Technology (EAWWG) Department of water& Sanitation in Developing Countries (SANDEC) of Swizerland and International water management institute (IWMI) of Ghana. Co-compositng of faecal sludge and municipal organic waste; A literature and state- of- knowledge review, May 2003.
33. Department of Agriculture Standard. Organic fertilizer standard ;2005.
34. Land Development Department. Division of soil and Warer Conservation. Officer Manual-Soil Improve by Adding Organic Matter 2002.
35. United States Environmental Protection Agency. Land Application of sewage sludge, Federal Register, 40 CFR Part 503, United States Environmental Protection agency, Washington, DC, USA; 1996.
36. Pasda N, Panichsakpatana S, Limthong P, Oliver R, Montange D. Evaluation of Bangkok sewage sludge for possible agricultural use. Waste Management & Research, 2005 Dec 24(2):167-174.
37. Uyasatian U. Characteristics and phototoxic Effects of sewage sludge for Agricultural Uses. Environment and natural resource 2009 June 7(1): 25-3
38. Trabdee T. Survival of ascaris eggs in soil applied with fecal sludge and sludge after passing through various drying process. [N.Sci Environmental Sanitation]. Bangkok: Faculty of Graduate Studies, Mahidol University; 2001.
39. Canadian society of soil science. Soil sampling and methods of analysis. Luwis publishers; 1993.
40. US Food and Drug Administration. Bacteriological analytical manual (BAM). [Online]. 2006 Feb [Cited 2009 6]; Available from: URL <http://www.fda.gov/Food/ScienceResearch/LaboratoryMethods/BacteriologicalAnalyticalManualBAM/ucm109656.htm#tab1>
41. Faust, E.C, Russell P.E. and Jung. R.C. Craig and Faust's Clinical Parasitology.8th ed. Philadelphia, Lea and Febiger; 1971.p.787.

42. Tiquia, S. M, N. F. Y. Tam and I. J. Hodgkiss, 1996, Microbial activities during composting of spent pig-manure sawdust litter at different moisture contents. *Bioresource Technology* 1996 March; 55(3):201-206.
43. Decera, D.D.M, Babel S, Parkpian P. Potential for land application of contaminated sewage sludge treated with fermented liquid from pineapple wastes. *Hazardous Materials* 2009 Aug; 167(1-3):866-872.
44. Ayed Ben L, Schijven J, Alouini Z, Jemli M, Sabbahi S. Presence of parasitic protozoa and helminth in sewage and efficiency of sewage treatment in Tunisia. *Parasitology Research* 2009 Aug; 105(2):393-406.
45. Deportes I, Benoit-Guyod J.L, Zmirou D. Hazard to man and the environment posed by the use of urban waste compost: a review. *The Science of the Total Environment* 1995 Nov 30;172:197-222.
46. Alidadi H, Najafpoor A.A, and Pararvaresh A. Determination of carbon/ nitrogen and Heavy Metals in Bulking Agent Use for Sewage sludge Composting. *Pakistan journal of Biological Science* 2007; 10(22): 4180-4182.
47. Stentiford, E.I. Stentiford, *Composting control: principles and practice*. In: M. de Bertoldi, P. Sequi, B. Lemmes and T. Papi, Editors, *The Science of Composting, Part 1*, Blackie, Glasgow 1996, p. 56–59.
48. Liesile et al. *Composting: Art and Science of Organic Waste Conversion to a Valuable Soil resource*. *Laboratory medicine*. [Online]. 2000 June. [cited 2011 Feb28]; 31(6):283-290. Available from: URL: <http://www.labmed.ascpjournals.org/content/31/5/283.full.pdf>
49. Finstein, M.S, Miller, F.C, MacGregor, S.T. and Psarianos, K.M. The Rutgers strategy for composting: process design and control. *Acta Horticulturae* 1992; 302:75-86.
50. Haug, R.T. *The Practical Handbook of Compost Engineering*, Boca Raton, Lewis Publisher. 1993.
51. Gareth M. Evans and Judith C. Furlong. *Environmental Biotechnology: Theory and Application*. England: John Wiley and Sons; 2003.
52. FAO, “ Soil management: Compost production and use in tropical and subtropical environments ”, FAO and Agriculture organization of the United Nations, 1987, p. 177

53. Huang G.F., Wong J. W. C., Wu Q. T., and Nagar B. B. Effect of C/N on composting of pig manure with sawdust. *Waste Management* 2004; 24(8): 805-813.
54. Farrell Mark, Davey L. Jones heavy metal contamination of a mixed waste compost: Metal speciation and fate. *Bioresource technology* 2009 Oct; 100(19):4423-4432.
55. Amir S, Hafidi M, Merlina G, Revel J.C. Sequential extraction of heavy metals during composting of sewage sludge. *Chemosphere* 2005 May; 59(6):801-810.
56. Haroun M, Idris A, Syed Omar S.R. A study of heavy metals and their fate in the composting of tannery sludge. *Waste management* 2007; 27(11): 1541-1550
57. Kowal NE, Pahren RH, Akin WE. Microbiological health effects on land application of municipal waste. In: D'itri FM, Aguirre-Martinez J, Athie'-La' mbarri M, editors. *Municipal wastewater in agriculture*. New York: Academic press;1981.p.271-342
58. Bitton G. *Wastewater microbiology*. New York: Wiley-Liss Publisher; 1994.
59. Young C.C, Rekha P.D, ArunA.B. What happened during composting? [Online]. 2005 Dec 1 [cited 2010 Dec 2] Available from: URL: <http://www.agnet.org/library/bc/53003/>.
60. Burge W.D, Colacicco D, Cramer W.N. Criteria for achieving pathogen destruction during composting. *Water Pollution Control Federation* 1981; 53 (12):1683-1690.
61. Sidhu J.P.S, Toze S.G. Human pathogens and their indicators in biosolids: a literature review. *Environmental International* 2009 Jan; 35(1):187-201.
62. Fechem, R.C, Bradley, D.J. Garelick, and Mara, D.D. *Health aspects of excreta and wastewater treatment management*; 1978. The international Bank. Washington D.C. 20433.

## **APPENDICES**

## APPENDIX A

### EXPERIMENTAL RESULTS

#### 1) Daily temperature (°C)

**Table A.1** The daily temperature (°C) of all treatment during compost process.

Day	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 With PC	Ratio 1:1 Without PC	Ratio 3:1 With PC	Ratio 3:1 without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC	Air Temp.
1	30.0	30.0	30.8	30.0	30.0	27.6	29.4	29.2	28
2	41.0	47.4	44.2	44.0	43.2	44.2	43.0	44.4	37
3	30.8	31.2	33.6	32.6	31.6	30.6	30.0	30.6	30
4	33.8	33.0	36.6	36.6	33.8	33.2	33.0	33.2	34
5	32.4	33.0	32.4	32.6	33.0	32.2	32.4	33.0	28
6	31.6	32.0	39.4	38.0	32.8	33.0	32.2	33.2	30
7	33.2	32.6	41.4	39.2	35.0	30.2	34.2	32.4	29
8	33.4	32.4	39.0	36.6	34.8	31.6	33.2	32.6	29
9	34.0	33.2	39.4	37.8	36.2	34.6	35.2	34.2	37
10	33.8	33.0	40.4	38.6	35.8	34.2	34.4	34.4	33
11	33.6	33.0	40.4	38.0	35.2	34.6	33.6	34.4	29
12	34.0	34.0	42.0	39.6	36.6	36.6	35.2	35.8	29
13	34.4	33.2	41.8	39.6	36.0	33.6	33.6	33.6	30.1
14	34.2	34.0	39.8	40.4	38.0	38.0	34.6	36.6	34
15	32.8	31.6	34.8	35.6	33.4	33.4	31.4	32.4	28
16	32.8	33.8	37.8	37.2	36.0	36	33.8	34.8	31
17	32.8	33.0	36.4	38.6	36.0	34.6	34.0	34.6	28
18	32.0	34.2	38.0	40.4	34.4	36.6	33.6	35.0	31
19	32.8	34.2	38.6	40.2	35.4	36.6	34.4	34.8	32
20	31.2	33.8	35.4	39.0	34.2	35.6	31.4	33.4	28
21	30.2	33.2	33.6	37.6	34.2	35.8	32.0	33.6	29
22	30.0	31.0	30.8	34.8	32.4	31.6	30.6	30.0	31
23	30.0	31.8	32.0	35.0	32.6	33.6	31.2	32.2	32
24	30.6	32.6	32.6	36.6	33.8	36.0	32.2	34.2	34
25	30.8	32.2	33.2	35.6	33.6	34.4	33.2	34.0	31
26	31.0	34.2	35.2	39.0	34.8	37.2	32.2	36.8	33
27	31.8	35.6	39.0	42.0	34.4	35.8	35.8	33.8	34

**2) Daily temperature (Cont.)****Table A.2** The daily temperature (°C) of all treatment during compost process (cont.)

Day	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 with PC	Ratio 3:1 Without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC	Air temp
28	31.4	35.2	36.8	41.4	33.8	35.4	31.8	36.0	32
29	30.2	32.0	33.0	35.2	32.8	31.6	32.4	31.4	30
30	32.6	32.8	33.8	36.0	34.0	33.4	33.6	33.2	32
31	32.2	35.8	33.6	40.6	34.6	35.4	34.0	34.6	31
32	33.4	36.8	34.6	37.0	34.4	37.8	33.0	36.0	33
30	32.6	32.8	33.8	36.0	34.0	33.4	33.6	33.2	32
34	33.6	37.0	35.4	36.6	34.8	38.0	34.0	36.4	34
35	33	36.8	35.6	37.2	35.4	37.2	34.6	35.6	33
36	32.4	35.8	33.4	36.2	33.2	36.4	33.0	33.6	33
37	33	37.6	35.8	41.8	36.0	40.0	33.2	39.0	34
38	32.4	37.4	33.4	39.6	35.4	39.0	33.8	37.4	35
39	33.8	37.8	36.2	41.2	37.0	39.6	34.2	39.6	34
40	33.4	38.2	37	40.8	37.0	40.6	34.4	39.6	34
41	34	39.4	36.6	39.6	35.0	36.4	34.2	36	30
42	33.8	40.4	39	40.8	35.6	37.8	35.4	39	29
43	34.6	37.8	36.4	37.6	36.4	37.2	35.0	36.8	30
44	36.8	39.8	37.6	39.8	37.6	39.8	36.4	40.4	31
45	37.6	42.0	38.4	40.4	37.6	44.0	38.0	42.0	34
46	38.2	42.4	39.2	40.6	38.2	43.6	39.4	42.4	34
47	38.2	42.4	39.2	40.2	38.8	43.0	39.2	42.4	34
48	37	44.0	39.2	40.6	39.6	46.2	37.0	44.8	32
49	35.8	41.2	38	41.6	37.8	43.4	37.0	42.2	32
50	35.8	40.6	37.2	37.6	36.8	40.2	37.0	38.2	30
51	34	42.2	37.6	37.6	38.8	38.8	37.2	43.0	33
52	36	42.8	37.6	38.2	37.2	40.6	36.2	40.2	30
53	36.6	42.8	38.4	39.0	40.6	36.6	37.2	41.0	33
54	37.6	43.8	40.2	38.4	38.4	40.8	39.2	41.2	34
55	39.6	46.0	40.0	39.6	41.2	42.2	40.8	44.2	36
56	39.8	46.0	42.2	41.8	40.4	43.4	40.2	40.2	35

### 3) Total solid

**Table A.3** The weekly total solids of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 with PC	Ratio 3:1 Without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	24.29	25.91	26.15	26.15	25.56	26.51	25.25	25.78
week 0	Rep 2	24.73	24.79	26.83	26.49	25.37	26.82	24.93	26.67
	Rep 3	24.7	24.88	26.28	26.04	25.78	26.89	24.85	25.92
	Rep 1	26.31	27.61	28.36	29.14	27.41	28.4	26.33	27.90
week 2	Rep 2	26.03	27.12	29.53	25.81	27.51	28.51	26.39	28.26
	Rep 3	25.79	27.93	37.27	32.97	27.22	28.01	25.75	28.42
	Rep 1	29.65	33.16	32.35	34.41	28.4	36.17	29.08	32.67
week 4	Rep 2	29.69	32.38	33.17	36.47	28.23	37.4	28.32	34.95
	Rep 3	29.24	32.19	32.96	33.34	29.07	34.01	29.13	34.17
	Rep 1	33.77	40.81	40.73	46.45	32.52	44.34	35.01	40.11
week 6	Rep 2	32.65	40.98	39.65	48.59	32.50	46.03	33.62	41.35
	Rep 3	32.7	41.08	40.32	47.17	32.34	44.98	34.14	40.59
	Rep 1	35.42	55.30	41.76	51.37	36.24	50.61	37.71	53.18
week 8	Rep 2	35.34	52.43	42.50	52.35	37.32	50.15	36.76	58.34
	Rep 3	35.24	51.90	44.97	52.61	36.37	52.39	37.30	58.66

### 4) Moisture content

**Table A.4** The weekly moisture contain of all treatment during compost process.

Week	REP.	Ratio 1:0 With PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 with PC	Ratio 3:1 Without PC	Ratio 6:1 With PC	Ratio 6:1 Without PC
	Rep 1	75.71	74.09	73.85	73.85	74.44	73.49	74.75	74.22
week 0	Rep 2	75.27	75.21	73.17	73.51	74.63	73.18	75.07	73.33
	Rep 3	75.30	75.12	73.72	73.96	74.22	73.11	75.15	74.08
	Rep 1	73.69	72.39	71.64	70.86	72.59	71.60	73.67	72.10
week 2	Rep 2	73.97	72.88	70.47	74.19	72.49	71.49	73.61	71.74
	Rep 3	74.21	72.07	62.73	67.03	72.78	71.99	74.25	71.58
	Rep 1	70.35	66.84	67.65	65.59	71.60	63.83	70.92	67.33
week 4	Rep 2	70.31	67.62	66.83	63.53	71.77	62.60	71.68	65.05
	Rep 3	70.76	67.81	67.04	66.66	70.93	65.99	70.87	65.83
	Rep 1	66.23	59.19	59.27	53.55	67.48	55.66	64.99	59.89
week 6	Rep 2	67.35	59.02	60.35	51.41	67.50	53.97	66.38	58.65
	Rep 3	67.30	58.92	59.68	52.83	67.66	55.02	65.86	59.41
	Rep 1	64.58	44.70	58.24	48.63	63.76	49.39	62.29	46.82
week 8	Rep 2	64.66	47.57	57.50	47.65	62.68	49.85	63.24	41.66
	Rep 3	64.76	48.10	55.03	47.39	63.63	47.61	62.70	41.34

**5) Volatile solids**

**Table A.5** The weekly volatile solids of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 Without PC	Ratio 1:1 With PC	Ratio 1:1 Without PC	Ratio 3:1 with PC	Ratio 3:1 Without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	41.47	41.34	44.85	46.49	43.90	45.01	43.45	44.02
week 0	Rep 2	45.22	41.49	46.11	46.95	44.18	44.42	43.59	43.98
	Rep 3	41.19	40.99	45.45	45.07	43.85	44.98	43.66	43.88
	Rep 1	40.06	39.79	42.90	42.08	41.44	42.17	41.09	40.12
week 2	Rep 2	40.22	39.80	42.89	42.37	42.19	42.31	41.50	39.99
	Rep 3	40.28	39.37	43.08	42.38	41.88	42.18	41.49	40.32
	Rep 1	39.12	38.63	40.91	41.98	40.91	40.38	41.49	40.28
week 4	Rep 2	39.41	38.73	40.97	43.44	41.41	40.97	41.68	39.99
	Rep 3	39.57	39.07	40.8	43.72	41.61	40.71	41.18	39.73
	Rep 1	38.33	37.56	42.5	41.03	40.77	39.82	39.99	38.9
week 6	Rep 2	38.3	37.57	42.4	41.48	41.33	39.91	39.80	38.98
	Rep 3	38.67	37.39	42.32	41.51	41.77	39.96	39.99	39.01
	Rep 1	37.42	35.96	42.01	40.46	39.35	38.18	38.03	38.14
week 8	Rep 2	37.75	36.25	41.91	40.40	39.46	38.84	39.00	38.04
	Rep 3	37.85	36.32	43.28	40.77	39.83	38.48	39.25	38.85

**6) pH**

**Table A.6** The weekly total of cadmium concentration of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 With PC	Ratio 3:1 without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	6.17	6.13	6.39	6.20	6.38	6.68	6.13	6.26
week 0	Rep 2	6.19	6.15	6.41	6.18	6.42	6.69	6.11	6.29
	Rep 3	6.20	6.13	6.43	6.19	6.42	6.66	6.10	6.30
	Rep 1	6.27	6.24	6.56	6.30	6.35	6.28	6.32	6.32
week 2	Rep 2	6.29	6.25	6.56	6.30	6.35	6.28	6.32	6.32
	Rep 3	6.29	6.23	6.57	6.30	6.35	6.30	6.34	6.32
	Rep 1	5.39	5.29	5.57	5.52	5.26	5.31	5.28	5.25
week 4	Rep 2	5.40	5.29	5.59	5.52	5.24	5.34	5.28	5.24
	Rep 3	5.39	5.29	5.61	5.53	5.23	5.31	5.29	5.25
	Rep 1	6.13	6.31	5.99	5.94	5.88	6.39	6.08	6.00
week 6	Rep 2	6.12	6.32	5.98	5.95	5.87	6.40	6.09	6.02
	Rep 3	6.12	6.32	5.97	5.96	5.86	6.40	6.10	6.03
	Rep 1	6.20	6.42	6.09	6.12	5.95	6.35	6.02	6.16
week 8	Rep 2	6.18	6.43	6.08	6.12	5.96	6.36	6.00	6.16
	Rep 3	6.19	6.44	6.06	6.11	5.96	6.37	6.00	6.16

## 7) Total cadmium

**Table A.7** The weekly total of cadmium concentration (mg/kg DS) of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 With PC	Ratio 3:1 without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	1.96	1.94	1.99	1.89	1.97	1.89	1.84	1.90
week 0	Rep 2	2.00	2.08	1.77	1.78	1.88	1.83	1.82	1.95
	Rep 3	2.20	2.08	1.81	1.97	2.11	1.98	1.74	1.84
	Rep 1	1.47	1.10	1.49	1.06	1.48	1.64	1.63	1.50
week 2	Rep 2	1.25	1.52	1.33	1.04	1.30	1.60	1.62	1.91
	Rep 3	1.25	1.53	1.56	1.08	1.54	1.54	1.22	1.65
	Rep 1	1.31	1.31	1.19	1.24	1.17	1.19	1.24	1.18
week 4	Rep 2	1.24	1.26	1.10	1.09	1.07	1.17	1.18	1.35
	Rep 3	1.26	1.30	1.11	1.25	1.06	1.18	1.25	1.31
	Rep 1	1.30	1.26	1.10	1.15	1.17	1.06	1.00	1.19
week 6	Rep 2	1.29	1.23	1.18	1.17	1.09	1.06	1.18	1.00
	Rep 3	1.17	1.37	1.27	1.20	1.09	1.03	1.12	1.14
	Rep 1	1.50	1.67	1.58	1.76	1.63	1.66	1.62	1.60
week 8	Rep 2	1.56	1.55	1.64	1.59	1.7	1.62	1.78	1.68
	Rep 3	1.58	1.51	1.54	1.57	1.61	1.75	1.52	1.57

## 8) Total copper

**Table A.8** The weekly total copper concentration of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 With PC	Ratio 3:1 without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	3170.95	2836.75	2665.15	2679.99	2706.48	2586.9	2601.79	2681.33
week 0	Rep 2	2960.17	2938.98	2391.96	2708.38	2627.76	2502.47	2630.68	2776.95
	Rep 3	2627.89	2622.07	2515.31	2441.56	2762.2	2455.41	2617.05	2868.18
	Rep 1	2433.74	2361.5	2317.93	2340.25	2229.56	2257.76	2341.53	2292.88
week 2	Rep 2	2303.44	2395.49	2269.44	2219.59	2202.95	2289.62	2309.36	2290.38
	Rep 3	2330.36	2481.2	2130.92	2348.62	2146.02	2236.44	2360.52	2306.33
	Rep 1	2402.1	2438.39	2338.6	2293.37	1729.29	2502.37	2486.53	2552.34
week 4	Rep 2	2388.26	2522.18	2070.37	2139.29	1905.9	2318.02	2340.16	2490.15
	Rep 3	2343.83	2366.69	2164.09	2201.22	2019.95	2465.3	2420.32	2520.84
	Rep 1	2345.89	2599.96	1958.92	2216.72	2311.07	2340.71	2183.92	2649.67
week 6	Rep 2	2356.49	2433.64	2473.69	2160.34	2333.48	2315.18	2119.97	2360.82
	Rep 3	2032.79	2573.69	2375.37	2160.46	2225.05	2113.31	2140.97	2612.59
	Rep 1	2515.19	2416.99	2158.65	2161.94	2212.89	2200.82	2701.73	2381.19
week 8	Rep 2	2314.21	2481.44	2083.75	2157.83	2252.22	2274.77	2291.76	2294.9
	Rep 3	2305.14	2234.46	2141.75	2163.73	2246.8	2189.74	2432.94	2376.44

**9) Total nickel**

**Table A.9** The weekly total nickel concentration of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 With PC	Ratio 3:1 without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	170.72	142.95	158.20	151.59	160.62	170.56	135.96	151.67
week 0	Rep 2	175.59	152.47	133.06	158.68	173.61	140.09	131.79	134.71
	Rep 3	154.51	160.01	162.36	143.49	170.05	134.93	138.53	152.02
	Rep 1	150.29	156.5	143.52	149.14	149.14	168.6	165.52	160.16
week 2	Rep 2	154.7	169.6	155.9	165.32	145.37	166.11	176.12	159.52
	Rep 3	160.26	157.69	153.57	169.03	152.16	169.22	173.92	152.74
	Rep 1	164.80	162.35	129.77	146.24	135.88	177.97	152.56	161.60
week 4	Rep 2	161.72	169.41	160.11	143.82	129.31	177.46	155.07	162.23
	Rep 3	153.64	147.25	153.8	143.79	145.47	168.61	143.67	158.7
	Rep 1	165.04	156.97	135.76	147.19	150.01	148.08	143.94	162.08
week 6	Rep 2	172.89	162.37	143.59	135.25	141.46	133.78	140.34	147.99
	Rep 3	155.57	177.9	152.25	141.16	140.36	139.07	124.42	160.7
	Rep 1	178.99	175.18	164.02	163.55	158.02	178.1	167.38	169.06
week 8	Rep 2	151.18	157.25	160.36	170.27	192.88	184.36	170.42	172.82
	Rep 3	164.18	165.13	171.53	175.43	179.03	165.54	178.54	173.59

**10) Total lead**

**Table A.10:** The weekly total lead concentration of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 With PC	Ratio 3:1 without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	60.93	61.05	47.95	58.43	57.99	57.07	70.87	59.46
week 0	Rep 2	45.57	52.26	59.95	57.4	51.5	47.89	72.12	67.1
	Rep 3	47.17	62.79	56.43	59.79	50.74	52.47	63.69	64.71
	Rep 1	49.57	54.8	56.08	61.56	51.83	47.65	50.87	64.27
week 2	Rep 2	47.61	53.06	53.87	61.07	52.86	54.88	66.37	57.26
	Rep 3	47.58	49.55	53.87	59.56	58.79	49.14	66	67.71
	Rep 1	59.37	58.37	51.82	56.91	60.3	55.64	52.65	57.93
week 4	Rep 2	61.11	50.7	48.06	55.95	58	56.42	53.2	64.81
	Rep 3	72.35	57.82	57.69	58.43	59.35	67.86	52.15	58.08
	Rep 1	59.21	61.57	56.61	67.71	68.66	56.65	59.73	57.84
week 6	Rep 2	75.17	61.96	62.24	65.43	57.4	56.43	52.77	63.6
	Rep 3	59.85	61.12	56.58	64.61	54.57	54.51	66.26	59.22
	Rep 1	70.07	59.42	55.52	72.19	69.93	64.11	54.61	58.17
week 8	Rep 2	67.47	57.8	60.78	72.96	76.28	64.89	55.08	57.75
	Rep 3	70.06	62.89	62.51	71.54	66.23	72.67	61.71	50.32

## 11) Total zinc

**Table A.11** The weekly total zinc concentration of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 With PC	Ratio 3:1 without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	1967.68	1862.20	1771.16	1732.51	1880.88	1758.89	1704.35	1784.65
week 0	Rep 2	1945.61	1950.38	1622.97	1770.49	1993.98	1703.00	1720.90	1831.76
	Rep 3	2026.89	1999.70	1922.98	1762.92	1998.41	1693.40	1752.16	1843.76
	Rep 1	1842.12	1801.58	1832.41	1853.25	1719.00	1583.60	1712.88	1613.36
week 2	Rep 2	1804.79	1826.92	1843.21	2077.27	1696.25	1681.22	1692.04	1610.73
	Rep 3	1787.41	1823.46	1714.46	1886.62	1704.61	1671.16	1714.73	1631.98
	Rep 1	1822.65	1784.32	1541.26	1718.42	1524.52	1900.10	1904.63	1915.25
week 4	Rep 2	1798.36	1820.61	1564.41	1677.91	1544.93	1782.67	1762.74	1829.10
	Rep 3	1783.50	1826.69	1709.54	1741.50	1625.69	1899.34	1898.04	1873.41
	Rep 1	1912.04	1926.65	1642.60	1737.42	1759.26	1740.99	1731.96	1678.63
week 6	Rep 2	1969.43	1855.85	1549.80	1786.57	1781.41	1732.34	1720.39	1751.97
	Rep 3	2103.89	2043.24	1521.76	1777.22	1782.53	1651.07	1664.84	1902.46
	Rep 1	1732.99	1659.03	1565.58	1507.25	1648.13	1620.92	1581.64	1620.75
week 8	Rep 2	1655.36	1683.44	1486.65	1521.32	1850.38	1544.30	1686.86	1644.76
	Rep 3	1608.99	1553.91	1492.01	1575.68	1535.64	1620.11	1640.49	1787.07

## 12) Available cadmium

**Table A.12** The weekly available cadmium concentration of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 With PC	Ratio 3:1 without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	0.63	0.60	0.63	0.75	0.73	0.77	0.69	0.68
week 0	Rep 2	0.61	0.59	0.66	0.70	0.71	0.76	0.69	0.74
	Rep 3	0.58	0.61	0.66	0.70	0.69	0.70	0.74	0.70
	Rep 1	0.62	0.49	0.71	0.77	0.61	0.78	0.71	0.59
week 2	Rep 2	0.59	0.51	0.77	0.82	0.62	0.78	0.72	0.62
	Rep 3	0.64	0.53	0.79	0.75	0.63	0.79	0.76	0.61
	Rep 1	0.53	0.53	0.71	0.65	0.57	0.69	0.80	0.55
week 4	Rep 2	0.5	0.54	0.72	0.62	0.57	0.65	0.80	0.55
	Rep 3	0.51	0.54	0.69	0.65	0.54	0.63	0.80	0.55
	Rep 1	0.49	0.61	0.61	0.68	0.58	0.73	0.57	0.61
week 6	Rep 2	0.48	0.62	0.64	0.64	0.55	0.62	0.60	0.56
	Rep 3	0.49	0.61	0.62	0.67	0.43	0.67	0.57	0.58
	Rep 1	0.66	0.74	0.78	0.68	0.69	0.71	0.60	0.64
week 8	Rep 2	0.74	0.72	0.76	0.78	0.68	0.71	0.60	0.64
	Rep 3	0.64	0.74	0.77	0.76	0.67	0.71	0.60	0.64

### 13) Available copper

**Table A.13** The weekly available copper concentration of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 With PC	Ratio 3:1 without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	417.33	457.28	381.06	417.85	419.41	429.40	401.88	433.37
week 0	Rep 2	467.42	455.94	406.53	327.95	406.13	419.59	406.10	486.32
	Rep 3	400.67	452.44	393.22	468.63	374.26	382.56	428.13	432.99
	Rep 1	435.23	460.01	414.73	450.41	472.03	448.84	484.03	427.04
week 2	Rep 2	415.80	482.62	447.56	458.10	473.89	440.88	477.10	530.95
	Rep 3	433.25	489.71	503.44	413.64	451.99	475.65	490.75	497.19
	Rep 1	426.46	432.58	357.46	392.74	405.17	472.82	450.03	404.84
week 4	Rep 2	412.59	468.16	345.78	385.00	409.54	439.66	441.83	406.84
	Rep 3	418.74	432.72	333.93	406.89	402.70	448.07	457.16	417.02
	Rep 1	471.77	524.12	348.71	419.14	426.08	460.42	456.30	463.80
week 6	Rep 2	453.48	527.05	371.19	388.02	399.91	440.92	447.86	443.46
	Rep 3	467.29	506.66	353.80	416.12	301.82	461.87	454.82	445.96
	Rep 1	554.38	591.44	489.34	533.59	475.52	497.28	526.83	512.72
week 8	Rep 2	493.40	569.40	502.72	576.08	467.27	492.22	510.35	517.65
	Rep 3	560.22	592.45	466.75	503.75	456.11	507.87	533.73	523.96

### 14) Available nickel

**Table A.14** The weekly available nickel concentration of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 With PC	Ratio 3:1 without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	30.73	41.89	33.97	41.39	43.10	38.82	39.94	39.21
week 0	Rep 2	39.81	41.19	36.16	26.79	37.21	34.13	42.89	43.14
	Rep 3	46.72	34.16	32.08	41.88	37.80	38.12	35.75	41.36
	Rep 1	46.82	36.27	38.68	48.07	32.89	36.24	44.81	35.52
week 2	Rep 2	38.66	30.44	41.62	43.84	37.20	43.8	37.42	42.25
	Rep 3	40.37	31.52	39.51	43.96	31.95	46.08	44.87	30.84
	Rep 1	25.63	31.95	35.96	31.30	27.64	40.33	37.07	35.18
week 4	Rep 2	31.49	27.33	36.17	30.80	33.61	31.25	41.96	35.20
	Rep 3	28.96	32.15	27.60	32.51	34.06	36.99	33.32	34.45
	Rep 1	34.46	35.01	32.67	37.67	33.43	35.89	35.45	24.27
week 6	Rep 2	34.58	39.20	36.10	39.36	33.58	36.68	24.28	34.28
	Rep 3	34.85	32.91	34.05	39.91	24.95	35.50	34.2	39.62
	Rep 1	40.30	46.89	42.23	31.63	35.74	46.15	41.64	36.25
week 8	Rep 2	36.24	44.64	41.49	50.37	34.64	44.23	41.95	43.84
	Rep 3	38.76	39.79	40.36	48.55	41.12	41.39	41.76	44.63

### 15) Available zinc

**Table A.15** The weekly available zinc concentration of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 With PC	Ratio 3:1 without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	171.28	180.18	181.32	190.00	210.84	204.61	192.61	185.47
week 0	Rep2	187.01	179.88	190.76	192.25	204.08	202.96	197.01	203.92
	Rep3	165.87	179.92	187.14	186.65	194.91	186.75	204.94	184.84
	Rep 1	156.32	125.17	152.84	159.12	136.67	150.78	153.75	133.02
week 2	Rep2	148.94	130.32	163.39	166.44	142.51	150.04	149.51	158.33
	Rep3	157.27	131.81	183.81	155.45	138.05	161.39	157.97	148.58
	Rep 1	125.32	118.43	135.61	106.04	102.07	110.38	87.49	81.69
week 4	Rep2	120.12	127.84	129.48	103.84	99.92	86.12	84.95	79.57
	Rep3	121.24	117.17	127.30	108.68	95.66	89.40	90.31	79.49
	Rep 1	107.72	130.12	114.35	127.08	119.39	132.62	126.76	119.31
week 6	Rep2	113.76	128.43	118.36	118.54	115.23	125.30	124.97	116.69
	Rep3	116.77	127.56	114.95	126.61	111.13	132.08	127.17	116.80
	Rep 1	100.95	125.78	114.04	100.22	104.23	114.84	96.93	107.64
week 8	Rep2	112.00	120.05	115.10	129.32	103.80	114.40	96.44	107.13
	Rep3	99.62	120.41	110.19	116.44	103.87	113.84	99.25	108.77

### 16) Fecal coliform bacteria

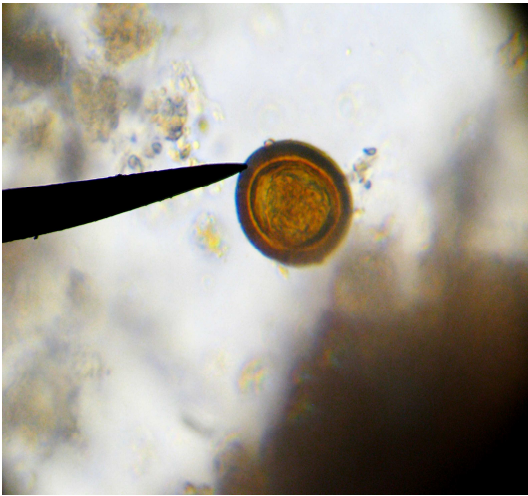
**Table A.16** The weekly fecal coliform bacteria ( $\log_{10}$ MPN/g DS) of all treatment during compost process.

Week	REP.	Ratio 1:0 with PC	Ratio 1:0 without PC	Ratio 1:1 with PC	Ratio 1:1 without PC	Ratio 3:1 With PC	Ratio 3:1 without PC	Ratio 6:1 with PC	Ratio 6:1 Without PC
	Rep 1	3.63	4.38	5.97	4.38	5.18	4.63	4.18	4.38
week 0	Rep 2	4.32	4.66	6.38	4.63	4.63	5.63	3.97	4.63
	Rep 3	3.88	5.88	5.63	4.36	6.66	4.63	3.63	4.97
	Rep 1	4.88	3.30	4.63	4.88	5.18	3.97	3.97	3.15
week 2	Rep 2	4.38	4.63	4.36	4.18	4.63	3.97	3.97	3.15
	Rep 3	3.97	5.18	5.97	4.36	3.97	3.04	3.04	3.88
	Rep 1	1.48	2.88	2.36	2.97	3.97	2.56	1.96	3.38
week 4	Rep 2	1.48	2.97	2.63	2.88	4.66	2.97	1.96	3.66
	Rep 3	1.56	4.63	3.97	2.88	4.36	3.18	1.96	4.04
	Rep 1	1.36	0.56	0.48	0.48	1.04	0.48	1.18	1.30
week 6	Rep 2	1.18	0.96	1.18	0.48	2.18	0.48	1.63	1.45
	Rep 3	0.96	0.56	1.97	0.48	0.96	0.48	1.36	1.04
	Rep 1	0.48	0.48	0.48	0.48	1.45	0.48	0.48	0.48
week 8	Rep 2	0.48	0.48	0.48	0.48	1.63	0.48	0.48	0.48
	Rep 3	0.48	0.48	0.48	0.48	0.86	0.48	0.48	0.48

## APPENDIX B

### EXPERIMENTAL PICTURES

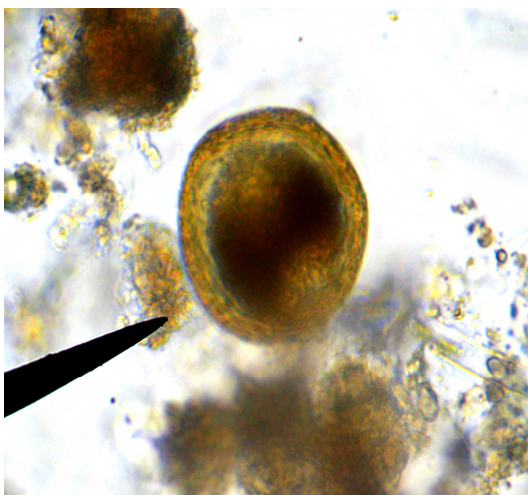
#### 1) Parasitic contamination



**Figure B.1**  
viable *Teania* Spp. Egg  
(20x40)



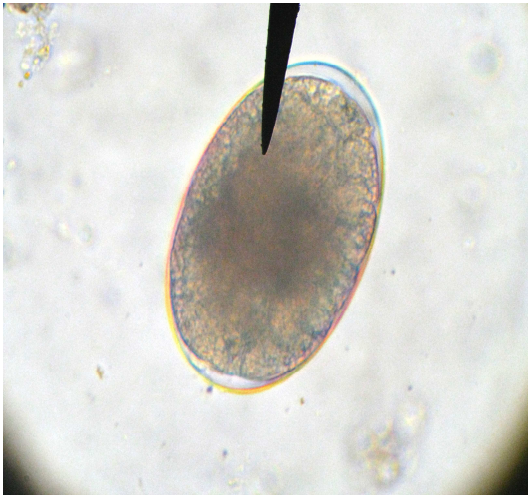
**Figure B.2**  
viable *Ascaris* Spp. Egg  
(20x40)



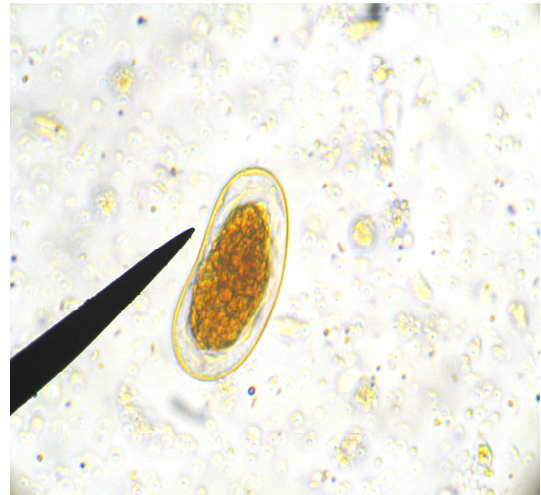
**Figure B.3**  
viable *Toxocara* Spp. Egg  
(20x40)



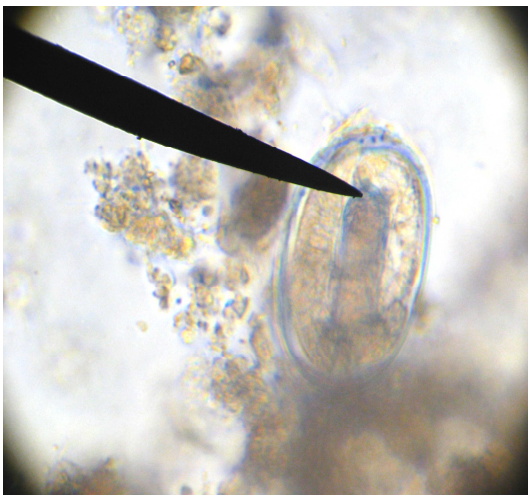
**Figure B.4**  
viable *Ascaris* Spp. Egg  
(20x40)



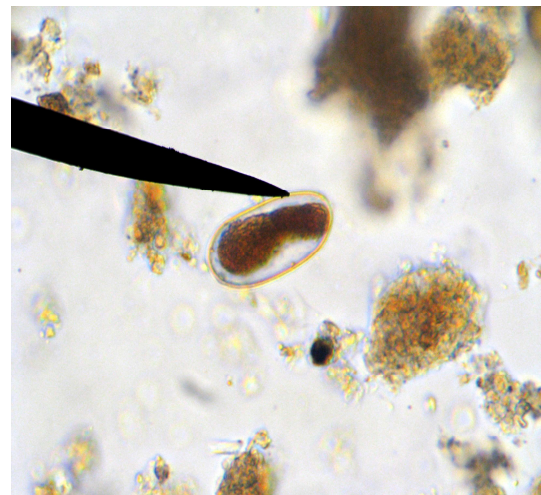
**Figure B.5**  
Viable *Trichostrongylous* spp. egg  
(20x40)



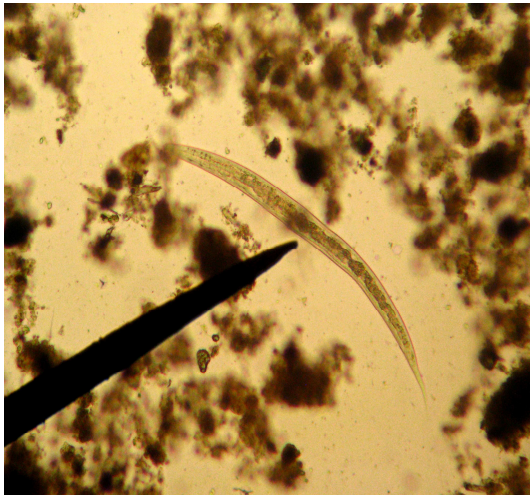
**Figure B.6**  
Viable hook worm Egg  
(20x40)



**Figure B.7**  
Viable hook worm Egg (20x40)  
Egg contained larva



**Figure B.8**  
Nonviable hook worm Egg (20x40)  
Nonhatch Egg



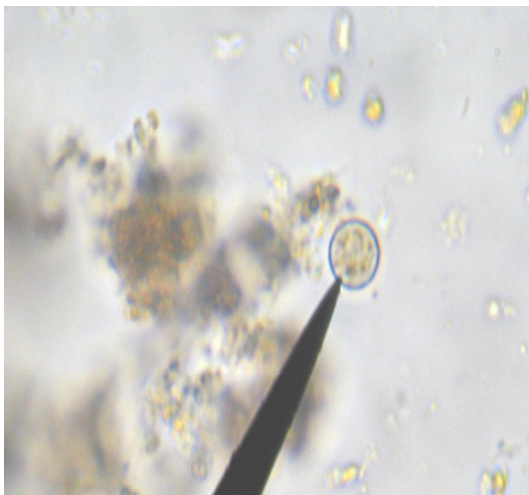
**Figure B.9**

Viable *strongyloides stercoralis* larva  
(10X10)



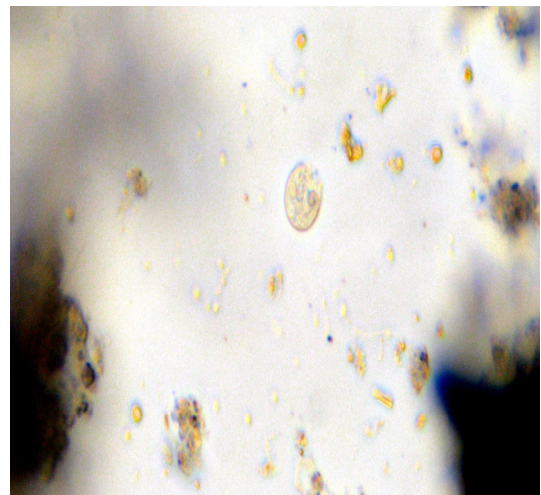
**Figure B.10**

Non viable *strongyloides stercoralis* larva  
(10X10)



**Figure B.11**

Active Form of  
*Entamoeba Histolytica* Cyst  
(20X40)



**Figure B.12**

Inactive form of  
*Entamoeba Histolytica* cyst  
(20x40)

## 2) Composting heap



**Figure B.13** Treatments of without plastic cover



**Figure B.14** Treatments of with plastic cover

## APPENDIX C

### THE THREE-WAY ANALYSES OF VARIANCE WITH ONE REPEATED FACTOR

The three - way analysis of variance with one repeated factor was used to analyze the main effect of mixing ratio and steam sterilization condition and their interaction effect (mixing ratio, steam sterilization, and composting time). The volatile solids were an example that to test with three-way ANOVA with one repeated factor. The other parameter was tested in same procedure.

**Table C.1** Mauchy’s Test of Sphericity.

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon <sup>a</sup>		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
compostingtime	.029	51.161	9	.000	.411	.653	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept + Mixzingratio + Steam + Mixzingratio \* Steam  
 Within Subjects Design: compostingtime

**Table C.2** Test of within- subjects effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
compostingtime	Sphericity Assumed	340.193	4	85.048	340.456	.000
	Greenhouse-Geisser	340.193	1.645	206.853	340.456	.000
	Huynh-Feldt	340.193	2.610	130.331	340.456	.000
	Lower-bound	340.193	1.000	340.193	340.456	.000
compostingtime * Mixingratio	Sphericity Assumed	11.349	12	.946	3.786	.000
	Greenhouse-Geisser	11.349	4.934	2.300	3.786	.011
	Huynh-Feldt	11.349	7.831	1.449	3.786	.002
	Lower-bound	11.349	3.000	3.783	3.786	.032
compostingtime * Steam	Sphericity Assumed	8.293	4	2.073	8.299	.000
	Greenhouse-Geisser	8.293	1.645	5.042	8.299	.003
	Huynh-Feldt	8.293	2.610	3.177	8.299	.000
	Lower-bound	8.293	1.000	8.293	8.299	.011
compostingtime * Mixingratio * Steam	Sphericity Assumed	16.589	12	1.382	5.534	.000
	Greenhouse-Geisser	16.589	4.934	3.362	5.534	.001
	Huynh-Feldt	16.589	7.831	2.118	5.534	.000
	Lower-bound	16.589	3.000	5.530	5.534	.008
Error(compostingtime)	Sphericity Assumed	15.988	64	.250		
	Greenhouse-Geisser	15.988	26.314	.608		
	Huynh-Feldt	15.988	41.764	.383		
	Lower-bound	15.988	16.000	.999		

2) When the interaction exist among volatile solids, F-test of ANOVA is used to test main effect of mixing ratio at each composting time were classified each level of steam sterilization conditions (with PC and without PC treatment), Then to test differences between group by bonferroni adjustment was used.

**Table C.3** Test main effect at each composting time in with PC and without PC treatment at each composting time.

Steam sterilization	Composting time	
With PC treatment	0	$F_{(0.95, 3, 8)} > 3.054$ (P=0.092)
	2	$F_{(0.95, 3, 8)} < 71.475$ (P<0.001)
	4	$F_{(0.95, 3, 8)} < 43.255$ (P<0.001)
	6	$F_{(0.95, 3, 8)} < 112.991$ (P<0.001)
	8	$F_{(0.95, 3, 8)} < 44.084$ (P<0.001)
Without PC treatment	0	$F_{(0.95, 3, 8)} > 44.768$ (P>0.092)
	2	$F_{(0.95, 3, 8)} < 183.550$ (P<0.001)
	4	$F_{(0.95, 3, 8)} < 35.079$ (P<0.001)
	6	$F_{(0.95, 3, 8)} < 342.856$ (P<0.001)
	8	$F_{(0.95, 3, 8)} < 100.499$ (P<0.001)

**Table C.4** Test differences between group by bonferroni adjustment for with PC treatment at week 0 of composting time.

ANOVA							
Composting time_0wk							
Steam		Sum of Squares	df	Mean Square	F	Sig.	
with	Between Groups	12.609	3	4.203	3.054	.092	
	Within Groups	11.008	8	1.376			
	Total	23.616	11				
Multiple Comparisons							
Composting time_0wk							
Bonferroni							
Steam	(I) Mixzingratio	(J) Mixzingratio	Mean Difference (I- J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
with	ratio 1:0	ratio 1:1	-2.84333	.95777	.107	-6.1753	.4886
		ratio 3:1	-1.35000	.95777	1.000	-4.6820	1.9820
		ratio 6:1	-.94000	.95777	1.000	-4.2720	2.3920
	ratio 1:1	ratio 1:0	2.84333	.95777	.107	-.4886	6.1753
		ratio 3:1	1.49333	.95777	.945	-1.8386	4.8253
		ratio 6:1	1.90333	.95777	.493	-1.4286	5.2353
	ratio 3:1	ratio 1:0	1.35000	.95777	1.000	-1.9820	4.6820
		ratio 1:1	-1.49333	.95777	.945	-4.8253	1.8386
		ratio 6:1	.41000	.95777	1.000	-2.9220	3.7420
ratio 6:1	ratio 1:0	.94000	.95777	1.000	-2.3920	4.2720	
	ratio 1:1	-1.90333	.95777	.493	-5.2353	1.4286	
	ratio 3:1	-.41000	.95777	1.000	-3.7420	2.9220	

**Table C.5** Test differences between group by bonferroni adjustment for with PC treatment at week 2 of composting time.

ANOVA							
Composting time_2wk							
Steam		Sum of Squares	df	Mean Square	F	Sig.	
with	Between Groups	11.852	3	3.951	71.475	.000	
	Within Groups	.442	8	.055			
	Total	12.295	11				
Multiple Comparisons							
Composting time_2wk							
Bonferroni							
Steam	(I) Mixzingratio	(J) Mixzingratio	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
with	ratio 1:0	ratio 1:1	-2.77000*	.19196	.000	-3.4378	-2.1022
		ratio 3:1	-1.65000*	.19196	.000	-2.3178	-.9822
		ratio 6:1	-1.17333*	.19196	.002	-1.8412	-.5055
	ratio 1:1	ratio 1:0	2.77000*	.19196	.000	2.1022	3.4378
		ratio 3:1	1.12000*	.19196	.002	.4522	1.7878
		ratio 6:1	1.59667*	.19196	.000	.9288	2.2645
	ratio 3:1	ratio 1:0	1.65000*	.19196	.000	.9822	2.3178
		ratio 1:1	-1.12000*	.19196	.002	-1.7878	-.4522
		ratio 6:1	.47667	.19196	.228	-.1912	1.1445
	ratio 6:1	ratio 1:0	1.17333*	.19196	.002	.5055	1.8412
		ratio 1:1	-1.59667*	.19196	.000	-2.2645	-.9288
		ratio 3:1	-.47667	.19196	.228	-1.1445	.1912
*. The mean difference is significant at the 0.05 level.							

**Table C.6** Test differences between group by bonferroni adjustment for with PC treatment at week 4 of composting time.

ANOVA							
Composting time_4wk							
Steam		Sum of Squares	df	Mean Square	F	Sig.	
with	Between Groups	8.213	3	2.738	43.255	.000	
	Within Groups	.506	8	.063			
	Total	8.719	11				
Multiple Comparisons							
Composting time_4wk							
Bonferroni							
Steam	(I) Mixzingratio	(J) Mixzingratio	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
with	ratio 1:0	ratio 1:1	-1.52667*	.20541	.000	-2.2413	-.8121
		ratio 3:1	-1.94333*	.20541	.000	-2.6579	-1.2287
		ratio 6:1	-2.08333*	.20541	.000	-2.7979	-1.3687
	ratio 1:1	ratio 1:0	1.52667*	.20541	.000	.8121	2.2413
		ratio 3:1	-.41667	.20541	.462	-1.1313	.2979
		ratio 6:1	-.55667	.20541	.160	-1.2713	.1579
	ratio 3:1	ratio 1:0	1.94333*	.20541	.000	1.2287	2.6579
		ratio 1:1	.41667	.20541	.462	-.2979	1.1313
		ratio 6:1	-.14000	.20541	1.000	-.8546	.5746
ratio 6:1	ratio 1:0	2.08333*	.20541	.000	1.3687	2.7979	
	ratio 1:1	.55667	.20541	.160	-.1579	1.2713	
	ratio 3:1	.14000	.20541	1.000	-.5746	.8546	
*. The mean difference is significant at the 0.05 level.							

**Table C.7** Test differences between group by bonferroni adjustment for with PC treatment at week 6 of composting time.

ANOVA							
Composting time_6wk							
Steam		Sum of Squares	df	Mean Square	F	Sig.	
with	Between Groups	26.575	3	8.858	112.991	.000	
	Within Groups	.627	8	.078			
	Total	27.203	11				
Multiple Comparisons							
Composting time_6wk							
Bonferroni							
Steam	(I) Mixzingratio	(J) Mixzingratio	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
with	ratio 1:0	ratio 1:1	-3.97333*	.22862	.000	-4.7687	-3.1780
		ratio 3:1	-2.85667*	.22862	.000	-3.6520	-2.0613
		ratio 6:1	-1.49333*	.22862	.001	-2.2887	-.6980
	ratio 1:1	ratio 1:0	3.97333*	.22862	.000	3.1780	4.7687
		ratio 3:1	1.11667*	.22862	.007	.3213	1.9120
		ratio 6:1	2.48000*	.22862	.000	1.6847	3.2753
	ratio 3:1	ratio 1:0	2.85667*	.22862	.000	2.0613	3.6520
		ratio 1:1	-1.11667*	.22862	.007	-1.9120	-.3213
		ratio 6:1	1.36333*	.22862	.002	.5680	2.1587
ratio 6:1	ratio 1:0	1.49333*	.22862	.001	.6980	2.2887	
	ratio 1:1	-2.48000*	.22862	.000	-3.2753	-1.6847	
	ratio 3:1	-1.36333*	.22862	.002	-2.1587	-.5680	
*. The mean difference is significant at the 0.05 level.							

**Table C.8** Test differences between group by bonferroni adjustment for with PC treatment at week 8 of composting time.

ANOVA							
Composting time_8wk							
Steam		Sum of Squares	df	Mean Square	F	Sig.	
with	Between Groups	36.781	3	12.260	44.084	.000	
	Within Groups	2.225	8	.278			
	Total	39.006	11				
Multiple Comparisons							
Composting time_8wk							
Bonferroni							
Steam	(I) Mixingratio	(J) Mixingratio	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
with	ratio 1:0	ratio 1:1	-4.72667*	.43059	.000	-6.2247	-3.2287
		ratio 3:1	-1.87333*	.43059	.015	-3.3713	-.3753
		ratio 6:1	-1.08667	.43059	.214	-2.5847	.4113
	ratio 1:1	ratio 1:0	4.72667*	.43059	.000	3.2287	6.2247
		ratio 3:1	2.85333*	.43059	.001	1.3553	4.3513
		ratio 6:1	3.64000*	.43059	.000	2.1420	5.1380
	ratio 3:1	ratio 1:0	1.87333*	.43059	.015	.3753	3.3713
		ratio 1:1	-2.85333*	.43059	.001	-4.3513	-1.3553
		ratio 6:1	.78667	.43059	.631	-.7113	2.2847
ratio 6:1	ratio 1:0	1.08667	.43059	.214	-.4113	2.5847	
	ratio 1:1	-3.64000*	.43059	.000	-5.1380	-2.1420	
	ratio 3:1	-.78667	.43059	.631	-2.2847	.7113	
*. The mean difference is significant at the 0.05 level.							

**Table C.9** Test differences between group by bonferroni adjustment for without PC treatment at week 0 of composting time.

ANOVA							
Composting time_0wk							
Steam		Sum of Squares	df	Mean Square	F	Sig.	
with out	Between Groups	38.340	3	12.780	44.768	.000	
	Within Groups	2.284	8	.285			
	Total	40.623	11				
Multiple Comparisons							
Composting time_0wk							
Bonferroni							
Steam	(I) Mixingratio	(J) Mixingratio	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
with out	ratio 1:0	ratio 1:1	-4.89667*	.43625	.000	-6.4143	-3.3790
		ratio 3:1	-3.53000*	.43625	.000	-5.0476	-2.0124
		ratio 6:1	-2.68667*	.43625	.002	-4.2043	-1.1690
	ratio 1:1	ratio 1:0	4.89667*	.43625	.000	3.3790	6.4143
		ratio 3:1	1.36667	.43625	.084	-.1510	2.8843
		ratio 6:1	2.21000*	.43625	.006	.6924	3.7276
	ratio 3:1	ratio 1:0	3.53000*	.43625	.000	2.0124	5.0476
		ratio 1:1	-1.36667	.43625	.084	-2.8843	.1510
		ratio 6:1	.84333	.43625	.536	-.6743	2.3610
ratio 6:1	ratio 1:0	2.68667*	.43625	.002	1.1690	4.2043	
	ratio 1:1	-2.21000*	.43625	.006	-3.7276	-.6924	
	ratio 3:1	-.84333	.43625	.536	-2.3610	.6743	
*. The mean difference is significant at the 0.05 level.							

**Table C.10** Test differences between group by bonferroni adjustment for without PC treatment at week 2 of composting time.

ANOVA							
Composting time_2wk							
Steam		Sum of Squares	df	Mean Square	F	Sig.	
with out	Between Groups	16.932	3	5.644	183.550	.000	
	Within Groups	.246	8	.031			
	Total	17.178	11				
Multiple Comparisons							
Composting time_2wk							
Bonferroni							
Steam	(I) Mixzingratio	(J) Mixzingratio	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
with out	ratio 1:0	ratio 1:1	-2.62333 <sup>*</sup>	.14318	.000	-3.1214	-2.1252
		ratio 3:1	-2.56667 <sup>*</sup>	.14318	.000	-3.0648	-2.0686
		ratio 6:1	-.49000	.14318	.054	-.9881	.0081
	ratio 1:1	ratio 1:0	2.62333 <sup>*</sup>	.14318	.000	2.1252	3.1214
		ratio 3:1	.05667	.14318	1.000	-.4414	.5548
		ratio 6:1	2.13333 <sup>*</sup>	.14318	.000	1.6352	2.6314
	ratio 3:1	ratio 1:0	2.56667 <sup>*</sup>	.14318	.000	2.0686	3.0648
		ratio 1:1	-.05667	.14318	1.000	-.5548	.4414
		ratio 6:1	2.07667 <sup>*</sup>	.14318	.000	1.5786	2.5748
	ratio 6:1	ratio 1:0	.49000	.14318	.054	-.0081	.9881
		ratio 1:1	-2.13333 <sup>*</sup>	.14318	.000	-2.6314	-1.6352
		ratio 3:1	-2.07667 <sup>*</sup>	.14318	.000	-2.5748	-1.5786
*. The mean difference is significant at the 0.05 level.							

**Table C.11** Test differences between group by bonferroni adjustment for without PC treatment at week 4 of composting time.

ANOVA							
Composting time_4wk							
Steam		Sum of Squares	df	Mean Square	F	Sig.	
with out	Between Groups	28.658	3	9.553	35.079	.000	
	Within Groups	2.179	8	.272			
	Total	30.836	11				
Multiple Comparisons							
Composting time_4wk							
Bonferroni							
Steam	(I) Mixzingratio	(J) Mixzingratio	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
with out	ratio 1:0	ratio 1:1	-4.23667 <sup>*</sup>	.42608	.000	-5.7189	-2.7544
		ratio 3:1	-1.87667 <sup>*</sup>	.42608	.014	-3.3589	-.3944
		ratio 6:1	-1.19000	.42608	.141	-2.6723	.2923
	ratio 1:1	ratio 1:0	4.23667 <sup>*</sup>	.42608	.000	2.7544	5.7189
		ratio 3:1	2.36000 <sup>*</sup>	.42608	.003	.8777	3.8423
		ratio 6:1	3.04667 <sup>*</sup>	.42608	.001	1.5644	4.5289
	ratio 3:1	ratio 1:0	1.87667 <sup>*</sup>	.42608	.014	.3944	3.3589
		ratio 1:1	-2.36000 <sup>*</sup>	.42608	.003	-3.8423	-.8777
		ratio 6:1	.68667	.42608	.874	-.7956	2.1689
	ratio 6:1	ratio 1:0	1.19000	.42608	.141	-.2923	2.6723
		ratio 1:1	-3.04667 <sup>*</sup>	.42608	.001	-4.5289	-1.5644
		ratio 3:1	-.68667	.42608	.874	-2.1689	.7956
*. The mean difference is significant at the 0.05 level.							

**Table C.12** Test differences between group by bonferroni adjustment for without PC treatment at week 6 of composting time.

ANOVA							
Composting time_6wk							
Steam		Sum of Squares	df	Mean Square	F	Sig.	
with out	Between Groups	23.348	3	7.783	342.856	.000	
	Within Groups	.182	8	.023			
	Total	23.530	11				
Multiple Comparisons							
Composting time_6wk							
Bonferroni							
Steam	(I) Mixzingratio	(J) Mixzingratio	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
with out	ratio 1:0	ratio 1:1	-3.83333 <sup>*</sup>	.12302	.000	-4.2613	-3.4054
		ratio 3:1	-2.39000 <sup>*</sup>	.12302	.000	-2.8180	-1.9620
		ratio 6:1	-1.45667 <sup>*</sup>	.12302	.000	-1.8846	-1.0287
	ratio 1:1	ratio 1:0	3.83333 <sup>*</sup>	.12302	.000	3.4054	4.2613
		ratio 3:1	1.44333 <sup>*</sup>	.12302	.000	1.0154	1.8713
		ratio 6:1	2.37667 <sup>*</sup>	.12302	.000	1.9487	2.8046
	ratio 3:1	ratio 1:0	2.39000 <sup>*</sup>	.12302	.000	1.9620	2.8180
		ratio 1:1	-1.44333 <sup>*</sup>	.12302	.000	-1.8713	-1.0154
		ratio 6:1	.93333 <sup>*</sup>	.12302	.000	.5054	1.3613
	ratio 6:1	ratio 1:0	1.45667 <sup>*</sup>	.12302	.000	1.0287	1.8846
		ratio 1:1	-2.37667 <sup>*</sup>	.12302	.000	-2.8046	-1.9487
		ratio 3:1	-.93333 <sup>*</sup>	.12302	.000	-1.3613	-.5054
*. The mean difference is significant at the 0.05 level.							

**Table C.13** Test differences between group by bonferroni adjustment for without PC treatment at week 8 of composting time.

ANOVA							
Composting time_8wk							
Steam		Sum of Squares	df	Mean Square	F	Sig.	
with out	Between Groups	28.650	3	9.550	100.499	.000	
	Within Groups	.760	8	.095			
	Total	29.410	11				
Multiple Comparisons							
Composting time_8wk							
Bonferroni							
Steam	(I) Mixzingratio	(J) Mixzingratio	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
with out	ratio 1:0	ratio 1:1	-4.36667 <sup>*</sup>	.25169	.000	-5.2423	-3.4911
		ratio 3:1	-2.32333 <sup>*</sup>	.25169	.000	-3.1989	-1.4477
		ratio 6:1	-2.16667 <sup>*</sup>	.25169	.000	-3.0423	-1.2911
	ratio 1:1	ratio 1:0	4.36667 <sup>*</sup>	.25169	.000	3.4911	5.2423
		ratio 3:1	2.04333 <sup>*</sup>	.25169	.000	1.1677	2.9189
		ratio 6:1	2.20000 <sup>*</sup>	.25169	.000	1.3244	3.0756
	ratio 3:1	ratio 1:0	2.32333 <sup>*</sup>	.25169	.000	1.4477	3.1989
		ratio 1:1	-2.04333 <sup>*</sup>	.25169	.000	-2.9189	-1.1677
		ratio 6:1	.15667	.25169	1.000	-.7189	1.0323
	ratio 6:1	ratio 1:0	2.16667 <sup>*</sup>	.25169	.000	1.2911	3.0423
		ratio 1:1	-2.20000 <sup>*</sup>	.25169	.000	-3.0756	-1.3244
		ratio 3:1	-.15667	.25169	1.000	-1.0323	.7189
*. The mean difference is significant at the 0.05 level.							

3) To test the simple main effect of steam sterilization condition at each level of time classified each level of mixing ratio. Then to test differences between group by bonferroni adjustment was used.

**Table C.14** Test the simple main effect of steam sterilization condition at each level of time classified each level of mixing ratio

Mixing ratio	Composting time	
1:0	0	$F_{(0.95, 1,4)} > 3.054$ (P=0.359)
	2	$F_{(0.95, 1,4)} < 11.663$ (P=0.027)
	4	$F_{(0.95, 1,4)} < 8.834$ (P=0.041)
	6	$F_{(0.95, 1,4)} < 112.991$ (P<0.001)
	8	$F_{(0.95, 1,4)} < 77.183$ (P=0.001)
1:1	0	$F_{(0.95, 1,4)} > 1.083$ (P=0.357)
	2	$F_{(0.95, 1,4)} < 34.280$ (P=0.004)
	4	$F_{(0.95, 1,4)} < 15.801$ (P=0.016)
	6	$F_{(0.95, 1,4)} < 42.437$ (P=0.003)
	8	$F_{(0.95, 1,4)} < 16.607$ (P=0.015)
3:1	0	$F_{(0.95, 1,4)} < 14.431$ (P=0.019)
	2	$F_{(0.95, 1,4)} > 2.976$ (P=0.160)
	4	$F_{(0.95, 1,4)} > 5.361$ (P=0.082)
	6	$F_{(0.95, 1,4)} > 22.730$ (P=0.009)
	8	$F_{(0.95, 1,4)} > 19.060$ (P=0.012)
6:1	0	$F_{(0.95, 1,4)} > 27.904$ (P=0.006)
	2	$F_{(0.95, 1,4)} < 53.937$ (P=0.002)
	4	$F_{(0.95, 1,4)} < 45.247$ (P=0.003)
	6	$F_{(0.95, 1,4)} < 182.360$ (P<0.001)
	8	$F_{(0.95, 1,4)} < 0.853$ (P=0.408)

**Table C.15** Test differences between group for mixing ratio 1:0 at each level of time.

ANOVA							
Mixingratio			Sum of Squares	df	Mean Square	F	Sig.
ratio 1:0	Composting time_0wk	Between Groups	2.747	1	2.747	1.071	.359
		Within Groups	10.259	4	2.565		
		Total	13.006	5			
	Composting time_2wk	Between Groups	.427	1	.427	11.663	.027
		Within Groups	.146	4	.037		
		Total	.573	5			
	Composting time_4wk	Between Groups	.465	1	.465	8.834	.041
		Within Groups	.210	4	.053		
		Total	.675	5			
	Composting time_6wk	Between Groups	1.288	1	1.288	49.100	.002
		Within Groups	.105	4	.026		
		Total	1.393	5			
	Composting time_8wk	Between Groups	3.360	1	3.360	77.183	.001
		Within Groups	.174	4	.044		
		Total	3.534	5			

**Table C.16** Test differences between group for mixing ratio 1:1 at each level of time.

ANOVA							
Mixingratio			Sum of Squares	df	Mean Square	F	Sig.
ratio 1:1	Composting time_0wk	Between Groups	.735	1	.735	1.083	.357
		Within Groups	2.715	4	.679		
		Total	3.450	5			
	Composting time_2wk	Between Groups	.694	1	.694	34.280	.004
		Within Groups	.081	4	.020		
		Total	.775	5			
	Composting time_4wk	Between Groups	6.955	1	6.955	15.801	.016
		Within Groups	1.761	4	.440		
		Total	8.716	5			
	Composting time_6wk	Between Groups	1.707	1	1.707	42.437	.003
		Within Groups	.161	4	.040		
		Total	1.868	5			
	Composting time_8wk	Between Groups	5.171	1	5.171	16.607	.015
		Within Groups	1.245	4	.311		
		Total	6.416	5			

**Table C.17** Test differences between groups for mixing ratio 3:1 at each level of time.

ANOVA							
Mixingratio			Sum of Squares	df	Mean Square	F	Sig.
ratio 3:1	Composting time_0wk	Between Groups	1.025	1	1.025	14.431	.019
		Within Groups	.284	4	.071		
		Total	1.309	5			
	Composting time_2wk	Between Groups	.220	1	.220	2.976	.160
		Within Groups	.296	4	.074		
		Total	.517	5			
	Composting time_4wk	Between Groups	.583	1	.583	5.361	.082
		Within Groups	.435	4	.109		
		Total	1.018	5			
	Composting time_6wk	Between Groups	2.912	1	2.912	22.730	.009
		Within Groups	.512	4	.128		
		Total	3.425	5			
	Composting time_8wk	Between Groups	1.643	1	1.643	19.060	.012
		Within Groups	.345	4	.086		
		Total	1.988	5			

**Table C.18** Test differences between for mixing ratio 6:1 at each level of time.

ANOVA							
Mixingratio			Sum of Squares	df	Mean Square	F	Sig.
ratio 6:1	Composting time_0wk	Between Groups	.232	1	.232	27.904	.006
		Within Groups	.033	4	.008		
		Total	.265	5			
	Composting time_2wk	Between Groups	2.220	1	2.220	53.937	.002
		Within Groups	.165	4	.041		
		Total	2.385	5			
	Composting time_4wk	Between Groups	3.154	1	3.154	45.247	.003
		Within Groups	.279	4	.070		
		Total	3.433	5			
	Composting time_6wk	Between Groups	1.392	1	1.392	182.360	.000
		Within Groups	.031	4	.008		
		Total	1.423	5			
	Composting time_8wk	Between Groups	.260	1	.260	.853	.408
		Within Groups	1.221	4	.305		
		Total	1.481	5			

4) To test the simple main effect of time classified each level of mixing ratio. Then, test difference between groups by bonferronu adjustment used to compare.

**Table C.19** The simple main effect of time classified each level of mixing ratio.

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Mix10with	Between Groups	43.848	4	10.962	10.497	.001
	Within Groups	10.443	10	1.044		
	Total	54.291	14			
Mix11with	Between Groups	33.301	4	8.325	41.316	.000
	Within Groups	2.015	10	.202		
	Total	35.316	14			
Mix31with	Between Groups	30.302	4	7.575	61.280	.000
	Within Groups	1.236	10	.124		
	Total	31.538	14			
Mix61with	Between Groups	39.266	4	9.817	88.093	.000
	Within Groups	1.114	10	.111		
	Total	40.380	14			
Mix10without	Between Groups	45.999	4	11.500	254.494	.000
	Within Groups	.452	10	.045		
	Total	46.451	14			
Mix11without	Between Groups	56.514	4	14.129	35.785	.000
	Within Groups	3.948	10	.395		
	Total	60.462	14			
Mix31without	Between Groups	69.823	4	17.456	274.289	.000
	Within Groups	.636	10	.064		
	Total	70.459	14			
Mix61without	Between Groups	57.371	4	14.343	233.749	.000
	Within Groups	.614	10	.061		
	Total	57.985	14			

**Table C.20** Test difference between groups by bonferroni adjustment for mixing ratio 1:0 with PC treatment.

Multiple Comparisons							
Bonferroni							
Dependent Variable	(I) Time steam	(J) Time steam	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Mix10with	0wk	2wk	2.44000	.83438	.152	-.5483	5.4283
		4 wk	3.26000*	.83438	.029	.2717	6.2483
		6wk	4.19333*	.83438	.005	1.2051	7.1816
		8wk	4.95333*	.83438	.001	1.9651	7.9416
	2wk	0wk	-2.44000	.83438	.152	-5.4283	.5483
		4 wk	.82000	.83438	1.000	-2.1683	3.8083
		6wk	1.75333	.83438	.619	-1.2349	4.7416
		8wk	2.51333	.83438	.131	-.4749	5.5016
	4 wk	0wk	-3.26000*	.83438	.029	-6.2483	-.2717
		2wk	-.82000	.83438	1.000	-3.8083	2.1683
		6wk	.93333	.83438	1.000	-2.0549	3.9216
		8wk	1.69333	.83438	.699	-1.2949	4.6816
	6wk	0wk	-4.19333*	.83438	.005	-7.1816	-1.2051
		2wk	-1.75333	.83438	.619	-4.7416	1.2349
		4 wk	-.93333	.83438	1.000	-3.9216	2.0549
		8wk	.76000	.83438	1.000	-2.2283	3.7483
	8wk	0wk	-4.95333*	.83438	.001	-7.9416	-1.9651
		2wk	-2.51333	.83438	.131	-5.5016	.4749
		4 wk	-1.69333	.83438	.699	-4.6816	1.2949
		6wk	-.76000	.83438	1.000	-3.7483	2.2283

**Table C.21** Test difference between groups by bonferroni adjustment for mixing ratio 1:1 with PC treatment.

Multiple Comparisons							
Bonferroni							
Dependent Variable	(I) Time steam	(J) Time steam	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Mix11with	0wk	2wk	2.51333*	.36652	.000	1.2007	3.8260
		4 wk	4.57667*	.36652	.000	3.2640	5.8893
		6wk	3.06333*	.36652	.000	1.7507	4.3760
		8wk	3.07000*	.36652	.000	1.7574	4.3826
	2wk	0wk	-2.51333*	.36652	.000	-3.8260	-1.2007
		4 wk	2.06333*	.36652	.002	.7507	3.3760
		6wk	.55000	.36652	1.000	-.7626	1.8626
		8wk	.55667	.36652	1.000	-.7560	1.8693
	4 wk	0wk	-4.57667*	.36652	.000	-5.8893	-3.2640
		2wk	-2.06333*	.36652	.002	-3.3760	-.7507
		6wk	-1.51333*	.36652	.020	-2.8260	-.2007
		8wk	-1.50667*	.36652	.021	-2.8193	-.1940
	6wk	0wk	-3.06333*	.36652	.000	-4.3760	-1.7507
		2wk	-.55000	.36652	1.000	-1.8626	.7626
		4 wk	1.51333*	.36652	.020	.2007	2.8260
		8wk	.00667	.36652	1.000	-1.3060	1.3193
	8wk	0wk	-3.07000*	.36652	.000	-4.3826	-1.7574
		2wk	-.55667	.36652	1.000	-1.8693	.7560
		4 wk	1.50667*	.36652	.021	.1940	2.8193
		6wk	-.00667	.36652	1.000	-1.3193	1.3060

**Table C.22** Test difference between groups by bonferroni adjustment for mixing ratio 3:1 with PC treatment.

Multiple Comparisons							
Bonferroni							
Dependent Variable	(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
	Time steam	Time steam				Lower Bound	Upper Bound
Mix31with	0wk	2wk	2.14000*	.28708	.000	1.1119	3.1681
		4 wk	2.66667*	.28708	.000	1.6385	3.6948
		6wk	2.68667*	.28708	.000	1.6585	3.7148
		8wk	4.43000*	.28708	.000	3.4019	5.4581
	2wk	0wk	-2.14000*	.28708	.000	-3.1681	-1.1119
		4 wk	.52667	.28708	.965	-.5015	1.5548
		6wk	.54667	.28708	.860	-.4815	1.5748
		8wk	2.29000*	.28708	.000	1.2619	3.3181
	4 wk	0wk	-2.66667*	.28708	.000	-3.6948	-1.6385
		2wk	-.52667	.28708	.965	-1.5548	.5015
		6wk	.02000	.28708	1.000	-1.0081	1.0481
		8wk	1.76333*	.28708	.001	.7352	2.7915
	6wk	0wk	-2.68667*	.28708	.000	-3.7148	-1.6585
		2wk	-.54667	.28708	.860	-1.5748	.4815
		4 wk	-.02000	.28708	1.000	-1.0481	1.0081
		8wk	1.74333*	.28708	.001	.7152	2.7715
	8wk	0wk	-4.43000*	.28708	.000	-5.4581	-3.4019
		2wk	-2.29000*	.28708	.000	-3.3181	-1.2619
		4 wk	-1.76333*	.28708	.001	-2.7915	-.7352
		6wk	-1.74333*	.28708	.001	-2.7715	-.7152

**Table C.23** Test difference between groups by bonferroni adjustment for mixing ratio 6:1 with PC treatment.

Multiple Comparisons							
Bonferroni							
Dependent Variable	(I) Time steam	(J) Time steam	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Mix61 with	0wk	2wk	2.20667*	.27256	.000	1.2305	3.1828
		4 wk	2.11667*	.27256	.000	1.1405	3.0928
		6wk	3.64000*	.27256	.000	2.6639	4.6161
		8wk	4.80667*	.27256	.000	3.8305	5.7828
	2wk	0wk	-2.20667*	.27256	.000	-3.1828	-1.2305
		4 wk	-.09000	.27256	1.000	-1.0661	.8861
		6wk	1.43333*	.27256	.004	.4572	2.4095
		8wk	2.60000*	.27256	.000	1.6239	3.5761
	4 wk	0wk	-2.11667*	.27256	.000	-3.0928	-1.1405
		2wk	.09000	.27256	1.000	-.8861	1.0661
		6wk	1.52333*	.27256	.002	.5472	2.4995
		8wk	2.69000*	.27256	.000	1.7139	3.6661
	6wk	0wk	-3.64000*	.27256	.000	-4.6161	-2.6639
		2wk	-1.43333*	.27256	.004	-2.4095	-.4572
		4 wk	-1.52333*	.27256	.002	-2.4995	-.5472
		8wk	1.16667*	.27256	.016	.1905	2.1428
	8wk	0wk	-4.80667*	.27256	.000	-5.7828	-3.8305
		2wk	-2.60000*	.27256	.000	-3.5761	-1.6239
		4 wk	-2.69000*	.27256	.000	-3.6661	-1.7139
		6wk	-1.16667*	.27256	.016	-2.1428	-.1905

**Table C.24** Test difference between groups by bonferroni adjustment for mixing ratio 1:0 without PC treatment.

Multiple Comparisons							
Bonferroni							
Dependent Variable	(I) Time ๐๐๓ steam	(J) Time ๐๐๓ steam	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Mix10without	0wk	2wk	1.62000*	.17356	.000	.9984	2.2416
		4 wk	2.46333*	.17356	.000	1.8417	3.0849
		6wk	3.76667*	.17356	.000	3.1451	4.3883
		8wk	5.09667*	.17356	.000	4.4751	5.7183
	2wk	0wk	-1.62000*	.17356	.000	-2.2416	-.9984
		4 wk	.84333*	.17356	.007	.2217	1.4649
		6wk	2.14667*	.17356	.000	1.5251	2.7683
		8wk	3.47667*	.17356	.000	2.8551	4.0983
	4 wk	0wk	-2.46333*	.17356	.000	-3.0849	-1.8417
		2wk	-.84333*	.17356	.007	-1.4649	-.2217
		6wk	1.30333*	.17356	.000	.6817	1.9249
		8wk	2.63333*	.17356	.000	2.0117	3.2549
	6wk	0wk	-3.76667*	.17356	.000	-4.3883	-3.1451
		2wk	-2.14667*	.17356	.000	-2.7683	-1.5251
		4 wk	-1.30333*	.17356	.000	-1.9249	-.6817
		8wk	1.33000*	.17356	.000	.7084	1.9516
	8wk	0wk	-5.09667*	.17356	.000	-5.7183	-4.4751
		2wk	-3.47667*	.17356	.000	-4.0983	-2.8551
		4 wk	-2.63333*	.17356	.000	-3.2549	-2.0117
		6wk	-1.33000*	.17356	.000	-1.9516	-.7084

**Table C.25** Test difference between groups by bonferroni adjustment for mixing ratio 1:1 without PC treatment.

Multiple Comparisons							
Bonferroni							
Dependent Variable	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
	steam	steam				Lower Bound	Upper Bound
Mix11without	0wk	2wk	3.89333*	.51304	.000	2.0559	5.7307
		4 wk	3.12333*	.51304	.001	1.2859	4.9607
		6wk	4.83000*	.51304	.000	2.9926	6.6674
		8wk	5.62667*	.51304	.000	3.7893	7.4641
	2wk	0wk	-3.89333*	.51304	.000	-5.7307	-2.0559
		4 wk	-.77000	.51304	1.000	-2.6074	1.0674
		6wk	.93667	.51304	.979	-.9007	2.7741
		8wk	1.73333	.51304	.070	-.1041	3.5707
	4 wk	0wk	-3.12333*	.51304	.001	-4.9607	-1.2859
		2wk	.77000	.51304	1.000	-1.0674	2.6074
		6wk	1.70667	.51304	.077	-.1307	3.5441
		8wk	2.50333*	.51304	.006	.6659	4.3407
	6wk	0wk	-4.83000*	.51304	.000	-6.6674	-2.9926
		2wk	-.93667	.51304	.979	-2.7741	.9007
		4 wk	-1.70667	.51304	.077	-3.5441	.1307
		8wk	.79667	.51304	1.000	-1.0407	2.6341
	8wk	0wk	-5.62667*	.51304	.000	-7.4641	-3.7893
		2wk	-1.73333	.51304	.070	-3.5707	.1041
		4 wk	-2.50333*	.51304	.006	-4.3407	-.6659
		6wk	-.79667	.51304	1.000	-2.6341	1.0407

**Table C.26** Test difference between groups by bonferroni adjustment for mixing ratio 3:1 without PC treatment.

Multiple Comparisons							
Bonferroni							
Dependent Variable	(I) Time steam	(J) Time steam	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Mix31without	0wk	2wk	2.58333*	.20598	.000	1.8456	3.3210
		4 wk	4.11667*	.20598	.000	3.3790	4.8544
		6wk	4.90667*	.20598	.000	4.1690	5.6444
		8wk	6.30333*	.20598	.000	5.5656	7.0410
	2wk	0wk	-2.58333*	.20598	.000	-3.3210	-1.8456
		4 wk	1.53333*	.20598	.000	.7956	2.2710
		6wk	2.32333*	.20598	.000	1.5856	3.0610
		8wk	3.72000*	.20598	.000	2.9823	4.4577
	4 wk	0wk	-4.11667*	.20598	.000	-4.8544	-3.3790
		2wk	-1.53333*	.20598	.000	-2.2710	-.7956
		6wk	.79000*	.20598	.033	.0523	1.5277
		8wk	2.18667*	.20598	.000	1.4490	2.9244
	6wk	0wk	-4.90667*	.20598	.000	-5.6444	-4.1690
		2wk	-2.32333*	.20598	.000	-3.0610	-1.5856
		4 wk	-.79000*	.20598	.033	-1.5277	-.0523
		8wk	1.39667*	.20598	.000	.6590	2.1344
	8wk	0wk	-6.30333*	.20598	.000	-7.0410	-5.5656
		2wk	-3.72000*	.20598	.000	-4.4577	-2.9823
		4 wk	-2.18667*	.20598	.000	-2.9244	-1.4490
		6wk	-1.39667*	.20598	.000	-2.1344	-.6590

**Table C.27** Test difference between groups by bonferroni adjustment for mixing ratio 6:1 without PC treatment.

Multiple Comparisons							
Bonferroni							
Dependent Variable	(I) Time steam	(J) Time steam	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Mix61without	0wk	2wk	3.81667*	.20225	.000	3.0923	4.5410
		4 wk	3.96000*	.20225	.000	3.2356	4.6844
		6wk	4.99667*	.20225	.000	4.2723	5.7210
		8wk	5.61667*	.20225	.000	4.8923	6.3410
	2wk	0wk	-3.81667*	.20225	.000	-4.5410	-3.0923
		4 wk	.14333	.20225	1.000	-.5810	.8677
		6wk	1.18000*	.20225	.002	.4556	1.9044
		8wk	1.80000*	.20225	.000	1.0756	2.5244
	4 wk	0wk	-3.96000*	.20225	.000	-4.6844	-3.2356
		2wk	-.14333	.20225	1.000	-.8677	.5810
		6wk	1.03667*	.20225	.004	.3123	1.7610
		8wk	1.65667*	.20225	.000	.9323	2.3810
	6wk	0wk	-4.99667*	.20225	.000	-5.7210	-4.2723
		2wk	-1.18000*	.20225	.002	-1.9044	-.4556
		4 wk	-1.03667*	.20225	.004	-1.7610	-.3123
		8wk	.62000	.20225	.119	-.1044	1.3444
	8wk	0wk	-5.61667*	.20225	.000	-6.3410	-4.8923
		2wk	-1.80000*	.20225	.000	-2.5244	-1.0756
		4 wk	-1.65667*	.20225	.000	-2.3810	-.9323
		6wk	-.62000	.20225	.119	-1.3444	.1044

\*. The mean difference is significant at the 0.05 level.

## **BIOGRAPHY**

<b>NAME</b>	Miss Taninporn Tippayamongkonkun
<b>DATE OF BIRTH</b>	18 May 1983
<b>PLACE OF BIRTH</b>	Ubonrachathani, Thailand
<b>INSTITUTIONS ATTENDED</b>	Mahidol University, 2002-2006: Bachelor of Science (Environmental health) Mahidol University, 2006-2011: Master of Science (Environmental Sanitation)
<b>HOME ADDRESS</b>	61 Chayanggul Road, Tumbol NaiMuang, Amphur Muang, Ubonrachathani, Thailand, 34000 Tel. 08-1547-9497 E-mail: taninka_tippy@hotmail.com
<b>RESEARCH GRANT</b>	This thesis is partially supported by Graduate Studies of Mahidol University Alumni Association.