

**THE WINDROW COMPOSTING CONDITIONS  
FOR SEWAGE SLUDGE MIXED WITH GRASS CLIPPINGS**

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**ABSTRACT**

The research was aimed at studying compost qualities influenced by different composting conditions of sewage sludge mixed with grass clippings through the windrow composting technique. The research design was a field experimental study and factorial design with multiple independent variables (4 mixing ratios: 1:0, 1:1, 3:1, and 6:1 (vol.:vol.); 2 steam sterilization conditions; with or without black plastic sheet cover (PC); and 5 composting times: 0, 2, 4, 6, 8 weeks). The physical and chemical characteristics of compost materials included total solids (TS), volatile solids (VS), temperature, pH, organic matter, organic nitrogen, inorganic nitrogen, C/N ratio, total phosphorus, available phosphorus, and total potassium which were determined every two weeks. Descriptive and analytical statistics, with three-way analysis of variance with one repeated measure, were used in the data analysis.

The results showed that mixing ratios and composting times resulted in significant differences ( $P < 0.05$ ) in temperature, TS, VS, pH, organic matter, organic nitrogen, inorganic nitrogen, C/N ratio, total phosphorus, available phosphorus, and total potassium changes, but steam sterilizations did not result in significant differences in temperature, organic matter, carbon to nitrogen ratio, total phosphorus, available phosphorus, and total potassium changes. At the end of experiment, the treatment that had the highest nutrients, and the one that was in line with the organic fertilizer standard of the Department of Agriculture, was mixing ratio 6:1 with PC and without PC (pH 6.01 and 6.16, organic matter 16.40% and 16.45%, total nitrogen 1.44% and 1.35%, C/N ratio 7:1 and 7:1, total phosphorus 0.50% and 0.56% and total potassium 1.51% and 1.53%, respectively). These two, 6:1 with PC and 6:1 without PC, were the recommended treatments for sludge application based on consideration of sludge optimization management and highest benefit on utilization.

The findings suggest that these research results should be a solution to sustainable management of both sewage sludge and the organic waste problem. It also can be used as a sewage sludge application criterion for agricultural areas and maximizing recycling nutrients to the environment.

**KEY WORDS:** SEWAGE SLUDGE / GRASS CLIPPINGS/  
AGRICULTURAL UTILIZATION / PLANT NUTRIENTS /  
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#### บทคัดย่อ

งานวิจัยมีวัตถุประสงค์เพื่อศึกษาคุณภาพของปุ๋ยหมัก เมื่อผ่านสภาวะการหมักแบบกองแถวของกากตะกอนน้ำเสียชุมชนผสมกับหญ้าแห้งที่แตกต่างกัน ออกแบบการวิจัยโดยทดลองในภาคสนามแบบแฟกทอเรียลที่มีตัวแปรต้นหลายตัว (4 อัตราส่วนการหมักกากตะกอนต่อเศษหญ้า; 1:0 1:1 3:1 และ 6:1 โดยปริมาตร, 2 สภาวะการทำสตริม สเตอริไรเซชัน; คลุมหรือไม่คลุมกองด้วยแผ่นพลาสติกสีดำ และ 5 ช่วงระยะเวลาการหมัก; 0 2 4 6 และ 8 สัปดาห์) วิเคราะห์ลักษณะสมบัติทางกายภาพและเคมีของวัสดุหมัก ได้แก่ ของแข็งทั้งหมด ของแข็งระเหยได้ อุณหภูมิ ค่าความเป็นกรด-ด่าง อินทรีย์วัตถุ อินทรีย์ไนโตรเจน อนินทรีย์ไนโตรเจน อัตราส่วนระหว่างคาร์บอนต่อไนโตรเจน ฟอสฟอรัสทั้งหมด ฟอสฟอรัสที่พืชสามารถนำไปใช้ประโยชน์ได้ และโพแทสเซียมทั้งหมด ทุก 2 สัปดาห์ ใช้สถิติเชิงพรรณนาและเชิงวิเคราะห์ คือ three-way analyses of variance with one repeated measure ในการวิเคราะห์ข้อมูล

ผลการศึกษาพบว่า อัตราส่วนการหมักกากตะกอนต่อเศษหญ้าและช่วงระยะเวลาการหมักมีอิทธิพลต่อความแตกต่างอย่างมีนัยสำคัญทางสถิติ ( $P < 0.05$ ) ของการเปลี่ยนแปลงอุณหภูมิ ของแข็งทั้งหมด ของแข็งระเหยได้ ค่าความเป็นกรด-ด่าง อินทรีย์วัตถุ อินทรีย์ไนโตรเจน อนินทรีย์ไนโตรเจน อัตราส่วนระหว่างคาร์บอนต่อไนโตรเจน ฟอสฟอรัสทั้งหมด ฟอสฟอรัสที่พืชสามารถนำไปใช้ประโยชน์ได้ และโพแทสเซียมทั้งหมด แต่สภาวะการทำสตริม สเตอริไรเซชันไม่มีอิทธิพลต่อความแตกต่างอย่างมีนัยสำคัญทางสถิติของการเปลี่ยนแปลงอุณหภูมิ อินทรีย์วัตถุ อัตราส่วนระหว่างคาร์บอนต่อไนโตรเจน ฟอสฟอรัสทั้งหมด ฟอสฟอรัสที่พืชสามารถนำไปใช้ประโยชน์ได้ และโพแทสเซียมทั้งหมด เมื่อสิ้นสุดการทดลองพบว่า อัตราส่วนการหมักกากตะกอนต่อเศษหญ้าที่อัตรา 6:1 ทั้งที่ทำการคลุมและไม่คลุมกองด้วยแผ่นพลาสติกสีดำ มีปริมาณธาตุอาหารต่างๆสูงสุดและเป็นไปตามเกณฑ์มาตรฐานปุ๋ยอินทรีย์ที่กรมวิชาการเกษตรกำหนดไว้ (ค่าความเป็นกรด-ด่าง 6.01 และ 6.16 อินทรีย์วัตถุ 16.40% และ 16.45% ไนโตรเจนทั้งหมด 1.44% และ 1.35% อัตราส่วนระหว่างคาร์บอนต่อไนโตรเจน 7:1 และ 7:1 ฟอสฟอรัสทั้งหมด 0.50% และ 0.56% และโพแทสเซียมทั้งหมด 1.51% และ 1.53% ตามลำดับ) จึงแนะนำให้ใช้สภาวะในทางปฏิบัติโดยพิจารณาบนพื้นฐานของการจัดการกากตะกอนอย่างเหมาะสม และใช้ประโยชน์ได้สูงสุด

ผลการวิจัยชี้แนะว่า ผลจากการหมักกากตะกอนร่วมกับเศษหญ้านี้สามารถนำไปใช้แก้ปัญหาและจัดการกากตะกอนและเศษหญ้าได้อย่างยั่งยืน สามารถนำไปใช้เป็นหลักเกณฑ์ในการนำกากตะกอนไปใช้ประโยชน์ในพื้นที่ทางการเกษตรและนำธาตุอาหารต่าง ๆ หมุนเวียนสู่สิ่งแวดล้อมได้สูงสุดอีกทางหนึ่ง

## CONTENTS

	<b>Page</b>
<b>ACKNOWLEDGEMENT</b>	<b>iii</b>
<b>ENGLISH ABSTRACT</b>	<b>iv</b>
<b>THAI ABSTRACT</b>	<b>v</b>
<b>LIST OF TABLES</b>	<b>xi</b>
<b>LIST OF FIGURES</b>	<b>xiv</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xxi</b>
<b>CHAPTER I</b>	
<b>INTRODUCTION</b>	<b>1</b>
1.1 Statement of problems	1
1.2 Objective of study	4
1.3 Hypotheses of study	4
1.4 Variables of study	5
1.5 Definition of terms	5
1.6 Scope of study	6
1.7 Limitation of study	7
1.8 Expected outcome	7
1.9 Conceptual framework	7
<b>CHAPTER II</b>	
<b>LITERATURE REVIEWS</b>	<b>8</b>
2.1 Sewage sludge; Sources and quantity	8
2.1.1 Sewage sludge	8
2.1.2 Sources of sewage sludge	8
2.1.3 Quantity of sewage sludge	8
2.2 Sewage sludge characteristics	9
2.3 Beneficial use of sewage sludge	13
2.4 Application of sewage sludge on land	13
2.5 Sewage sludge as soil conditioner	13

## **CONTENTS (cont.)**

		<b>Page</b>
<b>CHAPTER II</b>	<b>LITERATURE REVIEWS</b>	
	2.6 Effects of the sewage sludge application on soil properties	14
	2.7 Nitrogen mineralization	14
	2.8 Phosphorus mineralization	17
	2.9 Potassium	18
	2.10 Municipal yard waste	18
	2.11 Sewage sludge composting	19
	2.12 Composting	19
	2.12.1 The composting process	20
	2.12.2 The composting methods	22
	2.13 Factors affecting composting	26
	2.14 Steam sterilization	31
	2.15 Legislation and standards for Application of Sewage Sludge on Agricultural land in Thailand	32
	2.16 Related researches	34
<b>CHAPTER III</b>	<b>MATERIALS AND METHODS</b>	<b>38</b>
	3.1 Research design	38
	3.2 Place of the experiment	39
	3.3 Equipments and chemicals	39
	3.4 Experimental methods	41
	3.5 Research diagram	43
	3.6 Statistical analysis	44
<b>CHAPTER IV</b>	<b>RESULTS</b>	<b>45</b>
	4.1 Characteristics of sewage sludge and grass clippings	45
	4.2 Nutrients mineralization study	46

## CONTENTS (cont.)

		<b>Page</b>
<b>CHAPTER IV</b>	<b>RESULTS</b>	
	4.2.1 Physical characteristics	46
	4.2.1.1 Temperature	46
	4.2.1.2 Total solids	56
	4.2.1.3 Volatile solids	66
	4.2.2 Chemical characteristics	77
	4.2.2.1 pH	77
	4.2.2.2 Organic matter	88
	4.2.2.3 Total nitrogen	98
	4.2.2.4 Carbon to nitrogen ratio	120
	4.2.2.5 Phosphorus	127
	4.2.2.6 Total potassium	143
	4.3 Summary of the characteristic changes at the end of composting process	148
	4.3.1 The effects of mixing ratio to characteristic changes	148
	4.3.2 The effects of steam sterilization to characteristic changes	149
	4.3.3 The effects of composting time to characteristic changes	150
	4.3.4 The first and the second highest of characteristic changes	151
<b>CHAPTER V</b>	<b>DISCUSSION</b>	<b>154</b>
	5.1 Characteristics of sewage sludge and grass clippings	154
	5.2 Nutrients mineralization study	155

## CONTENTS (cont.)

		<b>Page</b>
<b>CHAPTER V</b>	<b>DISCUSSION</b>	
	5.2.1 Physical characteristics	155
	5.2.1.1 Temperature	155
	5.2.1.2 Total solids	156
	5.2.1.3 Volatile solids	157
	5.2.2 Chemical characteristics	159
	5.2.2.1 pH	159
	5.2.2.2 Organic matter	160
	5.2.2.3 Total nitrogen	161
	5.2.2.4 Carbon to nitrogen ratio	163
	5.2.2.5 Phosphorus	164
	5.2.2.6 Total potassium	167
	5.3 Selected suitable treatment for application	168
<b>CHAPTER VI</b>	<b>CONCLUSION AND RECOMMENDATION</b>	<b>173</b>
	6.1 Conclusion	173
	6.1.1 Physical and chemical characteristics of sewage sludge and grass clippings	173
	6.1.2 Physical and chemical characteristic changes from sewage sludge mixed with grass clippings at different mixing ratios	173
	6.1.3 Physical and chemical characteristic changes from sewage sludge mixed with grass clippings at two steam sterilization conditions	174
	6.1.4 Physical and chemical characteristic changes from sewage sludge mixed with grass clippings during different composting times	174

**CONTENTS (cont.)**

	<b>Page</b>
<b>CHAPTER VI</b>	
<b>CONCLUSION AND RECOMMENDATION</b>	
6.1.5 Comparing physical and chemical characteristics from sewage sludge mixed with grass clippings at different conditions with guideline or standard	174
6.1.6 Selected suitable treatment for application	175
6.2 Recommendation	177
<b>REFERENCES</b>	<b>178</b>
<b>APPENDICES</b>	<b>183</b>
<b>BIOGRAPHY</b>	<b>203</b>

## LIST OF TABLES

<b>Table</b>	<b>Page</b>
2.1 Amount of sludge records from the 7 of Central Wastewater Treatment Plants (CWTPs) in Bangkok	9
2.2 General characteristics of fecal sludge and sewage sludge	12
2.3 Comparison of nutrient levels in commercial fertilizer and wastewater sludge	12
2.4 Summaries of the four main manure composting methods	26
2.5 Characteristics for the composting process	31
3.1 Treatment combination of sewage sludge mixed with grass clippings composting and different composting time	39
3.2 Parameter and test method for sewage sludge mixed with grass clippings and composted	42
4.1 The moisture content and chemical characteristics of sewage sludge and grass clippings	45
4.2 The ambient temperature (°C) and temperature of all treatments during the composting process at the different composting times	47
4.3 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for temperature	49
4.4 The average total solids (%) of all treatments during the composting process at the different composting times	57
4.5 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for total solids	59
4.6 The average volatile solids (%) of all treatments during the composting process at the different composting times	67
4.7 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for volatile solids	69
4.8 The average pH of all treatments during the composting process at the different composting times	78

## LIST OF TABLES (cont.)

<b>Table</b>	<b>Page</b>
4.9 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for pH	80
4.10 The average organic matter (%) of all treatments during the composting process at the different composting times	89
4.11 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for organic matter	91
4.12 The average total nitrogen (%) of all treatments during the composting process at the different composting times	99
4.13 The average organic nitrogen (%) of all treatments during the composting process at the different composting times	100
4.14 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for organic nitrogen	102
4.15 The average inorganic nitrogen (%) of all treatments during the composting process at the different composting times	110
4.16 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for inorganic nitrogen	112
4.17 The average carbon to nitrogen ratio of all treatments during the composting process at the different composting times	121
4.18 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for carbon to nitrogen ratio	123
4.19 The average total phosphorus (%) of all treatments during the composting process at the different composting times	128
4.20 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for total phosphorus	130
4.21 The average available phosphorus (%) of all treatments during the composting process at the different composting times	139
4.22 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for available phosphorus	141

**LIST OF TABLES (cont.)**

<b>Table</b>	<b>Page</b>
4.23 The average total potassium (%) of all treatments during the composting process at the different composting times	143
4.24 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for total potassium	145
4.25 Compare nutrient values at the different conditions of composting with the organic fertilizer standard of the Department of Agriculture	153

## LIST OF FIGURES

<b>Figure</b>	<b>Page</b>
2.1 A wooden bin unit, with three compartments	23
2.2 An aerated static pile with a bio.filter	24
2.3 Four channel in-vessel composting	25
4.1 The temperature trend lines of all treatments	47
4.2 The temperature of all treatments before and after passed composting process	48
4.3 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to temperature	50
4.4 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to temperature	51
4.5 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to temperature	52
4.6 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to temperature	52
4.7 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to temperature	53
4.8 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to temperature	54
4.9 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to temperature	56
4.10 The total solids trend lines of all treatments	57
4.11 The total solids of all treatments before and after passed composting process	58
4.12 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to total solids	60
4.13 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to total solids	61

## LIST OF FIGURES (cont.)

<b>Figure</b>	<b>Page</b>
4.14 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to total solids	62
4.15 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to total solids	62
4.16 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to total solids	63
4.17 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to total solids	64
4.18 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to total solids	66
4.19 The volatile solids trend lines of all treatments	67
4.20 The volatile solids of all treatments before and after passed composting process	68
4.21 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to volatile solids	70
4.22 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to volatile solids	72
4.23 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to volatile solids	73
4.24 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to volatile solids	73
4.25 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to volatile solids	74
4.26 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to volatile solids	75
4.27 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to volatile solids	77

## LIST OF FIGURES (cont.)

<b>Figure</b>	<b>Page</b>
4.28 The pH trend lines of all treatments	78
4.29 The pH of all treatments before and after passed composting process	79
4.30 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to pH	81
4.31 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to pH	83
4.32 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to pH	84
4.33 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to pH	84
4.34 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to pH	85
4.35 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to pH	86
4.36 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to pH	88
4.37 The organic matter trend lines of all treatments	89
4.38 The organic matter of all treatments before and after passed composting process	90
4.39 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to organic matter	92
4.40 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to organic matter	93
4.41 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to organic matter	94
4.42 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to organic matter	95

## LIST OF FIGURES (cont.)

<b>Figure</b>	<b>Page</b>
4.43 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to organic matter	95
4.44 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to organic matter	96
4.45 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to organic matter	98
4.46 The organic nitrogen trend lines of all treatments	100
4.47 The organic nitrogen of all treatments before and after passed composting process	101
4.48 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to organic nitrogen	103
4.49 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to organic nitrogen	104
4.50 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to organic nitrogen	105
4.51 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to organic nitrogen	106
4.52 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to organic nitrogen	106
4.53 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to organic nitrogen	107
4.54 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to organic nitrogen	109
4.55 The inorganic nitrogen trend lines of all treatments	111
4.56 The inorganic nitrogen of all treatments before and after passed composting process	111
4.57 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to inorganic nitrogen	114

## LIST OF FIGURES (cont.)

<b>Figure</b>	<b>Page</b>
4.58 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to inorganic nitrogen	115
4.59 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to inorganic nitrogen	116
4.60 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to inorganic nitrogen	116
4.61 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to inorganic nitrogen	117
4.62 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to inorganic nitrogen	118
4.63 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to inorganic nitrogen	120
4.64 The carbon to nitrogen ratio trend lines of all treatments	121
4.65 The carbon to nitrogen ratio of all treatments before and after passed composting process	122
4.66 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to carbon to nitrogen ratio	124
4.67 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to carbon to nitrogen ratio	125
4.68 The simple main effect of composting time effect to carbon to nitrogen ratio classified by each level of mixing ratio at all of steam sterilization	127
4.69 The total phosphorus trend lines of all treatments	128
4.70 The total phosphorus of all treatments before and after passed composting process	129

## LIST OF FIGURES (cont.)

<b>Figure</b>	<b>Page</b>
4.71 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to total phosphorus	131
4.72 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to total phosphorus	133
4.73 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to total phosphorus	134
4.74 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to total phosphorus	134
4.75 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to total phosphorus	135
4.76 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to total phosphorus	136
4.77 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to total phosphorus	138
4.78 The available phosphorus trend lines of all treatments	139
4.79 The available phosphorus of all treatments before and after passed composting process	140
4.80 The simple main effect of composting time effect to available phosphorus classified by each level of mixing ratio at all of steam sterilization	142
4.81 The total potassium trend lines of all treatments	144
4.82 The total potassium of all treatments before and after passed composting process	144
4.83 The simple main effect of composting time effect to total potassium classified by each level of mixing ratio at all of steam sterilization	147
5.1 The characteristic changes of the treatment which had mixing ratio 6:1 and covered by black plastic sheet	169
5.2 The nutrient changes of the treatment which had the mixing ratio 6:1 and covered by black plastic sheet	170

**LIST OF FIGURES (cont.)**

<b>Figure</b>		<b>Page</b>
5.3	The characteristic changes of the treatment which had mixing ratio 6:1 and not covered by black plastic sheet.	171
5.4	The nutrient changes of the treatment which had mixing ratio 6:1 and not covered by black plastic sheet	172

## LIST OF ABBREVIATIONS

cm	Centimeter
mm	Millimeter
m	Meter
m <sup>3</sup>	Cubic meter
m <sup>3</sup> /d	Cubic meter per day
kg	Kilogram
g/cap.d	Gram per capital per day
g/kg	Gram per kilogram
g/ m <sup>3</sup>	Gram per cubic meter
mg/kg	Milligram per kilogram
ton/d	Ton per day
t/ ha	Ton per hectare
cap	Capital
CEC	Cation Exchange Capacity
C/N ratio	Carbon per nitrogen ratio
CWTPs	Central Wastewater Treatment Plants
BMA	Bangkok Metropolitan Administration
TS	Total Solid
VS	Volatile Solid
OM	Organic Matter
N	Nitrogen
P	Phosphorus
K	Potassium
MPN/g DS	Most Probable Number per gram of dried solid
WW	Waste water
<i>et.al</i>	Et alli (Latin), and other
S.D.	Standard Deviation

**LIST OF ABBREVIATIONS (cont.)**

°C	Degree Celsius
°F	Degree Fahrenheit
%	Percentage
v/v	Volume by volume
lbs	Pounds
PCD	Pollution Control Department
dS/m	Deciseimens per meter
EC	Electrical Conductivity
CSS	Composted Sewage Sludge
DS	Dried solid
C/N	Carbon to nitrogen
C/P	Carbon to phosphorus
TOC	Total organic compound

# CHAPTER I

## INTRODUCTION

### 1.1 Statement of Problems

Rapid urbanization, industrial development, and population growth are the major factors which cause the depletion and degradation in environment. Bangkok has been faced with rapidly raising population and it is the center of business, services and small scale industries. Thus, the pollution in Bangkok area consists of air and water pollution, and hazardous waste issues. The sources of municipal wastes are from residential, commercial, institutional, construction and demolition, municipal services, industrial solid wastes, organic wastes and sewage sludge from wastewater treatment plants [1].

Wastewater is the major pollution in Bangkok area. Thai government has concerned about water pollution as a consequence of water pollution prevention, regulation and the installation of new wastewater treatment plants had constructed to solve these problems. The increasing of these plants lead to an increase in the amount of sewage sludge production as one of significant environmental problems [2]. In 2007, the amount of sewage sludge generated from all wastewater treatment plants was approximately 187.85 tons DS per day [3]. The estimate of sewage sludge will increase to 302 tons DS per day in 2020 [4].

Sewage sludge could create health problems, contribute to the release of greenhouse gasses and climate change. It is also a reservoir of pest if it use without appropriate management. Sludge can cause health and environmental concerns such as disease-causing organism contamination, heavy metal contamination, and also nuisances. It may has direct and/or indirect impacts to ecosystems and humans if substances from the disposed material are leaching into nearby groundwater reservoirs, rivers, and lakes [5].

Most sewage sludge undergoes additional treatment on sites before they are used or disposed to protect health and the environment, facilitate handling, and reduce cost [6]. The basic sewage sludge disposal practices are surface disposal, land application, landfilling, dumping into the sea, and incineration [7]. Each option has different practical benefits and constraints. Most sewage sludge is disposed of in or land or landfilled but the surface disposal and landfill management practices include requirements for runoff collection, leachate collection and disposal (if the unit is lined), vector control, methane monitoring, ground-water monitoring or certification, restriction on public access, growing of crop, and grazing of animal. Incineration reduces sewage sludge to a residue primarily consisting of ash and destroy virtually all of the volatile solids, pathogens and degrades most toxic organic chemicals. However, the products of incomplete combustion must be controlled. Metals are not degraded and are concentrated in the ash and in the particulate matter that is contained in the exhaust gasses generated by the process [6].

By its own nature, sludge is a waste rich in organic matter and valuable nutrients. Sewage sludge potentially consists of 40-60% of organic matter, and contains both macronutrients (e.g. 3.3% nitrogen, 2.3% phosphorus and 0.3% potassium) and micronutrients [6]. It may potentially be contaminated by heavy metals, poorly biodegradable trace organic compounds as well as pathogenic microorganisms but presented in low concentration [8]. Thus, sludge is not possible to use directly as fertilizer in land application and sludge needs to be improved to meet the standard/guideline before apply [9].

When compared to other sewage sludge management options, using land treatment of sewage sludge especially for agriculture is being increasingly considered in many big cities throughout the world as the best alternative option for sludge treatment because it is a practical option that requires low operational cost and also causes less environmental problems [6, 10]. However, most data on sludge production and management in developing countries are not readily available because most cities do not have adequate systems for wastewater treatment plants [1]. Moreover, the 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, small amount of sewage sludge is recycled.

The benefits of sewage sludge composting include; waste stabilization, destruction of pathogens, resource recovery, and moisture removal and volume reduction. So, it can be applied to land with minimal concern about its environmental impact if sewage sludge was passed stabilization [11]. The critical factors for sewage sludge composting are mixing ratio, composting time and steam sterilization. If they are suitable, the compost can be reduced weeds and pathogens. When compost is used, fertilizers, metals, organic chemicals, and pesticides are less contaminate to ground water and surface water [12].

For those reasons, sludge should be continuously evaluated its suitability before applying to land in terms of its characteristics and nutrients. After that the improvability of sewage sludge with organic wastes especially grass clippings should be studied until the appropriate stabilized sewage sludge are available and give highly benefit.

Therefore, the aim of this study was to study different composting conditions to utilization sewage sludge mixed with grass clippings through the windrow composting. In addition, the factors include mixing ratios, steam sterilization conditions and composting times which influencing nutrients were evaluated.

Research results were expected to be a solution to sustainable management of both sewage sludge and organic waste problem. It also could be used as sewage sludge application criterion for agricultural areas and maximizing recycling nutrients to the environment.

## **1.2 Objective of study**

### **1.2.1 General objective**

To study different composting conditions to utilize sewage sludge mixed with grass clippings through the windrow composting technique.

### **1.2.2 Specific objectives**

1.2.2.1 To study physical and chemical characteristics of sewage sludge and grass clippings.

1.2.2.2 To compare physical and chemical characteristics from sewage sludge mixed with grass clippings at different mixing ratios.

1.2.2.3 To compare physical and chemical characteristics from sewage sludge mixed with grass clippings at two steam sterilization conditions.

1.2.2.4 To compare physical and chemical characteristics from sewage sludge mixed with grass clippings during different composting times.

1.2.2.5 To compare physical and chemical characteristics from sewage sludge mixed with grass clippings at different conditions with guideline or standard.

## **1.3 Hypotheses of study**

1.3.1 The sewage sludge mixed with grass clippings at different mixing ratios were differed physical and chemical characteristics.

1.3.2 The sewage sludge mixed with grass clippings at different steam sterilization conditions were differed physical and chemical characteristics.

1.3.3 The sewage sludge mixed with grass clippings at different composting times were differed physical and chemical characteristics.

## **1.4 Variables of study**

### **1.4.1 Independent variables**

- Mixing ratios (Sewage sludge: grass clippings; 1:0, 1:1, 3:1 and 6:1 volume by volume)
- Steam sterilization conditions (with PC and without PC)
- Composting times (0, 2, 4, 6, and 8 weeks)

### **1.4.2 Dependent variables**

- Physical characteristics of sewage sludge mixed with grass clippings
- Chemical characteristics of sewage sludge mixed with grass clippings

### **1.4.3 Control variables**

- Type of sludge
- Type of grass clippings
- Size of grass clippings (2-5 cm)
- Type of composting (windrow pile)
- Size of pile
- Field moisture capacity (40-60%)

## **1.5 Definition of terms**

1.5.1 Sewage sludge is the semi-solid by-product generated during the treatment of domestic sewage in a treatment work. Sewage sludge in this study was random sampled from Nong Khaem wastewater treatment plant which has been treated by anaerobic digestion and dewatered by belt press.

1.5.2 Grass clippings were random sampled from municipal yard waste in Bangkok area. Grass clippings sample was chopped to 2-5 cm and air-dried.

1.5.3 Sewage sludge utilization is benefit from nutrients to agriculture.

In this study, sewage sludge utilization was considered by nutrients indicators of sewage sludge mixed with grass clippings through the windrow composting. Which organic nutrients are converted to plant-available inorganic forms by bacteria and fungi [11].

1.5.4 Nutrients were referred to organic nitrogen, inorganic nitrogen, total phosphorus, available phosphorus and potassium in the compost which generated from an aerobic composting process of sewage sludge mixed with grass clippings.

1.5.5 Mixing ratio was the ratio of sewage sludge mixed with grass clippings. It will be 1:0, 1:1, 3:1, and 6:1 volume by volume.

1.5.6 Steam sterilization condition was a condition which the pile of sewage sludge mixed with grass clippings was covered with black plastic sheet in the day time for 6 hours from 10 am to 4 pm and removed out after that.

1.5.7 Composting time was the duration (0, 2, 4, 6, and 8 weeks) which the sludge is mixed with grass clippings and composted.

1.5.8 Composting was the composted process that sewage sludge mixed with grass clippings will be incubated in the windrow piles for 8 weeks in aerobic condition, maintained 40-60% field moisture capacity, and turned the pile every weeks by mechanical.

## **1.6 Scope of study**

This research was conducted in a laboratory and field experiment. Sewage sludge in this study was sampled from Nong Khaem wastewater treatment plant, and grass clippings were sampled from municipal yard waste in Bangkok area. Sewage sludge and grass clippings in this study were represent only matters at period (October 2009). The windrow pile composting process was studied in the field at Nong Khaem sludge composting site. The mixtures were sampled and analyzed in laboratory at Department of Environmental Health Science, Faculty of Public Health, Mahidol University, Bangkok, Thailand. The composting was start during November - December 2009.

## 1.7 Limitation of study

1.7.1 Sewage sludge in this study was represented only matters at period (October 2009).

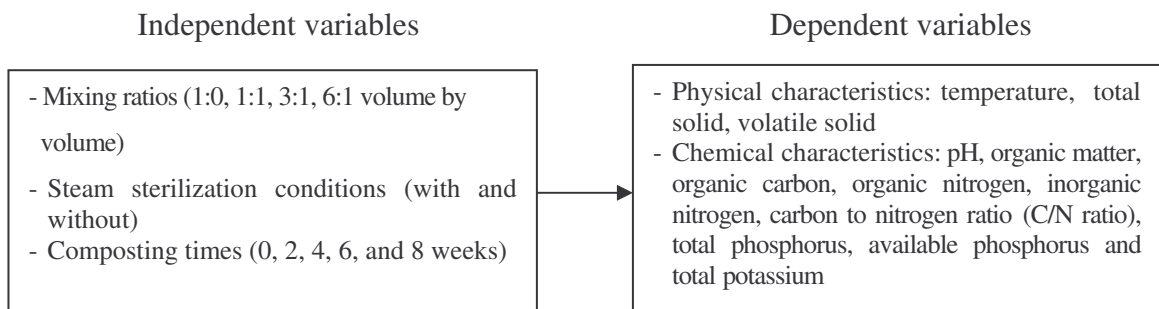
1.7.2 Grass clippings in this study may not represent all types and characteristics of grass clippings in Bangkok area.

1.7.3 Composting in this study was windrow composting, which is one type of composting. It may not represent all types of composting.

## 1.8 Expected outcome

The amounts of sewage sludge and organic wastes (grass clippings) required for the treatment and final disposal would reduce and it also could reduce environmental impacts from other disposal practices such as incineration, landfill, and ocean disposal. In addition, the results of this study are a guideline for sewage sludge application on land for Thailand. Public confidence and acceptance of sewage sludge utilization for agricultural purposes are increase.

## 1.9 Conceptual framework



## **CHAPTER II**

### **LITERAURE REVIEWS**

#### **2.1 Sewage sludge; Sources and quantity**

**2.1.1 Sewage sludge:** Sewage sludge, also referred as biosolids, is a by-product (the solid, semi-solid, and liquid) of the wastewater treatment process which generated during the primary (physical and/or chemical), the secondary (biological) and the tertiary (nutrient removal) treatment [10].

Sludge is the natural end products of a microbial food chain in the wastewater treatment process. Sludge consists of mostly cellular material and stable degradation products that are considered safe for application to agricultural or forest lands after microbes feed on organic components of waste until they can no longer derive energy from it [14].

It is also recently known as biosolids which reflected to the wastewater solids or organic products produced from treatment processes that can be beneficially used and recycled [13].

**2.1.2 Sources of sewage sludge:** The sources of sewage sludge vary according to wastewater treatment plant and its method of operation [15]. The main sources of sewage sludge are primary, secondary, and tertiary wastewater treatment process.

**2.1.3 Quantity of sewage sludge:** The quantities of sludge generated at wastewater treatment plant would vary widely depend on the composition of the wastewater, the type of wastewater treatment used, and the type of subsequent treatment applied to sludge [15]. The marked decrease in the amount of sludge generated resulting from the pretreatment and pollution prevention program but if they

are not to work, the higher degrees of wastewater treatment can increase the total volume of sludge generated.

Sludge generation rate in developing countries are not readily available. However, it can be estimated that each person generates about 800 kg of wet sludge per year or 25-40 kg dry solids of sludge per year. Sewage sludge production in Bangkok has been estimated to be around 108 and 168 tons dry matter per day in 2005 and 2010, respectively.

Table 2.1 Amount of sludge records from the 7 of Central Wastewater Treatment Plants (CWTPs) in Bangkok [16]

Wastewater treatment plants	Treatment capacity (m <sup>3</sup> /d)	Population served (cap)	Total amount of sludge (m <sup>3</sup> /d)
1. Sipraya	30,000	120,000	0.38
2. Rattanakosin	40,000	76,000	1.59
3. Dindang	350,000	1,080,000	8.64
4. Chongnonsi	200,000	1,580,000	5.00
5. Nongkham*	157,000	418,000	87.69
6. Thungkhru	177,000	65,000	13.16
7. Chatuchak	432,500	150,000	4.14
Total	1,386,500	3,489,000	120.60

\*Nongkham wastewater treatment plant has been treated by anaerobic digestion and dewatered by belt press. It can reduce amount of sewage sludge and volatile solids and it also could help more dewatered sewage sludge.

## 2.2 Sewage sludge characteristics

The characteristics of sewage sludge generated at wastewater treatment plant depend on the composition of the wastewater, the type of wastewater treatment used, and the type of subsequent treatment applied to the sludge. The characteristics of sludge can change annually, seasonally, or even daily within an individual plant

because of variations in the incoming wastewater composition and variations in treatment process.

The characterization of sludge properties include of physical, chemical, and biological. Chemical and biological characterizations are the important information to determine the appropriate sludge application rates, the suitability of sludge for agricultural land use, and monitoring parameters [15]. Generally, sewage sludge characteristics can be divided into 3 major characteristics as follows;

### **1. Physical characteristics**

Generally, sewage sludge is in semisolid state, dark brown to black color and has a flocculent appearance [15]. Unstabilized sludge usually has as offensive odor in contrast to well-stabilized sludge [17].

### **2. Chemical characteristics**

Chemical characteristics depend on wastewater characteristics and wastewater treatment process. Basically, chemical characteristics can be grouped into 2 groups as follows;

#### **- Nutrients**

Macronutrients, micronutrients, and trace elements are containing in sludge. Trace elements can be essential or detrimental to plants and animals whereas macronutrients and micronutrients are often considered as nutrients essential for plant growth.

#### **- Chemical pollutants**

Main chemical pollutants which affect the sludge quality are heavy metals and persistent organic pollutants (POPs) such as Cd, Hg, As, PCBs, PAHs, dioxins and endocrine disruptor [15].

### **3. Biological characteristics**

A large variety of microorganisms may contain in sludge (problems and perspectives of sludge utilization in agriculture). Bacteria, viruses, and helminthes are possibly found in sludge but a major concern is the presence of pathogenic microorganisms [18].

Sewage sludge characteristics that affect the suitability for beneficial use include organic content, nutrients, pathogens, metals, and toxic organics.

For physio-chemical composition, sludge should be characterized with the following properties:

- **Total Solid Content (TS):** Total solid content comprise of suspended and dissolved solids which is usually expressed as a percent of total solids percentage in sewage sludge. Generally, TS of dewatered sewage sludge has 12-40 percentage solids (including chemical additives). Transportation, application methods, equipment and storage methods are designed by total solid.

- **Volatile Solid Content (VS):** Organic content of sludge is estimated by volatile solids which is organic compounds. Unstable sewage sludge can cause potential odor problems because it contains 75-80 percentage of volatile solid on a dry weight basis.

- **pH:** Heavy metals contained in the sludge can leak through the soil at pH of sewage sludge less than 6.5, while micro-organisms can be killed and their movement in soil can be inhibited at pH of greater than 11.

- **Organic Matter (OM):** Organic matter help increases water holding capacity and hydraulic conductivity and organic matter also provides the adsorption sites for heavy metals.

- **Nutrients:** Nutrients such as N, P, K are essential for plant growth and endow sewage sludge with its fertilizing properties. Nutrient levels are key determinants of sewage sludge application rates. Low application rates can promote deficient plant growth, while high application rates can effect to environmental contamination of groundwater and water suppliers. Table 2.3 shows the comparison of nutrient levels in commercial fertilizer and wastewater sludge [19].

Table 2.2 General characteristics of fecal sludge and sewage sludge [20]

Parameter	Unit	Sewage sludge	Fecal sludge
Moisture content	%	79-87	75-82
Total dry solids	%	13-24	18-25
Total volatile solids	%	26-60	66-73
Total Nitrogen	g/kg	5-46	27-59
Total phosphorus	g/kg	5-12	3-10
Alkalinity	g/m <sup>3</sup>	625-865	2580
pH		6.6-7.8	6.5-7.5
Fecal coliform	MPN/g DS	3 x 10 <sup>3</sup> -3 x 10 <sup>6</sup>	1 x 10 <sup>4</sup> -1 x 10 <sup>6</sup>
<i>Ascaris lumbricoides</i> egg	No. of egg/g	none	1
<i>Trichuris trichiura</i>		0-0.3	0-0.3
Heavy metals	mg/kg dry base		3.47
Cadmium (Cd)		0.25-1.35	16.28
Chromium (Cr)		104.47-192.26	367.78
Copper (Cu)		1216.64-1637.64	37.37
Lead (Pb)		104.59-171.72	310.34
Manganese (Mn)		2087.36-2561.76	42.63
Nickel (Ni)		92.36-151.35	2169.33
Zinc (Zn)		1611.11-1727.02	

Table 2.3 Comparison of nutrient levels in commercial fertilizer and wastewater sludge [19]

Type	Nutrients (%)		
	Nitrogen	Phosphorus	Potassium
Fertilizer for typical agricultural use	5	10	10
Typical values for stabilized WW sludge	3.3	2.3	0.3

### **2.3 Beneficial use of sewage sludge**

Recovering and reusing valuable products are the effectively and beneficially management of sewage sludge.

Land application of sewage sludge is one of the important disposal alternatives so it has become a method which is being increasingly considered by many municipalities throughout the world. Sewage sludge contains nitrogen and phosphorus, resulting especially from nitrification–denitrification phases in wastewater treatment process so it offers the advantage of recycling nutrients back to the land at low cost and also improves soil qualities [19].

### **2.4 Application of sewage sludge on land**

Sewage sludge provides important plants nutrients and organic matter. The sewage sludge can be reduce pathogen and stabilize organic material for neutralize soil acidity by treated or stabilized sewage sludge with lime or other alkaline material. Continuing application of sewage sludge over several years will gradually increase soil organic matter. Increases in organic matter clearly improve soil properties, quality, and productivity in long-term. In addition to benefiting soil fertility and organic matter, sewage sludge also provide an economic benefit to farmers. Their short-term economic value is equivalent to the cost of the nutrients (N, P, and K) and limestone they have replaced and that therefore do not need to be purchased during a production year. M. Jamil et.al 2006 found that the different application rates of sewage sludge significantly increased the grain yield and also different application rates of sewage sludge along with NPK fertilizer brought significant changes in plant height [21].

### **2.5 Sewage sludge as soil conditioner**

By its own nature, vegetable crops require a constant supply of nutrients to be growing. Nitrogen, phosphorus and potassium have to be constantly supplied to the plants in order to maintain a steady crop production.

Mineral fertilizers are produced from a variety of sources and need energy to be produced them and extraction of raw materials. For instance, the production of a phosphorus-based fertilizer requires shipment of phosphate rocks and an appropriate

treatment in order to make the phosphorus readily available for plant growth. Moreover, phosphate rocks are usually contaminated by cadmium.

The use of sewage sludge allows the recycling to land of nutrients reducing or eliminating the need for mineral fertilizers. On average and depending on the wastewater treatment process, sewage sludge contains 35 kg of nitrogen and 20 kg of phosphorus per ton of dry matter [10].

## **2.6 Effects of the sewage sludge application on soil properties**

Physico-chemical properties: Physical conditions of soil have been improved by sewage sludge application. The calcium carbonate content of sludge and acid production during sludge decomposition has been correlated with the changes pH in soil [22].

Relatively high rates of sludge application increased the cation exchange capacity, which helped to retain essential plant nutrients within the rooting zone due to additional cation binding sites [23]. Such responses, however, depend upon the sewage: soil ratio. The higher organic matter proportion in sludge decreased bulk density and increased the aggregate stability. These improvements in soil physical properties increased water-holding capacity by promoting higher water retention in sludge-amended soils [23].

## **2.7 Nitrogen mineralization**

Most of the nitrogen (N) in the environment is in forms that are unavailable for plant uptake. Nitrogen in plant root zone is either nitrogen gas ( $N_2$ ), as a component of the air occupying the soil pores space, or organic N present in various forms, including plant and microbial proteins and amino acids, in the soil organic matter. In a process known as N mineralization, the organic N contained in soil organic matter is converted into plant-useable inorganic forms (ammonium,  $NH_4^+$ , and nitrate,  $NO_3^-$ ) as a result of the activities of soil microorganisms.

In undisturbed natural environments, plants obtain N for their growth from two microbial processes. The first is biological N fixation, the conversion of atmospheric  $N_2$  to inorganic N by various soil microorganisms, some symbiotic with

plants. The second is N mineralization, which is conversion of organic N contained in soil organic matter into inorganic, plant-available N as it is decomposed by soil bacteria and fungi. Enzymatic processes occurring during organic matter decomposition release ammonium into the soil solution [24].

Plants require nitrogen in relatively large amounts as compared with their need of other nutrients. The major source of natural nitrogen in the soil is provided by the decomposition of plant and animal residual added to the soil, and by the mineralization of soil organic matter [25].

The mineralization of soil organic matter normally provides most of the natural nitrogen taken up by a crop. The rate at which this organic matter mineralized is related to the amount of microbial activity, which in turn depends on factors such as soil temperature, soil moisture and the presence of a food supply.

The mineralization of nitrogen in soil organic matter follows these steps [25]:

**Step 1:** The ammonification is carried out by various non-special organisms and it is relatively slow. The rate of ammonification, being the slowest of the three steps, controls the overall rate of nitrogen production from organic matter. Under anaerobic condition, as in a flooded rice paddy, the process stops here with the formation of ammonium. On the other hand, under normal aerobic conditions, step 2 and 3 follow.

**Step 2:** The conversion of ammonium to nitrite is carried out by specialized organisms, especially *Nitrosomonas* and the rate of conversion is relatively fast. Because of this, ammonium released from step 1, if not taken by plant and soil organism, is quickly converted to nitrite. The population of *Nitrosomonas* in the soil changes rapidly according to conditions and to the supply of ions, but is normally adequate to ensure a rapid conversion.

**Step 3:** The conversion of nitrite to nitrate is also carried out by aerobic microorganisms, especially *Nitrobacter*. The rate of conversion is normally relatively very fast. It is the most rapid of the three steps. So, nitrite that is thought to be toxic does not accumulate in soils.

Smith et al [24] and Lindemann [25] et al reported that nitrogen mineralized is the changes of organic nitrogen. A nitrogen mineralization potential has been defined as a fraction of the organic nitrogen pool that is susceptible to

mineralization. It is generally based on the assumption that nitrogen mineralization follows first-order kinetics. Accurate estimates of the nitrogen mineralization potential ( $N_0$ ) and first-order rate constants ( $k$ ) initially entailed incubation periods.

Stanford and Smith [28] incubated soil under optimal conditions to determine the nitrogen mineralization potential ( $N_0$ ) and rate constant ( $k$ ) of soil. The  $N_0$  was estimated by an interactive statistical method from the first-order rate equation. The nitrogen mineralization rate was correlated to the quantity of mineralizable nitrogen and the square root of time.

For soil samples, Stanford and Smith calculated the first-order rate constant ( $k$ ) and potentially mineralizable nitrogen ( $N_0$ ) using by log transformed data [28]. Smith et al [26] evaluated this method and found that a nonlinear least square equation gave more accurate estimation of  $N_0$  and  $k$ . In the present study, the Smith method and a computer program were used to solve the following equation;

$$N_m = N_0(1 - e^{-kt})$$

Where;  $N_m$  is amount of nitrogen mineralized at a specific time

$N_0$  is the potentially mineralizable nitrogen

$k$  is the rate of mineralization (first-order rate constant)

$t$  is time of incubation

#### - Factor affecting N mineralization

Soil temperature and moisture content have a strong effect on N mineralization reactions. Microbial activity is limited at soil temperature near freezing and increases with rising soil temperature. Maximum N mineralization occurs when the soil temperature reaches 30-35 °C. In dry soils, N mineralization is low because soil microorganism activity is limited by water availability. In saturated soils, lack of oxygen limits N mineralization because only soil microorganisms that can survive under anaerobic conditions are active.

The amount and type of clay in a soil affects N mineralization reactions. Mineralization tends to be greater in coarse-textured soils, low in clay and less as the soil clay content increases. Finely textured soils high in clay are abundant in

micropores in which organic matter can find physical protection from microbial decomposition.

Compared to soil texture, the effects of soil mineralogy on N mineralization are less clear. Soils dominated by clay minerals that shrink and swell with fluctuations in soil moisture, such as montmorillonite, tend to have higher N mineralization rates than those containing clays that do not shrink and sell, such as kaolinite. Volcanic ash soils rich in organic matter tend to have high N mineralization rates [24].

## 2.8 Phosphorus mineralization

Phosphorus exists in soils in organic and inorganic forms. Organic forms of P are found in humus and other organic material [29].

Phosphorus is required as a small but vital ingredient in cell nuclei and it is essential for cell division and growth. It is concentrated in the fast growing parts of the plant, particularly in the root tips. It affects the maturing period of crops and is found in quantity in seeds and fruit. Plants absorb phosphorus wholly or mainly in the form of the di- or mono-hydrogen orthophosphate anions,  $\text{H}_2\text{PO}_4^{2-}$  and  $\text{HPO}_4^{2-}$ . Of these the mono-hydrogen ion,  $\text{HPO}_4^{2-}$  is the more important, particularly in acid soils [25].

Phosphorus mineralization reactions in a way are similar to that nitrogen. The reactions are dependent on the action of fungi, actinomycetes and bacteria that decompose carbonaceous residues containing phosphorus compounds. Mineralization of organic phosphorus is enhanced by pH values that are conducive to general microbial actions. Generally, increasing the soil pH from acid to alkaline enhances phosphorus mineralization of phosphorus likes mineralization of nitrogen. They were rapid at higher soil temperature. Higher rates of biochemical reactions can be expected as the temperature increases. Phosphorus can be rapidly fixed in from unavailable to plant and the reactions are depending on soil conditions and the mineral in soil [30].

## 2.9 Potassium

Potassium is an essential nutrient for plant growth. Almost of potassium is in the structural component of soil minerals and is not available for plant growth. The higher soil moisture usually means greater availability of K [31].

## 2.10 Municipal yard waste

Municipal yard waste includes leaves, brush and grass clippings that are collected curbside in most municipalities. Fresh yard trimmings can contain 1.2-2.3 % N, 0.2-0.3% P, 0.5-1.0 % K, 50-60% organic matter and pH values 5-6 [32]. Generally, the examination the natural of the feedstock can be approximated C/N ratio for yard trimming and grass clippings were 12-20:1 of C/N ratio [33].

Nutrient contents increase in relation to the proportion of grass clippings in the mix. Wisconsin, like most states in the U.S., has a ban on sending these materials to the landfill. In 2000, Wisconsin recovered and recycled approximately 225,000 tons of yard waste [34].

Yard wastes are either composted or applied directly to farmland. Composting municipal yard waste varies from intensive, well-managed operations that sell the finished compost to facilities that occasionally turn piles and give away the finished product. Low-intensity management of yard waste composts frequently leads to variable, low quality finished products that often contain woody debris, trash and weed seeds.

Biologically stable and screened finished compost used as guidelines for use composted municipal yard waste in home gardens, landscape plantings, establishment of turf grasses and green spaces and for erosion control on steep hillsides. Application rates vary from 1/2 to 3 inches applied to the surface of the soil. In most cases, it should be incorporated into the top 6 inches of the soil. It can also be used as mulch for trees and shrubs. Fresh yard trimmings can be applied to agricultural fields to build soil organic matter. However, it is best to apply leaves in the fall to give them ample opportunity to break down before the next year's crop is planted. In one study [11] 20-40 tons/acre of leaves were applied to a corn field each fall. The leaves decomposed in fall and early the next spring, increasing soil organic matter. The high

application rate of leaves received supplemental N to lower the C/N ratio of the leaves. All leaf-amended plots and controls (no leaves) produced similar corn yields the following year, demonstrating that fall leaf applications minimize the chances of decomposing leaves robbing N from the corn crop.

## **2.11 Sewage sludge composting**

The benefits of sewage sludge composting include; 1) waste stabilization, 2) destruction of pathogens, 3) resource recovery, and 4) moisture removal and volume reduction. Sewage sludge can be applied to land with minimal concern about its environmental impact if sewage sludge was passed stabilization because stabilization describes the changes in a waste whereby biological activity converts putrescible components in waste into stable organic and inorganic forms. Microbial activity during aerobic composting generates temperatures of 60 °C or more and if high temperature is maintained for several days, sufficient to destroy or inactivate most pathogens. This is an important consideration in the management of raw sewage sludges which contain large numbers of potentially pathogen organisms. Nitrogen, phosphorus, and potassium in mature compost from sewage sludge, albeit at relatively low concentrations; all essential nutrients for plant growth. In addition, the organic component of compost makes a good soil conditioner.

Sewage sludge composting has attracted considerable attention during the past decade because of its effectiveness in destroying pathogens and the compost's fertilizer value and potential for land application [11].

## **2.12 Composting**

Composting is one of stabilization technologies of sewage sludge. It is the decomposition of organic matter by microorganisms; transform raw organic waste materials into biologically stable, humic substances in an environment that controls the size and porosity of the pile and it make excellent soil amendment [36].

Composting involves mixing dewatered sewage sludge with a bulking agent such as wood chips, municipal yard trimmings, bark, rice hulls, or straw and allowing the sewage sludge mixture to decompose aerobically for a period of time.

The bulking agent is used to lower the moisture content of the sewage sludge mixture, increase porosity, and add a source of carbon. Sewage sludge compost can be ready in about 3 to 4 weeks of active composting followed by about one month of curing, depending on the method used [12].

The C/N ratio is the critical factor in the composting process, and the nitrogen-rich sludge must be mixed with a carbon-rich amendment to compost successfully. Although the compost contains lower concentrations of nitrogen, phosphorus, and potassium than commercial fertilizer but the sludge is considered to be a soil amendment rather than a fertilizer, if there is sufficient carbon, much of the nitrogen.

More importantly, the nutrients in sludge compost are present in an organic form which allows the gradual release of nutrient benefits. This slow release process satisfies the changing seasonal needs of plant over a longer period of time. In addition to being a source of nutrients, compost improves soil quality by increasing the moisture and nutrient retention capacity of sandy soil and the drainage and the aeration of heavy clay. Sewage sludge compost also helps pH stability, improves soil water-holding capacity, aeration, structural stability, and improves root penetration. Furthermore, when compost is used, fertilizers, metals, organic chemicals, and pesticides are less able to migrate to contaminate to ground water and surface water [12].

### **2.12.1 The Composting Process**

The composting process breaks down the organic matter in sewage sludge into stable humus [12] through the activity of microorganisms naturally found in soils. Under natural conditions, earthworms, nematodes and soil insects such as mites, sawbugs, springtails, ants, and beetles do most of the initial mechanical breakdown of organic materials into smaller particles. Under controlled conditions, composters break down large particles through grinding or chopping. At optimal physical conditions, the best at warm temperatures (10-45°C), mesophilic organisms such as soil bacteria, fungi, actinomycetes and protozoa colonize the organic material and initiate the composting process [36].

The rate at which composting occurs depends on physical as well as chemical factors. Temperature is a key parameter determining the success of composting operations. Physical characteristics of the compost ingredients, including moisture content and particle size, affect the rate at which composting occurs. Other physical considerations include the size and shape of the system, which affect the type and rate of aeration and the tendency of the compost to retain or dissipate the heat that is generated.

Compost heat is produced as a by-product of the microbial breakdown of organic material. The heat production depends on the size of the pile, its moisture content, aeration, and C/N ratio. Additionally, ambient (indoor or outdoor) temperature affects compost temperatures [37].

**2.12.1.1 The active phase of composting:** The temperature in the compost pile typically increases rapidly to 55-65°C within 24-72 hours of pile formation, which is maintained for several weeks. During this phase, oxygen must be replenished through passive or forced aeration, or turning the compost pile. In the active thermophilic phase, temperatures are high enough to kill pathogens and weed seeds and to break down phytotoxic compounds.

**2.12.1.2 The curing phase of composting:** As the active composting phase subsides, the mesophilic microorganisms recolonize the pile, and the compost enters the curing phase which temperatures gradually decline to around 37°C. Oxygen consumption rate declines to the point where compost can be stockpiled without turning. During curing, organic materials continue to decompose and are converted to biologically stable humic substances-the mature or finished compost. If the immature compost is amended to container mixes or the soil it can damage or kill plants because immature composts can contain high levels of organic acids, high C/N ratios, extreme pH values or high salt contents [36].

When the raw feedstocks are no longer actively decomposing, chemically stable, temperature at the center of the pile returns to near-ambient levels and oxygen concentrations in the middle of the pile remain greater than 10-15% for several days, compost is considered stable or finished. These measurements should be taken when the compost pile has at least 50% moisture content by weight [36].

### **2.12.2 The composting methods**

Some basic composting methods which have been developed include those that use passive windrows, bins, turned windrows, aerated static piles and in-vessel channels. The proper approach depends on the time to complete composting, the materials and volume to be decomposed, space available, the availability of resources (labor, finances, etc) and the quality of finished product required [12].

**2.12.2.1 Passive windrow:** passive windrow is simply pile of material with a more or less triangular cross-section and it can represent a low technology and labor approach. A windrow should measure about 3 m wide and 1.5 m high; its length will vary depending upon the amount of materials used. Aeration occurs naturally. Materials can be added as they become available to make a good sized pile or windrow.

The rate of decomposition of the organic matter is dependent on the moisture content. The optimal moisture level is 50-60%. Sludge should be dewatered as much as is economically feasible and mixed with a dry amendment or recycled product. If the moisture level exceeds 60%, the sludge mixture will not have the structural integrity to maintain shape and the windrow will slump, while the moisture level below 60%, the porosity is measurable and air will be able to penetrate the pile, and if it below 50% the biological activity will be reduced and the composting process slowed. The frequency that the windrows are turned has a marked influence on the composting process. Turning mixes the contents of the windrow, lightens the pile (increasing porosity and promoting aerobic conditions), releases water vapor, and exposes all of the material in the windrow to the high interior temperatures [12].

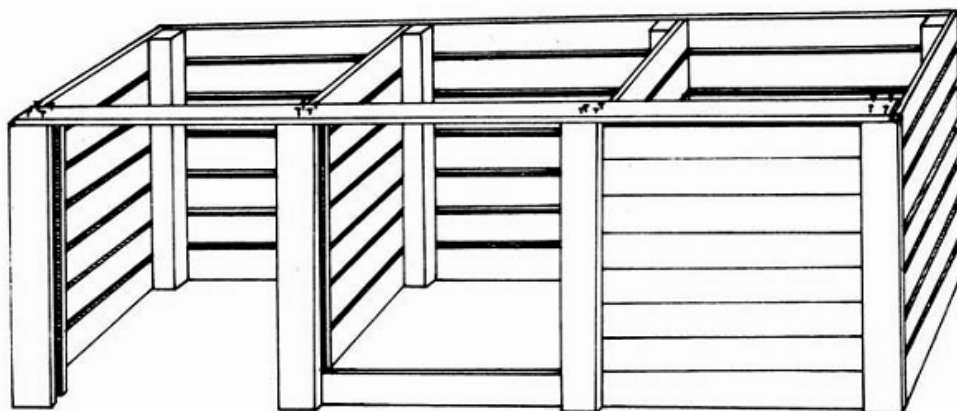
Covering the finished compost pile with a layer will help prevent moisture loss, reduce odor problems, and produce more uniform compost. Composting in these windrows can take from 6 months to 2 years. In addition, porosity of the initial mix, uniform product mixing and particle size greatly improves the speed of the process and product quality.

**2.12.2.2 Turned windrow:** Aeration of the windrow can be achieved through mechanical turning and it can also be done manually, but it is considered impractical with volumes larger than 1 or 2 m<sup>3</sup>. Uniform decomposition, as well as pathogen destruction, is best achieved by turning the outer edges into the

center of the pile at each turn. Turning should also be more frequent than under a regular schedule when the moisture content of the pile is too high so as to minimize the development of anaerobic conditions. The equipment used for turning the windrow, varies from front-end loaders or bulldozers to specially designed turning machines. Windrow turner is efficient turning machine; a minimum composting time is 1 month and followed by at least 2 months in curing pile. The compost may be ready to apply to land or be marketed. Loaders, inexpensive and have a tendency to compact the composting material, are comparatively inefficient, and can result in longer composting periods and less consistent quality [36].

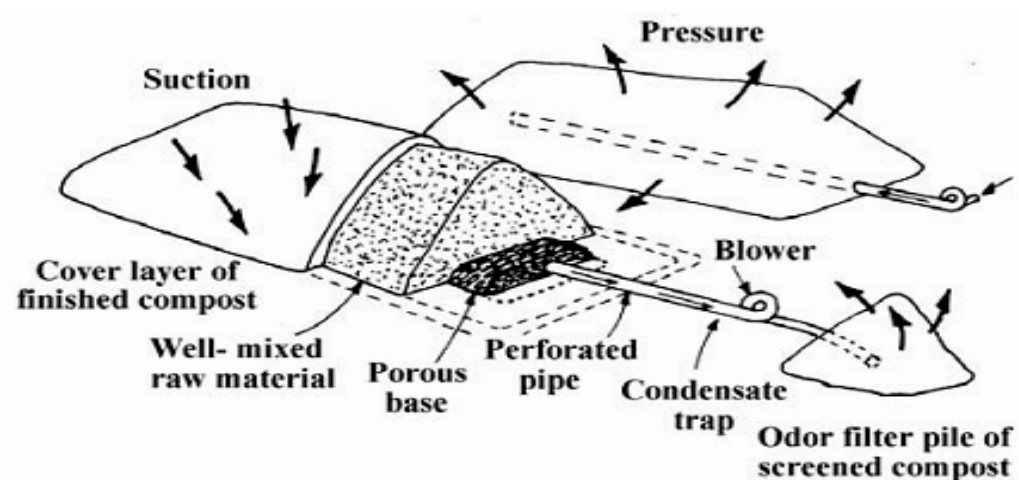
**2.12.2.3 Bin composting:** bin composting methods are commonly used for yard waste; smaller amount of manure; and for poultry, or pork mortalities. Turning compost can reduce decomposition time to 2 months or less. Wastes in bins must be mixed on a regular basis. Frequent turning speeds up the composting process by providing aerobic bacteria with the oxygen required need to break down materials. If piles are turned every 5 to 10 days, the high temperatures are produced from 32 °C to 60 °C. These actions are to provide an environment necessary for the most efficient decomposer organisms, necessary to kill disease organism and fly larvae and to help kill weed seeds [36].

Figure 2.1 A wooden bin unit, with three compartments



**2.12.2.4 Aerated static pile:** the aerated static pile method does not mechanically agitate compost material to achieve the desired level of aeration. Aerated static piles require additional equipment and infrastructure investment, and these assets are dedicated solely to the compost operation. The pile is constructed above an air source such as, perforated plastic pipes, aeration cones or a perforated floor; and aeration is accomplished either by forcing or drawing air through the compost pile. The pile should be placed after the floors are first covered with a layer of bulking agent, such as wood chips or finished handling system, since some or all of the existing farm machinery can be used for windrow composting. In addition, pre-compost product mixing is a very important step in aerated static pile systems. In contrast, the mixing and blending is done throughout the active composting stage in windrow composting [36].

Figure 2.2 An aerated static pile with a bio.filter



Source: NRAES-54 On-Farm Composting Handbook

**2.12.2.5 In-vessel:** in-vessel composting systems are designed to provide optimal composting conditions involving mechanical mixing of compost under controlled environmental conditions because it is high rate controlled aeration systems. There are availability various designs but each systems are similar in that they are both capital and management intensive. In-vessel or enclosed-vessel systems have 3 main categories: 1) rotating drum 2) horizontal or vertical silos 3) channels. In-

vessel system is more advantage than others (windrows, aerated static pile etc.) because it has the shortening of the mesophyllic and thermophylic stages, higher process efficiency, and a decreased number of pathogens. In addition, it is safer, more valuable end product and space requirements are generally less than that of other methods [36].

Figure 2.3 Four channel in-vessel composting

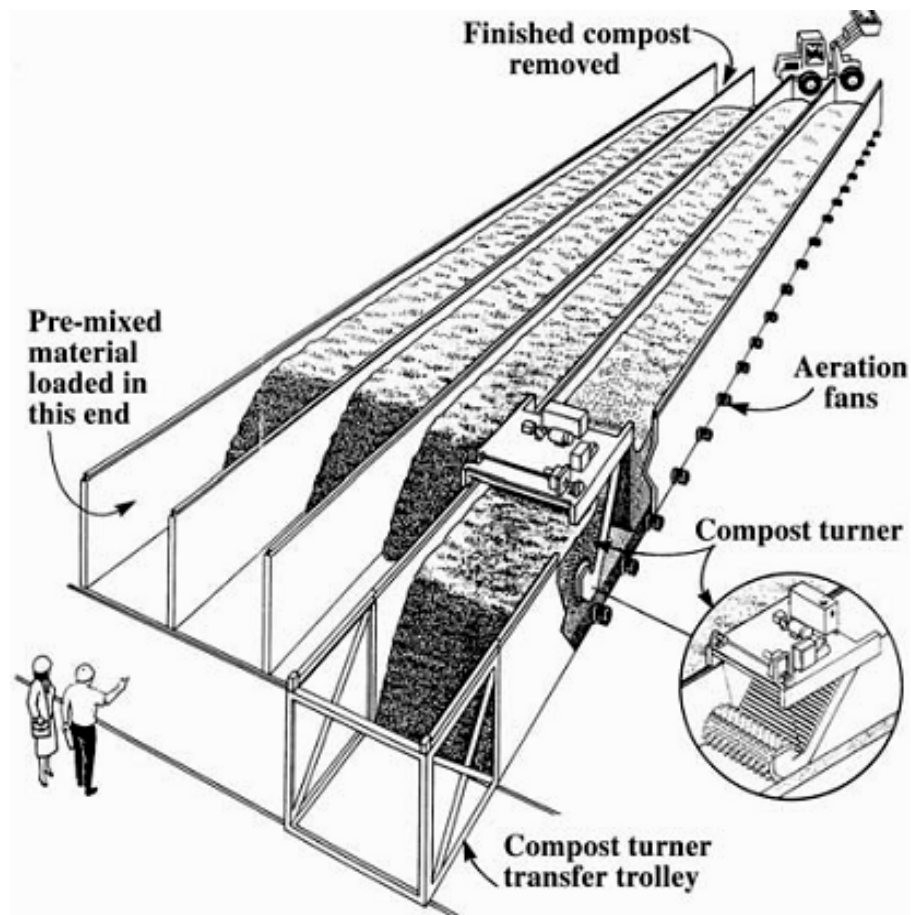


Table 2.4 Summaries of the four main manure composting methods [36]

	Passive windrow	Turned windrow	Aerated static pile	In-vessel
General	Low technology Quality problems	Active systems most common on farms	Effective for farm and municipal use	Large-scale systems for commercial applications
Labor	Low labor required	Increases with aeration frequency and poor planning	System design and planning important. Monitoring needed	Requires consistent level of management/ product flow to be cost efficient.
Bulking agent	Less flexible, Must be porous	Flexible	Less flexible, Must be porous	Flexible
Active period	Range: 6-24 months	Range: 21-40 days	Range: 21-40 days	Range: 21-40 days
Curing	Not applicable	30+ days	30+ days	30+ days
Process control	Initial mix only	Initial mix turning	Initial mix. Aeration temperature and/or time control	Initial mix. Aeration temperature and/or time control.
Odor factors	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, but controls can be used, such as pile insulation and filters on air system.	Odor can occur. Often due to equipment failure or system

## 2.13 Factors affecting composting

**2.13.1 Nutrient ratio (C/N ratio):** Carbon and nitrogen content ratio in the feedstock strongly affects to the rate of microbial activity. With few exceptions, all other nutrients are present in organic waste in adequate amounts and ratios.

Carbon and nitrogen are used by microbes to obtain energy and for the synthesis of new cellular material. During metabolic activities, almost of the carbon substrate is oxidized to CO<sub>2</sub> and the remaining carbon is converted into cell wall or

membrane, protoplasm, and the storage products. The principal use of nitrogen is in the synthesis of protoplasm (e.g., proteins, amino acids, nucleic acids); carbon supplies energy and growth while nitrogen is used for protein and reproduction of microorganisms in the composting process. Much more carbon is required than nitrogen for adequate microbial growth.

The ideal ratio 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 and the optimum C/N ratio for soil and compost microorganisms has been established at approximately 25:1. If the C/N ratio is lower than 20:1, composting will be inhibited due to low-energy supplies and nitrogen will be lost both by leaching and volatilization as ammonia ( $\text{NH}_3(\text{g})$ ). In contrast, if the ratio higher than this the decomposition will slow down; the initial ratio is over 35, the microbial consortium must pass through many life cycles, oxidizing the excess carbon to  $\text{CO}_2$  until a more suitable ratio is attained. However, Of course, these ratios may vary widely depending on the type of carbonaceous materials initially present [38].

If the ratio is too low, a carbonaceous waste (straw, wood shavings, saw dust, shredded paper) can be added. If the initial C/N ratio of a waste is too high, a nitrogenous waste (e.g., blood meal) can be added because it can bring the C/N ratio to acceptable levels.

**2.13.2 Moisture:** The preferred moisture content and oxygen availability for composting are closely interrelated. The interstices in the waste feedstock will contain either water or air, so the presence of one will directly affect the concentration of the other. The optimal moisture content for successful composting varies depending on the physical state and size of the particles and on the composting system used.

Less moisture in the pile will result in dehydration, which slows biological processes because water is required for numerous cellular processes, and properties including nutrient transport, waste removal, turgidity, and as a component in innumerable biochemical reactions. Excess water interferes with aeration by clogging pores. Anaerobic conditions develop within the mass if the moisture content of the mass is so high as to displace most of the air from the interstices. Therefore, the

maximum acceptable moisture content is a level which nuisance conditions (e.g. anaerobiosis) will not develop and which the process will proceed satisfactorily.

Moisture content of the pile can be measured in laboratory by taken sample to the laboratory and measured field-moist and oven-dry (i.e., an oven at 105 °C, 48 hours). These data are used to calculate the gravimetric moisture content.

Moisture is rapidly depleted from an active compost pile and must be replaced by regular addition of water or, in some case, application of wastewater sludge (also a rich source of heterotrophic microorganisms). The optimum amount of water to be applied to a compost pile can be calculated from a mass balance equation (Vesilind et al., 2002)

$$M_p = (M_s X_s + 100 X_w) / (X_w + X_s)$$

Where  $M_p$  is the moisture content of the compost pile at the start of composting (%),  $M_s$  the moisture content of the solids [38].

40-60% of moisture content is recommended for most materials. Lower moisture content may retard microbial activity whereas exceeding moisture level will lead to anaerobic conditions, odors, and slower decomposition.

**2.13.3 Aeration:** The atmosphere within the interstices of the composting mass will vary significantly during decomposition. When the organic feedstock is delivered to the compost site, the oxygen supply available to microbes occurs from the diffusion of ambient air, and in air originally trapped within the voids. Interstitial air is the major source of oxygen because the rate of diffusion of ambient air into the mass is very limited.

At the outset, the composition of air in voids is similar to that of ambient air (i.e., approximately 20.9% O<sub>2</sub> and 0.03% CO<sub>2</sub>, v/v). Within a short time (hours to days) the heterotrophic pioneer communities become activated and begin decomposition of the raw organic substrates, with the concurrent increase in CO<sub>2</sub> content and decrease in O<sub>2</sub> level [36].

Aeration is one key factor affecting composting process. Aeration must provide the oxygen required by the microorganisms used in breaking down the waste. Ideal oxygen content for composting is 16-18.5% [38].

**2.13.4 pH:** The optimum pH range in composting is so broad that difficulties due to an excessively high or low pH level are rarely encountered. A pH range of organic materials from 3 to 11 can be composted. Composting can work effectively at the pH ranges 5.5-9.0. However, the process is most effective at 6.5-8.0.

Bacteria are the key catalysts in organic matter transformations, and typically prefer a near-neutral pH. In contrast, fungi develop better in an acid environment. The pH level normally decreases (perhaps to as low as 5.0) in during the early stages of composting because the production of organic acids (e.g., formic, acetic, and pyruvic). These acids serve as substrates for succeeding microbial populations. As the acids are decomposed, pH rises and often stabilizes at approximately neutral.

The pH will drop to inhibitory levels, there is no need to buffer the feedstock by adding liming materials (e.g. limestone, calcium hydroxide). The addition of lime should be avoided because it can lead to excessive losses of ammonium nitrogen. The lime dose, however, promotes the formation of aggregates which in turn improves physical properties such as air and water movement.

The pH of the compost pile is commonly measured by a standard glass electrode pH meter. A known mixture, for example, a 2:1 ratio of water/solids is mixed and the resultant pH is read on the meter [38].

**2.13.5 Surface area:** Smaller particles of raw materials have more surface area than bigger particles which makes nutrients and energy more available to microorganisms. But smaller particles can also reduce the space within the composting mass. Generally, particle diameter from 1/8-2 inches produces good results [38].

**2.13.6 Temperature:** Temperature is a good indicator of the composting process because there is a direct relationship between temperature of the pile and microbial activity. High temperatures result from biological activity, i.e., heat liberated from microbial respiration and the resultant breaking of chemical bonds of substrate compounds. This heat builds up within the pile; dispersal of this heat is limited due to the insulating effects of the pile. Internal pile temperature must maintain 50-55 °C. The temperatures that enhance microbial activity are in the range 28 to 55 °C. The highest O<sub>2</sub> consumption also occurs within this range.

High temperatures are commonly considered as necessary conditions for good composting. The result of excessively high temperatures is slowing decomposition of feedstock because it inhibits growth of most microorganisms. The tendency is for spore formers (e.g., *Bacillus* and *Clostridium*) to convert into spores when the temperature rises beyond approximately 65 to 70 °C. This transition is undesirable, because the spore-forming stage is a resting stage and therefore the rate of decomposition is reduced. Moreover, microbes incapable of forming spores are strongly inhibited or killed at those temperatures. Consequently, the maximum temperature should be kept at about 65°C.

The temperature distribution within a composting mass is resulted from the surrounding climatic conditions and the aeration method. In static piles, the highest temperatures develop at the center of the mass and the lowest temperatures occur at the edges of the pile. These temperature gradients promote a small degree of convection (i.e., natural airflow). The degree of air movement is a function of ambient conditions as well as porosity of the composting mass. The problem of temperature control is best solved, however, by either periodically turning the pile or using forced ventilation throughout the process [38]. Increasing temperature would increase the decomposition rate of organic matter [39]. Anaerobic condition is decreased temperature in the pile. The temperature can vary by size of the pile, ambient temperature, moisture content, aeration and raw material characteristics [40].

**2.13.7 Retention time:** The period of time required to decompose raw materials to compost depends on the six factors described above. The shortest composting period results from suitable 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.

**2.13.8 Particle size:** The ideal particle size is around 2-3 inches. In some cases, the raw material such as grass clipping, may be too dense to permit adequate air flow or may be too moist. A common solution to this problem is too adding a bulking agent (straw, dry leaves, paper and cardboard) to allow for proper airflow. The different sizes and texture of mixing materials also helps aerate the compost pile [9].

Table 2.5 Characteristics for the composting process

Characteristic	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%
pH	5.5-9.0	6.5-8.5
Bulk density	< 40 lbs per cubic foot	-
Temperature	110-140 °F	130-140 °F
Particle size	1/8-2 inches diameter	Varies*

\* Depends on raw materials, pile size, and/or weather conditions.

## 2.14 Steam sterilization

Soil has many of living things such as bacteria, fungi, worms and insects. They can help break down larger pieces of organic matter into small particles of humus and also break down nutrients into forms that plants can take it up easily through their roots. In the other hand, living things in soil can be detrimental fungi, bacteria and insects in the soil along with the beneficial.

Steam sterilization is a great technique to avoid bringing weeds and pathogens from soil or compost into indoor plants [41].

The objectives of soil and compost sterilization, each with their own time and temperature requirements are;

- To eliminate animals such as nematodes, insects, larvae and their eggs. Fungus gnats are problem in compost amended and they can be a nuisance in the greenhouse. The larvae are adverse effects to some plant roots and they are also largely aesthetic problem. Moderate temperatures can kill Nematodes, insects and their larvae easily.

- To kill off weed seeds.

- To reduce suspected pathogens, fusarium and other mold types of fungi. They are cause root rot and damping off [42].

## **2.15 Legislation and standards for Application of Sewage Sludge on Agricultural land in Thailand**

### **2.15.1 BMA guideline for sewage sludge and nightsoil application to agricultural [9]**

The following standards and regulations are suggested with respect to the agricultural application of sludge in BMA and its surrounding

- The sludge should not be applied normally to soil having a pH value less than 5, however, extensive monitoring is essential for soil having a pH value less than 5.

- 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.

- The concentration limits of heavy metals in the sludge are given as: 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.

- 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)

- The sludge must be applied to the soil before plantation or seeding.

### **2.15.2 Pollution Control Department (PCD) Guideline (2003) [43]**

The concentration limits of heavy metals in the sludge are given as: As  $\leq$  60 mg/kg, 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, Se  $\leq$  50 mg/kg, Zn  $\leq$  3,000 mg/kg.

### **2.15.3 Standard of Department of Agriculture (2005) [44]**

Organic fertilizer standard are:

- Sizing of composting  $\leq$  12.5 x 12.5 mm.
- % moisture content  $\leq$  35 %.
- Crush stone and gravel size  $>$  5 mm  $\leq$  5 % by weight.
- No plastic, glass and steel.
- Organic material  $>$  30 % by weight.
- pH 5.5-8.5, C/N ratio  $\leq$  20:1, EC  $\leq$  6 dS/m.
- Nutrients: total N  $\geq$  1 % by weight, total P<sub>2</sub>O<sub>5</sub>  $\geq$  0.5 % by weight, total K<sub>2</sub>O  $\geq$  0.5 % by weight.
- The concentration limits of heavy metals in the sludge are given as: As  $\leq$  50 mg/kg, Cd  $\leq$  5 mg/kg, Cr  $\leq$  300 mg/kg, Cu  $\leq$  500 mg/kg, Pb  $\leq$  500 mg/kg, Hg  $\leq$  2 mg/kg.

### **2.15.4 Land Development Department (mature compost) [45]**

There are many criteria to determine the mature compost as follows:

- Compost particle is dark-brown or black color.
- The compost characteristics like an earthlike mass or softer than the initial materials characteristics.
- Odorless
- The temperature of compost pile is stable or equal to the ambient temperature.
- C/N ratio of the mature compost is 20:1 or less than 20:1.

### 2.15.5 Land Development Department (suitable compost) [45]

There are the criteria for suitable compost as follows:

- C/N ratio of the mature compost is 20:1 or less than 20:1.
- Plant macronutrient: nitrogen (N), available phosphorus ( $P_2O_5$ ) and available potassium ( $K_2O$ ) are equals or more than 0.5%, 0.5% and 1.0% respectively.
- Moisture of compost is equals or less than 35-40%.
- Organic matter is 25-50%.
- pH value is 6.0-7.5.
- It is non-toxic substances.

### 2.16 Related researches

Water Quality Management Office, Department of drainage and sewerage, Bangkok metropolitan administration [3] studied about sewage sludge qualities and suitable mixing ratio of different bulking material composted with sewage sludge. The experimental results show that sewage sludge characteristics of Nong Khaem wastewater treatment plant (2007) were contained nitrogen 21,675.50-32,454.50 mg/kg dry solid, total phosphate 10,412.00-22,015.00 mg/kg dry solid and potassium 249.95-6860.50 mg/kg dry solid. After 21 days of composting time, the C/N ratio of sewage sludge composted with saw dust (18.54:1) higher than sewage sludge composted with grass clippings (6.32:1) but nutrients of sewage sludge composted with grass clippings at 7:3 ratio was higher than other ratio of its and sewage sludge composted with saw dust.

Xin Wang, Tao Chen, Yinghua Ge, Yongfeng Jia [46] studied about sewage sludge and its limiting factors on land application. The sewage sludge was obtained from Northern Shenyang Wastewater Treatment Plant, China, and applied at 0, 15, 30, 60, 120 and 150 t ha<sup>-1</sup>. Native grasses *Zoysia japonica* and *Poa annua* were chosen as experimental plants. The experimental results showed that nutrient content of the soil, especially organic matter, was increased after sewage sludge application. The grass biomass was increased and the grass growing season was longer.

H. Cheng, W. Xu, J. Liu, Q. Zhao, Y. He, G. Chen [47] studied about application of composted sewage sludge (CSS) as a soil amendment for turfgrass growth. The studied the growth of perennial ryegrass in soils amended with 5-100%

composted sewage sludge, and the impacts of its amendment on soil physical and chemical properties. Soil amended with  $\leq 20\%$  composted sewage sludge did not significantly affect the seedling emergence, while the contents of chlorophyll, nitrogen, phosphorus, and potassium of perennial ryegrass grown in such soil were also improved. Bulk density, water retention, and nutrient contents of the soil were also improved with the amendment of composted sewage sludge. The findings suggest that addition of composted sewage sludge at 10-20% levels can greatly improve the soil nutrient supply for turfgrass growth without significantly affecting heavy metal and soluble salt contents of the soil.

J. Casado-Vela, S. Selles, C. Diaz-Crespo, J. Navarro-Pedreno, J. Mataix-Beneyto, I. Gomez [48] studied about the Effect of composted sewage sludge application to soil on sweet pepper crop (*Capsicum annuum* var. *annuum*) grown under two exploitation regimes. The aim of this study is to monitor the effect of the application of three increasing amounts of composted sewage sludge (3, 6, and 9 kg compost/m<sup>2</sup>) on the physico-chemical properties of a horticultural calcareous soil where sweet pepper plants (*Capsicum annuum* var. *annuum*) cv. California were grown. A comparative study of two different exploitation regimes was carried out; the first was an open-air-field grown plot and the second plot was kept under controlled conditions in a greenhouse. Organic matter, total nitrogen kjeldahl and available phosphorus contents increased in soil after composted sewage sludge applications. The 9 kg compost/m<sup>2</sup> application promoted the appearance of deleterious effects on the properties of soil, such as soil accumulation, a significant increase in the electrical conductivity and an input of heavy metals (Pb > Cr > Cd). The 6 kg compost/m<sup>2</sup> application provided a supply of nutrients necessary to grow peppers plants under both exploitation regimes.

The final report of compost demonstration project on the use of yard trimmings products: agriculture in partnership with San Jose [49] studied about the performance on different types of agricultural plot and the effect of yard trimming for land application. The results found uncomposted yard trimming was 1.2% of nitrogen and it can improve soil quality.

Cabañas-Vargas et al [50] studied about assessing the stability and maturity of compost at large-scale plants. The result found the majority of volatile

solids reduction occurred during the first 6 to 8 weeks and little further decrease was detected during the maturation process. All the physico-chemical characteristics indicated that after 10 weeks, the active phase of composting process was finished, and it was allowed to mature for an additional period of 8 weeks.

W. O. Enwezor [51] studied about the mineralization of nitrogen and phosphorus in organic materials of varying C:N and C:P ratios. It was studied for 12 weeks of incubation experiment to determine the trend of nitrogen and phosphorus mineralization after added plant materials. The result was found nitrogen mineralization increased with decreasing C/N ratio because of the microorganisms decomposed total nitrogen to inorganic nitrogen.

Sanchez-Montero, M.A., A. Roig, C. Paredes and M.P. Bernal [52] studied about nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. The aim of the research was to studied the different form of nitrogen changes during the composting several wastes; sewage sludge, municipal solid waste, brewery sludge, sorghum bagasse, cotton waste and pine bark. The result was found carbon to nitrogen ratios increased would be a result from decreased total nitrogen because of it was due to conversion of organic nitrogen to ammonia by microorganisms.

Vicente Espinosa Hernandez et al [53] studied about the effect of incubation periods on phosphate sorption from three P sources in Morelos soil. The research design was completely randomized design with three fertilizer treatment and the phosphorus was incubated at 0, 3, 7, 14, 28, 56 and 90 days. The result was found phosphorus is highest on the first day and it will gradually decrease with increasing duration.

Indiati, R. et al [54] study about changes of soil phosphorus availability in Italian alfisols as estimated by short-term soil + phosphorus equilibration procedures using olsen, mehlich 3, and paper-strip methods. The result was found the available phosphorus to decrease according to increasing composting time. This was because of soluble phosphate ion reacted with calcium and free lime in soil, it was become to the phosphate compounds and converted into insoluble compound that cause the soluble phosphate immobility in soil.

M. Kianirad, S. Mirdamadi, M. Muazardalan, G. Savaghebi, M. Farahbakhsh [55] studied about Effects of temperature treatment on corn cob composting and reducing of composting time. The results show as the peak temperature in low-temperature treatment during the active stage was 48–53°C, and, at the end of the process, it was concluded that higher organic carbon molecules were not able to be degraded. In contrast, at high-temperature treatment, microbial thermophiles adapted to the new conditions and hence organic carbon degradation and transformation to humic substances continued. Composting time and quality of compost are important factors influencing the economy of the composting process, and are strongly affected by the treatment temperature. Two temperatures of high and low level have been considered in the treatment of corn cob composting. The high temperature treatment was the best choice for improvement of the process, due to increased activities of thermophilic microbes at the matured stage. Under this condition, the lignocellulose compounds show higher degradation, resulting in reduced C/N compared to the low-temperature treatment. Additionally, greater amounts of water extractable carbon are utilized by micro-organisms. The phytotoxic compounds are greatly reduced during the high-temperature treatment, resulting in higher germination index. The transformation of the organic carbon under high-temperature conditions produces more functional groups, which cause higher CEC/TOC ratio. Moreover, the high-temperature treatment shortens the composting time due to the faster onset of the matured stage compared to the low-temperature treatment.

## **CHAPTER III**

### **MATERIALS AND METHODS**

#### **3.1 Research design**

This study was three way repeated measure ANOVA and it was a study in different composting conditions to utilize sewage sludge mixed with grass clippings through the windrow composting technique. It was conducted in laboratory and field. The sewage sludge was sampled from Nong Khaem wastewater treatment plant. Grass clippings were sampled from municipal yard waste in Bangkok area. The research design was field experiment with multiple independent variables (4 mixing ratios, 2 steam sterilization conditions and 5 composting times). These experimental units were 40 units with three replications as shown in Table 3.1.

##### **3.1.1 Characteristics of sewage sludge and grass clippings**

Sewage sludge and grass clippings were used as raw material for composting through the windrow composting technique at different conditions. These raw materials were analyzed for moisture content and chemical characteristics before composting. The chemical characteristics were pH, organic matter, total nitrogen, and C/N ratio. This sewage sludge and grass clippings were mixed at different mixing ratios for determination the physical and chemical characteristics and they were done three replications.

##### **3.1.2 Nutrients mineralization study**

The study was involved with monitoring of mineralization process in sewage sludge mixed with grass clippings and composted at different conditions.

Table 3.1 Treatment combination of sewage sludge mixed with grass clippings composting and different composting time

Treatment	Mixing ratio (Sewage sludge: Grass clippings)	Steam sterilization condition	Composting time
1:0 with PC	1:0	with PC	0, 2, 4, 6, 8
1:0 without PC	1:0	without PC	0, 2, 4, 6, 8
1:1 with PC	1:1	with PC	0, 2, 4, 6, 8
1:1 without PC	1:1	without PC	0, 2, 4, 6, 8
3:1 with PC	3:1	with PC	0, 2, 4, 6, 8
3:1 without PC	3:1	without PC	0, 2, 4, 6, 8
6:1 with PC	6:1	with PC	0, 2, 4, 6, 8
6:1 without PC	6:1	without PC	0, 2, 4, 6, 8

Remark: PC is plastic cover

## 3.2 Place of the experiment

3.2.1 The experiment of composting process was carried out in the field at Nong Khaem sludge composting site.

3.2.2 The physical and chemical characteristics of sewage sludge, grass clippings, and composted were analyzed in laboratory at Department of Environmental Health Science, Faculty of Public Health, Mahidol University, Bangkok, Thailand.

## 3.3 Equipments and chemicals

### 3.3.1 Equipments

- pH meter (HACH model sensION 156)
- Analytical balance (mettler model AB204-s)
- 2 mm. sieving equipment
- Oven (memmert model UNE 400)
- Desiccator (Patron model gH-51)
- Hot plate (stuart model CB 302)
- Spectrophotometer (Thermo electro corporation model

Helios Delta)

- Atomic Absorption Spectrophotometer (Varian model spectra-220FS)
- Distillation apparatus (Buchi model K-314)
- Whatman filter paper No.1 or 5
- Glassware
- Mortar
- Computer for data processing

### 3.3.2 Chemicals

- Buffer solution pH 7, 4 and 10
- Potassium dichromate ( $K_2Cr_2O_7$ ) 1 N
- Sulfuric acid (conc.  $H_2SO_4$ )
- Phosphoric acid (conc.  $H_3PO_4$ )
- Barium diphenylamine sulfonate indicator (BDS) 0.16%
- Ferrous ammonium sulfate (FAS) 0.5 N
- Mixed catalyst
- Sodium hydroxide (NaOH) 40%
- Boric acid indicator 2%
- Magnesium oxide (MgO)
- Deverda alloy
- Potassium chloride (KCl) 2N
- Perchloric acid ( $HClO_4$ ) 70-72 %
- Nitric acid ( $HNO_3$ ) 65 %
- Free acid molybdovanadate solution
- Standard phosphorus solution
- Ammonium fluoride ( $NH_4F$ ) 1 N
- Hydrochloric acid (HCl) 0.5 N
- Developing color solution
- Ascorbic acid

## **3.4 Experimental methods**

### **3.4.1 Experimental process**

3.4.1.1 Sewage sludge was sampled from Nong Khaem wastewater treatment plant which had been treated by anaerobic digestion and dewatered. Grass clippings were sampled from municipal yard waste in Bangkok area which was chopped to 2-5 cm. Size of pile was 5 x 1.2 x 6 m<sup>3</sup> (width x height x length m<sup>3</sup>).

3.4.1.2 This study had 8 treatments. The first 4 treatments were sewage sludge mixed with grass clippings and composted by windrow pile composting at 1:0, 1:1, 3:1, and 6:1 ratio. They were covered by black plastic sheet in day time during 10 am to 4 pm for steam sterilization process. The other 4 treatments were sewage sludge mixed with grass clippings, and composted by windrow pile composting at 1:0, 1:1, 3:1, and 6:1 ratio which they were not covered by black plastic sheet. The treatments were composted in the windrow pile for 8 weeks in aerobic condition by mechanically turning the windrow compost pile every week to provide the oxygen for break down organic contents by microorganisms. The temperature was monitored every two weeks at the middle of piles.

3.4.1.3 All treatments from each windrow compost pile were sampled for determination the physical and chemical characteristics. The windrow compost piles were turned and took sub-samples from 5 locations where evenly spaced on each side of them at 60 cm depth below piles surface. Mixed sub-samples of each treatment thoroughly, filled it in plastic bag, and placed in cooler with ice for bring it back to the laboratory.

### **3.4.2 Preparation of sewage sludge, grass clippings, and composted samples for the physical and chemical characterization.**

The sewage sludge, grass clippings and composted were air-dried at ambient temperature, crushed, and sieved through a 2 mm stainless steel screen.

This studied sewage sludge, grass clippings and composted were analyzed for physical and chemical characteristics as shown in Table 3.2.

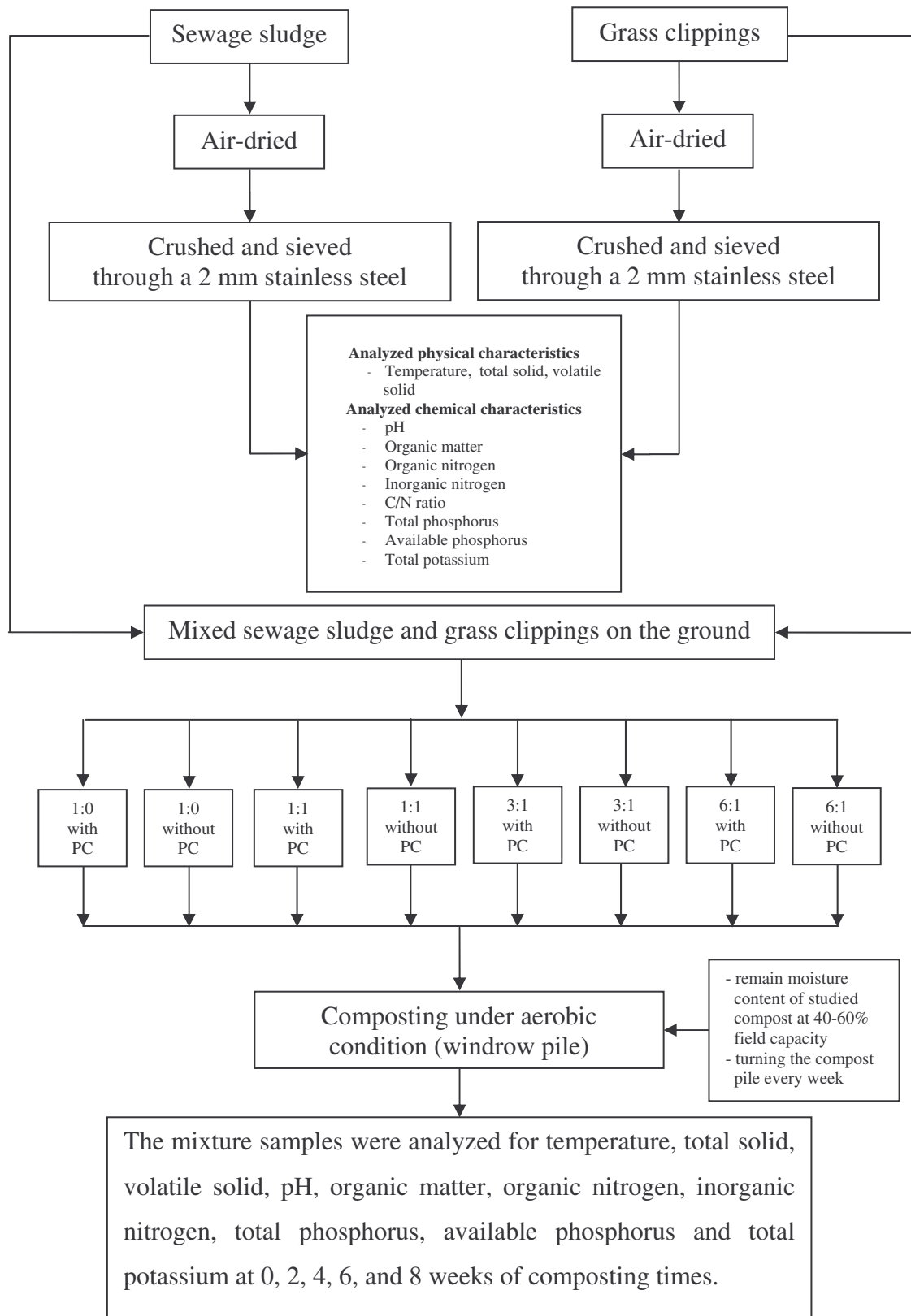
### 3.4.3 Nutrients Mineralization

The mixture samples were analyzed for temperature, total solid, volatile solid, pH, organic matter, organic nitrogen, inorganic nitrogen, total phosphorus, available phosphorus and total potassium at 0, 2, 4, 6, and 8 weeks of composting times.

Table 3.2 Parameter and test method for sewage sludge mixed with grass clippings and composted

Parameter	Test method
<b>Physical properties</b>	
Temperature	Thermometer
Total solid	Gravimetric method, dried at 103-105°C
Volatile solid	Gravimetric method, ignited at 500°C
<b>Chemical properties</b>	
pH	1:2.5 water/sample, measurement by pH meter
% organic matter	Walkley & Black method
Organic nitrogen	Kjedahl method
Inorganic nitrogen	Steam distillation method
C/N ratio	Calculated from organic carbon and organic Nitrogen
Total phosphorus	Colorimetric method
Available phosphorus	Bray II extraction, colorimetric method
Total potassium	Wet digestion, AAS

### 3.5 Research diagram



### **3.6 Statistical analysis**

The statistical analysis for testing the hypothesis of the study is as follow;

#### **3.6.1 Descriptive statistics**

The average, standard deviation and percentage were used for physical and chemical characteristics of sewage sludge, grass clippings, sewage sludge mixed with grass clippings, and composted.

#### **3.6.2 Analytical statistics**

The three-way analysis of variance with one repeated measure was used to analyze main effects and interaction effects. When an interaction exists, main effects are ignore.

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

In case of double interaction, the F test of ANOVA was used to test a simple main effect of mixing ratio at each time period.

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

This chapter is showed the results of nutrients changed at different composting conditions which were the sewage sludge from Nong Khaem wastewater treatment plant mixed with grass clippings from municipal yard waste in Bangkok area through the windrow composting technique. The study was conducted in the laboratory at Department of Environmental Health Science, Faculty of Public Health, Mahidol University, Bangkok, Thailand and a field experimental at Nong Khaem sludge composting site. All treatments from each windrow compost pile were turned and took sub-samples from 5 locations which evenly spaced on each side of them at 60 cm depth below piles surface every two weeks for analysis in the laboratory.

#### 4.1 characteristics of sewage sludge and grass clippings

Sewage sludge and grass clippings were used as raw material for composting through the windrow composting technique at different conditions. These raw materials were analyzed for moisture content and chemical characteristics before composting. The chemical characteristics were pH, organic matter, total nitrogen, and C/N ratio. The results are shown in Table 4.1.

Table 4.1 The moisture content and chemical characteristics of sewage sludge and grass clippings

Parameter	Sewage sludge	Grass clippings
Moisture content (%)	78.09	2.64
pH	6.66	5.70
Organic matter (%)	19.01	28.87
Total nitrogen (%)	2.17	0.98
C/N ratio	5.08:1	17.08:1

The results of initial chemical characteristics of sewage sludge and grass clippings showed moisture content 78.09% and 2.64%, pH 6.66 and 5.70, organic matter 19.01% and 28.87%, total nitrogen 2.17% and 0.98%, and C/N ratio 5.08 and 17.08, respectively. Three out of five characteristics of sewage sludge were higher than that of the grass clippings.

## **4.2 Nutrients mineralization study**

The study was involved with monitoring of nutrients mineralization process in sewage sludge mixed with grass clippings and composted at different conditions. The studied physical characteristics were temperature, total solids and volatile solids. The studied chemical characteristics were pH, organic matter, carbon to nitrogen ratio, organic nitrogen, inorganic nitrogen, total phosphorus, available phosphorus and total potassium.

### **4.2.1 Physical characteristics**

#### **4.2.1.1 Temperature**

The temperature of all treatments was measured at every two weeks of composting time starting from week 0 until the composting process was finished at week 8 as shown in Table 4.2.

The average of ambient temperature was 31.92°C while the average temperatures of all treatments were in the range of 27.33-44.00°C. The maximum temperature was the treatment which had mixing ratio 1:0 and not covered by black plastic sheet (44.00°C). The minimum temperature was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet (37.67°C). The results are showed in table 4.2. The temperature trend lines of all treatments were increased during increasing composting time, except between week 2 and week 4 (Figure 4.1).

Table 4.2 The ambient temperature (°C) and temperature of all treatments during the composting process at the different composting times

Treatments	Composting times				
	week 0	week 2	week 4	week 6	week 8
	(SD)	(SD)	(SD)	(SD)	(SD)
1:0 with PC	30.33 (0.58)	32.67 (0.58)	30.00 (0.00)	35.00 (1.00)	40.00 (1.00)
1:0 without PC	30.00 (0.00)	31.67 (0.58)	31.67 (0.58)	38.00 (1.00)	44.00 (0.00)
1:1 with PC	30.33 (0.58)	34.33 (1.15)	33.00 (0.00)	37.33 (0.58)	38.00 (1.00)
1:1 without PC	30.00 (0.00)	35.00 (1.00)	35.33 (1.15)	36.33 (0.58)	37.67 (0.58)
3:1 with PC	30.33 (0.58)	33.33 (0.58)	32.67 (0.58)	37.00 (1.00)	40.00 (1.00)
3:1 without PC	27.33 (0.58)	33.67 (0.58)	31.67 (0.58)	35.00 (0.00)	43.00 (1.00)
6:1 with PC	29.33 (1.15)	31.67 (0.58)	32.67 (0.58)	35.00 (0.00)	40.00 (0.00)
6:1 without PC	29.00 (0.00)	32.33 (0.58)	31.67 (1.15)	37.33 (0.58)	39.33 (1.53)
Ambient	29.00	31.00	31.00	32.60	36.00

Remark: PC is plastic cover

SD is standard deviation

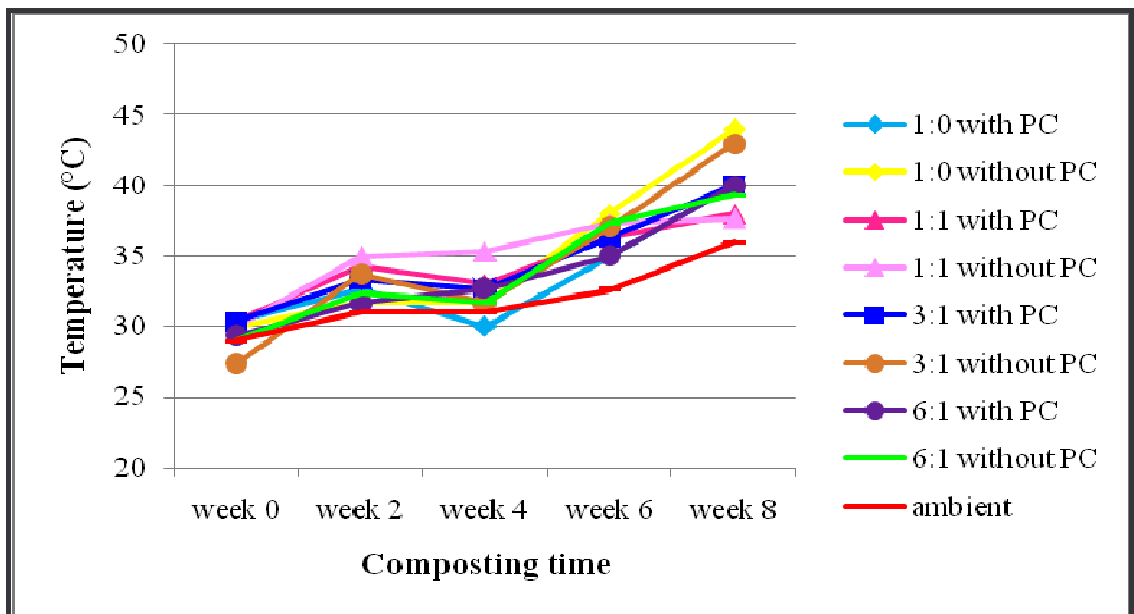


Figure 4.1 The temperature trend lines of all treatments

As referred, the results indicated that the temperature of all treatments after passed composting process had the higher than the before passed composting process (Figure 4.2).

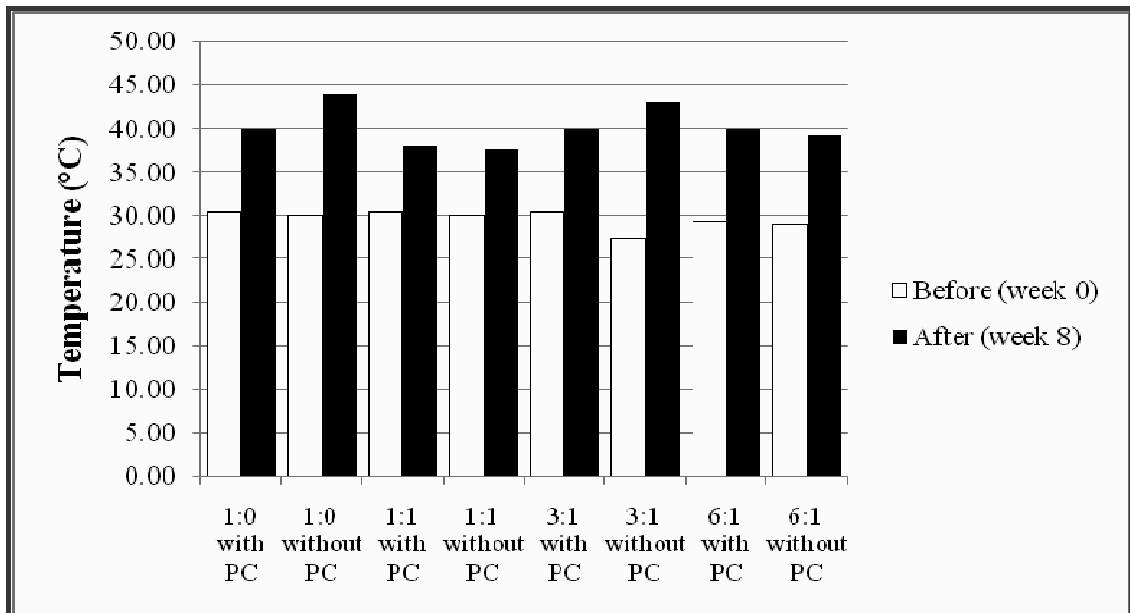


Figure 4.2 The temperature of all treatments before and after passed composting process

The Three-Way Analyses of Variance with one Repeated Factors is used to analyze main effects (mixing ratio, steam sterilization, and composting time) and their interaction effects of temperature values.

- The main effect of mixing ratio of all treatments was significantly different ( $P = 0.005$ ).
- The main effect of steam sterilization of all treatments was not significantly different ( $P = 0.121$ ).
- The main effect of composting time of all treatments was significantly different ( $P < 0.001$ ).

- The interaction among mixing ratio, steam sterilization and composting time were significantly different ( $P < 0.001$ ) on within subject effect. There were also had interactions between composting time and mixing ratio ( $P < 0.001$ ); between composting time and steam sterilization ( $P < 0.001$ ) and an interaction between mixing ratios and steam sterilizations ( $P = 0.006$ ). The results of analytical statistics are shown in Table 4.3.

Table 4.3 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for temperature

Source	SS	df	MS	F	p-value
<b>Between-Subjects Effects</b>					
Intercept	141110.208	1	141110.208	1.568E5	< 0.001
Mixing ratio	16.758	3	5.586	6.207	0.005
Steam sterilization	2.408	1	2.408	2.676	0.121
Mixing ratio * steam sterilization	16.425	3	5.475	6.083	0.006
Error	14.400	16	0.900		
<b>Within-Subjects Effects</b>					
Composting times	1653.667	4	413.417	668.148	< 0.001
composting times * mixing ratio	126.533	12	10.544	17.042	< 0.001
composting times * steam sterilization	25.467	4	6.367	10.290	< 0.001
composting times * mixing ratio * steam sterilization	59.533	12	4.961	8.018	< 0.001
Error	39.600	64	0.619		

When interaction exist among the three factors, F test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilizations (with and without plastic cover) at each time period.

With plastic cover, temperature was found significant difference in 3 periods, except at the composting time week 0 and week 8.

To test difference between group, Bonferroni adjustment is used to compare.

- For with plastic cover at composting time week 2, the temperature of mixing ratio 1:1 was significantly different from mixing ratio 6:1.

- For with plastic cover at composting time week 4, the temperature of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1.

- For with plastic cover at composting time week 6, the temperature of mixing ratio 1:1 was significantly different from mixing ratio 1:0 and 6:1.

- For with plastic cover, at mixing ratio 1:1 between composting time week 2 to 6 had highest temperature followed by mixing ratio 3:1 as shown in Figure 4.3.

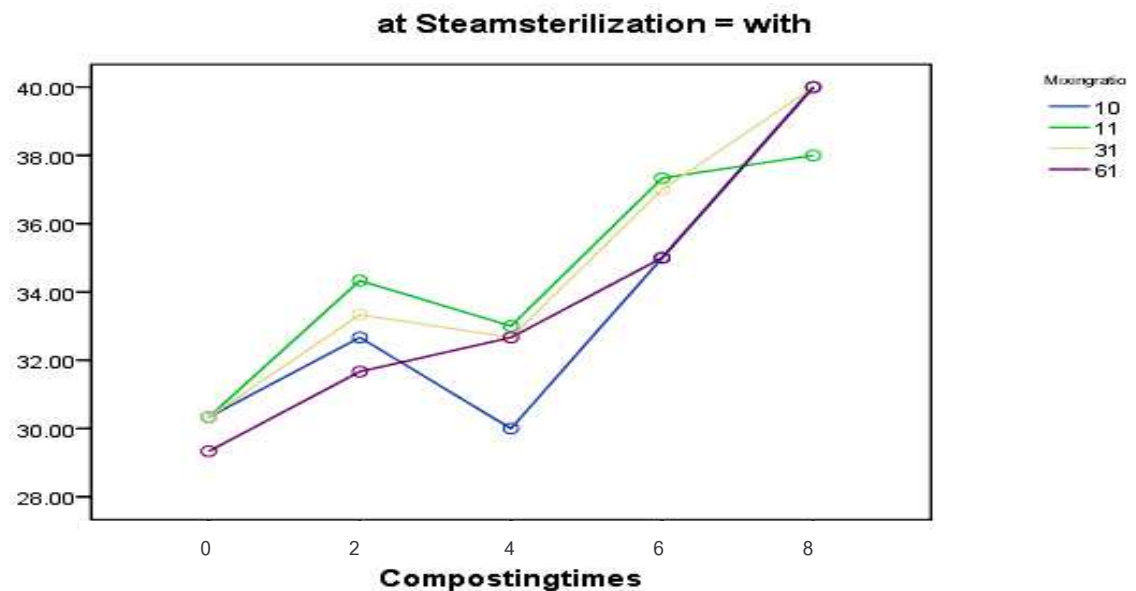


Figure 4.3 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to temperature

Without plastic cover, the temperature was found significant difference at all periods.

To test difference between group, Bonferroni adjustment is used to compare.

- For without plastic cover at composting time week 2, the temperature of mixing ratio 1:1 was significantly different from mixing ratio 1:0 and 6:1.

- For without plastic cover at composting time week 4, the temperature of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.

- For without plastic cover at composting time week 6, the temperature of mixing ratio 3:1 was significantly different from mixing ratio 1:0 and 6:1.
- For without plastic cover at composting time week 8, the temperature of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 6:1; mixing ratio 3:1 was significantly different from mixing ratio 1:1 and 6:1.
- For without plastic cover, at mixing ratio 1:0 between composting time week 6 to 8 had highest temperature followed by mixing ratio 6:1 as shown in Figure 4.4.

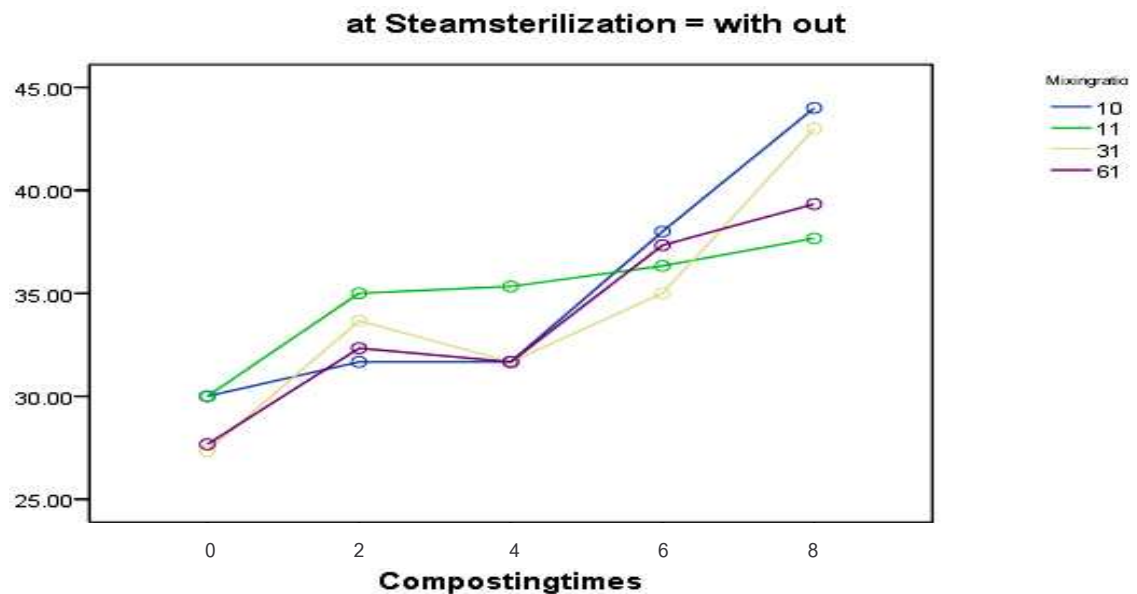


Figure 4.4 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to temperature

When an interaction exists among the three factors, F test of ANOVA is used to test the simple main effect of steam sterilizations classified by each level of mixing ratios (1:0, 1:1, 3:1 and 6:1) at each time period.

To test difference between group, Bonferroni adjustment is used to compare.

- For mixing ratio 1:0 at composting time week 4, 6 and 8, the temperature of with plastic cover was significantly different from without plastic cover as shown in Figure 4.5.

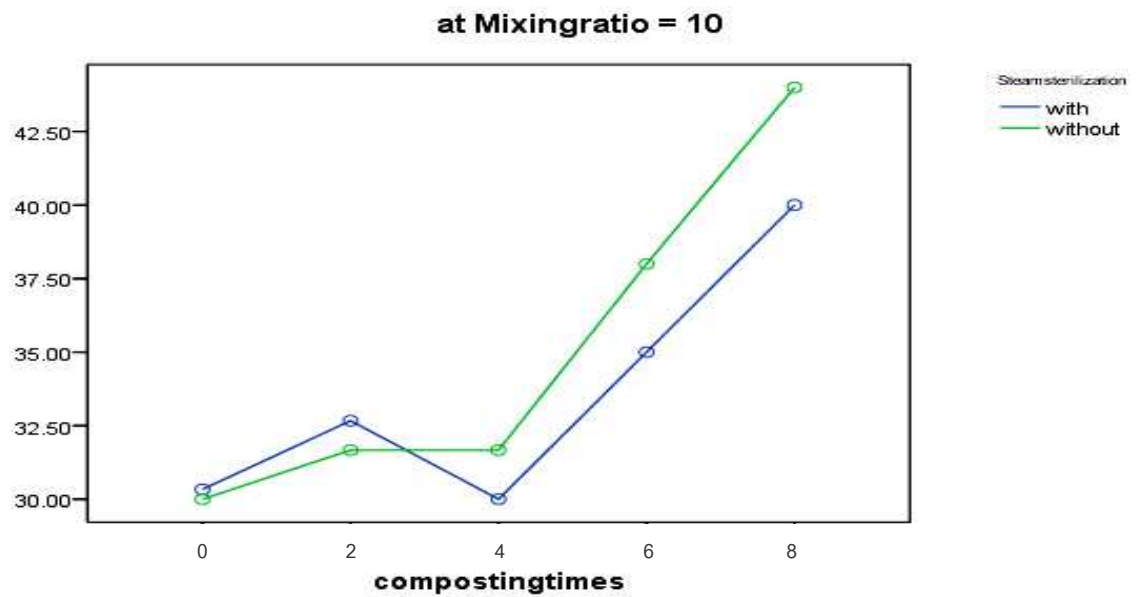


Figure 4.5 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to temperature

- For mixing ratio 1:1 at composting time week 4, the temperature of with plastic cover was significantly different from without plastic cover as shown in Figure 4.6.

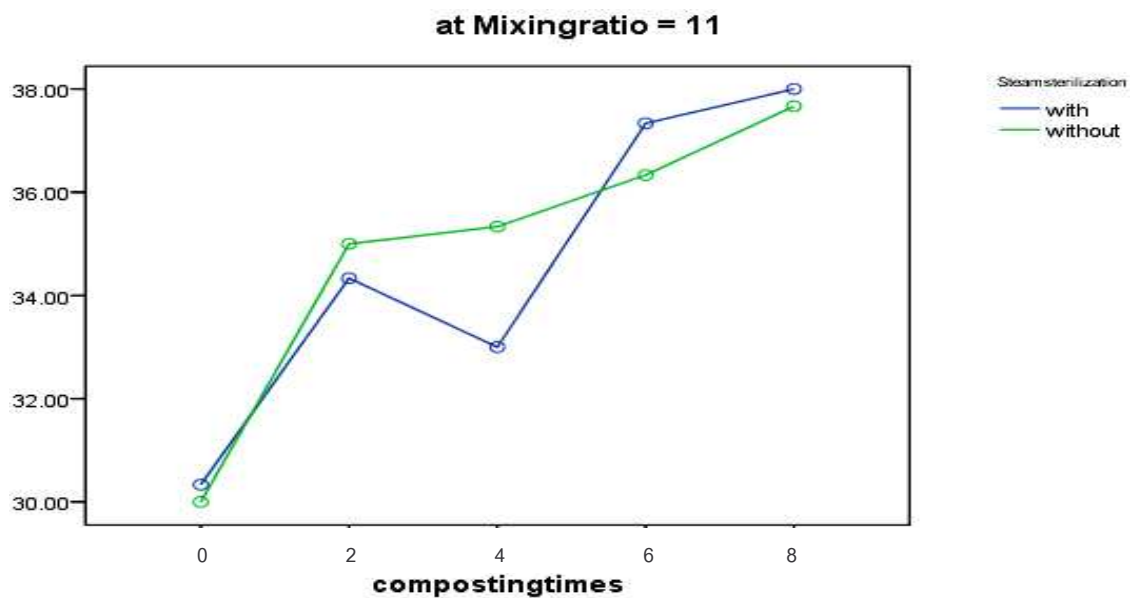


Figure 4.6 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to temperature

- For mixing ratio 3:1 at composting time week 0, 6 and 8, the temperature of with plastic cover was significantly different from without plastic cover as shown in Figure 4.7.

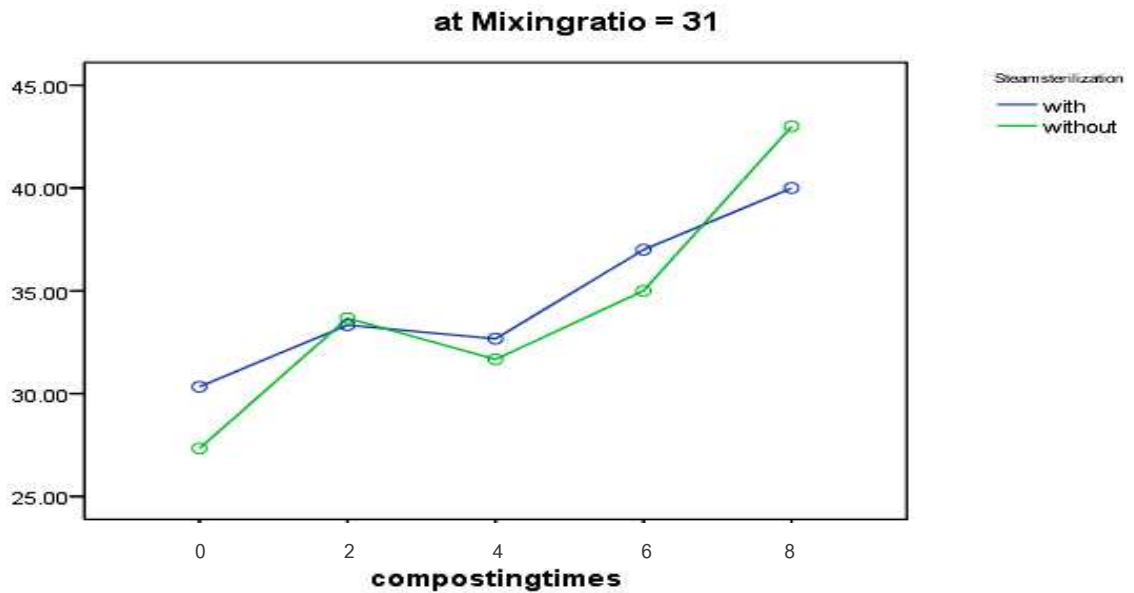


Figure 4.7 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to temperature

- For mixing ratio 6:1 at composting time week 0, 2, 4 and 8, temperature of with plastic cover was significantly different from without plastic cover as shown in Figure 4.8.

- For all mixing ratio, at composting time week 4 to 8 with plastic cover treatment had not difference temperature from without plastic cover treatment.

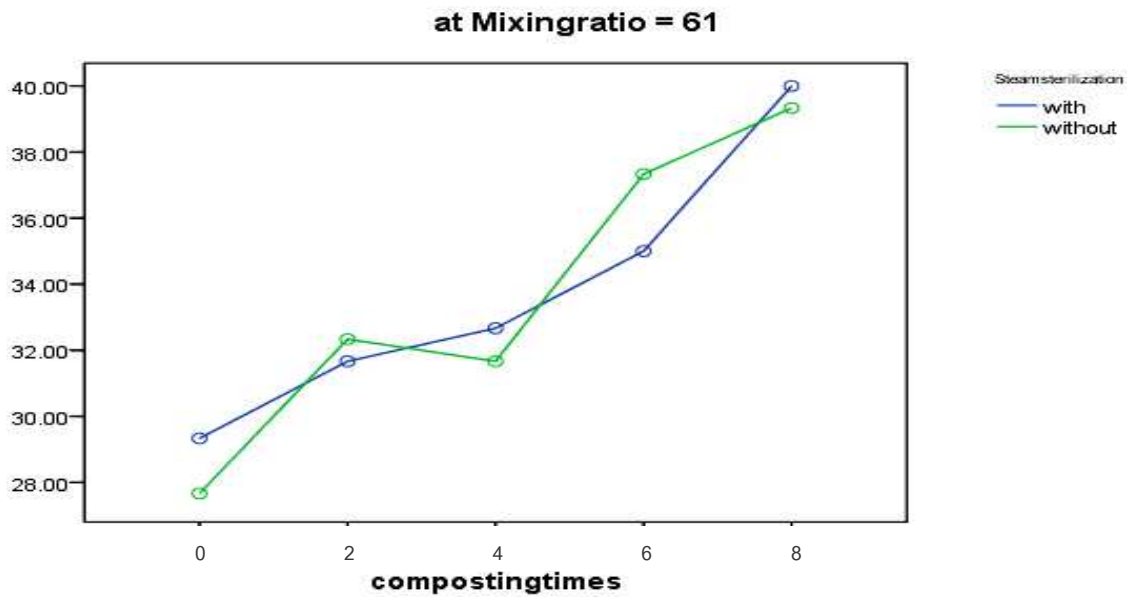


Figure 4.8 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to temperature

To test the simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition, Bonferroni adjustment is used to test the difference between each pair of treatment.

- For mixing ratio 1:0 with plastic cover, the temperature of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 2 was significantly different from composting time week 0 and 4.

- For mixing ratio 1:0 without plastic cover, the temperature of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4.

- For mixing ratio 1:1 with plastic cover, the temperature of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 0 was significantly different from composting time week 2 and 4.

- For mixing ratio 1:1 without plastic cover, the temperature of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 0 was significantly different from composting time week 2, 4 and 6.

- For mixing ratio 3:1 with plastic cover, the temperature of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0.

- For mixing ratio 3:1 without plastic cover, the temperature of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 6:1 with plastic cover, the temperature of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 0 was significantly different from composting time week 2 and 4.

- For mixing ratio 6:1 without plastic cover, the temperature of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 2 was significantly different from composting time week 0.

- For all treatments, at composting time week 8 had highest temperature followed by at composting time week 6 as shown in Figure 4.9.

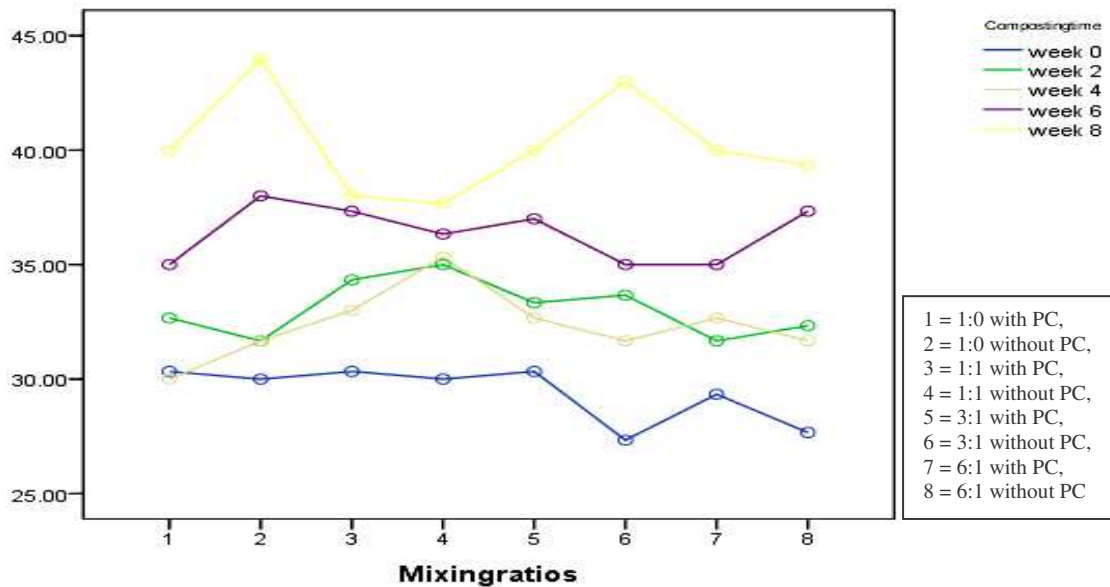


Figure 4.9 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to temperature

#### 4.2.1.2 Total solids

The total solids were measured at every two weeks of composting time starting from week 0 until the composting process was finished at week 8.

During composting process, the average total solids of all treatments were in the range of 24.57-56.73%. The maximum total solids content at the end of composting process was the treatment which had mixing ratio 6:1 and not covered by black plastic sheet (56.73%). The minimum total solids content were the treatment which had mixing ratio 1:0 and covered by black plastic sheet (35.33%). The results are shown in Table 4.4. The total solids of all treatments trend to increase according to increasing of composting time (Figure 4.10).

Table 4.4 The average total solids (%) of all treatments during the composting process at the different composting times

Treatments	Composting times				
	week 0	week 2	week 4	week 6	week 8
	(SD)	(SD)	(SD)	(SD)	(SD)
1:0 with PC	24.57 (0.25)	26.04 (0.26)	29.53 (0.25)	33.04 (0.63)	35.33 (0.09)
1:0 without PC	25.19 (0.62)	27.55 (0.41)	32.58 (0.51)	40.96 (0.14)	53.21 (1.83)
1:1 with PC	26.42 (0.36)	31.72 (4.84)	32.83 (0.43)	40.23 (0.55)	43.08 (1.68)
1:1 without PC	26.23 (0.24)	29.31 (3.58)	34.74 (1.59)	47.40 (1.09)	52.11 (0.65)
3:1 with PC	25.57 (0.21)	27.38 (0.15)	28.57 (0.44)	32.45 (0.10)	36.64 (0.59)
3:1 without PC	26.72 (0.18)	28.31 (0.26)	35.86 (1.72)	45.12 (0.85)	51.05 (1.18)
6:1 with PC	25.01 (0.21)	26.16 (0.35)	28.84 (0.45)	34.26 (0.70)	37.26 (0.48)
6:1 without PC	26.12 (0.48)	28.19 (0.27)	33.93 (1.16)	40.68 (0.63)	56.73 (3.08)

Remark: PC is plastic cover

SD is standard deviation

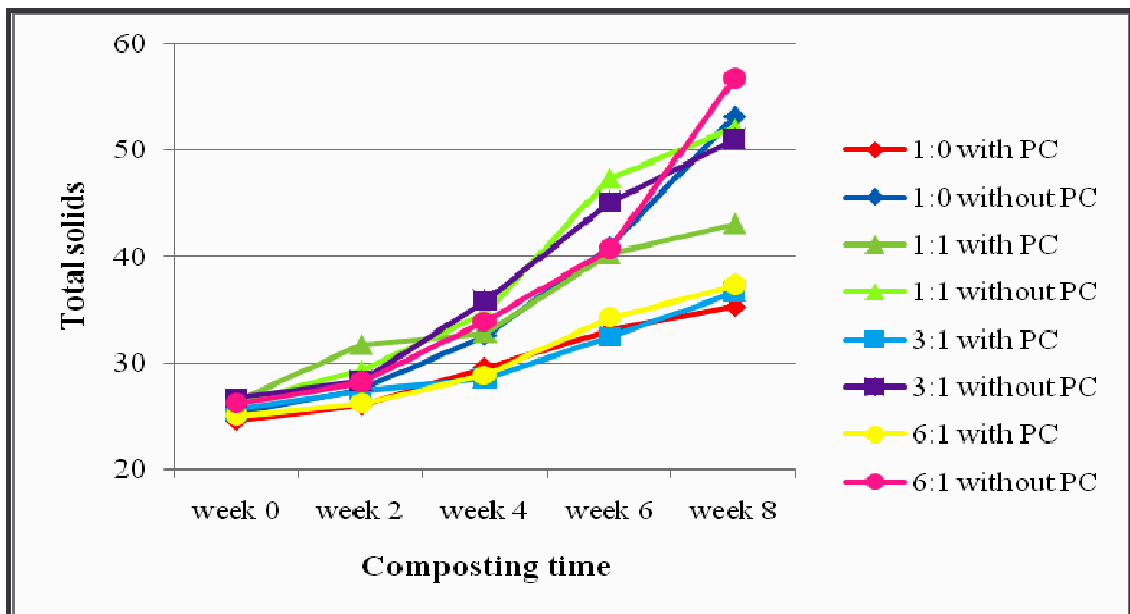


Figure 4.10 The total solids trend lines of all treatments

As referred, the results indicated that the total solids of all treatments after passed composting process had the higher than the before passed composting process (Figure 4.4).

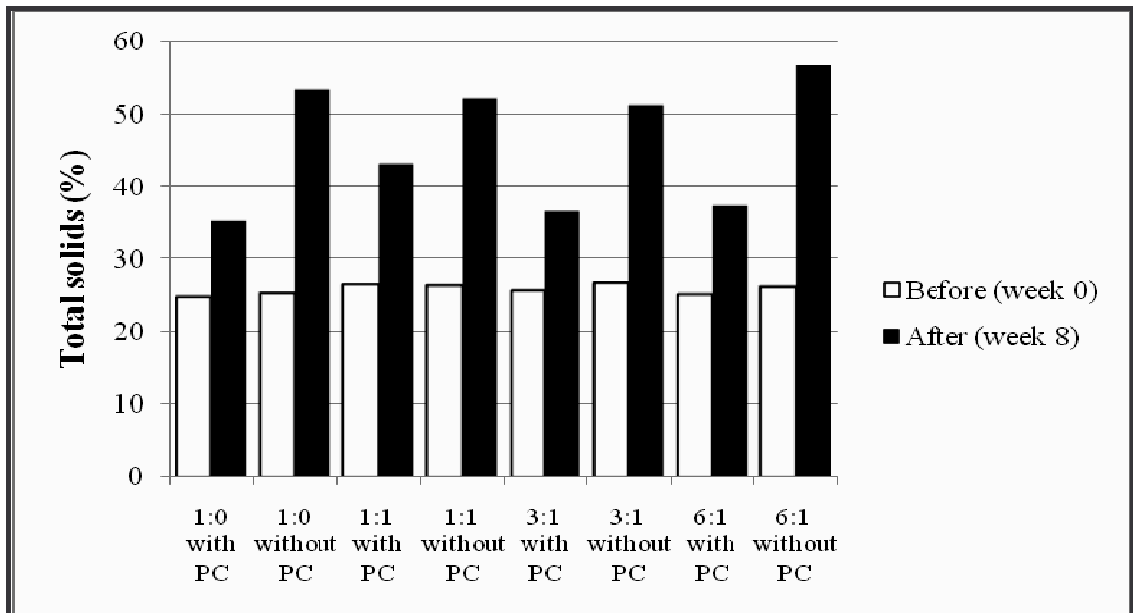


Figure 4.11 The total solids of all treatments before and after passed composting process

The Three-Way Analyses of Variance with one Repeated Factors is used to analyze main effects (mixing ratio, steam sterilization, and composting time) and their interaction effects of total solids values.

- The main effect of mixing ratio of all treatments was significantly different ( $P < 0.001$ ).
- The main effect of steam sterilization 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 and composting time were significantly different ( $P = 0.001$ ) on within subject effect. There were also had interactions between composting time and mixing ratio ( $P < 0.001$ ); between composting time and steam sterilization ( $P < 0.001$ ) and an interaction between mixing ratios and steam sterilizations ( $P < 0.001$ ). The results of analytical statistics are shown in Table 4.5.

Table 4.5 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for total solids

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

When interaction exist among the three factors, F test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilizations (with and without plastic cover) at each time period.

With plastic cover, total solids were found significant difference in 4 periods, except at composting time week 2.

To test difference between group, Bonferroni adjustment is used to compare.

- For with plastic cover at composting time week 0, the total solids of mixing ratio 1:0 was significantly different from mixing ratio 3:1; mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.

- For with plastic cover at composting time week 4, the total solids of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.
- For with plastic cover at composting time week 6, the total solids of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.
- For with plastic cover at composting time week 8, the total solids of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.
- For with plastic cover, at mixing ratio 1:1 between composting time week 4 to 8 had highest total solids followed by mixing ratio 6:1 as shown in Figure 4.12.

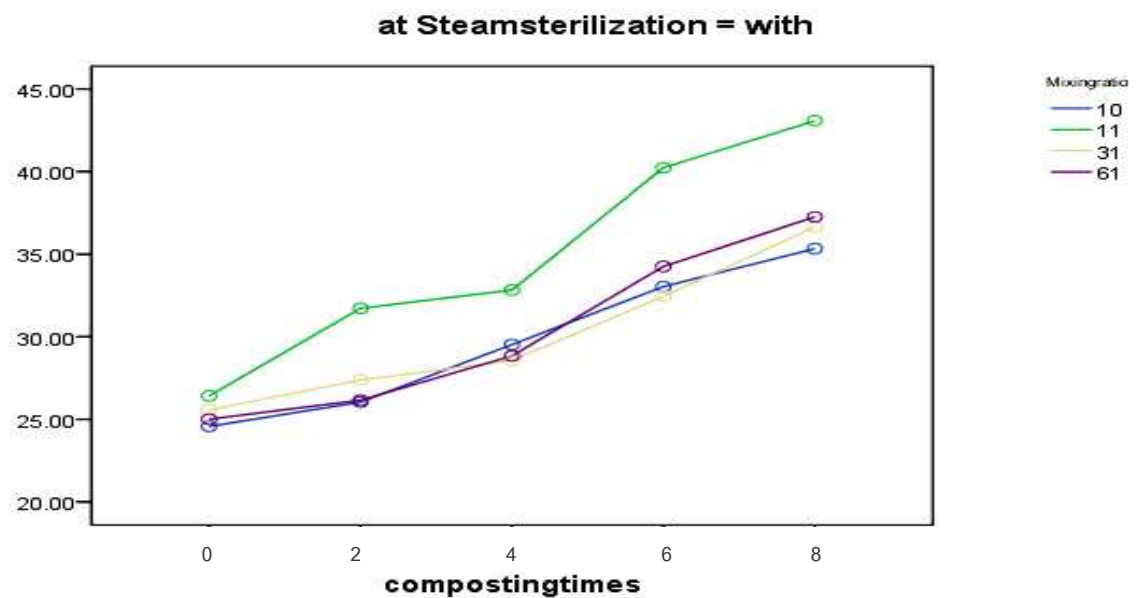


Figure 4.12 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to total solids

Without plastic cover, the total solids were found significant difference at all periods.

To test difference between group, Bonferroni adjustment is used to compare.

- For without plastic cover at composting time week 0, the total solids of mixing ratio 1:0 was significantly different from mixing ratio 3:1.

- For without plastic cover at composting time week 6, the total solids of mixing ratio 3:1 was significantly different from mixing ratio 1:0 and 6:1; mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.
- For without plastic cover at composting time week 8, the total solids of mixing ratio 3:1 was significantly different from mixing ratio 6:1.
- For without plastic cover, at mixing ratio 1:1 between composting time week 6 to 8 had highest total solids followed by mixing ratio 6:1 as shown in Figure 4.13.

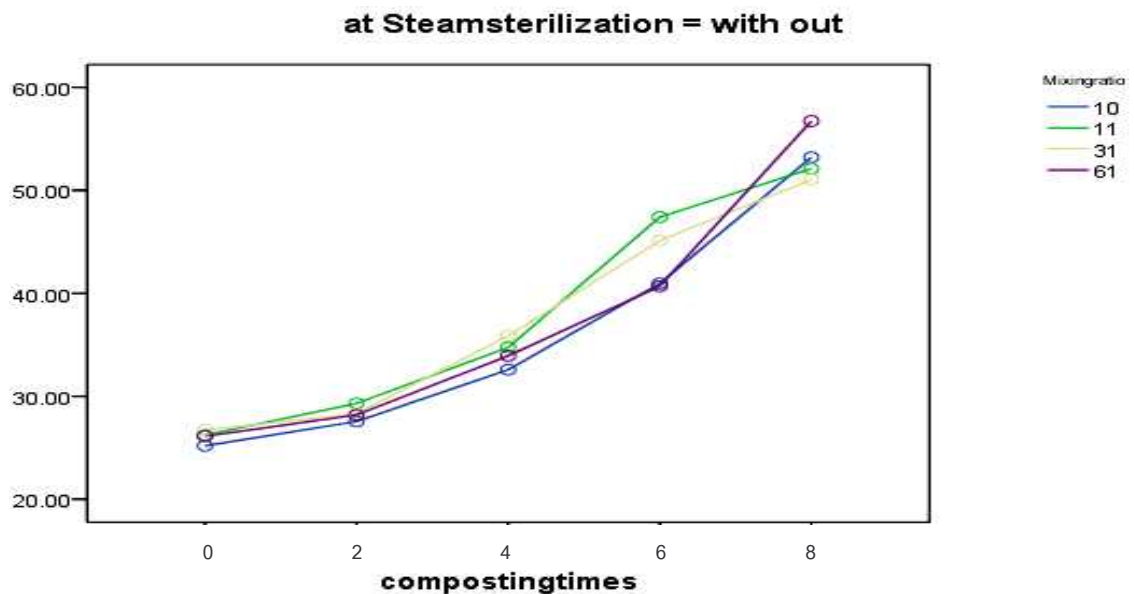


Figure 4.13 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to total solids

When an interaction exists among the three factors, F test of ANOVA is used to test the simple main effect of steam sterilizations classified by each level of mixing ratios (1:0, 1:1, 3:1 and 6:1) at each time period.

To test difference between group, Bonferroni adjustment is used to compare.

- For mixing ratio 1:0 at composting time week 2, 4, 6 and 8, the total solids of with plastic cover was significantly different from without plastic cover as shown in Figure 4.14.

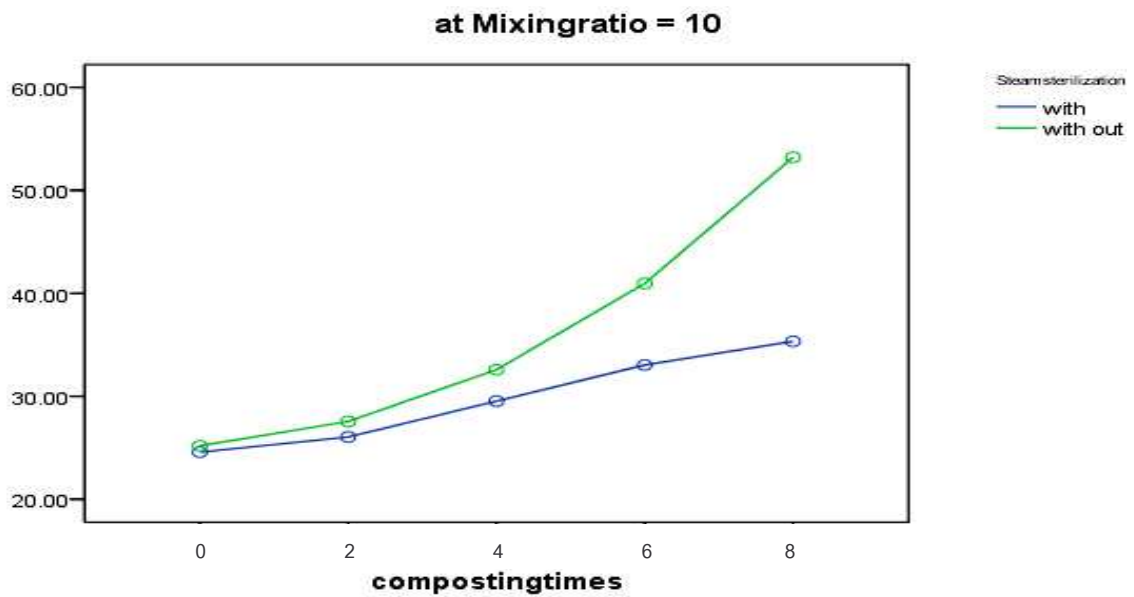


Figure 4.14 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to total solids

- For mixing ratio 1:1 at composting time week 6 and 8, the total solids of with plastic cover was significantly different from without plastic cover as shown in Figure 4.15.

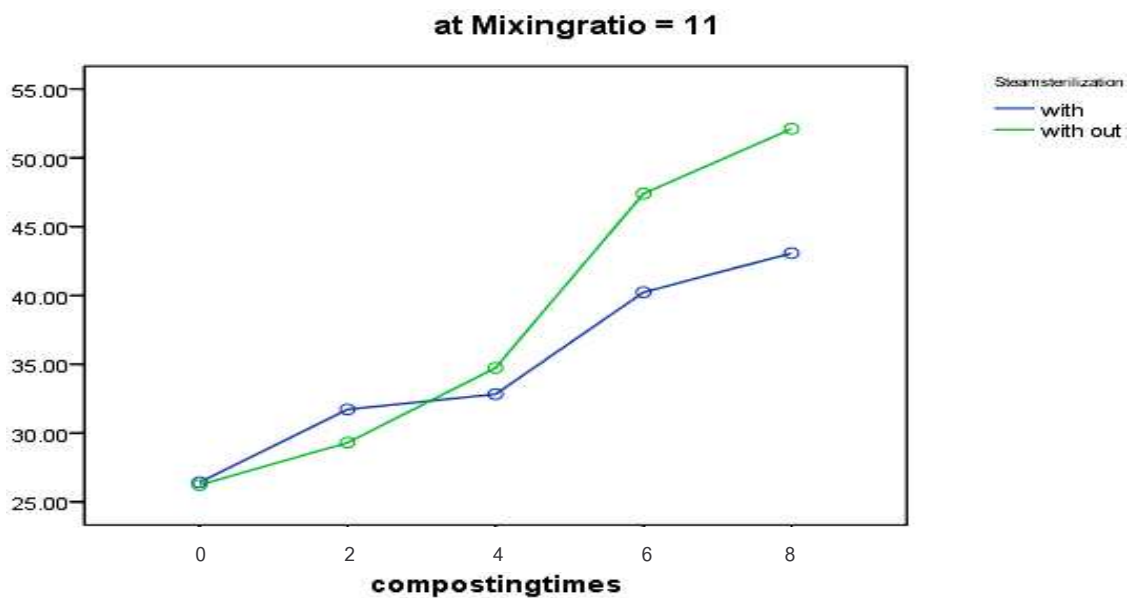


Figure 4.15 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to total solids

- For mixing ratio 3:1 at composting time week 0, 2, 4, 6 and 8, the total solids of with plastic cover was significantly different from without plastic cover as shown in Figure 4.16.

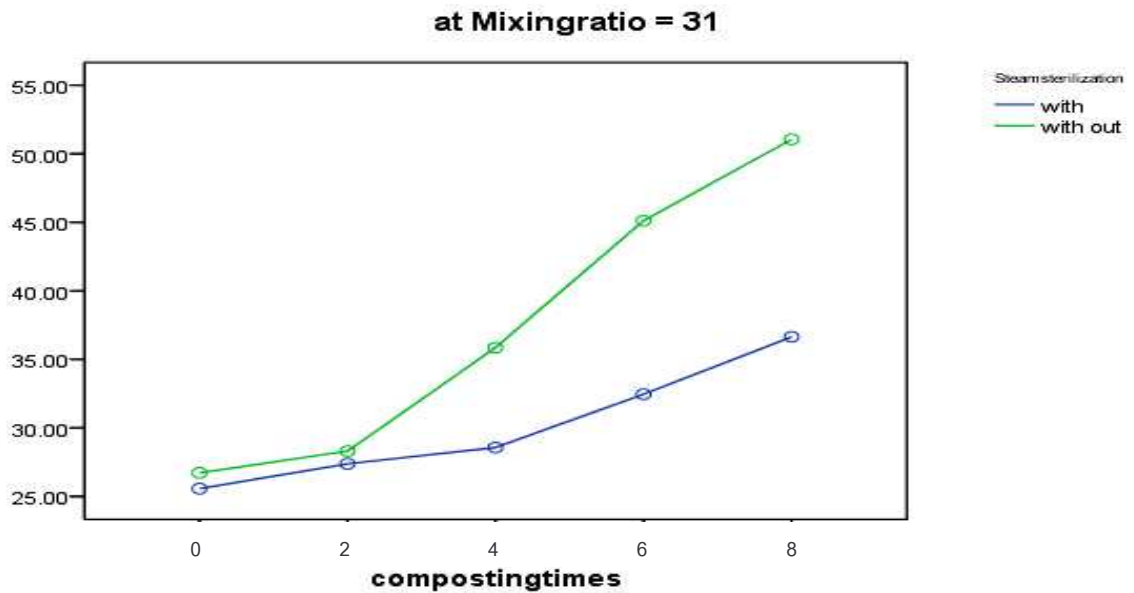


Figure 4.16 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to total solids

- For mixing ratio 6:1 at composting time week 0, 2, 4, 6 and 8, the total solids of with plastic cover was significantly different from without plastic cover as shown in Figure 4.17.

- For all mixing ratio, at composting time week 4 to 8 without plastic cover treatment had higher total solids than with plastic cover treatment.

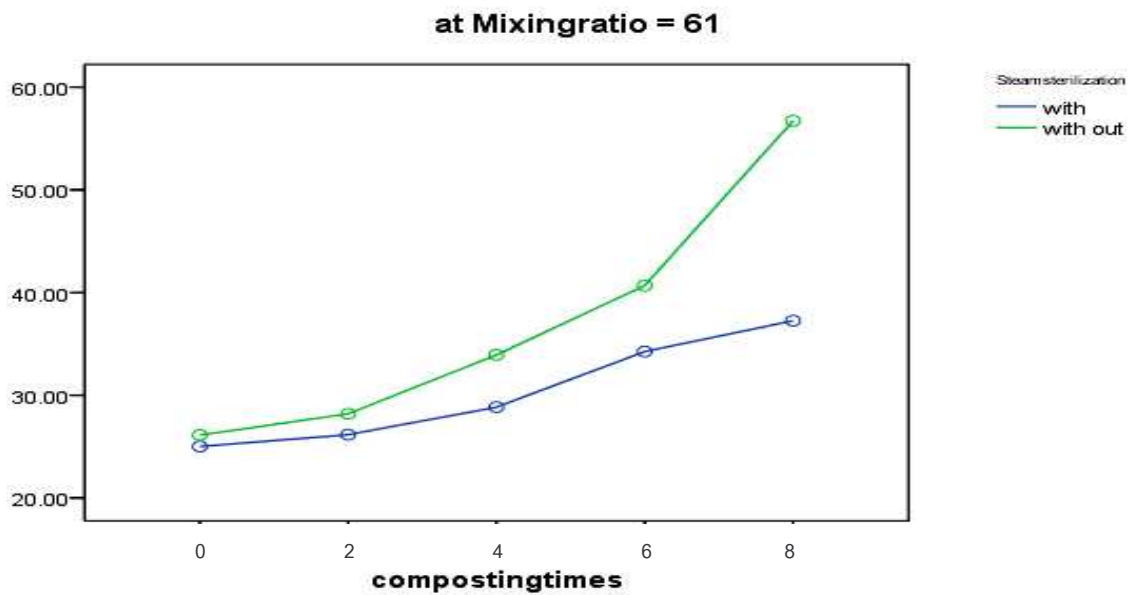


Figure 4.17 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to total solids

To test the simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition, Bonferroni adjustment is used to test the difference between each pair of treatment.

- For mixing ratio 1:0 with plastic cover, the total solids of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2; composting time week 2 was significantly different from composting time week 0.

- For mixing ratio 1:0 without plastic cover, the total solids of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 1:1 with plastic cover, the total solids of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 6 was significantly different from composting time week 0, 2 and 4.

- For mixing ratio 1:1 without plastic cover, the total solids of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 3:1 with plastic cover, the total solids of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2; composting time week 2 was significantly different from composting time week 0.

- For mixing ratio 3:1 without plastic cover, the total solids of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 6:1 with plastic cover, the total solids of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 6:1 without plastic cover, the total solids of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For all treatments, at composting time week 8 had highest total solids followed by at composting time week 6 as shown in Figure 4.18.

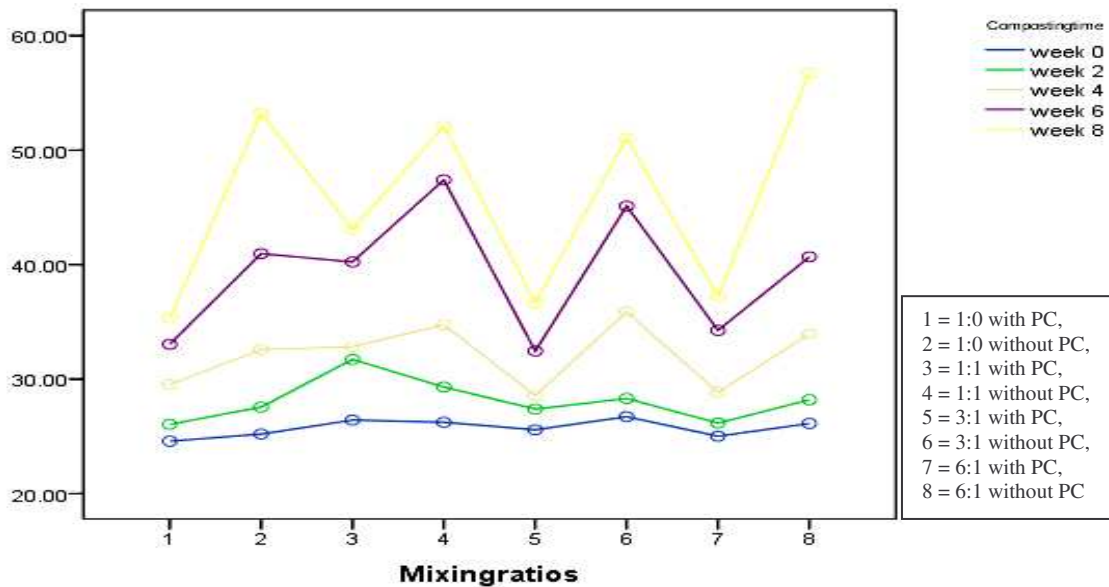


Figure 4.18 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to total solids

#### 4.2.1.3 Volatile solids

The volatile solids were measured at every two weeks of composting time starting from week 0 until the composting process was finished at week 8.

During composting process, the average volatile solids of all treatments were in the range of 36.18-46.17%. The maximum volatile solids at the end of composting process was the treatment which had mixing ratio 1:1 and covered by black plastic sheet (42.40%). The minimum volatile solids were the treatment which had mixing ratio 1:0 and not covered by black plastic sheet (36.18%). The results are shown in Table 4.6. The volatile solids of all treatments had slightly decreased trend (Figure 4.19).

Table 4.6 The average volatile solids (%) of all treatments during the composting process at the different composting times

Treatments	Composting times				
	week 0	week 2	week 4	week 6	week 8
	(SD)	(SD)	(SD)	(SD)	(SD)
1:0 with PC	42.63 (2.25)	40.19 (0.11)	39.37 (0.23)	38.43 (0.20)	37.67 (0.23)
1:0 without PC	41.27 (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 (0.10)	40.89 (0.09)	42.41 (0.09)	42.40 (0.76)
1:1 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 (0.38)	41.31 (0.36)	41.29 (0.50)	39.55 (0.25)
3:1 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)
6:1 without PC	43.96 (0.07)	40.14 (0.17)	40.00 (0.28)	38.96 (0.06)	38.34 (0.44)

Remark: PC is plastic cover

SD is standard deviation

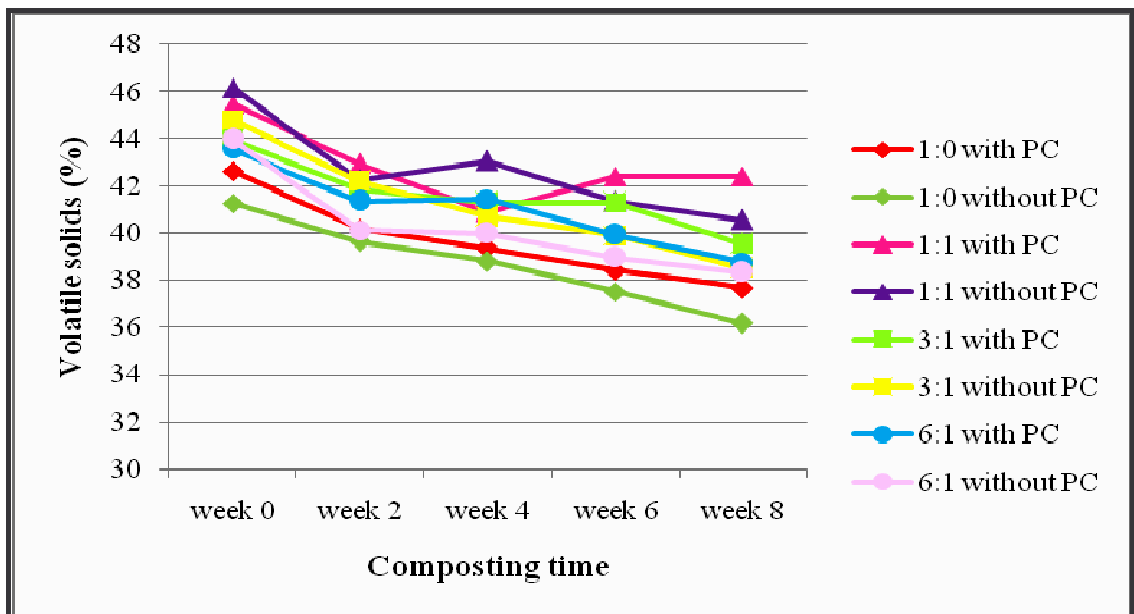


Figure 4.19 The volatile solids trend lines of all treatments

As referred, the results indicated that the volatile solids of all treatments after passed composting process had the lower than the before passed composting process (Figure 4.20).

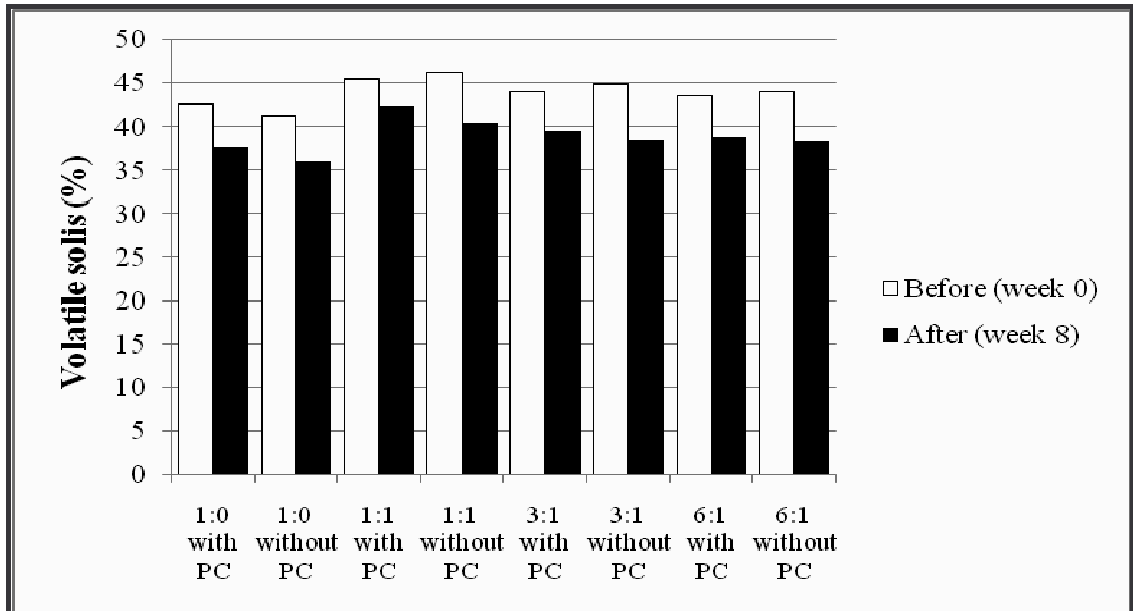


Figure 4.20 The volatile solids of all treatments before and after passed composting process

The Three-Way Analyses of Variance with one Repeated Factors is used to analyze main effects (mixing ratio, steam sterilization, and composting time) and their interaction effects of volatile solids values.

- The main effect of mixing ratio of all treatments was significantly different ( $P < 0.001$ ).
- The main effect of steam sterilization 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 and composting time were significantly different ( $P = 0.001$ ) on within subject effect. There were also had interactions between composting time and mixing ratio ( $P = 0.011$ ); between composting time and steam sterilization ( $P = 0.003$ ) and an interaction between mixing ratios and steam sterilizations ( $P = 0.036$ ). The results of analytical statistics are shown in Table 4.7.

Table 4.7 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for volatile solids

Source	SS	df	MS	F	p-value
<b>Between-Subjects Effects</b>					
Intercept	201658.505	1	201658.505	7.217E5	< 0.001
Mixing ratio	200.992	3	66.997	239.765	< 0.001
Steam sterilization	9.280	1	9.280	33.209	< 0.001
Mixing ratio * steam sterilization	3.029	3	1.010	3.613	0.036
Error	4.471	16	0.279		
<b>Within-Subjects Effects</b>					
Composting times	340.193	1.645	206.853	340.456	< 0.001
composting times * mixing ratio	11.349	4.934	2.300	3.786	0.011
composting times * steam sterilization	8.293	1.645	5.042	8.299	0.003
composting times * mixing ratio * steam sterilization	16.589	4.934	3.362	5.534	0.001
Error	15.988	26.314	0.608		

When interaction exist among the three factors, F test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilizations (with and without plastic cover) at each time period.

With plastic cover, volatile solids were found significant difference in 4 periods, except at composting time week 0.

To test difference between group, Bonferroni adjustment is used to compare.

- For with plastic cover at composting time week 2, the volatile solids of mixing ratio 1:0 was significantly different from mixing ratio 3:1 and 6:1; mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.

- For with plastic cover at composting time week 4, the volatile solids of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1.

- For with plastic cover at composting time week 6, the volatile solids 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For with plastic cover at composting time week 8, the volatile solids of mixing ratio 1:0 was significantly different from mixing ratio 3:1; mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.

- For with plastic cover, at mixing ratio 1:0 between composting time week 4 to 8 had lowest volatile solids followed by mixing ratio 6:1 as shown in Figure 4.21.

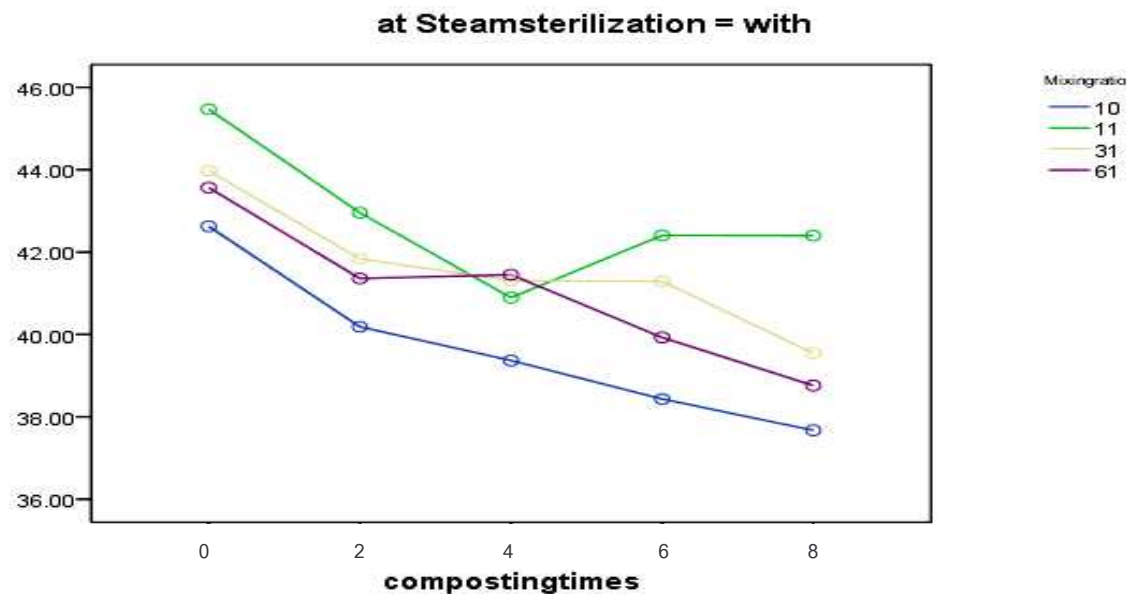


Figure 4.21 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to volatile solids

Without plastic cover, the volatile solids were found significant difference at all periods.

To test difference between group, Bonferroni adjustment is used to compare.

- For without plastic cover at composting time week 0, the volatile solids 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 6:1.

- For without plastic cover at composting time week 2, the volatile solids of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 3:1; mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.

- For without plastic cover at composting time week 4, the volatile solids of mixing ratio 1:0 was significantly different from mixing ratio 3:1; mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.

- For without plastic cover at composting time week 6, the volatile solids 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For without plastic cover at composting time week 8, the volatile solids 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.

- For without plastic cover, at mixing ratio 1:0 between composting time week 4 to 8 had lowest volatile solids followed by mixing ratio 6:1 as shown in Figure 4.22.

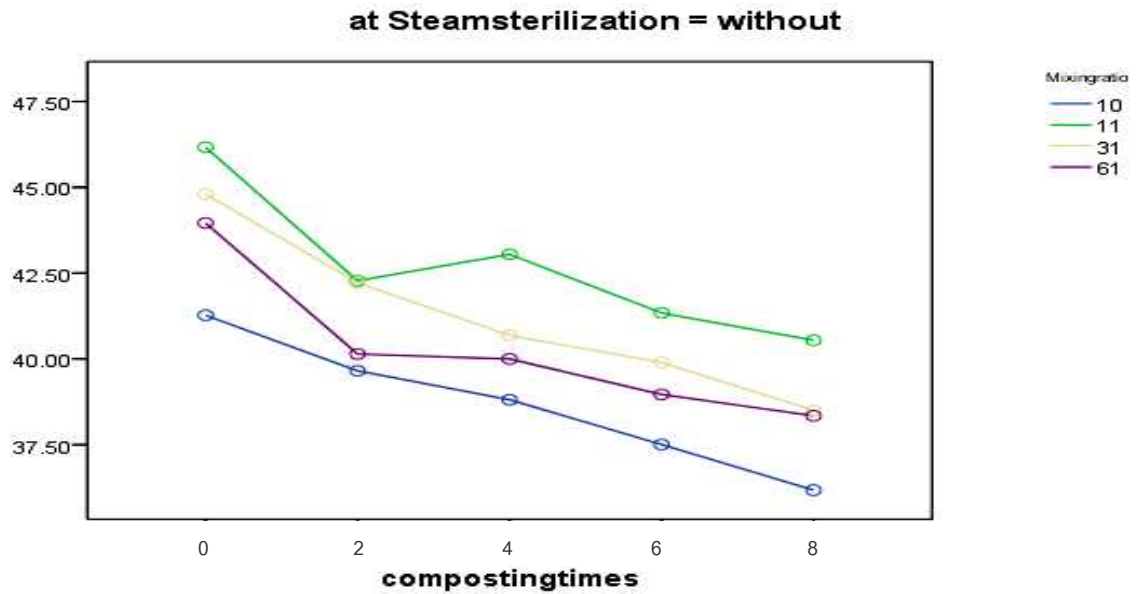


Figure 4.22 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to volatile solids

When an interaction exists among the three factors, F test of ANOVA is used to test the simple main effect of steam sterilizations classified by each level of mixing ratios (1:0, 1:1, 3:1 and 6:1) at each time period.

To test difference between group, Bonferroni adjustment is used to compare.

- For mixing ratio 1:0 at composting time week 2, 4, 6 and 8, the volatile solids of with plastic cover was significantly different from without plastic cover as shown in Figure 4.23.

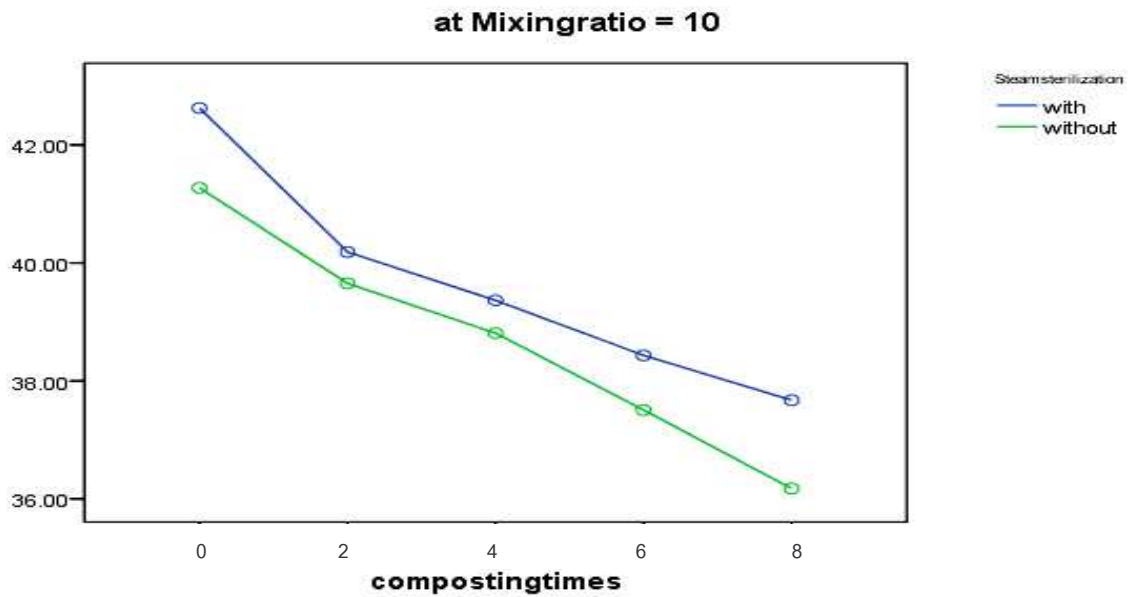


Figure 4.23 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to volatile solids

- For mixing ratio 1:1 at composting time week 2, 4, 6 and 8, the volatile solids of with plastic cover was significantly different from without plastic cover as shown in Figure 4.24.

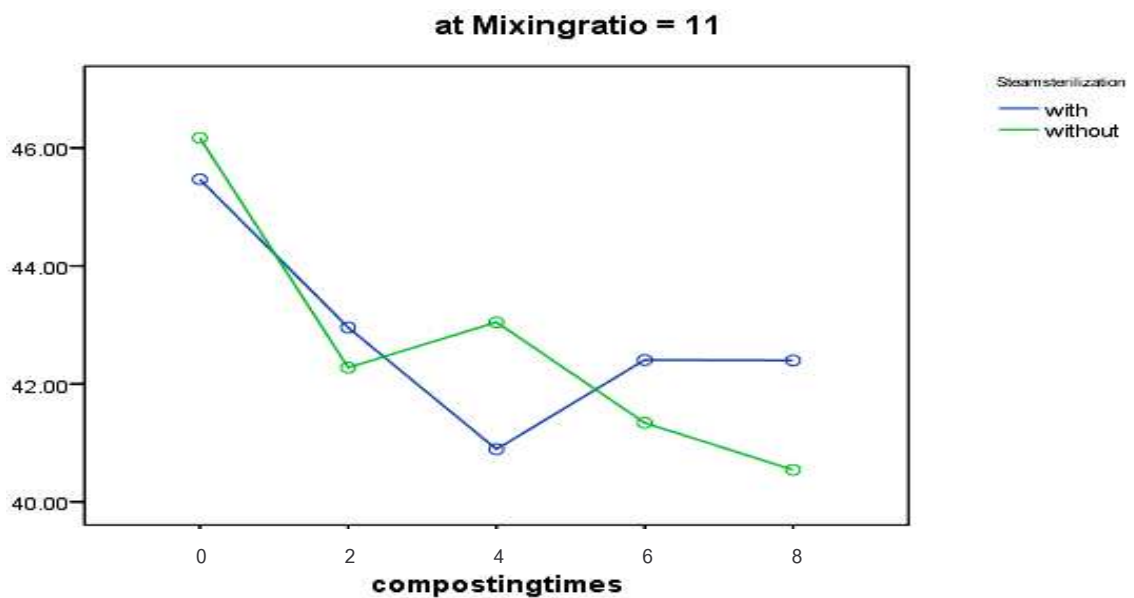


Figure 4.24 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to volatile solids

- For mixing ratio 3:1 at composting time week 0, 6 and 8, the volatile solids of with plastic cover was significantly different from without plastic cover as shown in Figure 4.25.

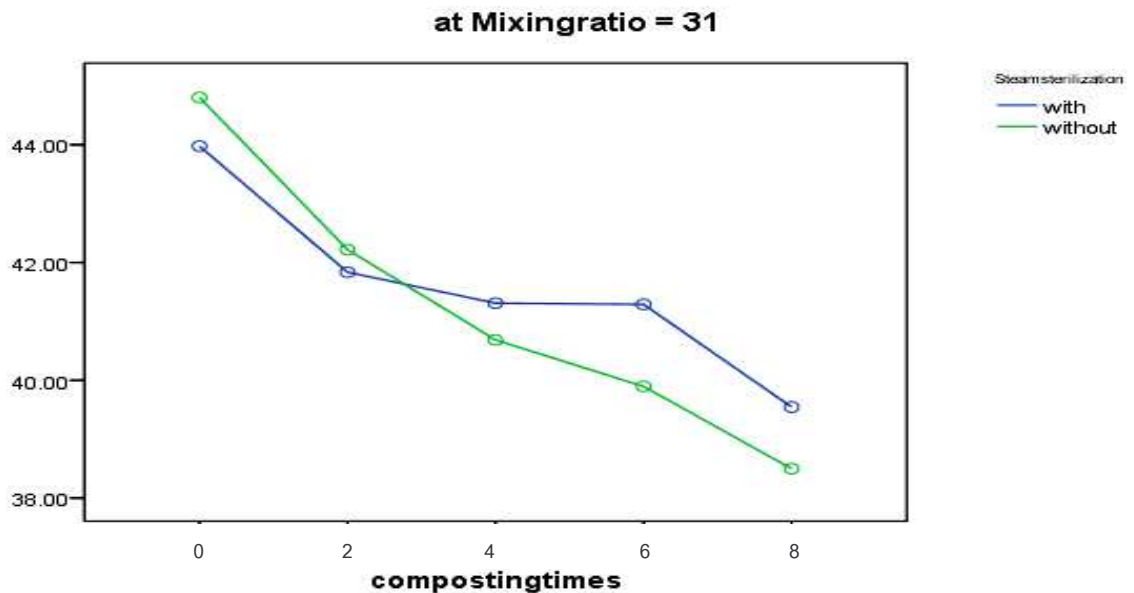


Figure 4.25 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to volatile solids

- For mixing ratio 6:1 at composting time week 0, 2, 4 and 6, the volatile solids of with plastic cover was significantly different from without plastic cover as shown in Figure 4.26.

- For all mixing ratio, at composting time week 6 to 8 without plastic cover treatment had lower volatile solids than with plastic cover treatment.

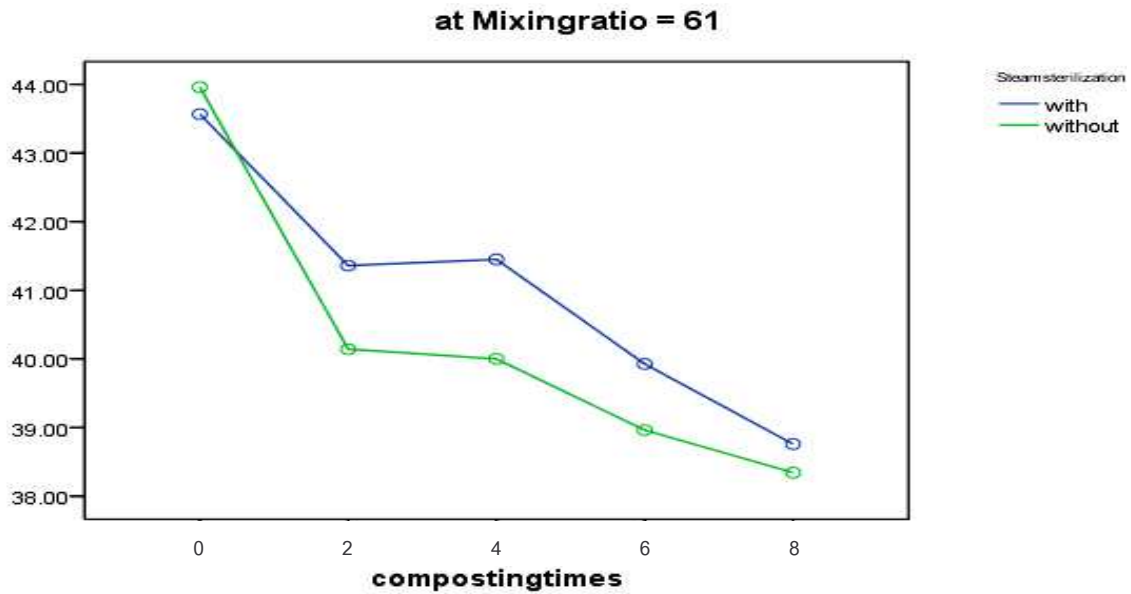


Figure 4.26 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to volatile solids

To test the simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition, Bonferroni adjustment is used to test the difference between each pair of treatment.

- For mixing ratio 1:0 with plastic cover, the volatile solids of composting time week 0 was significantly different from composting time week 4, 6 and 8.

- For mixing ratio 1:0 without plastic cover, the volatile solids of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 1:1 with plastic cover, the volatile solids of composting time week 8 was significantly different from composting time week 0 and 4; composting time week 6 was significantly different from composting time week 0 and 4; composting time week 4 was significantly different from composting time week 0 and 2; composting time week 2 was significantly different from composting time week 0.

- For mixing ratio 1:1 without plastic cover, the volatile solids of composting time week 8 was significantly different from composting time week 0 and 4; composting time week 0 was significantly different from composting time week 2, 4 and 6.

- For mixing ratio 3:1 with plastic cover, the volatile solids of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 0 was significantly different from composting time week 2, 4 and 6.

- For mixing ratio 3:1 without plastic cover, the volatile solids of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 6:1 with plastic cover, the volatile solids of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 0 was significantly different from composting time week 2 and 4.

- For mixing ratio 6:1 without plastic cover, the volatile solids of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 0 was significantly different from composting time week 2 and 4.

- For almost treatments, at composting time week 8 had lowest volatile solids followed by at composting time week 6 as shown in Figure 4.27.

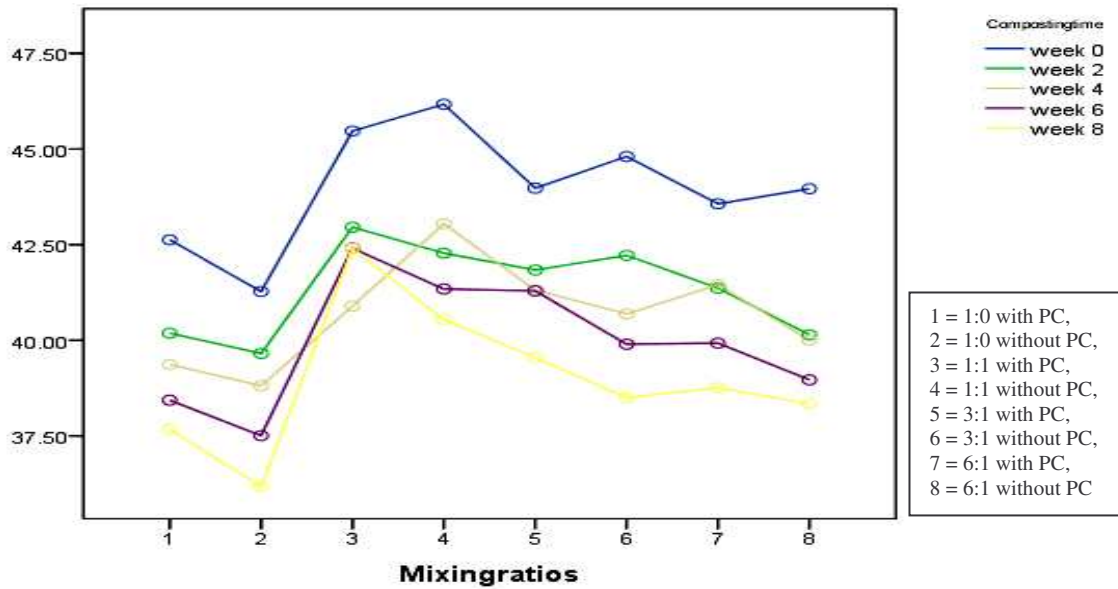


Figure 4.27 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to volatile solids

## 4.2.2 Chemical characteristics

### 4.2.2.1 pH

The pH was measured at every two weeks of composting time starting from week 0 until the composting process was finished at week 8.

During composting process, the average pH of all treatments was in the range of 5.24-6.68. The maximum pH was the treatment which had mixing ratio 3:1 and not covered by black plastic sheet (6.68). The minimum pH was the treatment which had mixing ratio 3:1 and covered by black plastic sheet (5.24). The results are shown in Table 4.8. The pH of all treatments was slightly decreased at the first four weeks after that they were slightly increased. At the last week of composting time, the pH ranges were close to the initial pH values (Figure 4.28).

Table 4.8 The average pH of all treatments during the composting process at the different composting times

Treatments	Composting times				
	week 0	week 2	week 4	week 6	week 8
	(SD)	(SD)	(SD)	(SD)	(SD)
1:0 with PC	6.19 (0.02)	6.28 (0.01)	5.39 (0.01)	6.12 (0.01)	6.19 (0.01)
1:0 without PC	6.14 (0.01)	6.24 (0.01)	5.29 (0.00)	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)
1:1 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	6.41 (0.02)	6.35 (0.00)	5.24 (0.02)	5.87 (0.01)	5.96 (0.01)
3:1 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)
6:1 without PC	6.28 (0.02)	6.32 (0.00)	5.25 (0.01)	6.02 (0.02)	6.16 (0.00)

Remark: PC is plastic cover

SD is standard deviation

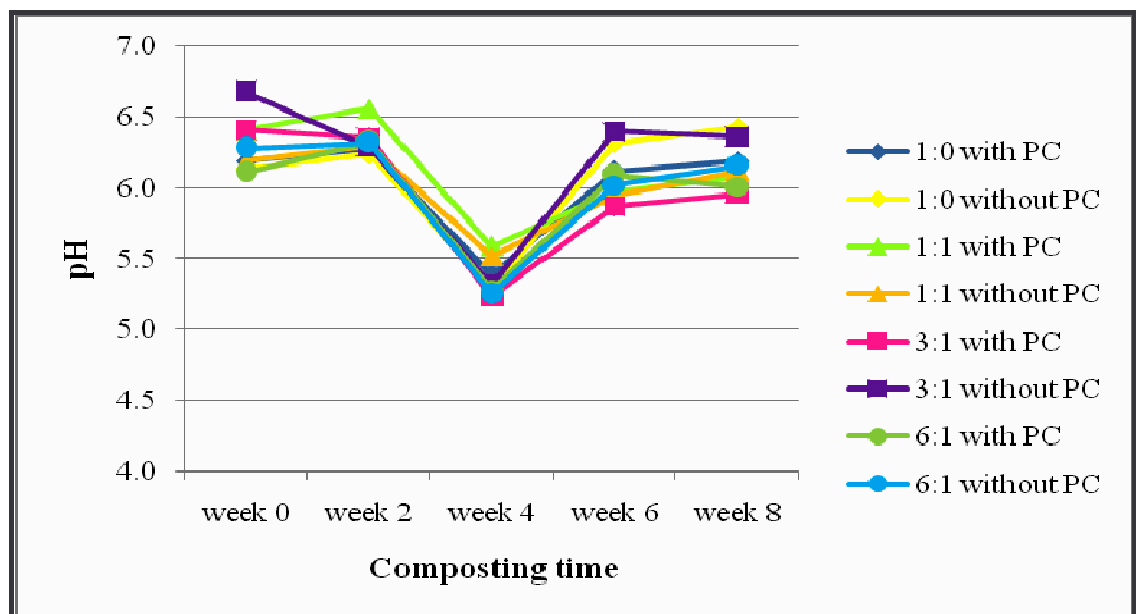


Figure 4.28 The pH trend lines of all treatments

As referred, the results indicated that the pH of all treatments after passed composting process had close to the before passed composting process (Figure 4.29).

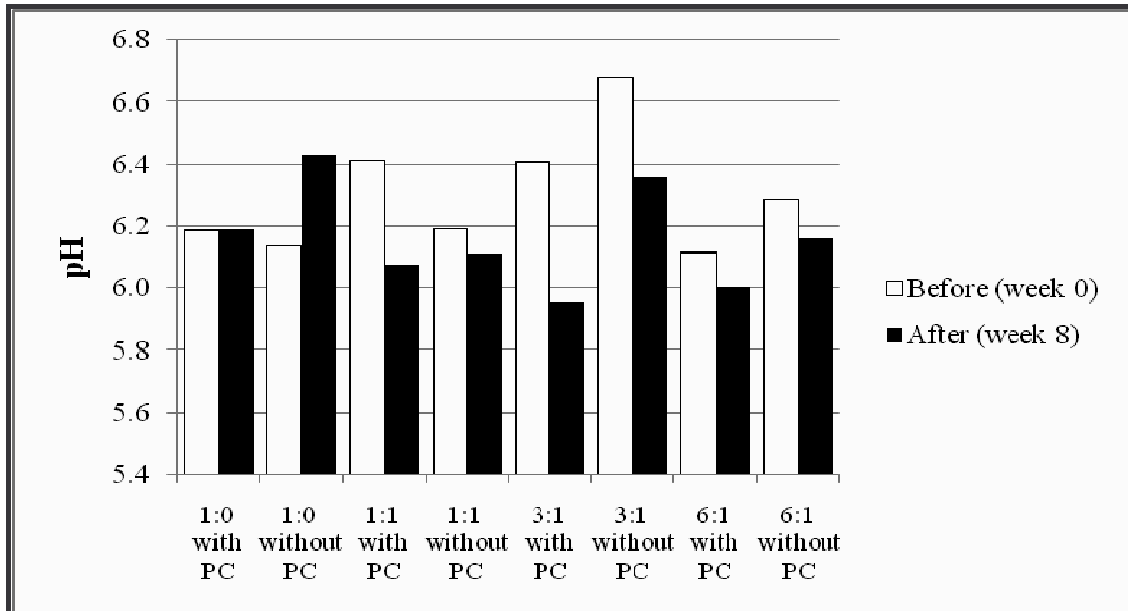


Figure 4.29 The pH of all treatments before and after passed composting process

The Three-Way Analyses of Variance with one Repeated Factors is used to analyze main effects (mixing ratio, steam sterilization, and composting time) and their and interaction effect of pH values.

- The main effect of mixing ratio of all treatments was significantly different ( $P < 0.001$ ).
- The main effect of steam sterilization 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 and composting time were significantly different ( $P < 0.001$ ) on within subject effect. There were also had interactions between composting time and mixing ratio ( $P < 0.001$ ); between composting time and steam sterilization ( $P < 0.001$ ) and an interaction between mixing ratios and steam sterilizations ( $< 0.001$ ). The results of analytical statistics are shown in Table 4.9.

Table 4.9 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for pH

Source	SS	df	MS	F	p-value
<b>Between-Subjects Effects</b>					
Intercept	4392.421	1	4392.421	3.561E7	< 0.001
Mixing ratio	0.183	3	0.061	494.097	< 0.001
Steam sterilization	0.094	1	0.094	758.277	< 0.001
Mixing ratio * steam sterilization	0.465	3	0.155	1.257E3	< 0.001
Error	0.002	16	< 0.001		
<b>Within-Subjects Effects</b>					
Composting times	15.168	4	3.792	2.770E4	< 0.001
composting times * mixing ratio	1.169	12	0.097	711.566	< 0.001
composting times * steam sterilization	0.382	4	0.095	697.656	< 0.001
composting times * mixing ratio * steam sterilization	0.284	12	0.024	173.151	< 0.001
Error	0.009	64	< 0.001		

When interaction exist among the three factors, F test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilizations (with and without plastic cover) at each time period.

With plastic cover, pH was found significant difference at all periods.

To test difference between group, Bonferroni adjustment is used to compare.

- For with plastic cover at composting time week 0, the pH of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1; mixing ratio 6:1 was significantly different from mixing ratio 1:1 and 3:1.

- For with plastic cover at composting time week 2, the 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.

- For with plastic cover at composting time week 4, the 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.

- For with plastic cover at composting time week 6, the 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For with plastic cover at composting time week 8, the 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For with plastic cover, at mixing ratio 1:0 between composting time week 6 to 8 had highest pH followed by mixing ratio 1:1 as shown in Figure 4.30.

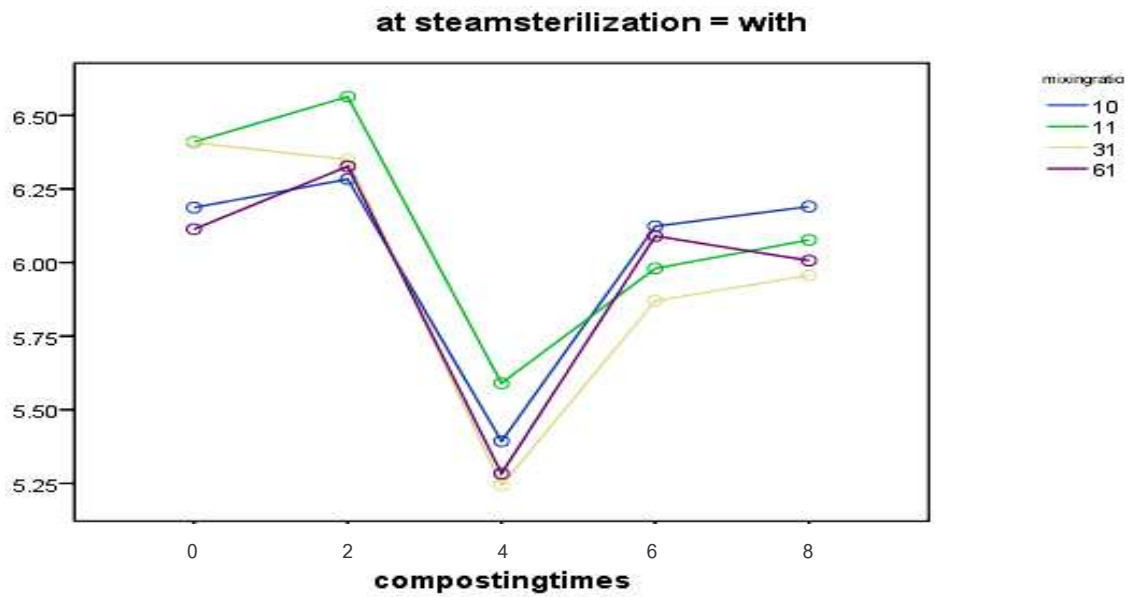


Figure 4.30 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to pH

Without plastic cover, the pH was found significant difference at all periods.

To test difference between group, Bonferroni adjustment is used to compare.

- For without plastic cover at composting time week 0, the 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For without plastic cover at composting time week 2, the pH of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For without plastic cover at composting time week 4, the 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For without plastic cover at composting time week 6, the 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For without plastic cover at composting time week 8, the 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For without plastic cover, at mixing ratio 1:0 between composting time week 6 to 8 had highest pH followed by mixing ratio 3:1 as shown in Figure 4.31.

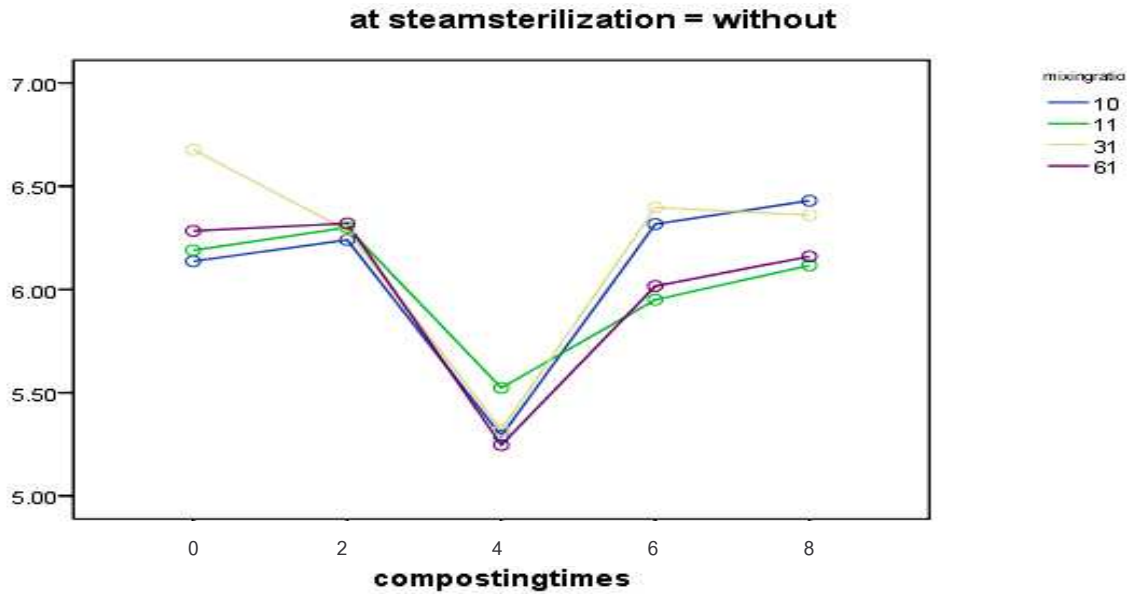


Figure 4.31 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to pH

When an interaction exists among the three factors, F test of ANOVA is used to test the simple main effect of steam sterilizations classified by each level of mixing ratios (1:0, 1:1, 3:1 and 6:1) at each time period.

To test difference between group, Bonferroni adjustment is used to compare.

- For mixing ratio 1:0 at composting time week 0, 2, 4, 6 and 8, the pH of with plastic cover was significantly different from without plastic cover as shown in Figure 4.32.

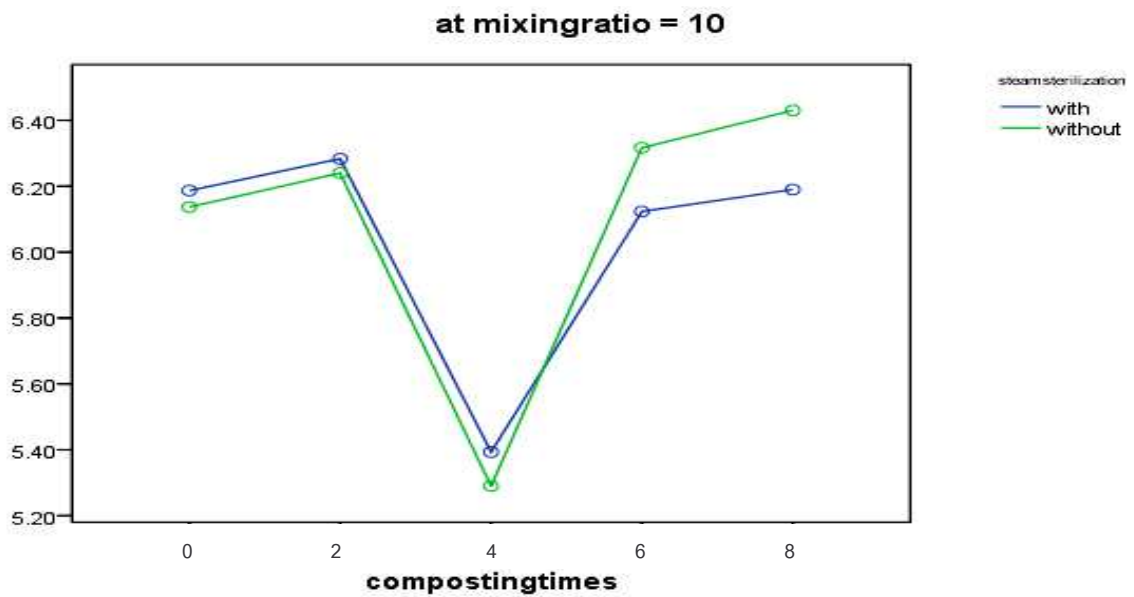


Figure 4.32 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to pH

- For mixing ratio 1:1 at composting time week 0, 2, 4, 6 and 8, the pH of with plastic cover was significantly different from without plastic cover as shown in Figure 4.33.

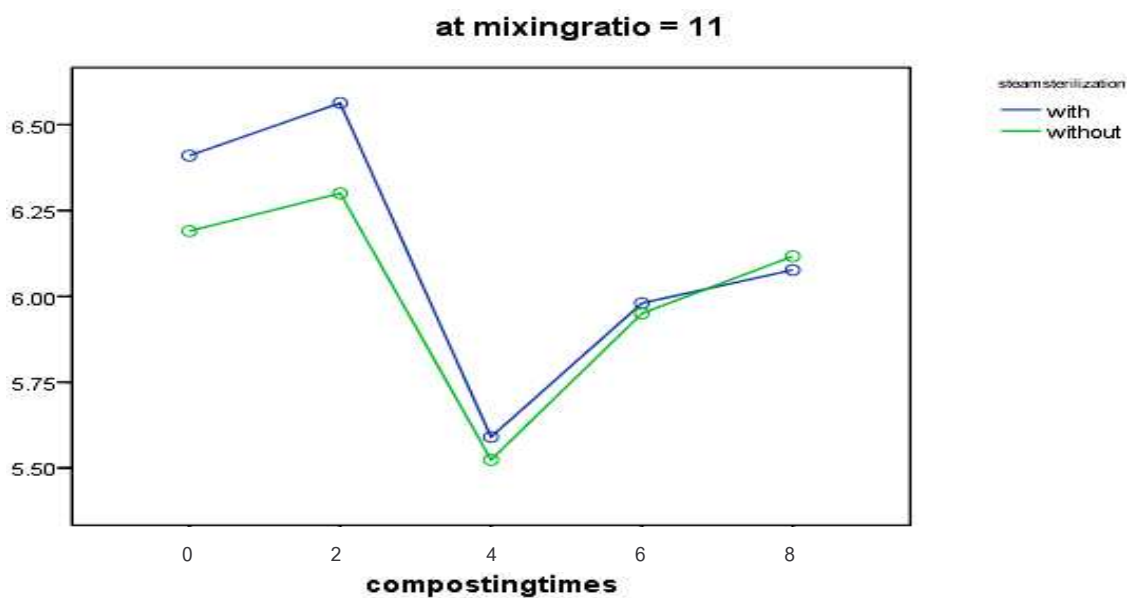


Figure 4.33 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to pH

- For mixing ratio 3:1 at composting time week 0, 2, 4, 6 and 8, the pH of with plastic cover was significantly different from without plastic cover as shown in Figure 4.34.

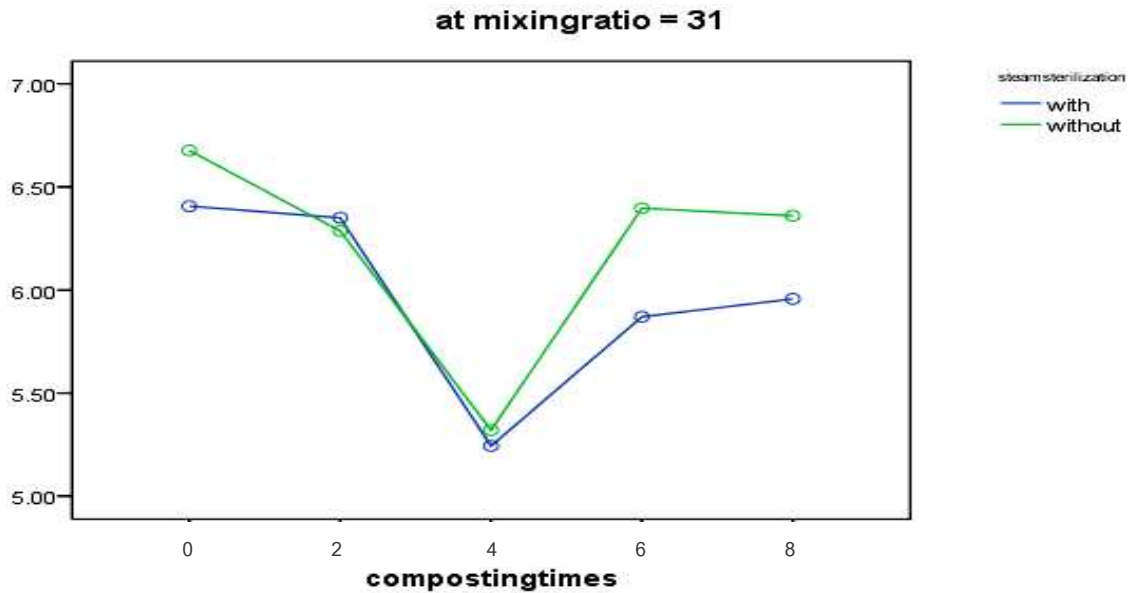


Figure 4.34 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to pH

- For mixing ratio 6:1 at composting time week 0, 4, 6 and 8, the pH of with plastic cover was significantly different from without plastic cover as shown in Figure 4.35.

- For all mixing ratio, at composting time week 6 to 8 without plastic cover treatment had higher pH than with plastic cover treatment.

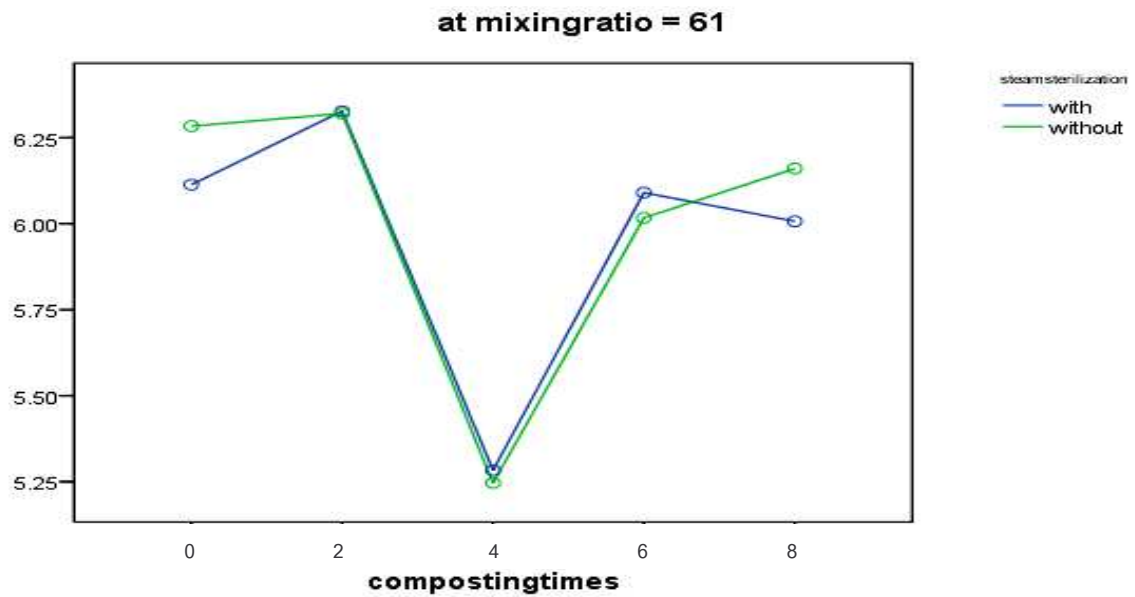


Figure 4.35 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to pH

To test the simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition, Bonferroni adjustment is used to test the difference between each pair of treatment.

- For mixing ratio 1:0 with plastic cover, the pH of composting time week 8 was significantly different from composting time week 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2; composting time week 2 was significantly different from composting time week 0.

- For mixing ratio 1:0 without plastic cover, the pH of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 1:1 with plastic cover, the pH of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 1:1 without plastic cover, the pH of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 3:1 with plastic cover, the pH of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 3:1 without plastic cover, the pH of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2; composting time week 2 was significantly different from composting time week 0.

- For mixing ratio 6:1 with plastic cover, the pH of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2; composting time week 2 was significantly different from composting time week 0.

- For mixing ratio 6:1 without plastic cover, the pH of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For almost treatments after active phase (week 4), at composting time week 8 had highest pH followed by at composting time week 6 as shown in Figure 4.36.

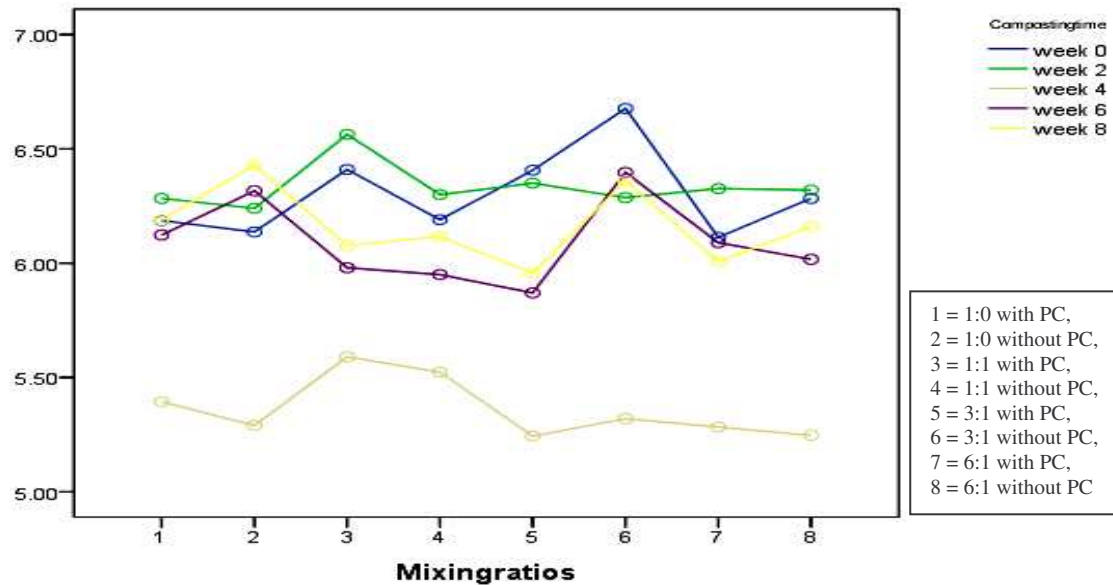


Figure 4.36 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to pH

#### 4.2.2.2 Organic matter

The organic matter was measured at every two weeks of composting time starting from week 0 until the composting process was finished at week 8.

During composting process, the average organic matters of all treatments were in the range of 13.51-22.97%. The maximum organic matter at the end of composting process was the treatment which had mixing ratio 1:1 and covered by black plastic sheet (18.44%). The minimum organic matter was the treatment which had mixing ratio 1:0 and not covered by black plastic sheet (14.88%). The results are shown in Table 4.10. The organic matters of all treatments were increased at first two weeks but during the second week until the sixth week they were decreased. The trends after that were increased until the composting process was finished at week 8 (Figure 4.37).

Table 4.10 The average organic matter (%) of all treatments during the composting process at the different composting times

Treatments	Composting times				
	week 0	week 2	week 4	week 6	week 8
	(SD)	(SD)	(SD)	(SD)	(SD)
1:0 with PC	17.51 (0.42)	17.55 (0.99)	16.23 (0.05)	13.51 (0.52)	15.18 (0.66)
1:0 without PC	18.04 (0.87)	18.08 (0.58)	16.31 (0.18)	13.87 (0.41)	14.88 (0.16)
1:1 with PC	18.19 (0.28)	22.97 (0.78)	17.42 (0.24)	16.58 (0.99)	18.44 (0.43)
1:1 without PC	19.71 (0.45)	22.61 (0.48)	16.36 (0.61)	18.82 (0.09)	18.13 (0.47)
3:1 with PC	18.50 (0.30)	21.58 (0.56)	16.65 (0.31)	17.61 (0.54)	16.10 (1.55)
3:1 without PC	17.74 (0.24)	20.97 (0.16)	16.16 (0.58)	16.25 (0.50)	16.70 (0.19)
6:1 with PC	18.58 (0.49)	20.20 (1.02)	16.88 (0.60)	15.95 (0.93)	16.40 (0.70)
6:1 without PC	16.54 (0.37)	19.72 (0.41)	15.76 (0.10)	14.28 (2.36)	16.45 (0.68)

Remark: PC is plastic cover

SD is standard deviation

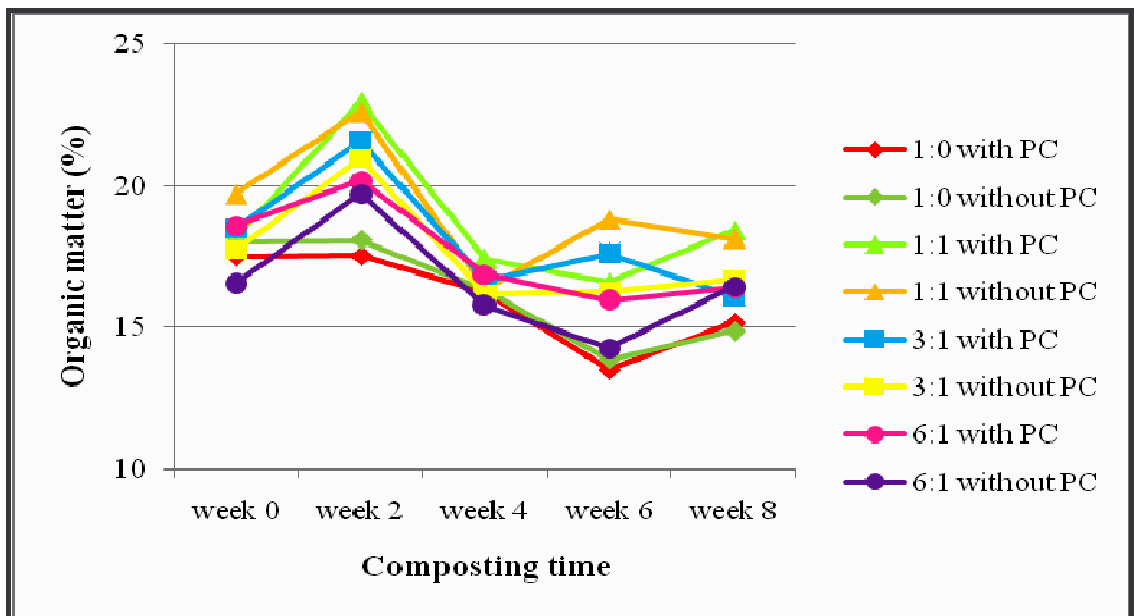


Figure 4.37 The organic matter trend lines of all treatments

As referred, the results indicated that the organic matter of all treatments after passed composting process had lower than the before passed composting process (Figure 4.38).

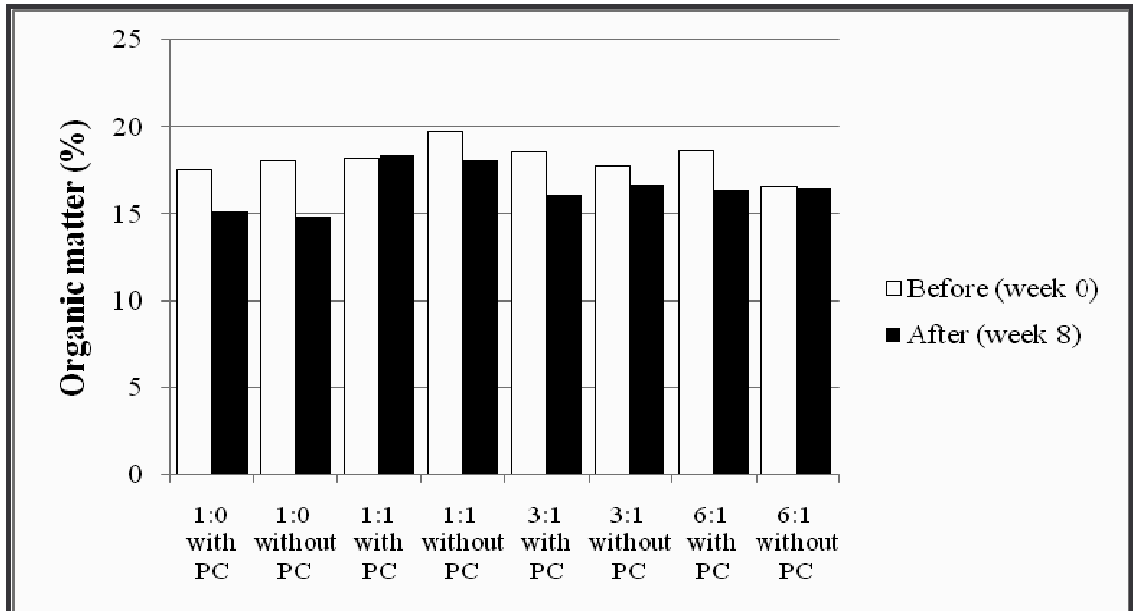


Figure 4.38 The organic matter of all treatments before and after passed composting process

The Three-Way Analyses of Variance with one Repeated Factors is used to analyze main effects (mixing ratio, steam sterilization, and composting time) and their and interaction effect of organic matter values.

- The main effect of mixing ratio of all treatments was significantly different ( $P < 0.001$ .)
- The main effect of steam sterilization of all treatments was not significantly different ( $P = 0.149$ ).
- The main effect of composting time of all treatments was significantly different ( $P < 0.001$ ).

- The interaction among mixing ratio, steam sterilization and composting time were significantly different ( $P < 0.001$ ) on within subject effect. There were also had interactions between composting time and mixing ratio ( $P < 0.001$ ); between composting time and steam sterilization ( $P = 0.481$ ) and an interaction between mixing ratios and steam sterilizations ( $P = 0.013$ ). The results of analytical statistics are shown in Table 4.11.

Table 4.11 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for organic matter

Source	SS	df	MS	F	p-value
<b>Between-Subjects Effects</b>					
Intercept	36685.690	1	36685.690	5.200E4	< 0.001
Mixing ratio	126.890	3	42.297	59.953	< 0.001
Steam sterilization	1.618	1	1.618	2.293	0.149
Mixing ratio * steam sterilization	10.392	3	3.464	4.910	0.013
Error	11.288	16	0.705		
<b>Within-Subjects Effects</b>					
Composting times	331.522	4	82.881	193.341	< 0.001
composting times * mixing ratio	52.332	12	4.361	10.173	< 0.001
composting times * steam sterilization	1.508	4	0.377	0.879	0.481
composting times * mixing ratio * steam sterilization	18.452	12	1.538	3.587	< 0.001
Error	27.435	64	0.429		

When interaction exist among the three factors, F test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilizations (with and without plastic cover) at each time period.

With plastic cover, organic matter was found significant difference at all periods.

To test difference between group, Bonferroni adjustment is used to compare.

- For with plastic cover at composting time week 0, the organic matter of mixing ratio 1:0 was significantly different from mixing ratio 6:1.

- For with plastic cover at composting time week 2, the organic matter of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1; mixing ratio 6:1 was significantly different from mixing ratio 1:1 and 3:1.
- For with plastic cover at composting time week 4, the organic matter of mixing ratio 1:0 was significantly different from mixing ratio 1:1.
- For with plastic cover at composting time week 6, the organic matter of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1.
- For with plastic cover at composting time week 8, the organic matter of mixing ratio 1:0 was significantly different from mixing ratio 1:1.
- For with plastic cover, at mixing ratio 1:1 between composting time week 4 to 8 had highest organic matter followed by mixing ratio 3:1 as shown in Figure 4.39.

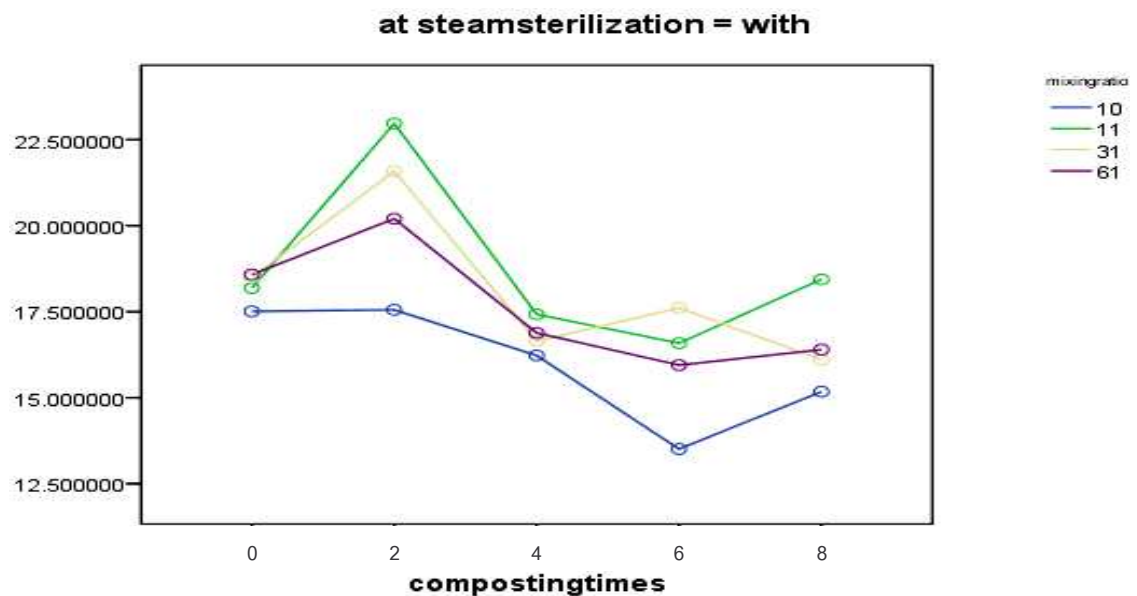


Figure 4.39 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to organic matter

Without plastic cover, the organic matter was found significant difference in 4 periods, except composting time week 4.

To test difference between group, Bonferroni adjustment is used to compare.

- For without plastic cover at composting time week 0, the organic matter of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.
- For without plastic cover at composting time week 2, the organic matter 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.
- For without plastic cover at composting time week 6, the organic matter of mixing ratio 1:1 was significantly different from mixing ratio 1:0 and 6:1.
- For without plastic cover at composting time week 8, the organic matter 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.
- For without plastic cover, at mixing ratio 1:1 between composting time week 4 to 8 had highest organic matter followed by mixing ratio 3:1 as shown in Figure 4.40.

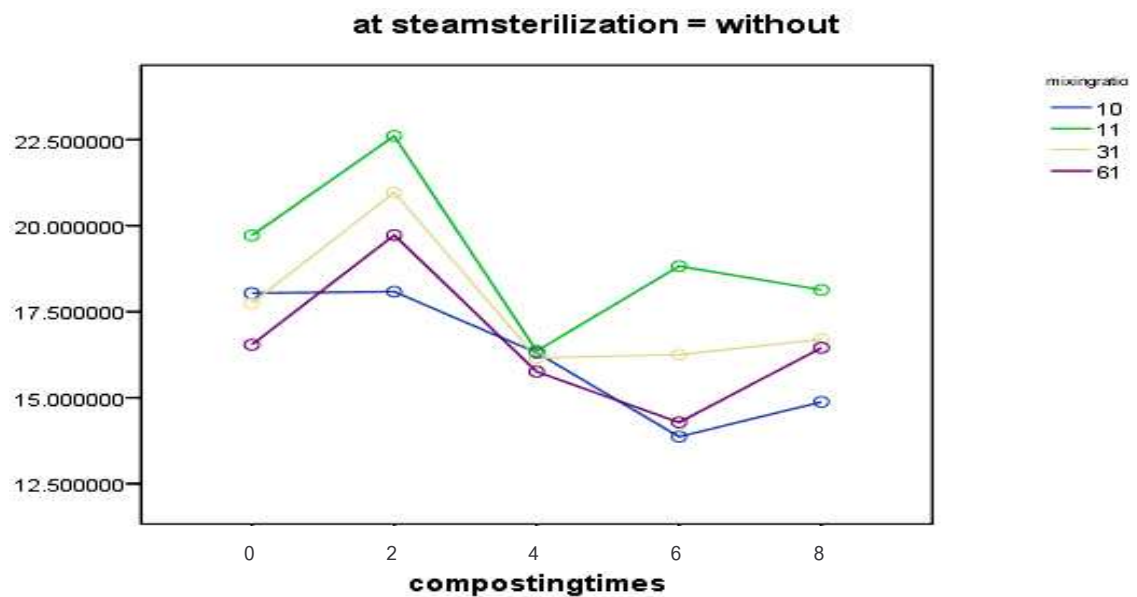


Figure 4.40 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to organic matter

When an interaction exists among the three factors, F test of ANOVA is used to test the simple main effect of steam sterilizations classified by each level of mixing ratios (1:0, 1:1, 3:1 and 6:1) at each time period.

To test difference between group, Bonferroni adjustment is used to compare.

- For mixing ratio 1:0 at composting time week 0, 2, 4, 6 and 8, the organic matter of with plastic cover was not significantly different from without plastic cover as shown in Figure 4.41.

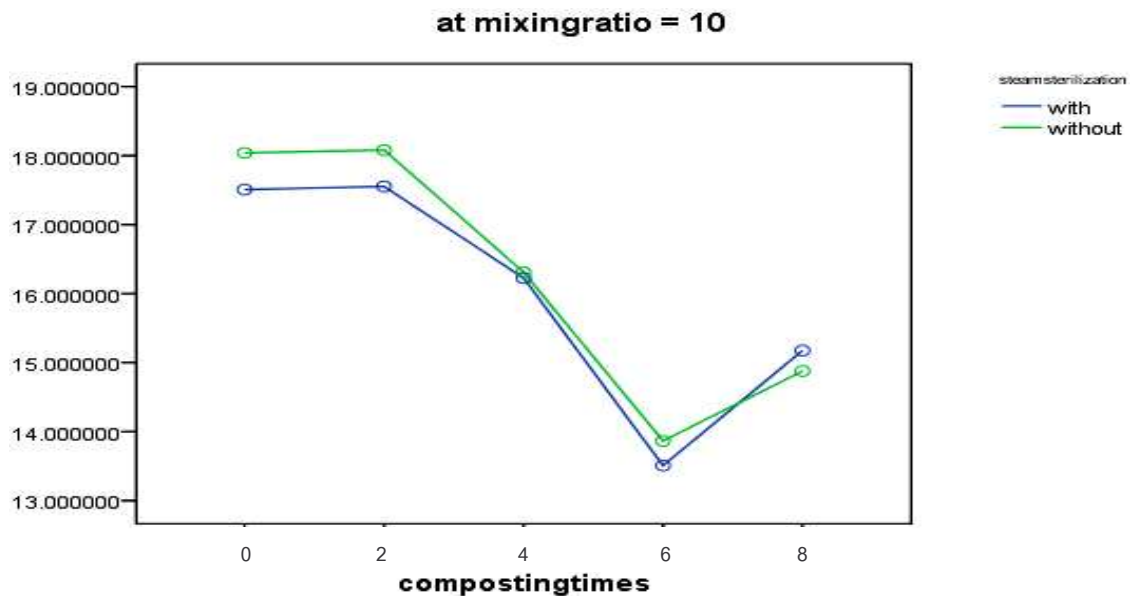


Figure 4.41 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to organic matter

- For mixing ratio 1:1 at composting time week 0, 4 and 6, the organic matter of with plastic cover was significantly different from without plastic cover as shown in Figure 4.42.

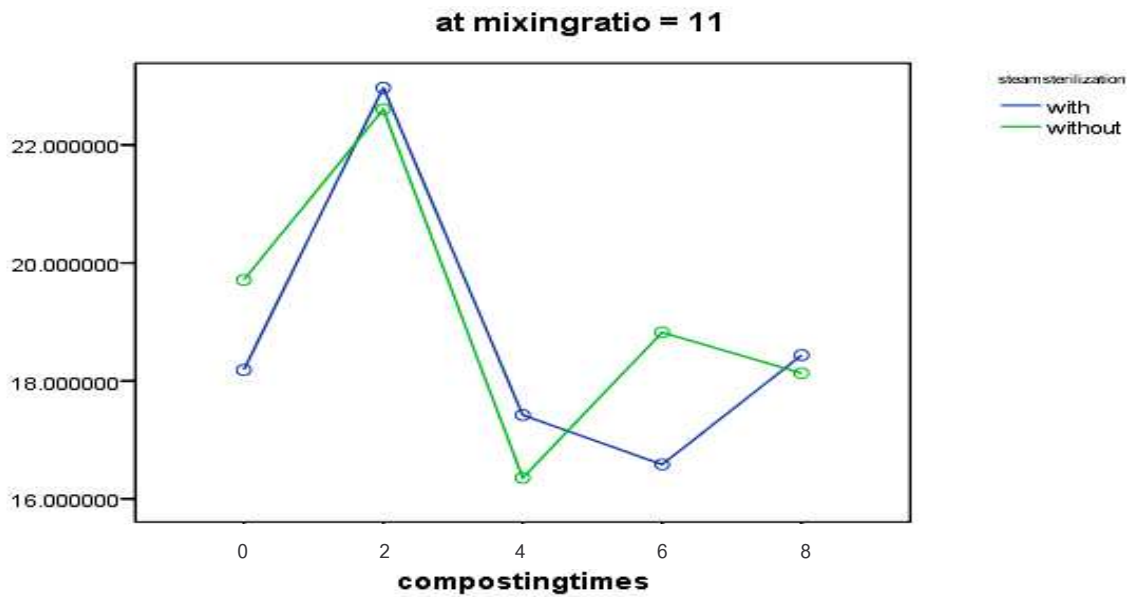


Figure 4.42 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to organic matter

- For mixing ratio 3:1 at composting time week 0 and 6, the organic matter of with plastic cover was significantly different from without plastic cover as shown in Figure 4.43.

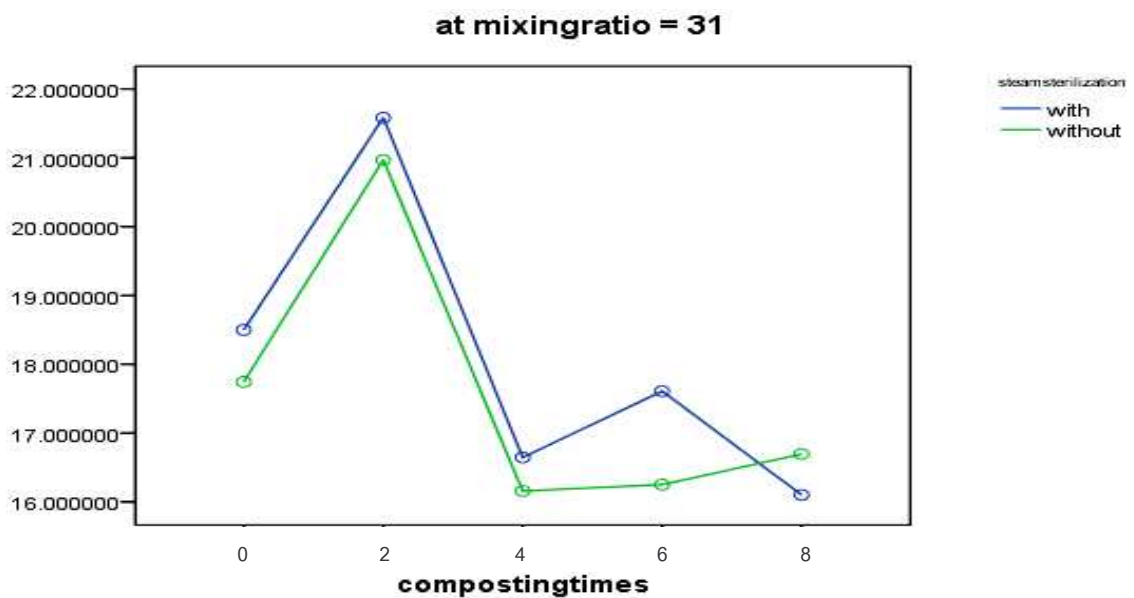


Figure 4.43 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to organic matter

- For mixing ratio 6:1 at composting time week 0 and 4, the organic matter of with plastic cover was significantly different from without plastic cover as shown in Figure 4.44.

- For all mixing ratio, at composting time week 4 to 8 with plastic cover treatment had not difference organic matter from without plastic cover treatment.

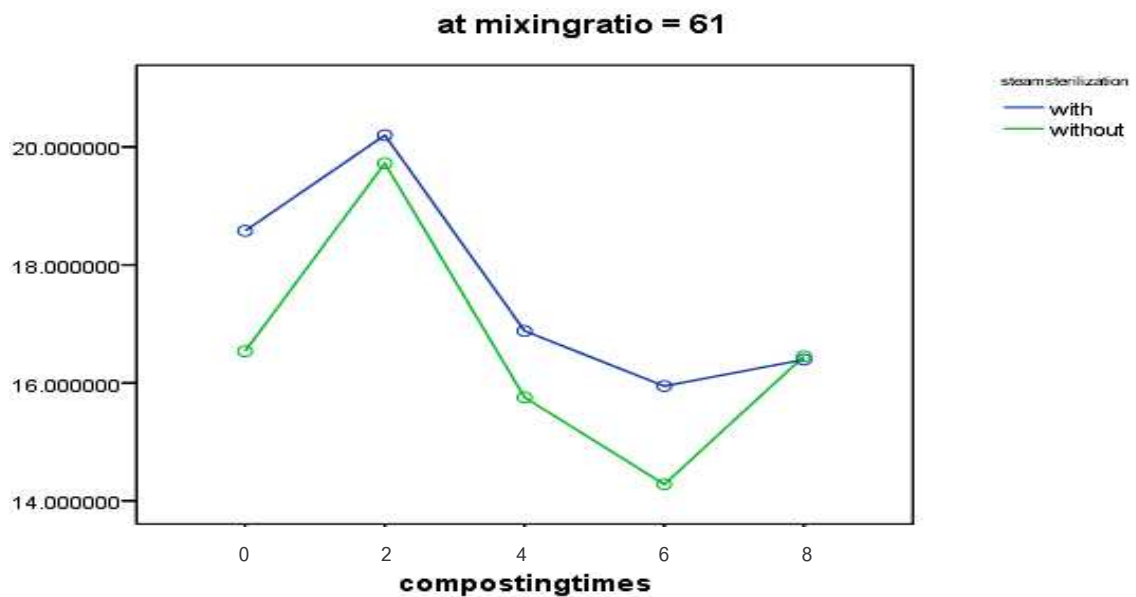


Figure 4.44 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to organic matter

To test the simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition, Bonferroni adjustment is used to test the difference between each pair of treatment.

- For mixing ratio 1:0 with plastic cover, the organic matter of composting time week 8 was significantly different from composting time week 0 and 2; composting time week 6 was significantly different from composting time week 0, 2 and 4.

- For mixing ratio 1:0 without plastic cover, the organic matter of composting time week 8 was significantly different from composting time week 0 and 2; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 1:1 with plastic cover, the organic matter of composting time week 8 was significantly different from composting time week 2 and 6; composting time week 2 was significantly different from composting time week 0, 4 and 6.

- For mixing ratio 1:1 without plastic cover, the organic matter of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0, 2 and 6; composting time week 2 was significantly different from composting time week 0 and 6.

- For mixing ratio 3:1 with plastic cover, the organic matter of composting time week 8 was significantly different from composting time week 0; composting time week 2 was significantly different from composting time week 0, 4 and 6.

- For mixing ratio 3:1 without plastic cover, the organic matter of composting time week 2 was significantly different from composting time week 4, 6 and 8; composting time week 0 was significantly different from composting time week 2, 4 and 6.

- For mixing ratio 6:1 with plastic cover, the organic matter of composting time week 6 was significantly different from composting time week 0 and 2; composting time week 2 was significantly different from composting time week 4 and 8.

- For mixing ratio 6:1 without plastic cover, the organic matter of composting time week 2 was significantly different from composting time week 4 and 6.

- For all treatments after active phase (week 4), at composting time week 8 had highest organic matter followed by at composting time week 6 as shown in Figure 4.45.

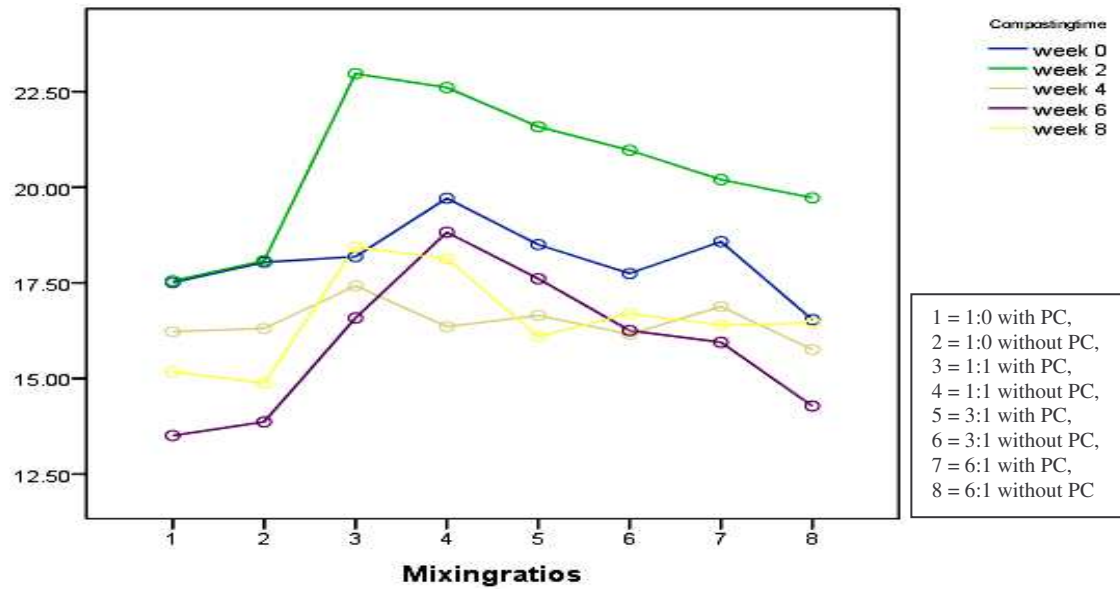


Figure 4.45 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to organic matter

#### 4.2.2.3 Total nitrogen

The total nitrogen was measured at every two weeks of composting time starting from week 0 until the composting process was finished at week 8. The results of total nitrogen were used to calculate with the organic carbon content for carbon to nitrogen ratio. The results are shown in Table 4.12.

Table 4.12 The average total nitrogen (%) of all treatments during the composting process at the different composting times

Treatments	Composting times				
	week 0 (SD)	week 2 (SD)	week 4 (SD)	week 6 (SD)	week 8 (SD)
1:0 with PC	1.99 (0.02)	1.80 (0.05)	1.55 (0.30)	1.40 (0.09)	1.41 (0.11)
1:0 without PC	2.00 (0.18)	1.80 (0.02)	1.83 (0.14)	1.43 (0.14)	1.35 (0.09)
1:1 with PC	1.61 (0.06)	1.77 (0.05)	0.58 (0.09)	1.30 (0.16)	1.29 (0.05)
1:1 without PC	1.61 (0.14)	1.79 (0.03)	0.49 (0.09)	1.37 (0.05)	1.48 (0.11)
3:1 with PC	1.78 (0.22)	1.71 (0.15)	1.55 (0.06)	1.34 (0.14)	1.41 (0.14)
3:1 without PC	1.59 (0.02)	1.84 (0.13)	0.64 (0.05)	1.49 (0.00)	1.35 (0.09)
6:1 with PC	1.83 (0.11)	1.80 (0.06)	1.61 (0.14)	1.58 (0.00)	1.44 (0.09)
6:1 without PC	1.77 (0.08)	1.63 (0.00)	1.64 (0.11)	1.46 (0.05)	1.35 (0.09)

Remark: PC is plastic cover

SD is standard deviation

#### - Organic nitrogen

The organic nitrogen was measured at every two weeks of composting time starting from week 0 until the composting process was finished at week 8.

During composting process, the average organic nitrogen of all treatments was in the range of 0.08-1.84%. The maximum organic nitrogen at the end of composting process was the treatment which had mixing ratio 6:1 and covered by black plastic sheet (0.56%). The minimum organic nitrogen was the treatment which had mixing ratio 3:1 and not covered by black plastic sheet (0.08%). The results are shown in Table 4.13. The organic nitrogen of all treatments was trend decreased until the composting process was finished at week 8 (Figure 4.46).

Table 4.13 The average organic nitrogen (%) of all treatments during the composting process at the different composting times

Treatments	Composting times				
	week 0	week 2	week 4	week 6	week 8
	(SD)	(SD)	(SD)	(SD)	(SD)
1:0 with PC	1.82 (0.01)	1.55 (0.06)	1.27 (0.31)	1.09 (0.08)	0.23 (0.15)
1:0 without PC	1.84 (0.17)	1.54 (0.04)	1.42 (0.15)	0.84 (0.14)	0.13 (0.08)
1:1 with PC	1.34 (0.06)	1.36 (0.06)	0.83 (0.10)	0.46 (0.13)	0.36 (0.07)
1:1 without PC	1.45 (0.12)	1.02 (0.05)	0.685 (0.10)	0.37 (0.06)	0.13 (0.09)
3:1 with PC	1.62 (0.21)	1.52 (0.16)	1.33 (0.07)	1.12 (0.14)	0.35 (0.12)
3:1 without PC	1.39 (0.04)	1.16 (0.16)	0.68 (0.07)	0.29 (0.01)	0.08 (0.04)
6:1 with PC	1.66 (0.09)	1.09 (0.05)	0.86 (0.16)	0.69 (0.07)	0.56 (0.15)
6:1 without PC	1.62 (0.19)	1.29 (0.01)	1.34 (0.11)	0.62 (0.05)	0.34 (0.07)

Remark: PC is plastic cover

SD is standard deviation

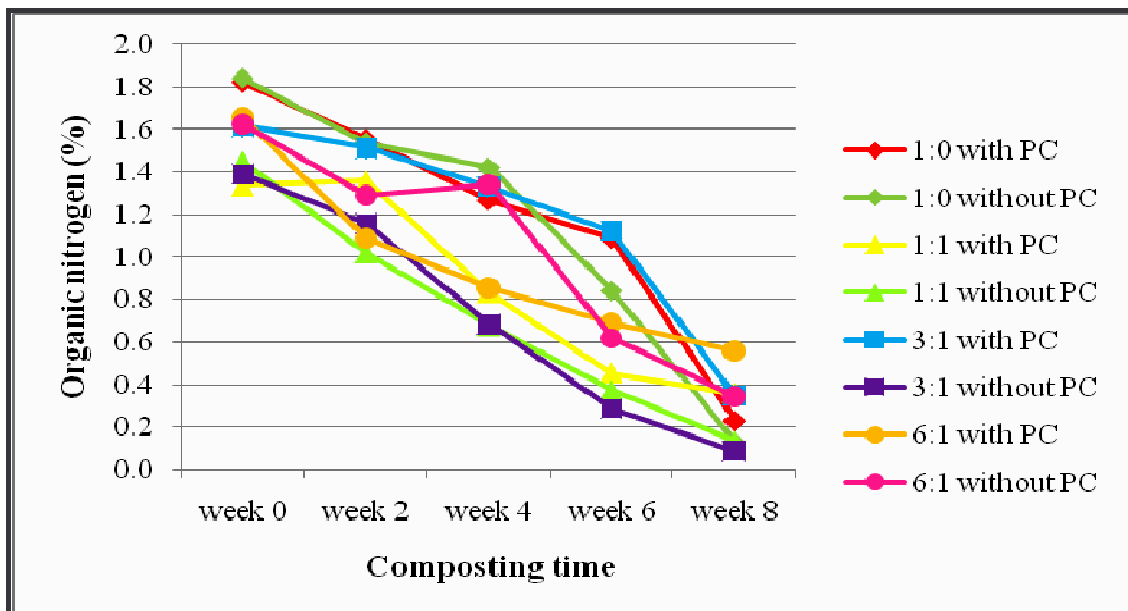


Figure 4.46 The organic nitrogen trend lines of all treatments.

As referred, the results indicated that the organic nitrogen of all treatments after passed composting process had lower than the before passed composting process (Figure 4.47).

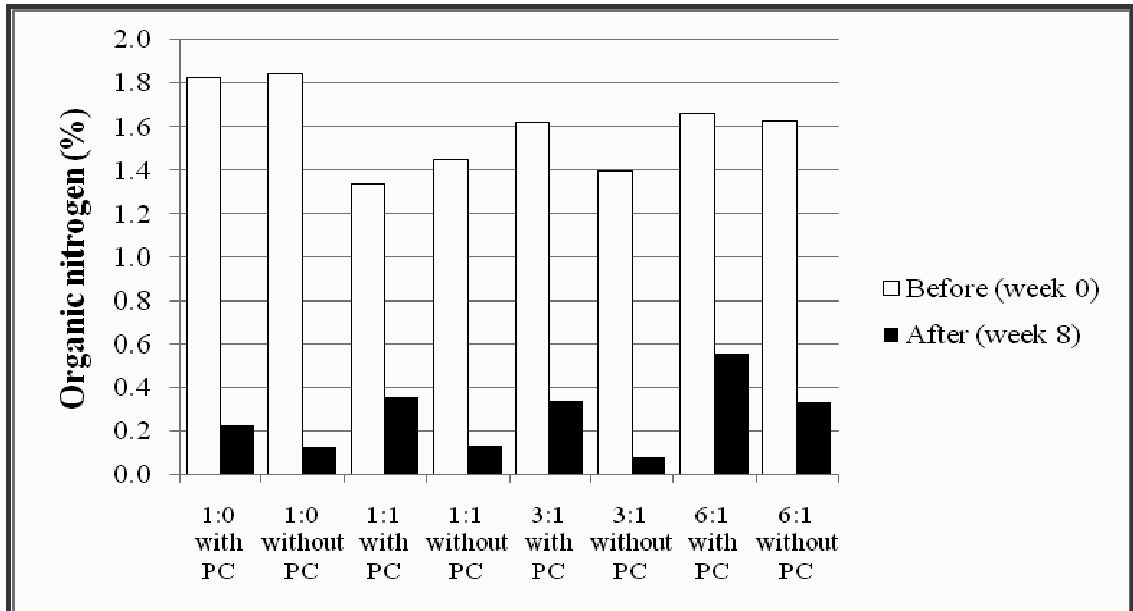


Figure 4.47 The organic nitrogen of all treatments before and after passed composting process

The Three-Way Analyses of Variance with one Repeated Factors is used to analyze main effects (mixing ratio, steam sterilization, and composting time) and their and interaction effect of organic nitrogen values.

- The main effect of mixing ratio of all treatments was significantly different ( $P < 0.001$ ).
- The main effect of steam sterilization 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 and composting time were significantly different ( $P < 0.001$ ) on within subject effect. There were also had interactions between composting time and mixing ratio ( $P < 0.001$ ); between composting time and steam sterilization ( $P = 0.001$ ) and an interaction between mixing ratios and steam sterilizations ( $P < 0.001$ ). The results of analytical statistics are shown in Table 4.14.

Table 4.14 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for organic nitrogen

Source	SS	df	MS	F	p-value
<b>Between-Subjects Effects</b>					
Intercept	116.062	1	116.062	1.257E4	< 0.001
Mixing ratio	2.134	3	0.711	77.044	< 0.001
Steam sterilization	0.611	1	0.611	66.115	< 0.001
Mixing ratio * steam sterilization	1.204	3	0.401	43.461	< 0.001
Error	0.148	16	0.009		
<b>Within-Subjects Effects</b>					
Composting times	26.011	4	6.503	446.472	< 0.001
composting times * mixing ratio	1.271	12	0.106	7.272	< 0.001
composting times * steam sterilization	0.327	4	0.082	5.609	0.001
composting times * mixing ratio * steam sterilization	0.856	12	0.071	4.895	< 0.001
Error	0.932	64	0.015		

When interaction exist among the three factors, F test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilizations (with and without plastic cover) at each time period.

With plastic cover, organic nitrogen was found significant difference in 4 periods, except at composting time week 8.

To test difference between group, Bonferroni adjustment is used to compare.

- For with plastic cover at composting time week 0, the organic nitrogen of mixing ratio 1:0 was significantly different from mixing ratio 1:1.

- For with plastic cover at composting time week 2, the organic nitrogen of mixing ratio 6:1 was significantly different from mixing ratio 1:0, 1:1 and 3:1.
- For with plastic cover at composting time week 4, the organic nitrogen of mixing ratio 1:0 was significantly different from mixing ratio 1:1.
- For with plastic cover at composting time week 6, the organic nitrogen of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 6:1; mixing ratio 3:1 was significantly different from mixing ratio 1:1 and 6:1.
- For with plastic cover, at mixing ratio 3:1 between composting time week 4 to 6 had highest organic nitrogen followed by mixing ratio 1:0 as shown in Figure 4.48.

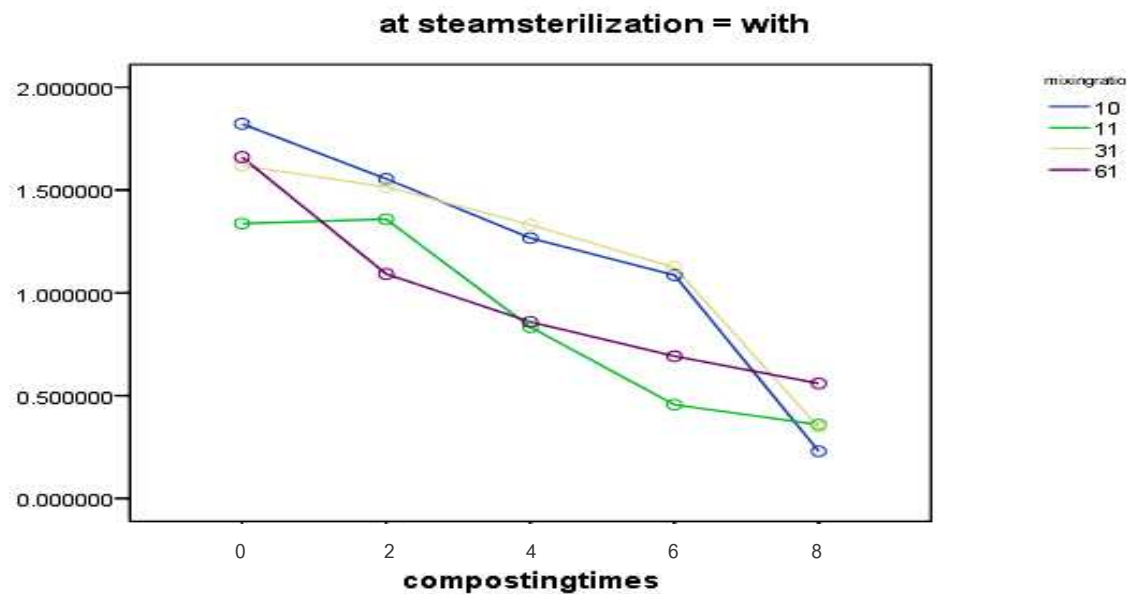


Figure 4.48 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to organic nitrogen

Without plastic cover, the organic nitrogen was found significant difference in 4 periods, except composting time week 4.

To test difference between group, Bonferroni adjustment is used to compare.

- For without plastic cover at composting time week 0, the organic nitrogen of mixing ratio 1:0 was significantly different from mixing ratio 3:1.

- For without plastic cover at composting time week 2, the organic nitrogen 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 6:1.

- For without plastic cover at composting time week 4, the organic nitrogen of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 3:1; mixing ratio 6:1 was significantly different from mixing ratio 1:1 and 3:1.

- For without plastic cover at composting time week 6, the organic nitrogen of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 3:1; mixing ratio 6:1 was significantly different from mixing ratio 1:1 and 3:1.

- For without plastic cover at composting time week 8, the organic nitrogen of mixing ratio 6:1 was significantly different from mixing ratio 1:0, 1:1 and 3:1.

- For without plastic cover, at mixing ratio 1:0 between composting time week 4 to 8 had highest organic nitrogen followed by mixing ratio 6:1 as shown in Figure 4.49.

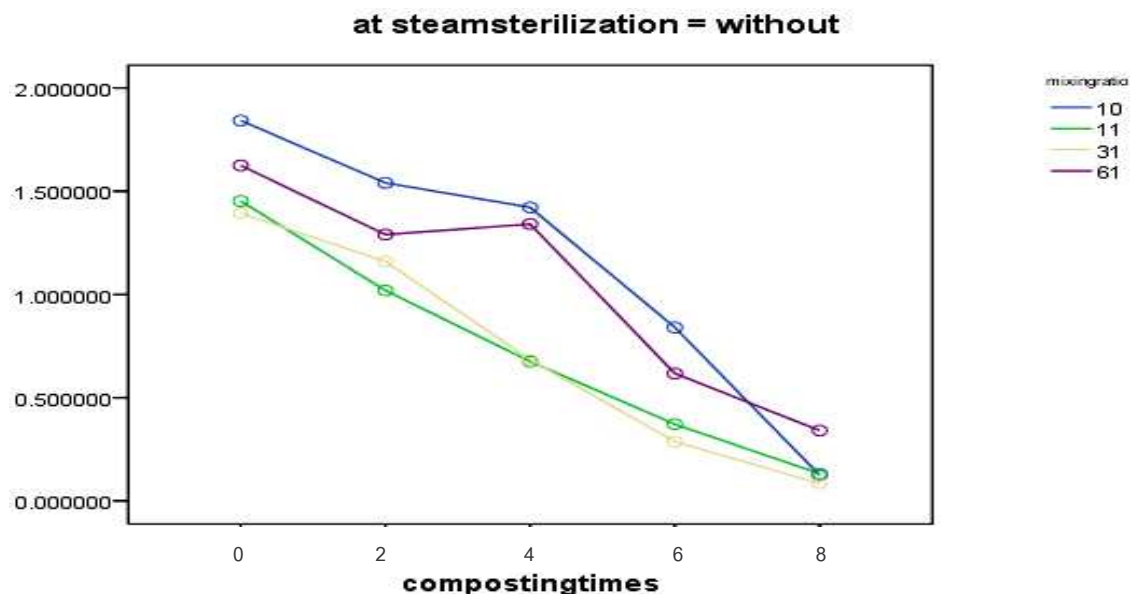


Figure 4.49 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to organic nitrogen

When an interaction exists among the three factors, F test of ANOVA is used to test the simple main effect of steam sterilizations classified by each level of mixing ratios (1:0, 1:1, 3:1 and 6:1) at each time period.

To test difference between group, Bonferroni adjustment is used to compare.

- For mixing ratio 1:0 at composting time week 0, 2, 4, 6 and 8, the organic nitrogen of with plastic cover was not significantly different from without plastic cover as shown in Figure 4.50.

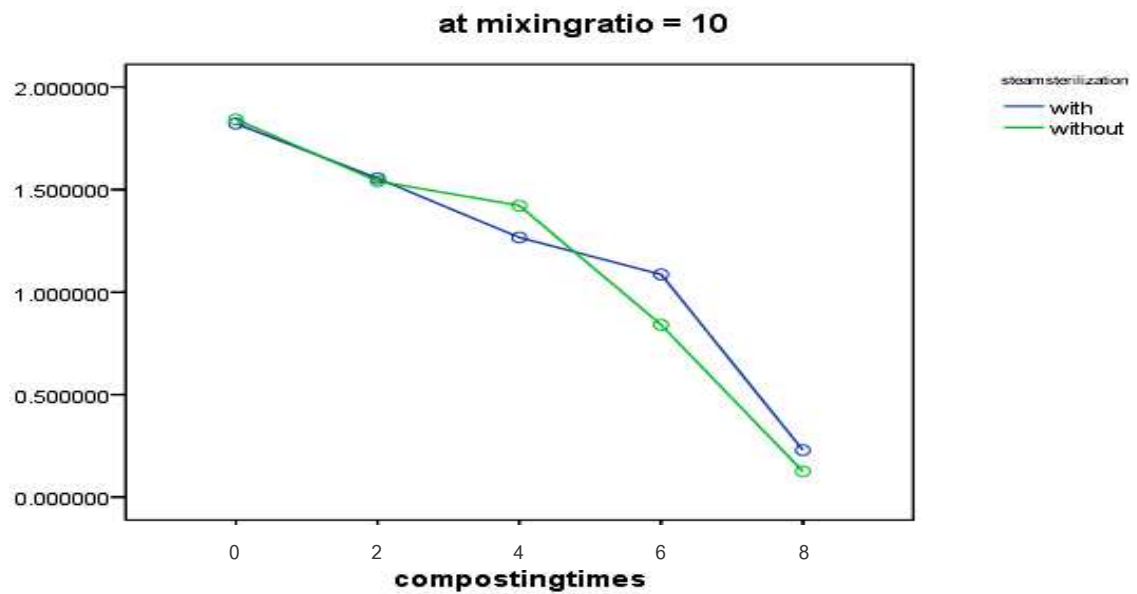


Figure 4.50 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to organic nitrogen

- For mixing ratio 1:1 at composting time week 2 and 8, the organic nitrogen of with plastic cover was significantly different from without plastic cover as shown in Figure 4.51.

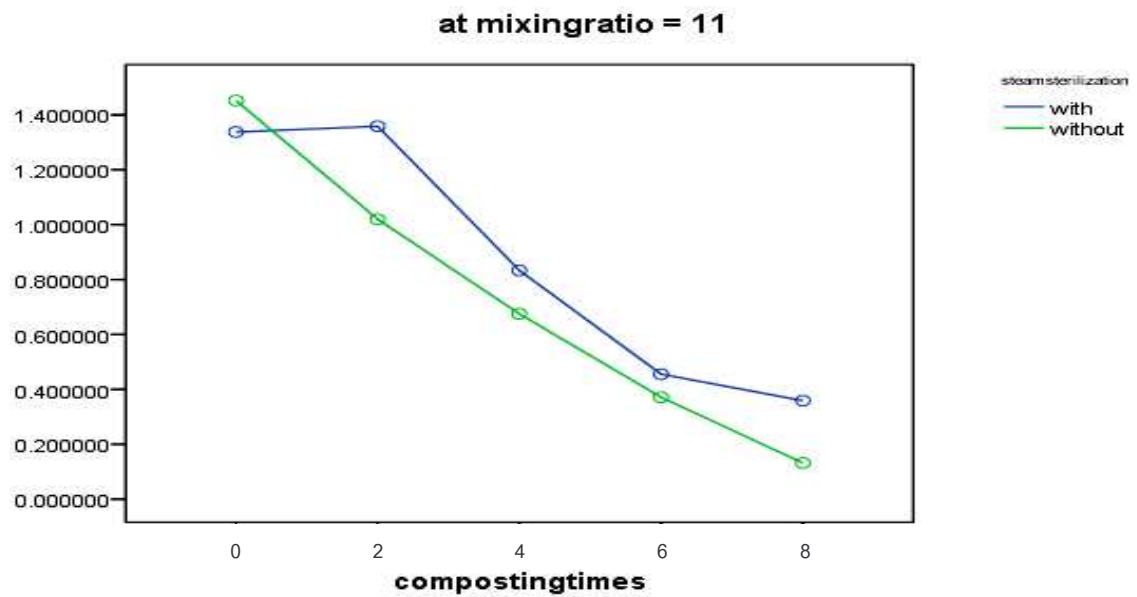


Figure 4.51 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to organic nitrogen

- For mixing ratio 3:1 at composting time week 2, 4, 6 and 8, the organic nitrogen of with plastic cover was significantly different from without plastic cover as shown in Figure 4.52.

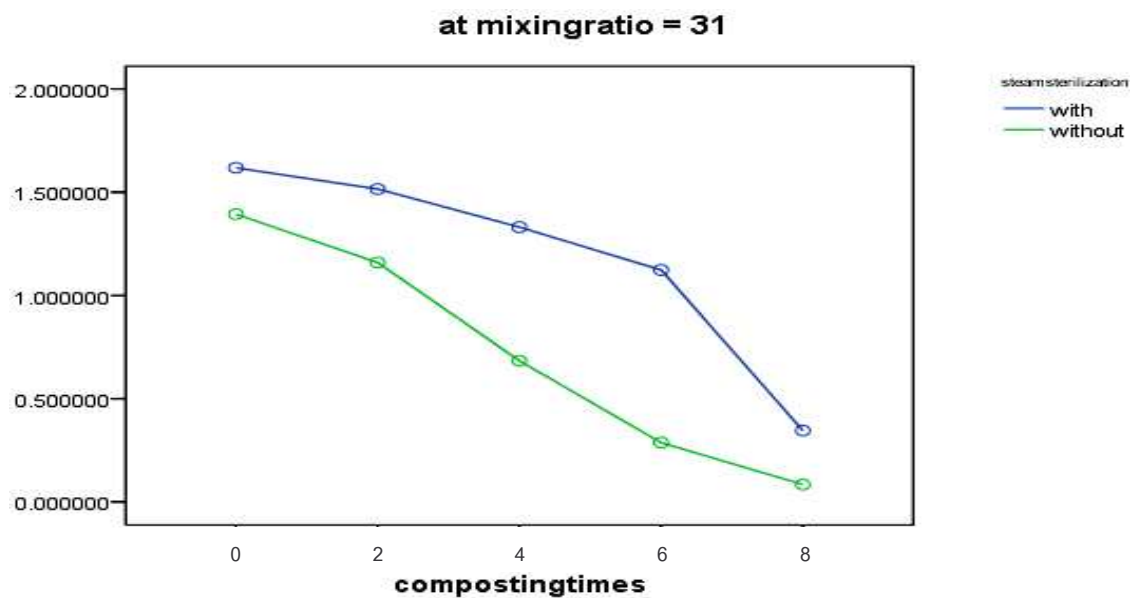


Figure 4.52 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to organic nitrogen

- For mixing ratio 6:1 at composting time week 2 and 4, the organic nitrogen of with plastic cover was significantly different from without plastic cover as shown in Figure 4.53.

- For all mixing ratio, at composting time week 6 to 8 with plastic cover treatment had higher organic nitrogen than without plastic cover treatment.

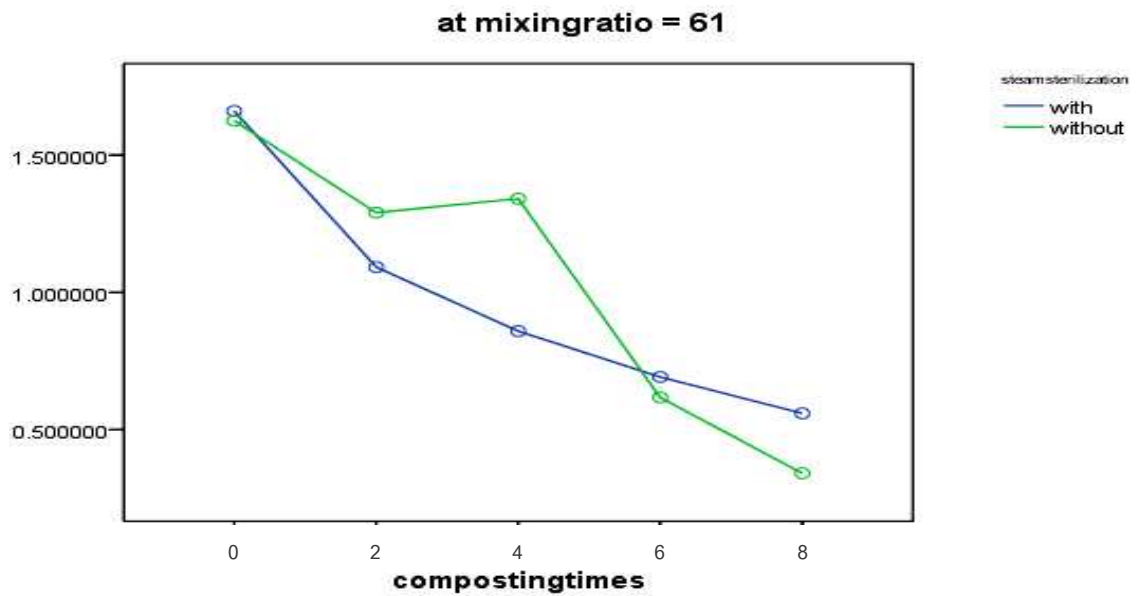


Figure 4.53 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to organic nitrogen

To test the simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition, Bonferroni adjustment is used to test the difference between each pair of treatment.

- For mixing ratio 1:0 with plastic cover, the organic nitrogen of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0 and 2; composting time week 4 was significantly different from composting time week 0.

- For mixing ratio 1:0 without plastic cover, the organic nitrogen of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0.

- For mixing ratio 1:1 with plastic cover, the organic nitrogen of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 1:1 without plastic cover, the organic nitrogen of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2; composting time week 2 was significantly different from composting time week 0.

- For mixing ratio 3:1 with plastic cover, the organic nitrogen of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0.

- For mixing ratio 3:1 without plastic cover, the organic nitrogen of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 6:1 with plastic cover, the organic nitrogen of composting time week 2 was significantly different from composting time week 6 and 8; composting time week 0 was significantly different from composting time week 2, 4, 6 and 8.

- For mixing ratio 6:1 without plastic cover, the organic nitrogen of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 2 was significantly different from composting time week 0.

- For all treatments after active phase (week 4), at composting time week 6 had highest organic nitrogen followed by at composting time week 8 as shown in Figure 4.54.

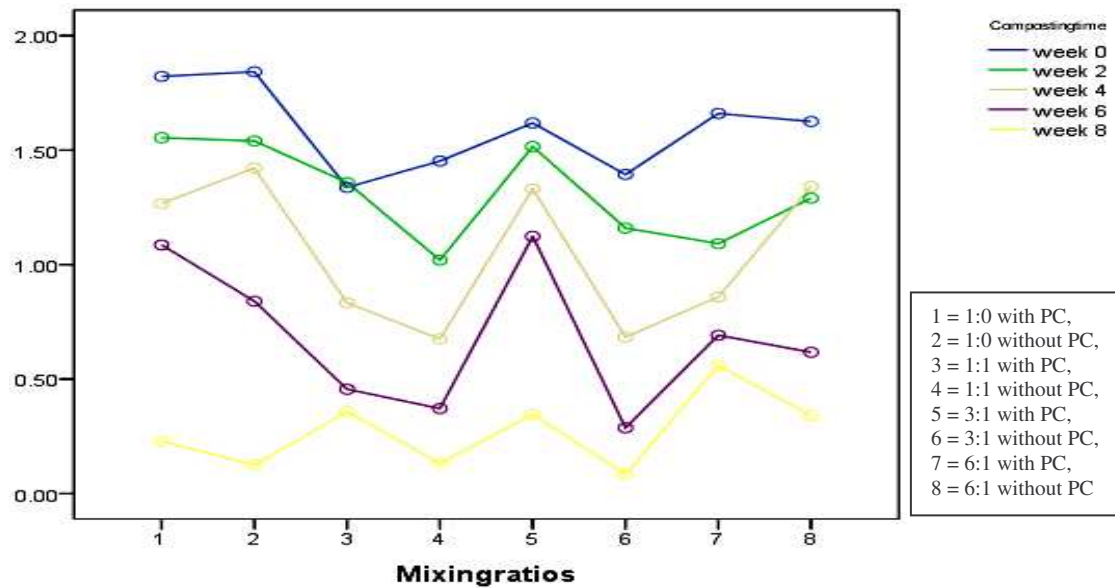


Figure 4.54 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to organic nitrogen

### - Inorganic nitrogen

The inorganic nitrogen was measured at every two weeks of composting time starting from week 0 until the composting process was finished at week 8.

During composting process, the average inorganic nitrogen of all treatments was in the range of 0.14-1.34%. The maximum inorganic nitrogen at the end of composting process was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet (1.34%). The minimum inorganic nitrogen was the treatment which had mixing ratio 6:1 and covered by black plastic sheet (0.89%). The results are shown in Table 4.15. The inorganic nitrogen of all treatments was trend increased until the composting process was finished at week 8 (Figure 4.55).

Table 4.15 The average inorganic nitrogen (%) of all treatments during the composting process at the different composting times

Treatments	Composting times				
	week 0 (SD)	week 2 (SD)	week 4 (SD)	week 6 (SD)	week 8 (SD)
1:0 with PC	0.16 (0.01)	0.25 (0.01)	0.28 (0.01)	0.31 (0.02)	1.18 (0.05)
1:0 without PC	0.15 (0.01)	0.26 (0.02)	0.41 (0.02)	0.59 (0.00)	1.23 (0.01)
1:1 with PC	0.28 (0.00)	0.41 (0.01)	0.75 (0.01)	0.85 (0.06)	0.93 (0.05)
1:1 without PC	0.16 (0.02)	0.77 (0.03)	0.81 (0.01)	1.00 (0.01)	1.34 (0.08)
3:1 with PC	0.16 (0.01)	0.19 (0.01)	0.22 (0.02)	0.21 (0.01)	1.07 (0.03)
3:1 without PC	0.20 (0.02)	0.68 (0.03)	0.96 (0.03)	1.20 (0.01)	1.31 (0.03)
6:1 with PC	0.17 (0.02)	0.71 (0.03)	0.75 (0.03)	0.89 (0.07)	0.89 (0.11)
6:1 without PC	0.14 (0.11)	0.34 (0.01)	0.30 (0.01)	0.84 (0.02)	1.01 (0.07)

Remark: PC is plastic cover

SD is standard deviation

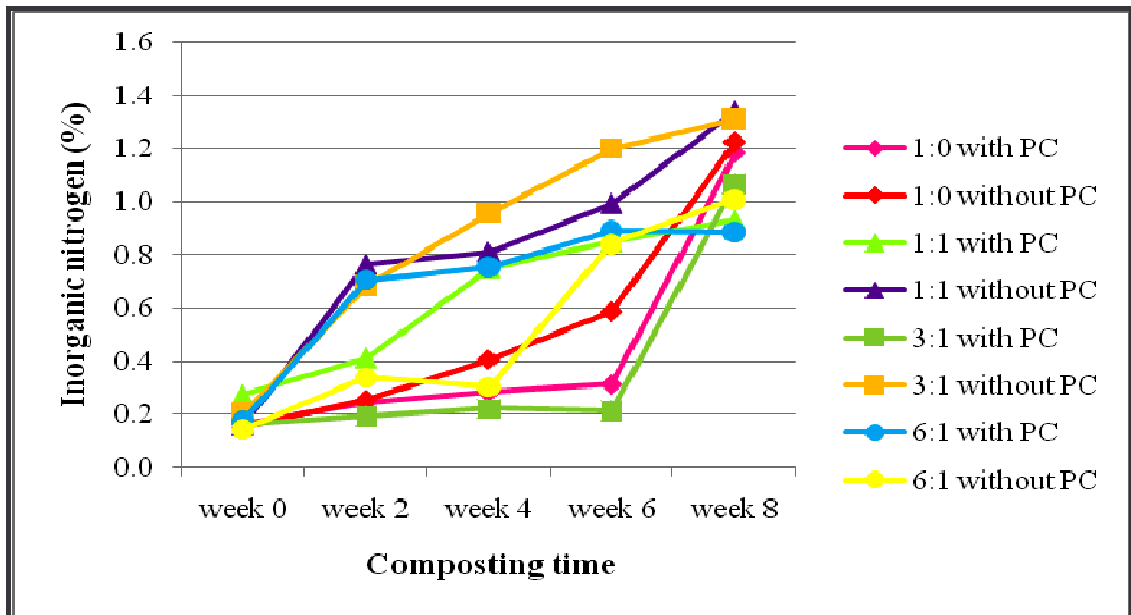


Figure 4.55 The inorganic nitrogen trend lines of all treatments

As referred, the results indicated that the inorganic nitrogen of all treatments after passed composting process had higher than the before passed composting process (Figure 4.56).

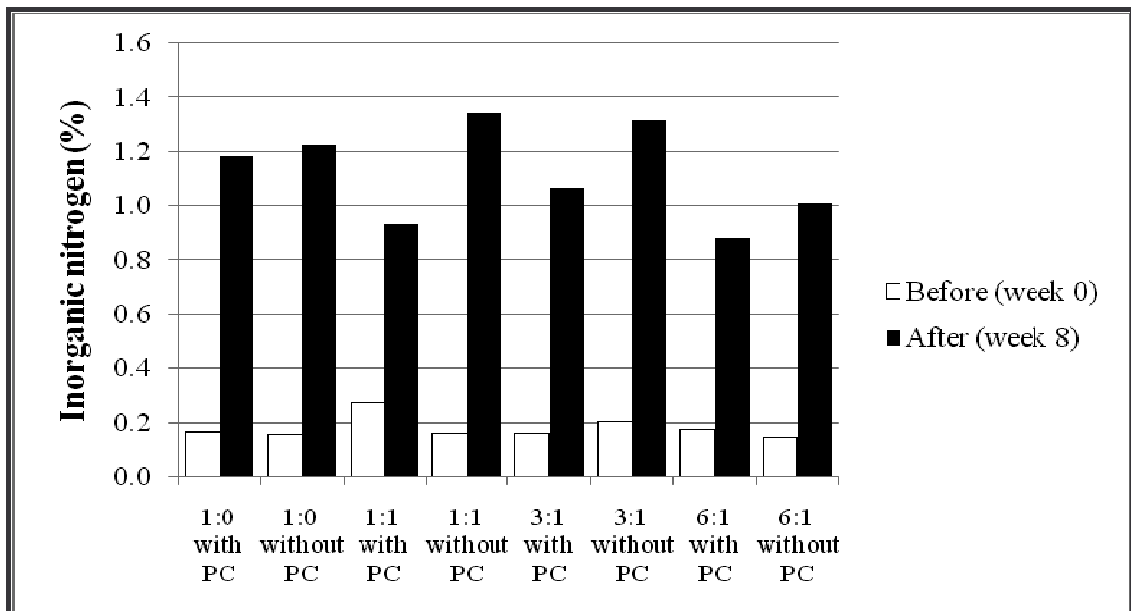


Figure 4.56 The inorganic nitrogen of all treatments before and after passed composting process

The Three-Way Analyses of Variance with one Repeated Factors is used to analyze main effects (mixing ratio, steam sterilization, and composting time) and their and interaction effect of inorganic nitrogen values.

- The main effect of mixing ratio of all treatments was significantly different ( $P < 0.001$ ).

- The main effect of steam sterilization 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 and composting time were significantly different ( $P < 0.001$ ) on within subject effect. There were also had interactions between composting time and mixing ratio ( $P < 0.001$ ); between composting time and steam sterilization ( $P < 0.001$ ) and an interaction between mixing ratios and steam sterilizations ( $P < 0.001$ ). The results of analytical statistics are shown in Table 4.16.

Table 4.16 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for inorganic nitrogen

Source	SS	df	MS	F	p-value
<b>Between-Subjects Effects</b>					
Intercept	44.606	1	44.606	2.203E4	< 0.001
Mixing ratio	0.924	3	0.308	152.148	< 0.001
Steam sterilization	0.690	1	0.690	340.695	< 0.001
Mixing ratio * steam sterilization	1.653	3	0.551	272.207	< 0.001
Error	0.032	16	0.002		
<b>Within-Subjects Effects</b>					
Composting times	11.759	2.446	4.808	2.344E3	< 0.001
composting times * mixing ratio	1.114	7.337	0.152	74.067	< 0.001
composting times * steam sterilization	0.441	2.446	0.180	87.854	< 0.001
composting times * mixing ratio * steam sterilization	1.138	7.337	0.155	75.633	< 0.001
Error	0.080	39.129	0.002		

When interaction exist among the three factors, F test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilizations (with and without plastic cover) at each time period.

With plastic cover, inorganic nitrogen was found significant difference at all periods.

To test difference between group, Bonferroni adjustment is used to compare.

- For with plastic cover at composting time week 0, the inorganic nitrogen of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.

- For with plastic cover at composting time week 2, the inorganic nitrogen 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For with plastic cover at composting time week 4, the inorganic nitrogen 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For with plastic cover at composting time week 6, the inorganic nitrogen of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 6:1; mixing ratio 3:1 was significantly different from mixing ratio 1:1 and 6:1.

- For with plastic cover at composting time week 8, the inorganic nitrogen of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 6:1.

- For with plastic cover, at mixing ratio 6:1 between composting time week 4 to 6 had highest inorganic nitrogen followed by mixing ratio 1:1 as shown in Figure 4.57.

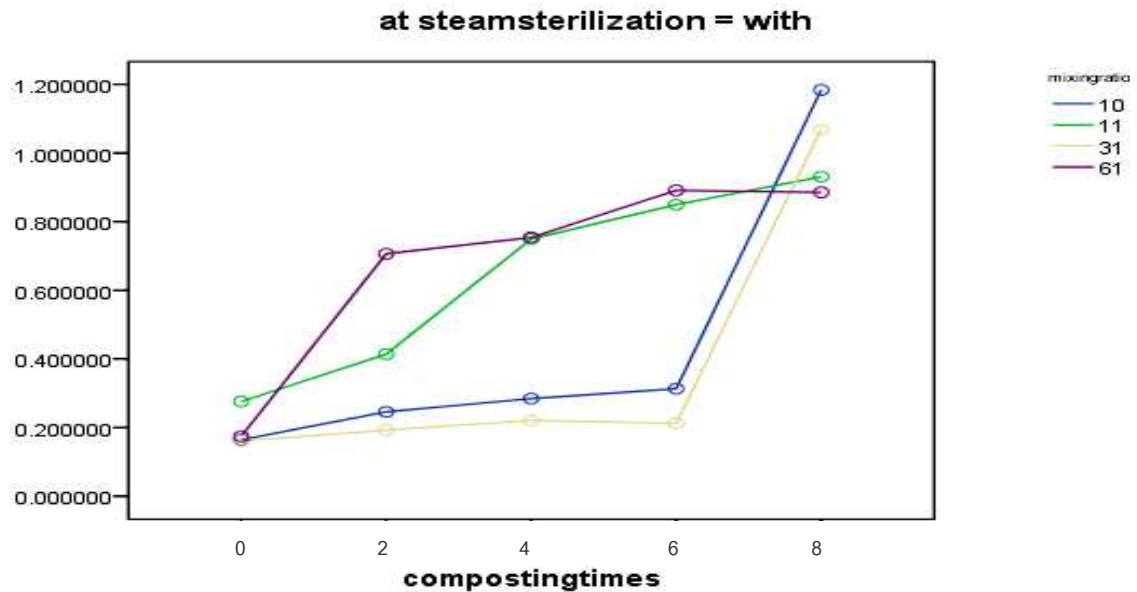


Figure 4.57 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to inorganic nitrogen

Without plastic cover, the inorganic nitrogen was found significant difference in 4 periods, except composting time week 0.

To test difference between group, Bonferroni adjustment is used to compare.

- For without plastic cover at composting time week 2, the inorganic nitrogen 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For without plastic cover at composting time week 4, the inorganic nitrogen 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For without plastic cover at composting time week 6, the inorganic nitrogen 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; mixing ratio 3:1 was significantly different from mixing ratio 6:1.

- For without plastic cover at composting time week 8, the inorganic nitrogen of mixing ratio 6:1 was significantly different from mixing ratio 1:0, 1:1 and 3:1.

- For without plastic cover, at mixing ratio 3:1 between composting time week 4 to 8 had highest inorganic nitrogen followed by mixing ratio 1:1 as shown in Figure 4.58.

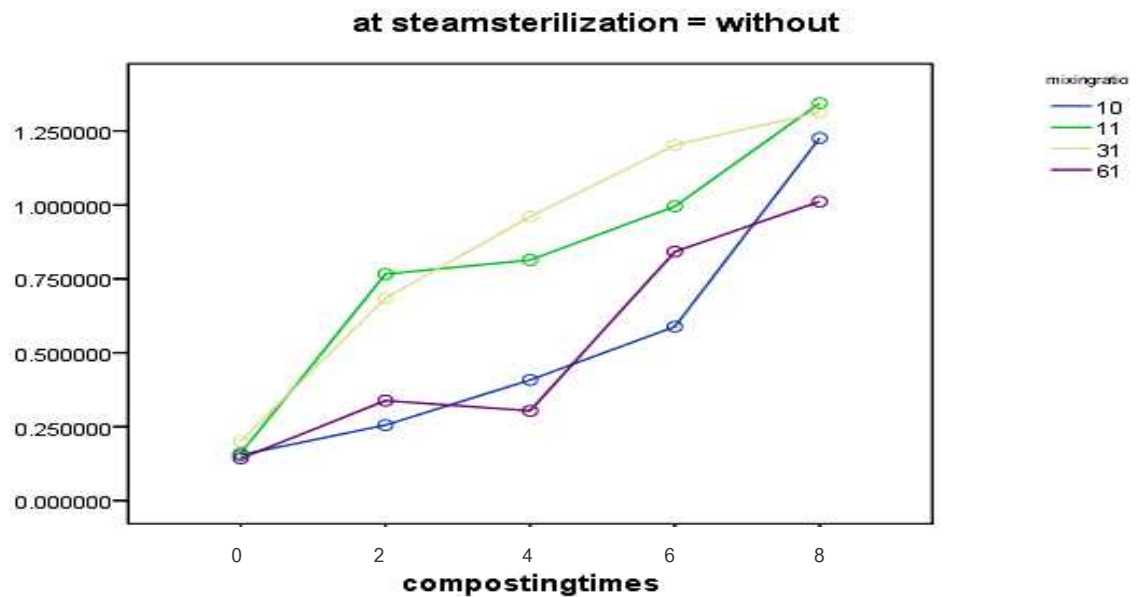


Figure 4.58 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to inorganic nitrogen

When an interaction exists among the three factors, F test of ANOVA is used to test the simple main effect of steam sterilizations classified by each level of mixing ratios (1:0, 1:1, 3:1 and 6:1) at each time period.

To test difference between group, Bonferroni adjustment is used to compare.

- For mixing ratio 1:0 at composting time week 4 and 6, the inorganic nitrogen of with plastic cover was significantly different from without plastic cover as shown in Figure 4.59.

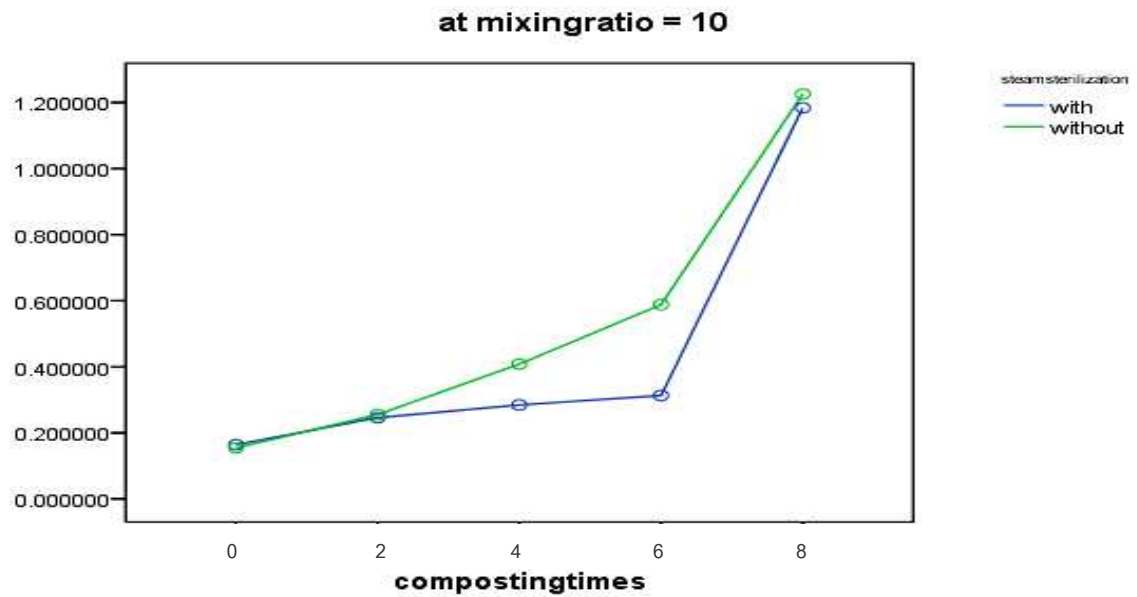


Figure 4.59 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to inorganic nitrogen

- For mixing ratio 1:1 at composting time week 0, 2, 4, 6 and 8, the inorganic nitrogen of with plastic cover was significantly different from without plastic cover as shown in Figure 4.60.

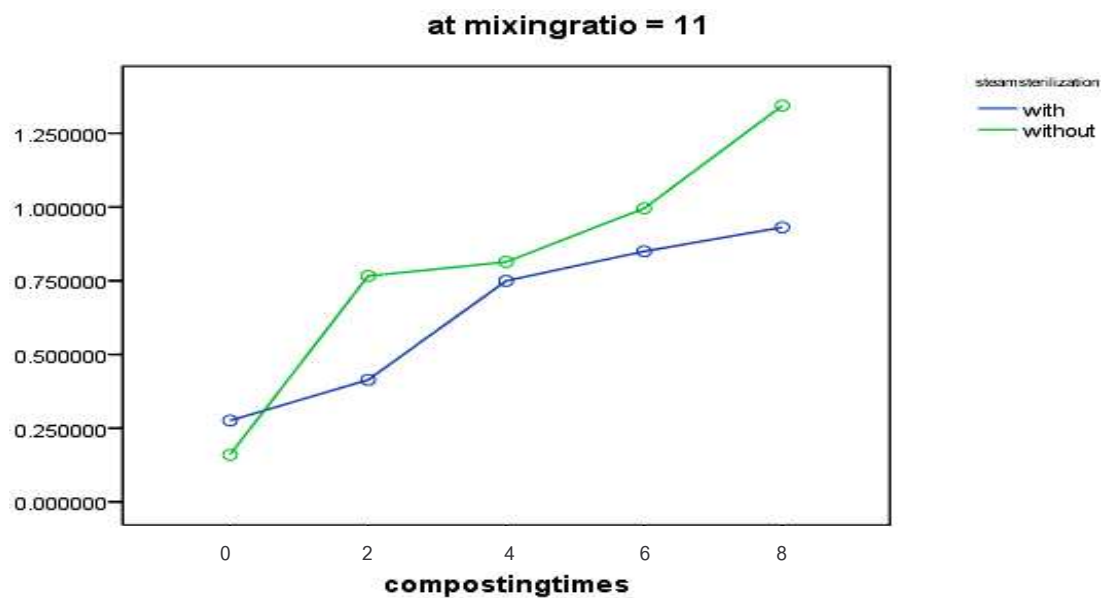


Figure 4.60 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to inorganic nitrogen

- For mixing ratio 3:1 at composting time week 0, 2, 4, 6 and 8, the inorganic nitrogen of with plastic cover was significantly different from without plastic cover as shown in Figure 4.61.

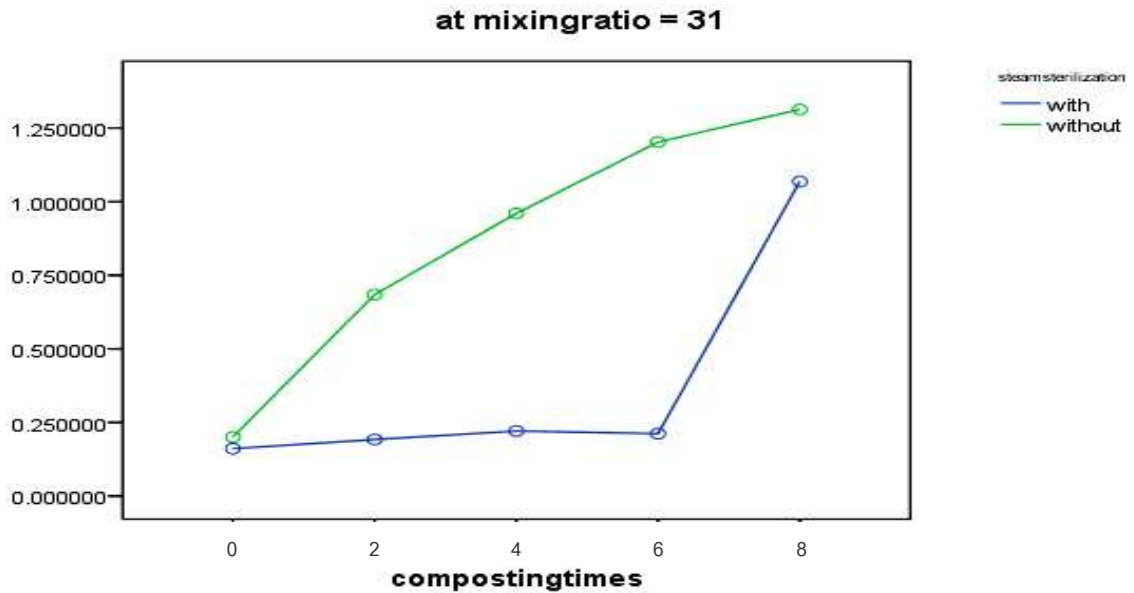


Figure 4.61 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to inorganic nitrogen

- For mixing ratio 6:1 at composting time week 2 and 4, the inorganic nitrogen of with plastic cover was significantly different from without plastic cover as shown in Figure 4.62.

- For almost mixing ratios, at composting time week 4 to 8 without plastic cover treatment had higher inorganic nitrogen than with plastic cover treatment.

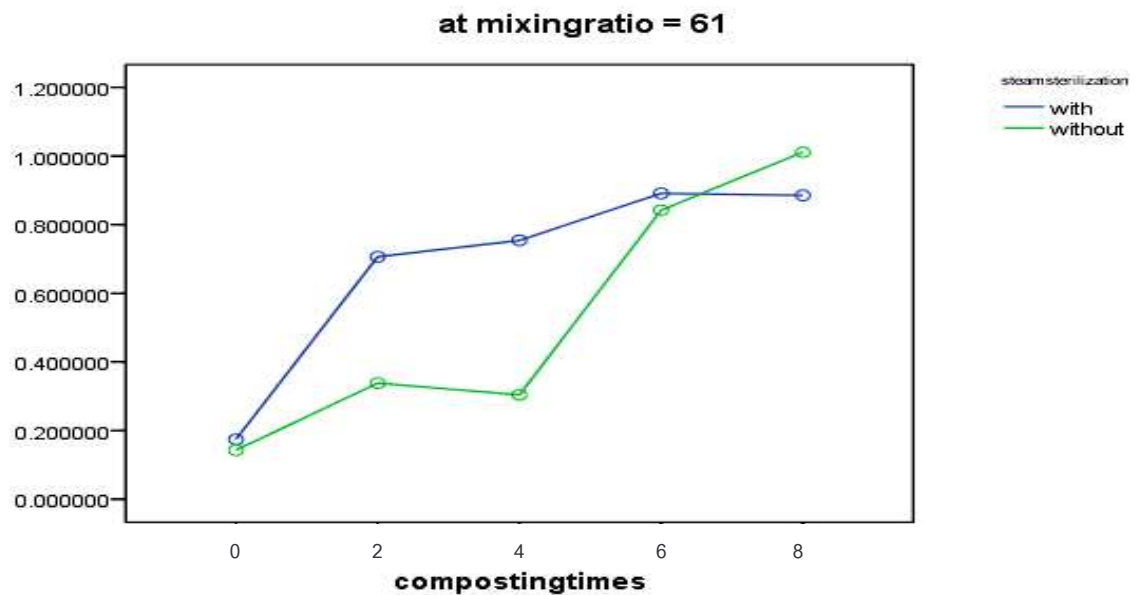


Figure 4.62 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to inorganic nitrogen

To test the simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition, Bonferroni adjustment is used to test the difference between each pair of treatment.

- For mixing ratio 1:0 with plastic cover, the inorganic nitrogen of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 0 was significantly different from composting time week 2, 4 and 6.

- For mixing ratio 1:0 without plastic cover, the inorganic nitrogen of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 1:1 with plastic cover, the inorganic nitrogen of composting time week 8 was significantly different from composting time week 0, 2 and 4; composting time week 6 was significantly different from composting time week 0 and 2; composting time week 4 was significantly different from composting time week 0 and 2; composting time week 2 was significantly different from composting time week 0.

- For mixing ratio 1:1 without plastic cover, the inorganic nitrogen of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 0 was significantly different from composting time week 2 and 4.

- For mixing ratio 3:1 with plastic cover, the inorganic nitrogen of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 0 was significantly different from composting time week 4 and 6.

- For mixing ratio 3:1 without plastic cover, the inorganic nitrogen of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 6:1 with plastic cover, the inorganic nitrogen of composting time week 8 was significantly different from composting time week 0 and 2; composting time week 6 was significantly different from composting time week 0 and 2; composting time week 0 was significantly different from composting time week 2 and 4.

- For mixing ratio 6:1 without plastic cover, the inorganic nitrogen of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 2 was significantly different from composting time week 0.

- For all treatments, at composting time week 8 had highest inorganic nitrogen followed by at composting time week 6 as shown in Figure 4.63.

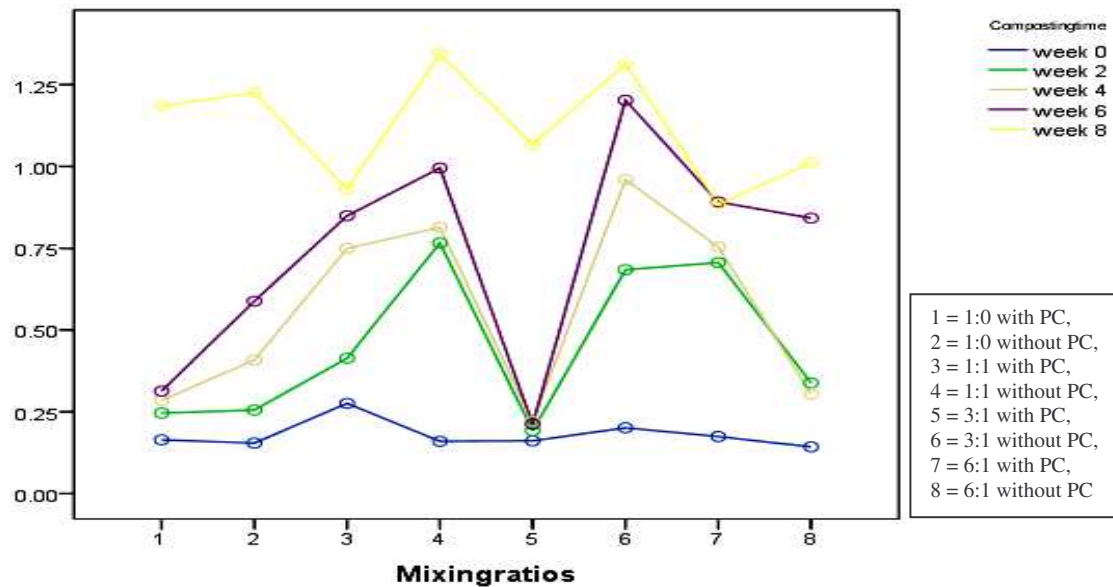


Figure 4.63 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to inorganic nitrogen

#### 4.2.2.4 Carbon to nitrogen ratio

The carbon to nitrogen ratio was calculated from organic carbon content (%) divided by amount of total nitrogen (%) at every two weeks of composting time starting from week 0 until the composting process was finished at week 8.

During composting process, the average carbon to nitrogen ratio of all treatments was in the range of 5:1-8:1. The maximum carbon to nitrogen ratio at the end of composting process was the treatment which had mixing ratio 1:1 and covered by black plastic sheet (8:1). The minimum carbon to nitrogen ratio was the treatment which had mixing ratio 1:0 and both covered and not covered by black plastic sheet (6:1). The results are shown in Table 4.17. The carbon to nitrogen ratio of all treatments were increased at the first two weeks, but during the second week until fourth week the carbon to nitrogen ratio were decreased. After that, the carbon to nitrogen ratio was increased until the composting process was finished at week 8. Except the treatment which had mixing ratio 1:1 and not covered by black plastic sheet and mixing ratio 3:1 and covered by black plastic sheet, the carbon to nitrogen ratio of them were increased at the first two weeks and during the second week until fourth week they were decreased. At the fourth week until sixth week, they were increased again and after that decreased until the composting process was finished at week 8 (Figure 4.64).

Table 4.17 The average carbon to nitrogen ratio of all treatments during the composting process at the different composting times

Treatments	Composting times				
	week 0	week 2	week 4	week 6	week 8
	(SD)	(SD)	(SD)	(SD)	(SD)
1:0 with PC	5:1 (0.15)	6:1 (0.28)	6:1 (1.32)	6:1 (0.55)	6:1 (0.62)
1:0 without PC	5:1 (0.53)	6:1 (0.14)	5:1 (0.37)	6:1 (0.62)	6:1 (0.48)
1:1 with PC	7:1 (0.12)	8:1 (0.43)	6:1 (0.33)	7:1 (1.08)	8:1 (0.29)
1:1 without PC	7:1 (0.75)	7:1 (0.07)	6:1 (0.50)	8:1 (0.33)	7:1 (0.73)
3:1 with PC	6:1 (0.64)	7:1 (0.49)	6:1 (0.33)	8:1 (0.63)	7:1 (1.22)
3:1 without PC	6:1 (0.18)	7:1 (0.42)	6:1 (0.35)	6:1 (0.19)	7:1 (0.54)
6:1 with PC	6:1 (0.52)	7:1 (0.50)	6:1 (0.74)	6:1 (0.35)	7:1 (0.22)
6:1 without PC	5:1 (0.35)	7:1 (0.15)	6:1 (0.37)	6:1 (0.75)	7:1 (0.78)

Remark: PC is plastic cover

SD is standard deviation

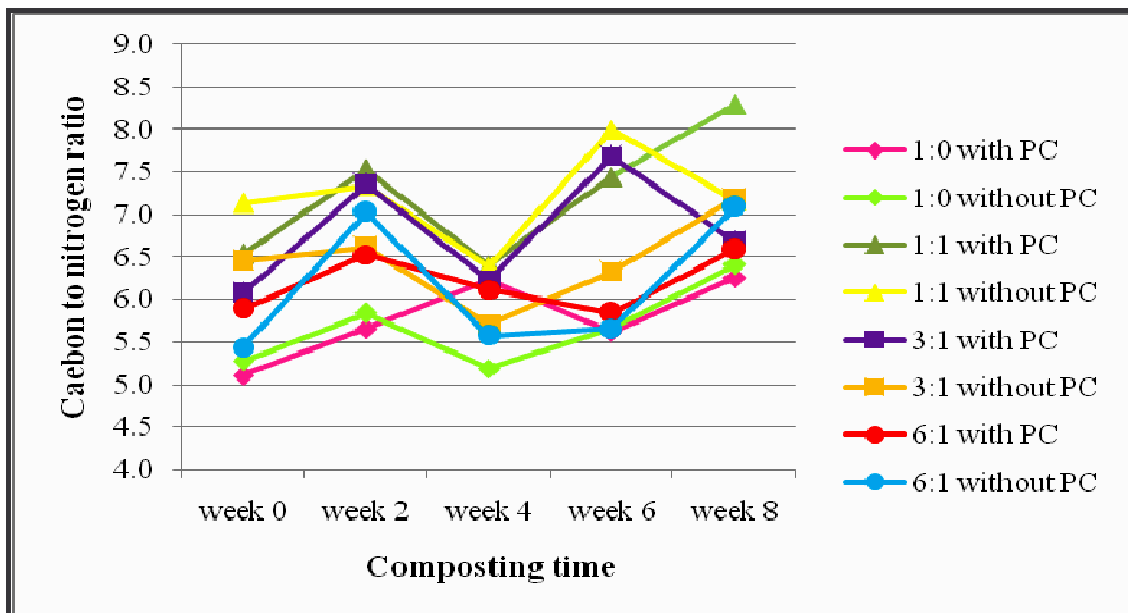


Figure 4.64 The carbon to nitrogen ratio trend lines of all treatments

As referred, the results indicated that the carbon to nitrogen ratio of all treatments after passed composting process had higher than the before passed composting process (Figure 4.65).

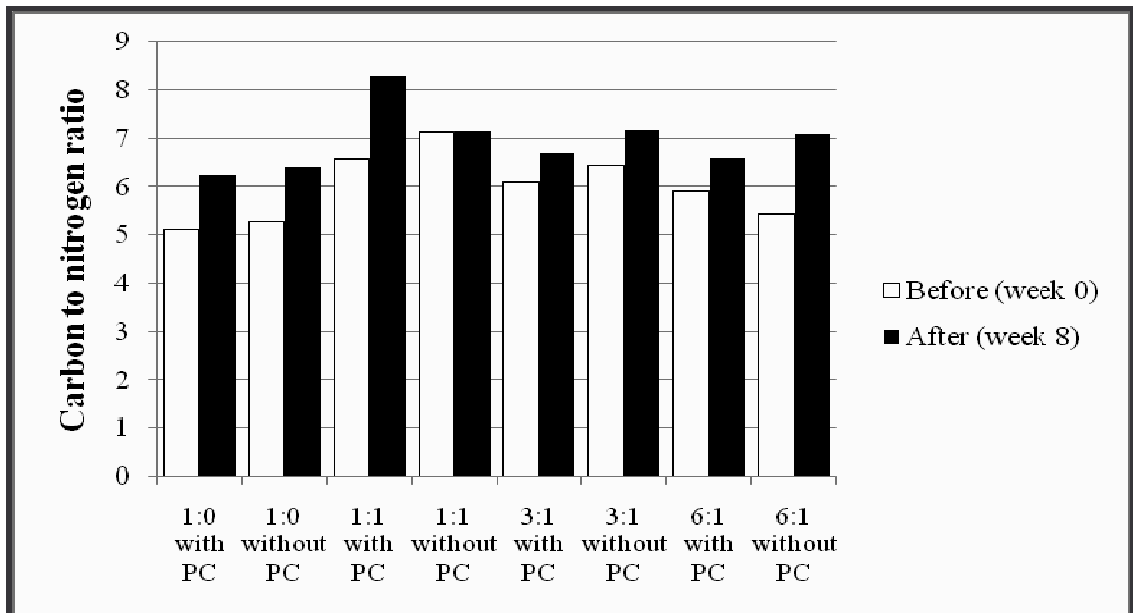


Figure 4.65 The carbon to nitrogen ratio of all treatments before and after passed composting process

The Three-Way Analyses of Variance with one Repeated Factors is used to analyze main effects (mixing ratio, steam sterilization, and composting time) and their and interaction effect of carbon to nitrogen ratio values.

- The main effect of mixing ratio of all treatments was significantly different ( $P < 0.001$ ).
- The main effect of steam sterilization of all treatments was not significantly different ( $P = 0.252$ ).
- The main effect of composting time of all treatments was significantly different ( $P < 0.001$ ).

- The interaction among mixing ratio, steam sterilization and composting time were significantly different ( $P = 0.018$ ) on within subject effect. There were also had interactions between composting time and mixing ratio ( $P = 0.037$ ); between composting time and steam sterilization ( $P = 0.240$ ) and an interaction between mixing ratios and steam sterilizations ( $P = 0.724$ ). The results of analytical statistics are shown in Table 4.18.

Table 4.18 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for carbon to nitrogen ratio

Source	SS	df	MS	F	p-value
<b>Between-Subjects Effects</b>					
Intercept	4977.538	1	4977.538	1.351E4	< 0.001
Mixing ratio	36.959	3	12.320	33.426	< 0.001
Steam sterilization	0.521	1	0.521	1.412	0.252
Mixing ratio * steam sterilization	0.492	3	0.164	0.445	0.724
Error	5.897	16	0.369		
<b>Within-Subjects Effects</b>					
Composting times	18.718	4	4.680	15.551	< 0.001
composting times * mixing ratio	7.293	12	0.608	2.020	0.037
composting times * steam sterilization	1.699	4	0.425	1.412	0.240
composting times * mixing ratio * steam sterilization	8.205	12	0.684	2.272	0.018
Error	19.258	64	0.301		

When interaction exist among the three factors, F test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilizations (with and without plastic cover) at each time period.

With plastic cover, carbon to nitrogen ratio was found significant difference in 4 periods, except at composting time week 4.

To test difference between group, Bonferroni adjustment is used to compare.

- For with plastic cover at composting time week 0, the carbon to nitrogen ratio of mixing ratio 1:0 was significantly different from mixing ratio 1:1.

- For with plastic cover at composting time week 2, the carbon to nitrogen ratio of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 3:1.

- For with plastic cover at composting time week 6, the carbon to nitrogen ratio of mixing ratio 1:0 was significantly different from mixing ratio 3:1.

- For with plastic cover at composting time week 8, the carbon to nitrogen ratio of mixing ratio 1:0 was significantly different from mixing ratio 1:1 as shown in Figure 4.66.

- For with plastic cover, at mixing ratio 1:1 between composting time week 4 to 8 had highest carbon to nitrogen ratio followed by mixing ratio 3:1 as shown in Figure 4.49.

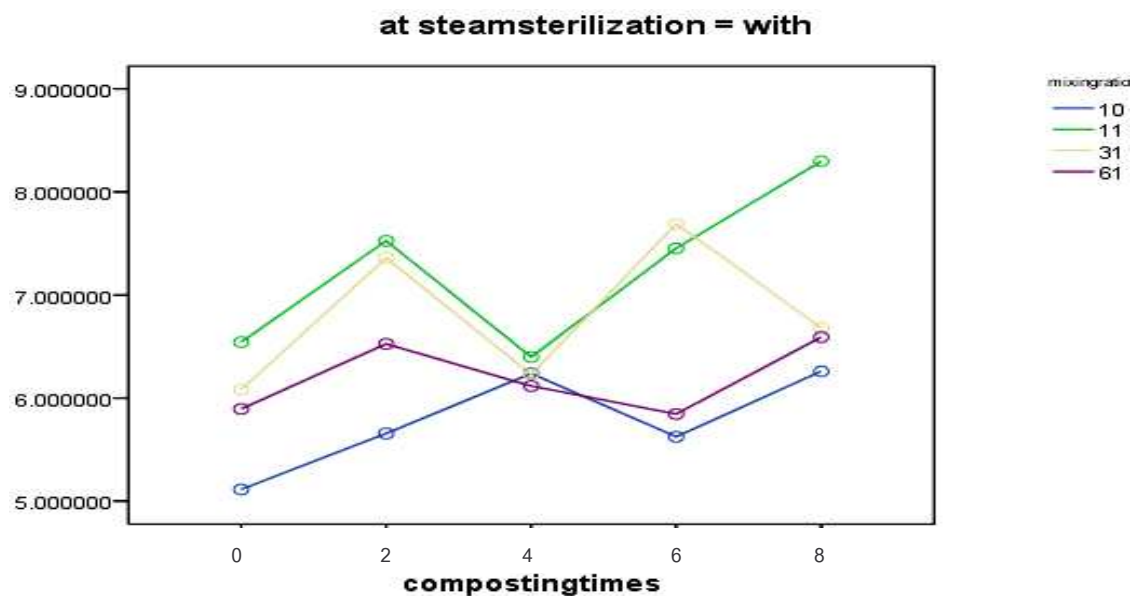


Figure 4.66 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to carbon to nitrogen ratio

Without plastic cover, the carbon to nitrogen ratio was found significant difference in 4 periods, except composting time week 8.

To test difference between group, Bonferroni adjustment is used to compare.

- For without plastic cover at composting time week 0, the carbon to nitrogen ratio of mixing ratio 1:1 was significantly different from mixing ratio 1:0 and 6:1.

- For without plastic cover at composting time week 2, the carbon to nitrogen ratio 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.

- For without plastic cover at composting time week 4, the carbon to nitrogen ratio of mixing ratio 1:0 was significantly different from mixing ratio 1:1.

- For without plastic cover at composting time week 6, the carbon to nitrogen ratio of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.

- For without plastic cover, at mixing ratio 1:1 between composting time week 4 to 8 had highest carbon to nitrogen ratio followed by mixing ratio 3:1 as shown in Figure 4.67.

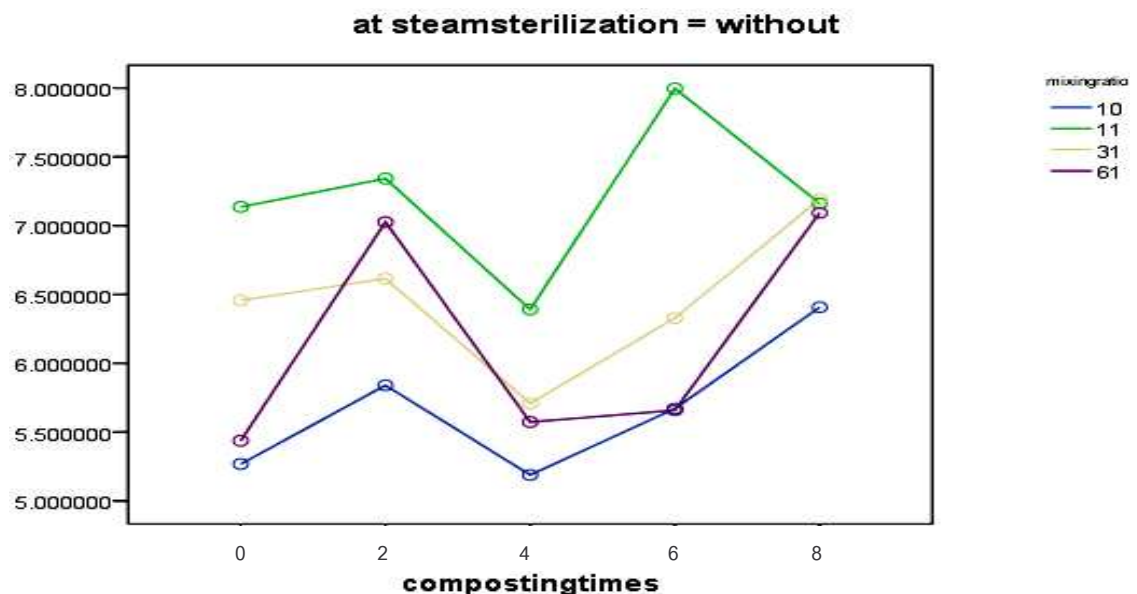


Figure 4.67 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to carbon to nitrogen ratio

When interaction exist among the two factors, F test of ANOVA is used to test the simple main effect of composting time effect to carbon to nitrogen ratio classified by each level of mixing ratio (1:0, 1:1, 3:1 and 6:1) at all of steam sterilization.

To test difference between group, Bonferroni adjustment is used to compare.

- For mixing ratio 1:0, the carbon to nitrogen ratio of composting time week 0 was significantly different from composting time week 8.

- For mixing ratio 1:1, the carbon to nitrogen ratio of composting time week 4 was significantly different from composting time week 6 and 8.

- For mixing ratio 3:1, the carbon to nitrogen ratio of composting time week 8 was not significantly different from other composting time.

- For mixing ratio 6:1, the carbon to nitrogen ratio of composting time week 8 was significantly different from composting time week 0, 4 and 6; composting time week 2 was significantly different from composting time week 0 and 6.

- For all treatments after active phase (week 4), at composting time week 8 had highest carbon to nitrogen ratio followed by at composting time week 6 as shown in Figure 4.68.

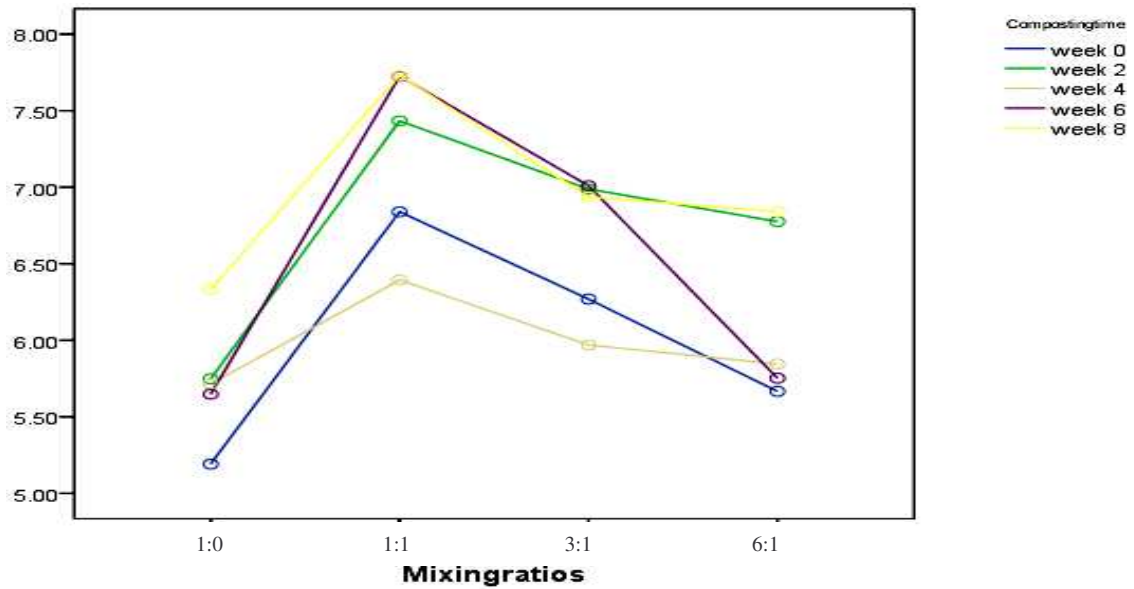


Figure 4.68 The simple main effect of composting time effect to carbon to nitrogen ratio classified by each level of mixing ratio at all of steam sterilization

#### 4.2.2.5 Phosphorus

##### - Total phosphorus

The total phosphorus was measured at every two weeks of composting time starting from week 0 until the composting process was finished at week 8.

During composting process, the average total phosphorus of all treatments was in the range of 0.25-2.203%. The maximum total phosphorus at the end of composting process was the treatment which had mixing ratio 6:1 and not covered by black plastic sheet (0.56%). The minimum total phosphorus was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet (0.25%). The results are shown in Table 4.19. The total phosphorus of all treatments continuously decreased until the composting process was finished at week 8 (Figure 4.69).

Table 4.19 The average total phosphorus (%) of all treatments during the composting process at the different composting times

Treatments	Composting times				
	week 0	week 2	week 4	week 6	week 8
	(SD)	(SD)	(SD)	(SD)	(SD)
1:0 with PC	1.98 (0.03)	2.20 (0.04)	1.84 (0.04)	0.94 (0.05)	0.51 (0.02)
1:0 without PC	2.06 (0.06)	2.13 (0.12)	1.72 (0.01)	0.95 (0.03)	0.36 (0.03)
1:1 with PC	1.60 (0.04)	1.78 (0.10)	1.55 (0.06)	0.69 (0.04)	0.35 (0.02)
1:1 without PC	1.76 (0.13)	1.85 (0.08)	1.54 (0.02)	1.00 (0.02)	0.25 (0.05)
3:1 with PC	1.92 (0.11)	1.67 (0.11)	1.51 (0.01)	0.79 (0.04)	0.40 (0.05)
3:1 without PC	1.71 (0.00)	1.68 (0.03)	1.56 (0.08)	0.80 (0.02)	0.44 (0.08)
6:1 with PC	1.92 (0.01)	1.86 (0.04)	1.59 (0.01)	0.90 (0.02)	0.50 (0.07)
6:1 without PC	2.06 (0.09)	1.90 (0.05)	1.60 (0.01)	0.92 (0.03)	0.56 (0.02)

Remark: PC is plastic cover

SD is standard deviation

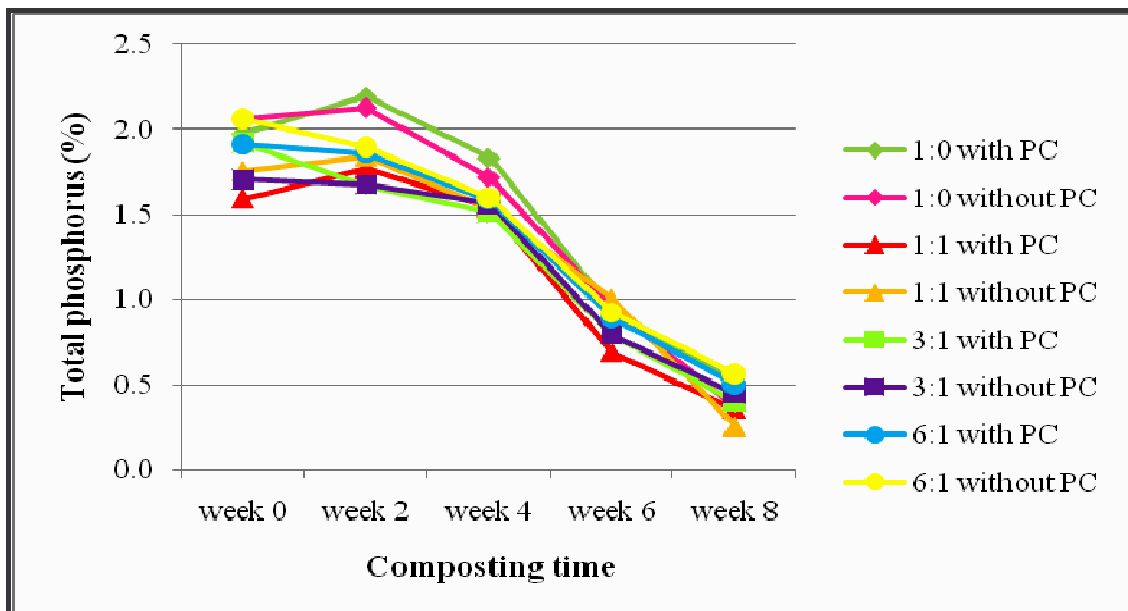


Figure 4.69 The total phosphorus trend lines of all treatments

As referred, the results indicated that the total phosphorus of all treatments after passed composting process had lower than the before passed composting process (Figure 4.70).

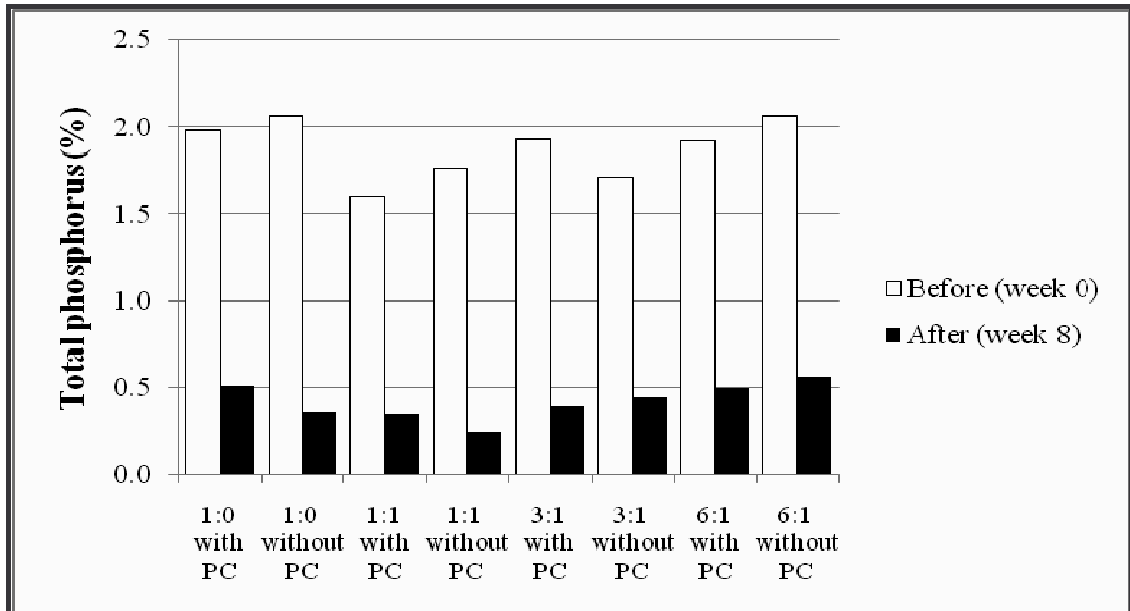


Figure 4.70 The total phosphorus of all treatments before and after passed composting process

The Three-Way Analyses of Variance with one Repeated Factors is used to analyze main effects (mixing ratio, steam sterilization, and composting time) and their and interaction effect of total phosphorus values.

- The main effect of mixing ratio of all treatments was significantly different ( $P < 0.001$ ).
- The main effect of steam sterilization of all treatments was not significantly different ( $P = 0.107$ ).
- The main effect of composting time of all treatments was significantly different ( $P < 0.001$ ).

- The interaction among mixing ratio, steam sterilization and composting time were significantly different ( $P < 0.001$ ) on within subject effect. There were also had interactions between composting time and mixing ratio ( $P < 0.001$ ); between composting time and steam sterilization ( $P = 0.003$ ) and an interaction between mixing ratios and steam sterilizations ( $P = 0.001$ ). The results of analytical statistics are shown in Table 4.20.

Table 4.20 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for total phosphorus

Source	SS	df	MS	F	p-value
<b>Between-Subjects Effects</b>					
Intercept	213.554	1	213.554	6.363E4	< 0.001
Mixing ratio	1.117	3	0.372	110.974	< 0.001
Steam sterilization	0.010	1	0.010	2.908	0.107
Mixing ratio * steam sterilization	0.090	3	0.030	8.984	0.001
Error	0.054	16	0.003		
<b>Within-Subjects Effects</b>					
Composting times	41.092	4	10.273	3.232E3	< 0.001
composting times * mixing ratio	0.575	12	0.048	15.088	< 0.001
composting times * steam sterilization	0.057	4	0.014	4.513	0.003
composting times * mixing ratio * steam sterilization	0.239	12	0.020	6.266	< 0.001
Error	0.203	64	0.003		

When interaction exist among the three factors, F test of ANOVA is used to test the simple main effect of mixing ratio classified by each level of steam sterilizations (with and without plastic cover) at each time period.

With plastic cover, total phosphorus was found significant difference at all periods.

To test difference between group, Bonferroni adjustment is used to compare.

- For with plastic cover at composting time week 0, the total phosphorus of mixing ratio 1:1 was significantly different from mixing ratio 1:0, 3:1 and 6:1.

- For with plastic cover at composting time week 2, the total phosphorus of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1.
- For with plastic cover at composting time week 4, the total phosphorus of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1.
- For with plastic cover at composting time week 6, the total phosphorus of mixing ratio 1:0 was significantly different from mixing ratio 1:1 and 3:1; mixing ratio 1:1 was significantly different from mixing ratio 6:1.
- For with plastic cover at composting time week 8, the total phosphorus of mixing ratio 1:1 was significantly different from mixing ratio 1:0 and 6:1.
- For with plastic cover, at mixing ratio 1:0 between composting time week 4 to 8 had highest total phosphorus followed by mixing ratio 6:1 as shown in Figure 4.71.

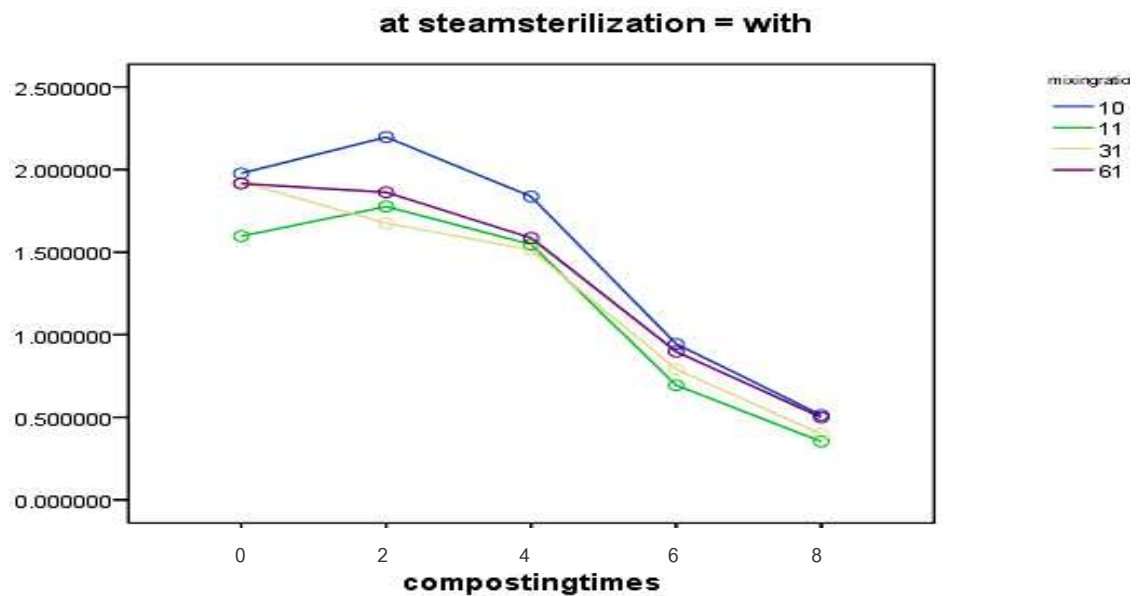


Figure 4.71 The simple main effect of mixing ratio classified by each level of steam sterilizations (with plastic cover) at each time period to total phosphorus

Without plastic cover, the total phosphorus was found significant difference in 4 periods, except composting time week 0.

To test difference between group, Bonferroni adjustment is used to compare.

- For without plastic cover at composting time week 0, the total phosphorus of mixing ratio 1:0 and 6:1 were significantly different from mixing ratio 1:1 and 3:1.

- For without plastic cover at composting time week 2, the total phosphorus of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1.

- For without plastic cover at composting time week 4, the total phosphorus of mixing ratio 1:0 was significantly different from mixing ratio 1:1, 3:1 and 6:1.

- For without plastic cover at composting time week 6, the total phosphorus of mixing ratio 1:1 was significantly different from mixing ratio 6:1; mixing ratio 3:1 was significantly different from mixing ratio 1:0, 1:1 and 6:1.

- For without plastic cover at composting time week 8, the total phosphorus of mixing ratio 1:0 was significantly different from mixing ratio 6:1; mixing ratio 1:1 was significantly different from mixing ratio 3:1 and 6:1.

- For without plastic cover, at mixing ratio 6:1 between composting time week 4 to 8 had highest total phosphorus followed by mixing ratio 1:0 as shown in Figure 4.72.

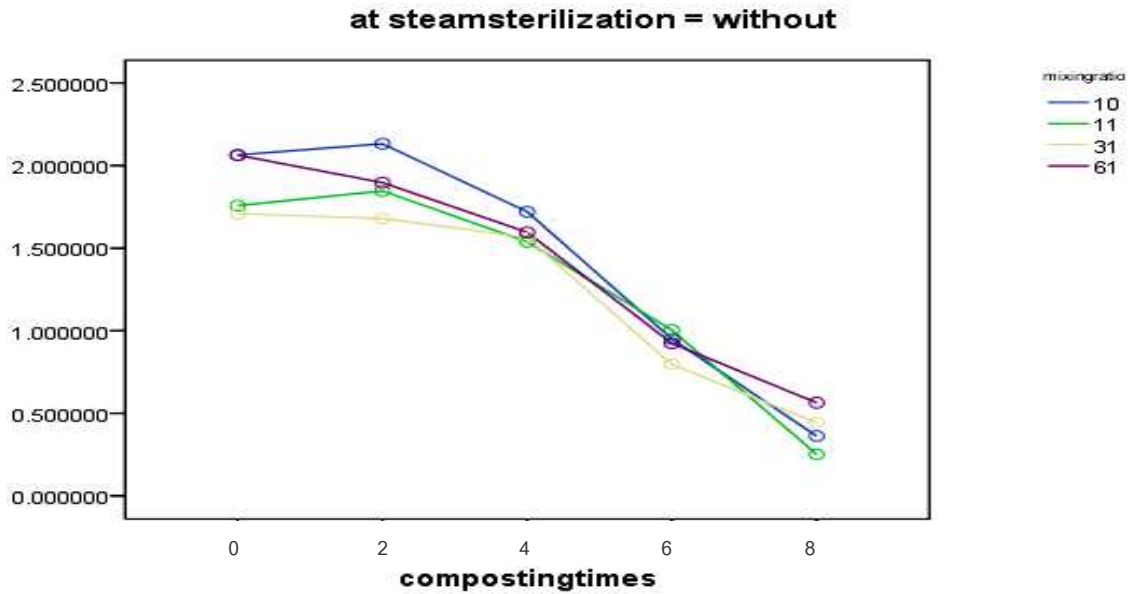


Figure 4.72 The simple main effect of mixing ratio classified by each level of steam sterilizations (without plastic cover) at each time period to total phosphorus

When an interaction exists among the three factors, F test of ANOVA is used to test the simple main effect of steam sterilizations classified by each level of mixing ratios (1:0, 1:1, 3:1 and 6:1) at each time period.

To test difference between group, Bonferroni adjustment is used to compare.

- For mixing ratio 1:0 at composting time week 4 and 8, the total phosphorus of with plastic cover was significantly different from without plastic cover as shown in Figure 4.73.

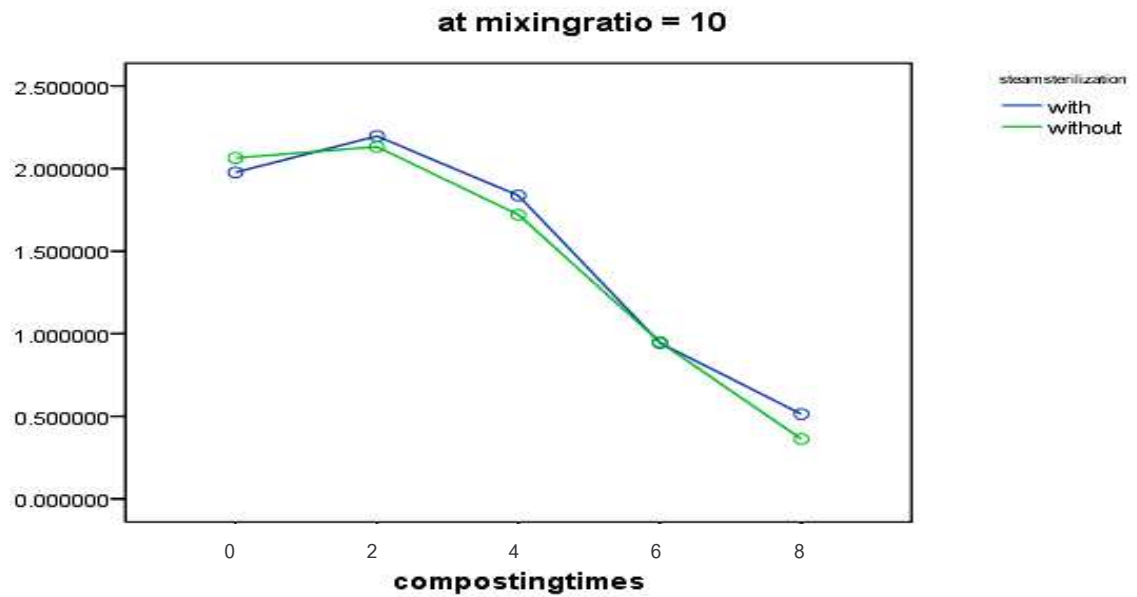


Figure 4.73 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0) at each time period to total phosphorus

- For mixing ratio 1:1 at composting time week 6 and 8, the total phosphorus of with plastic cover was significantly different from without plastic cover as shown in Figure 4.74.

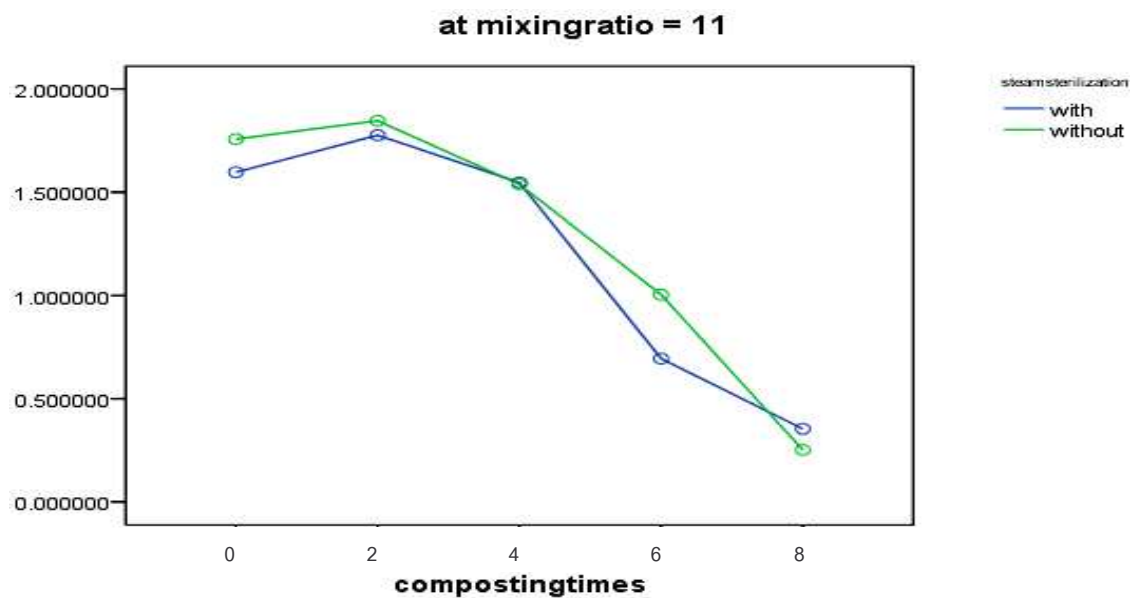


Figure 4.74 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:1) at each time period to total phosphorus

- For mixing ratio 3:1 at composting time week 0, the total phosphorus of with plastic cover was significantly different from without plastic cover as shown in Figure 4.75.

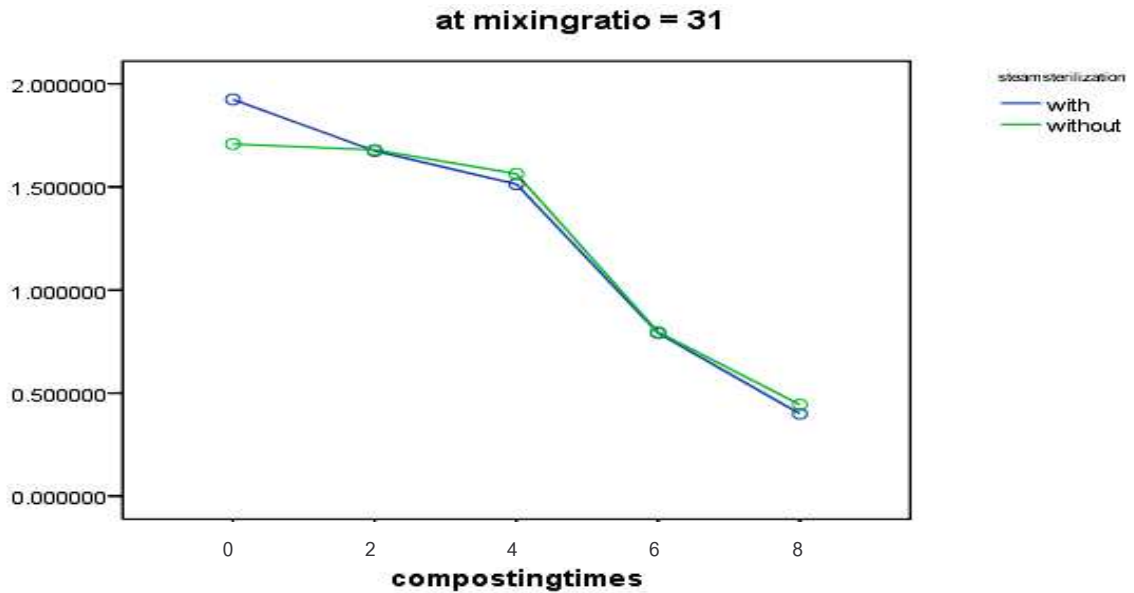


Figure 4.75 The simple main effect of steam sterilizations classified by each level of mixing ratios (3:1) at each time period to total phosphorus

- For mixing ratio 6:1 at composting time week 0, the total phosphorus of with plastic cover was significantly different from without plastic cover as shown in Figure 4.76.

- For all mixing ratio, at composting time week 4 to 8 with plastic cover treatment had not difference total phosphorus from without plastic cover treatment.

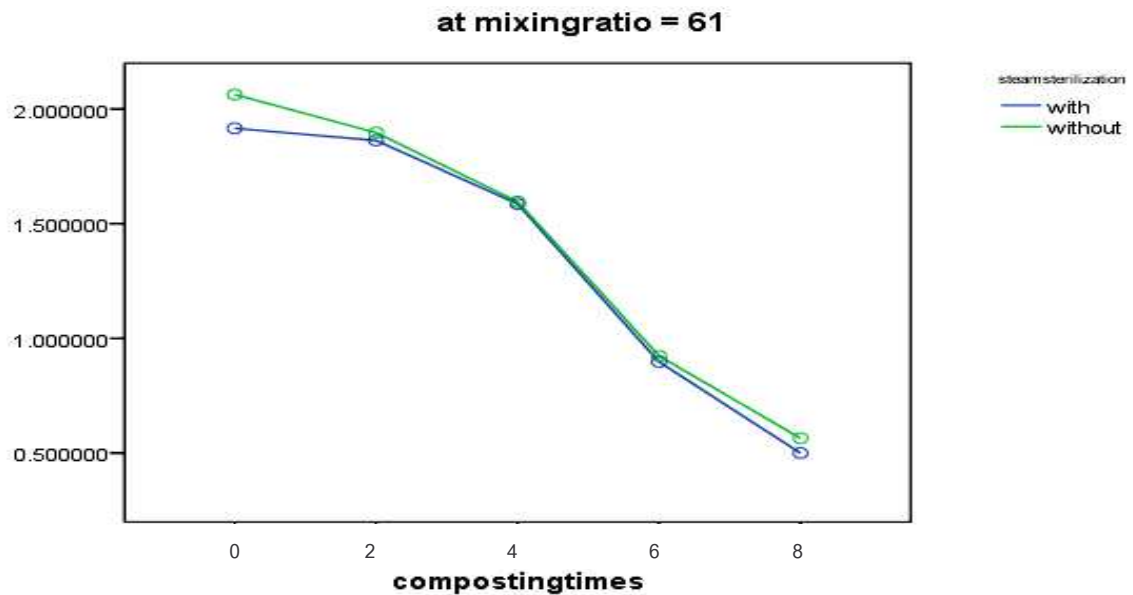


Figure 4.76 The simple main effect of steam sterilizations classified by each level of mixing ratios (6:1) at each time period to total phosphorus

To test the simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition, Bonferroni adjustment is used to test the difference between each pair of treatment.

- For mixing ratio 1:0 with plastic cover, the total phosphorus of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 1:0 without plastic cover, the total phosphorus of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 1:1 with plastic cover, the total phosphorus of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 2 was significantly different from composting time week 0 and 4.

- For mixing ratio 1:1 without plastic cover, the total phosphorus of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 3:1 with plastic cover, the total phosphorus of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 0 was significantly different from composting time week 2 and 4.

- For mixing ratio 3:1 without plastic cover, the total phosphorus of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4.

- For mixing ratio 6:1 with plastic cover, the total phosphorus of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For mixing ratio 6:1 without plastic cover, the total phosphorus of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 4 was significantly different from composting time week 0 and 2.

- For all treatments after active phase (week 4), at composting time week 6 had highest total phosphorus followed by at composting time week 8 as shown in Figure 4.77.

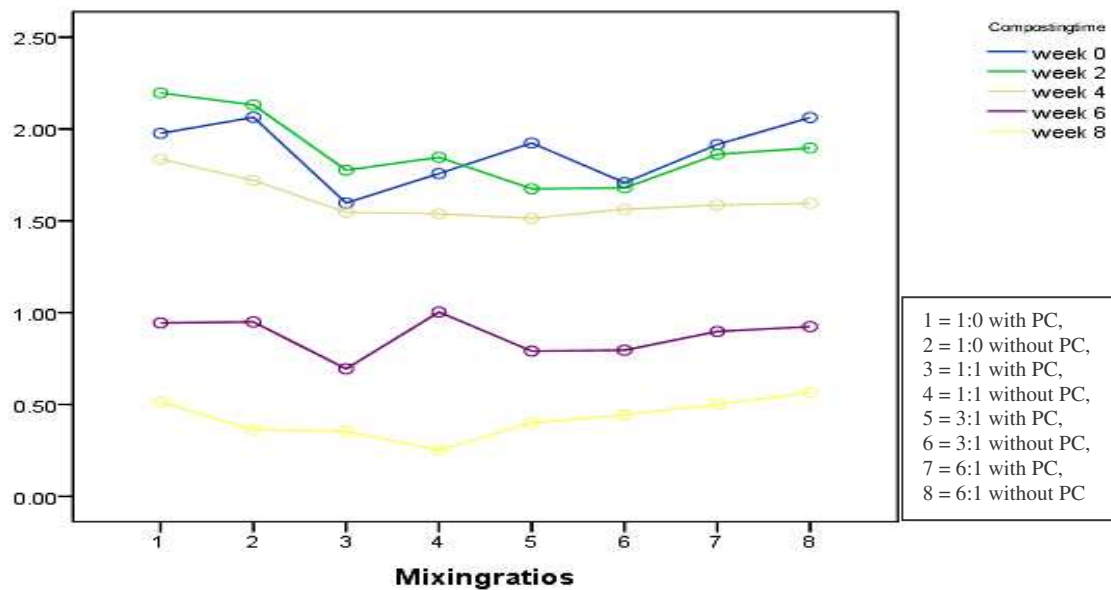


Figure 4.77 The simple main effect of composting time at each interaction level of mixing ratio and steam sterilization condition to total phosphorus

#### - Available phosphorus

The available phosphorus was measured at every two weeks of composting time starting from week 0 until the composting process was finished at week 8.

During composting process, the average available phosphorus of all treatments was in the range of 0.025-0.066%. The maximum available phosphorus at the end of composting process was the treatment which had mixing ratio 6:1 and not covered by black plastic sheet (0.042%). The minimum available phosphorus was the treatment which had mixing ratio 1:0 and covered by black plastic sheet (0.037%). The results are shown in Table 4.21. The available phosphorus of all treatments were increased at the first two weeks, after that they trended to decrease until the composting process was finished at week 8 (Figure 4.78).

Table 4.21 The average available phosphorus (%) of all treatments during the composting process at the different composting times

Treatments	Composting times				
	week 0	week 2	week 4	week 6	week 8
	(SD)	(SD)	(SD)	(SD)	(SD)
1:0 with PC	0.035 (0.00)	0.058 (0.00)	0.046 (0.00)	0.040 (0.00)	0.037 (0.01)
1:0 without PC	0.030 (0.00)	0.055 (0.00)	0.053 (0.01)	0.044 (0.01)	0.039 (0.00)
1:1 with PC	0.026 (0.01)	0.066 (0.00)	0.053 (0.00)	0.049 (0.01)	0.040 (0.01)
1:1 without PC	0.030 (0.00)	0.061 (0.00)	0.052 (0.00)	0.048 (0.01)	0.038 (0.00)
3:1 with PC	0.025 (0.00)	0.057 (0.01)	0.054 (0.00)	0.045 (0.00)	0.039 (0.00)
3:1 without PC	0.025 (0.00)	0.055 (0.00)	0.054 (0.00)	0.048 (0.00)	0.040 (0.00)
6:1 with PC	0.027 (0.00)	0.058 (0.00)	0.058 (0.01)	0.048 (0.00)	0.039 (0.00)
6:1 without PC	0.026 (0.00)	0.054 (0.00)	0.058 (0.00)	0.050 (0.00)	0.042 (0.00)

Remark: PC is plastic cover

SD is standard deviation

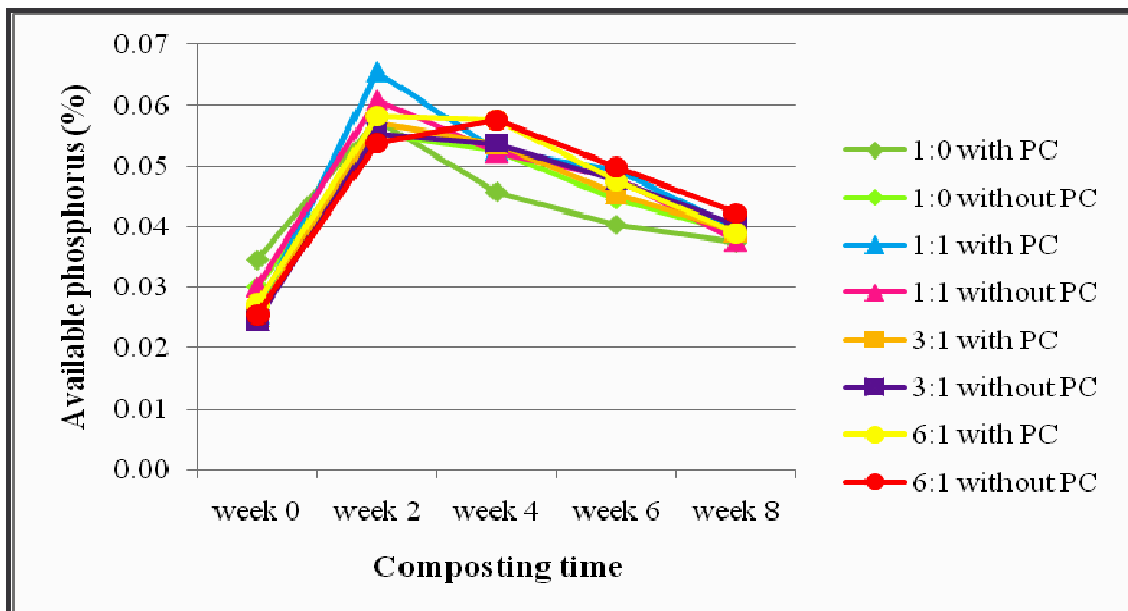


Figure 4.78 The available phosphorus trend lines of all treatments

As referred, the results indicated that the available phosphorus of all treatments after passed composting process had higher than the before passed composting process (Figure 4.79).

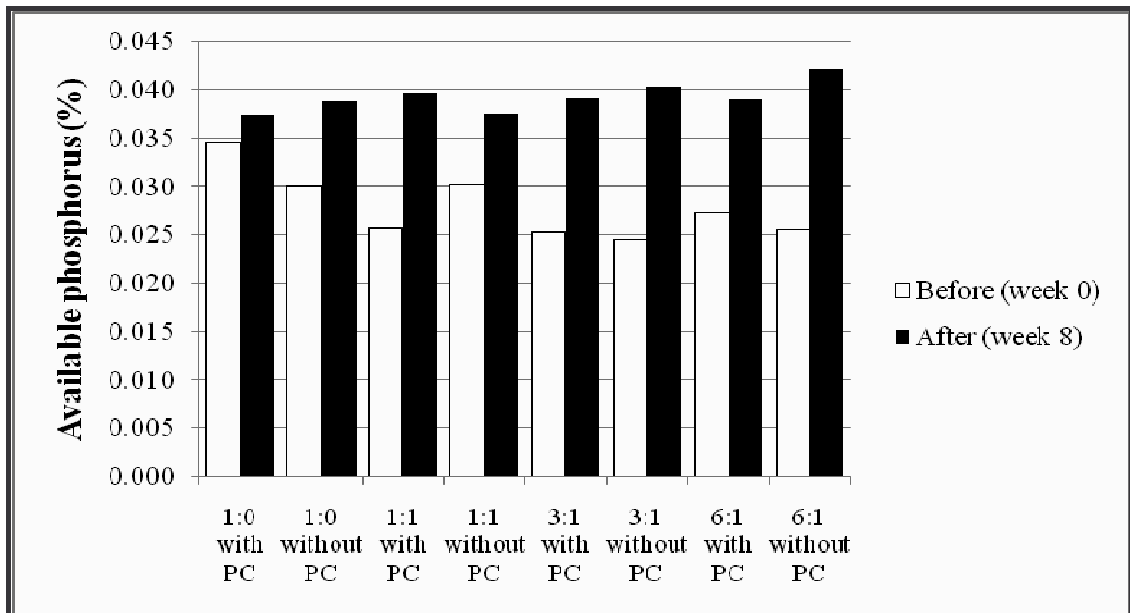


Figure 4.79 The available phosphorus of all treatments before and after passed composting process

The Three-Way Analyses of Variance with one Repeated Factors is used to analyze main effects (mixing ratio, steam sterilization, and composting time) and their and interaction effect of available phosphorus values

- The main effect of mixing ratio of all treatments was significantly different ( $P = 0.038$ ).
- The main effect of steam sterilization of all treatments was not significantly different ( $P = 0.885$ ).
- The main effect of composting time of all treatments was significantly different ( $P < 0.001$ ).

- The interaction among mixing ratio, steam sterilization and composting time were significantly different ( $P = 0.351$ ) on within subject effect. There were also had interactions between composting time and mixing ratio ( $P < 0.001$ ); between composting time and steam sterilization ( $P < 0.001$ ) and an interaction between mixing ratios and steam sterilizations ( $P = 0.762$ ). The results of analytical statistics are shown in Table 4.22.

Table 4.22 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for available phosphorus

Source	SS	df	MS	F	p-value
<b>Between-Subjects Effects</b>					
Intercept	0.243	1	0.243	1.991E4	< 0.001
Mixing ratio	< 0.001	3	4.357E-5	3.570	0.038
Steam sterilization	2.637E-7	1	2.637E-7	0.022	0.885
Mixing ratio * steam sterilization	1.425E-5	3	4.750E-6	0.389	0.762
Error	< 0.001	16	1.220E-5		
<b>Within-Subjects Effects</b>					
Composting times	0.014	4	0.003	291.901	< 0.001
composting times * mixing ratio	0.001	12	5.573E-5	4.800	< 0.001
composting times * steam sterilization	< 0.001	4	2.678E-5	2.307	< 0.001
composting times * mixing ratio * steam sterilization	< 0.001	12	1.315E-5	1.132	0.351
Error	0.001	64	1.161E-5		

When interaction exist among the two factors, F test of ANOVA is used to test the simple main effect of composting time effect to available phosphorus classified by each level of mixing ratio (1:0, 1:1, 3:1 and 6:1) at all of steam sterilization.

To test difference between group, Bonferroni adjustment is used to compare.

- For mixing ratio 1:0, the available phosphorus of composting time week 8 was significantly different from composting time week 2 and 4; composting time week 6 was significantly different from composting time week 0 and 2; composting time week 0 was significantly different from composting time week 2 and 4.

- For mixing ratio 1:1, the available phosphorus of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0 and 2; composting time week 4 was significantly different from composting time week 0 and 2; composting time week 2 was significantly different from composting time week 0.

- For mixing ratio 3:1, the available phosphorus of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 0 was significantly different from composting time week 2 and 4.

- For mixing ratio 6:1, the available phosphorus of composting time week 8 was significantly different from composting time week 0, 2, 4 and 6; composting time week 6 was significantly different from composting time week 0, 2 and 4; composting time week 0 was significantly different from composting time week 2 and 4.

- For all treatments after active phase (week 4), at composting time week 6 had highest available phosphorus followed by at composting time week 8 as shown in Figure 4.80.

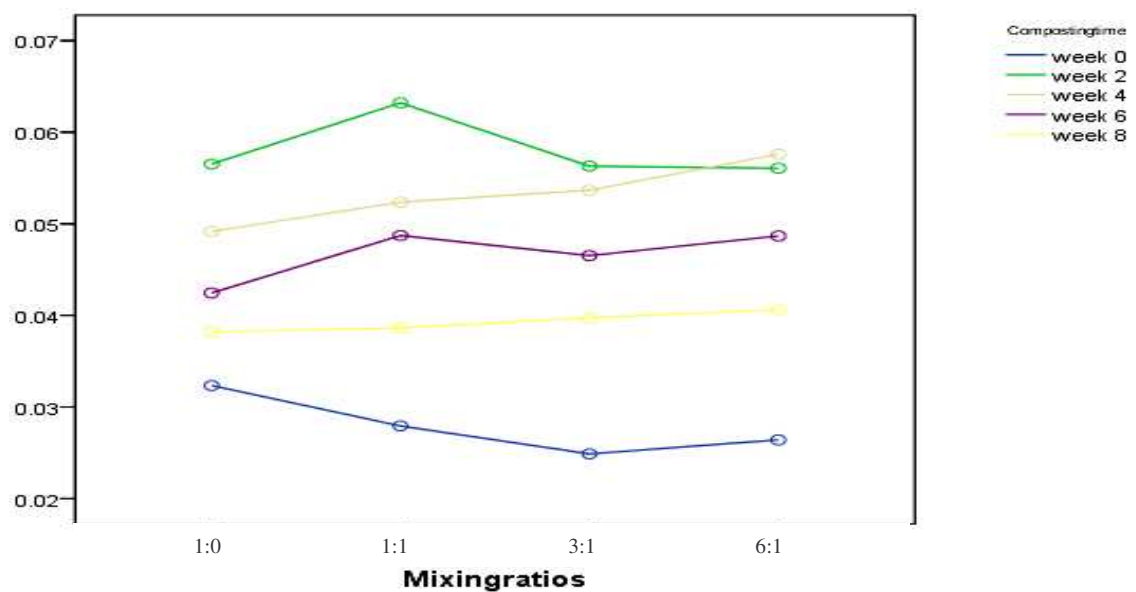


Figure 4.80 The simple main effect of composting time effect to available phosphorus classified by each level of mixing ratio at all of steam sterilization

#### 4.2.2.6 Total potassium

The total potassium was measured at every two weeks of composting time starting from week 0 until the composting process was finished at week 8.

During composting process, the average total potassium of all treatments was in the range of 1.16-1.65%. The maximum total potassium at the end of composting process was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet (1.59%). The minimum total potassium was the treatment which had mixing ratio 1:0 and both covered and not covered by black plastic sheet (1.45%). The results are shown in Table 4.23. The total potassium of all treatments was slightly increased until the composting process was finished at week 8 (Figure 4.81).

Table 4.23 The average total potassium (%) of all treatments during the composting process at the different composting times

Treatments	Composting times				
	week 0 (SD)	week 2 (SD)	week 4 (SD)	week 6 (SD)	week 8 (SD)
1:0 with PC	1.22 (0.05)	1.38 (0.05)	1.45 (0.03)	1.42 (0.10)	1.45 (0.02)
1:0 without PC	1.16 (0.22)	1.44 (0.07)	1.35 (0.06)	1.34 (0.04)	1.45 (0.07)
1:1 with PC	1.23 (0.36)	1.44 (0.01)	1.51 (0.09)	1.59 (0.09)	1.58 (0.05)
1:1 without PC	1.23 (0.25)	1.46 (0.02)	1.43 (0.03)	1.65 (0.04)	1.59 (0.04)
3:1 with PC	1.49 (0.12)	1.39 (0.06)	1.42 (0.07)	1.57 (0.03)	1.56 (0.02)
3:1 without PC	1.45 (0.17)	1.36 (0.08)	1.43 (0.03)	1.63 (0.03)	1.55 (0.05)
6:1 with PC	1.26 (0.06)	1.42 (0.05)	1.45 (0.02)	1.60 (0.03)	1.51 (0.02)
6:1 without PC	1.33 (0.02)	1.45 (0.01)	1.46 (0.09)	1.58 (0.06)	1.53 (0.07)

Remark: PC is plastic cover

SD is standard deviation

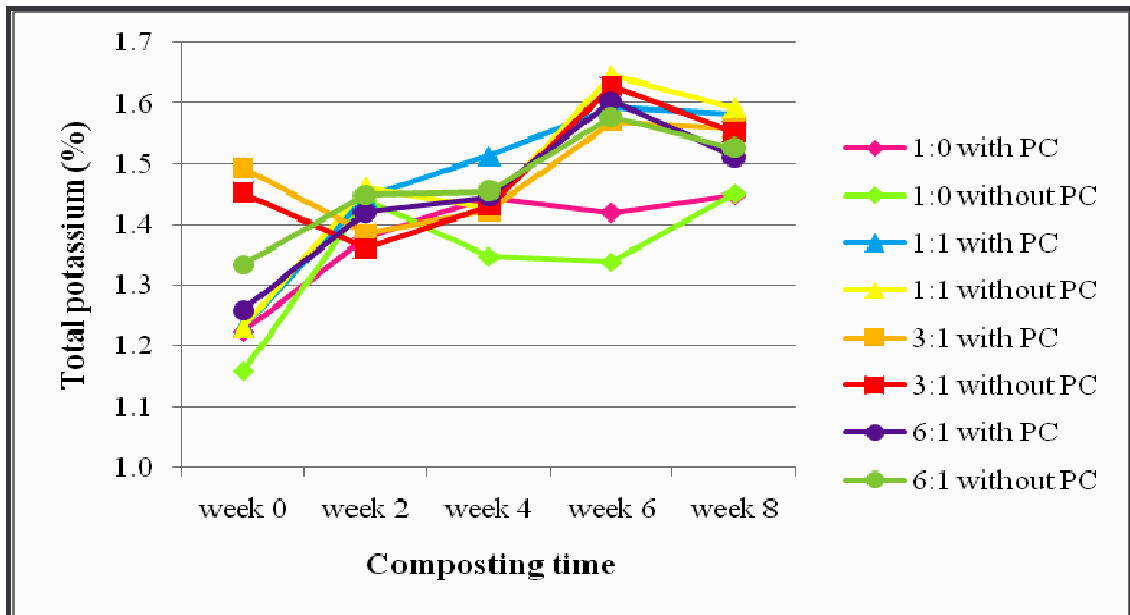


Figure 4.81 The total potassium trend lines of all treatments

As referred, the results indicated that the total potassium of all treatments after passed composting process had higher than the before passed composting process (Figure 4.82).

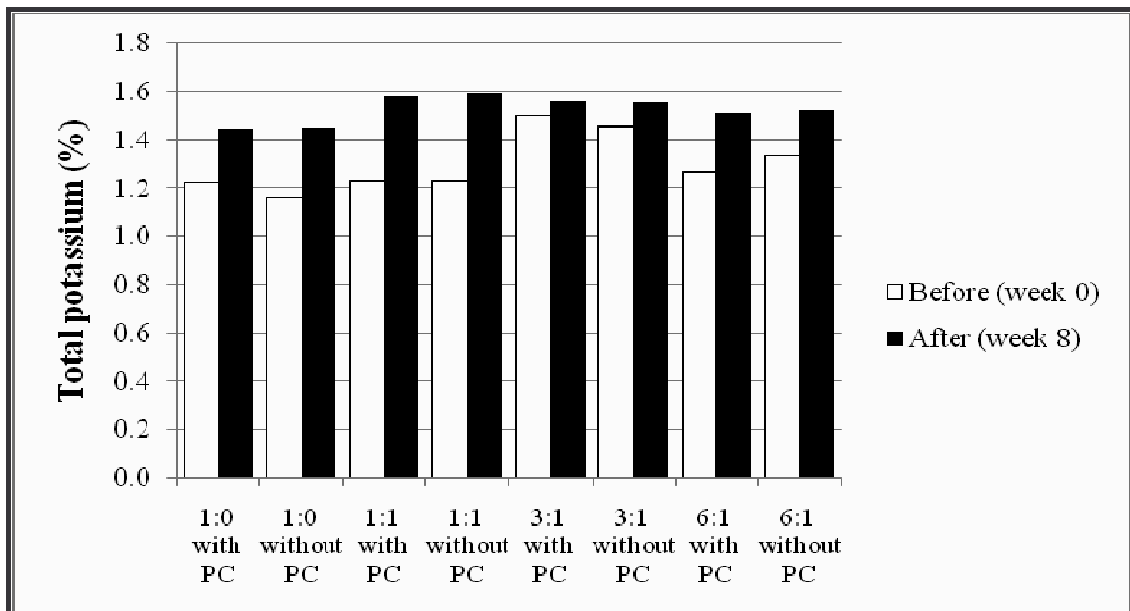


Figure 4.82 The total potassium of all treatments before and after passed composting process

The Three-Way Analyses of Variance with one Repeated Factors is used to analyze main effects (mixing ratio, steam sterilization, and composting time) and their and interaction effect of total potassium values

- The main effect of mixing ratio of all treatments was significantly different ( $P = 0.001$ ).

- The main effect of steam sterilization of all treatments was not significantly different ( $P = 0.790$ ).

- The main effect of composting time of all treatments was significantly different ( $P < 0.001$ ).

- The interaction among mixing ratio, steam sterilization and composting time were significantly different ( $P = 0.822$ ) on within subject effect. There were also had interactions between composting time and mixing ratio ( $P = 0.036$ ); between composting time and steam sterilization ( $P = 0.651$ ) and an interaction between mixing ratios and steam sterilizations ( $P = 0.718$ ). The results of analytical statistics are shown in Table 4.24.

Table 4.24 The statistic results of Three-Way Analyses of Variance with one Repeated Factor for total potassium

Source	SS	df	MS	F	p-value
<b>Between-Subjects Effects</b>					
Intercept	250.687	1	250.687	2.787E4	< 0.001
Mixing ratio	0.266	3	0.089	9.877	0.001
Steam sterilization	0.001	1	0.001	0.073	0.790
Mixing ratio * steam sterilization	0.012	3	0.004	0.454	0.718
Error	0.144	16	0.009		
<b>Within-Subjects Effects</b>					
Composting times	0.955	1.461	0.654	24.953	< 0.001
composting times * mixing ratio	0.344	4.384	0.078	2.995	0.036
composting times * steam sterilization	0.013	1.461	0.009	0.335	0.651
composting times * mixing ratio * steam sterilization	0.046	4.384	0.011	0.401	0.822
Error	0.613	23.383	0.026		

When interaction exist among the two factors, F test of ANOVA is used to test the simple main effect of composting time effect to total potassium classified by each level of mixing ratio (1:0, 1:1, 3:1 and 6:1) at all of steam sterilization.

To test difference between group, Bonferroni adjustment is used to compare.

- For mixing ratio 1:0, the total potassium of composting time week 0 was significantly different from composting time week 2, 4, 6 and 8.

- For mixing ratio 1:1, the total potassium of composting time week 0 was significantly different from composting time week 4, 6 and 8.

- For mixing ratio 3:1, the total potassium of composting time week 8 was significantly different from composting time week 2; composting time week 6 was significantly different from composting time week 2 and 4.

- For mixing ratio 6:1, the total potassium of composting time week 6 was significantly different from composting time week 2 and 4; composting time week 0 was significantly different from composting time week 2, 4, 6 and 8.

- For almost treatments after active phase (week 4), at composting time week 6 had highest total potassium followed by at composting time week 8 as shown in Figure 4.83.

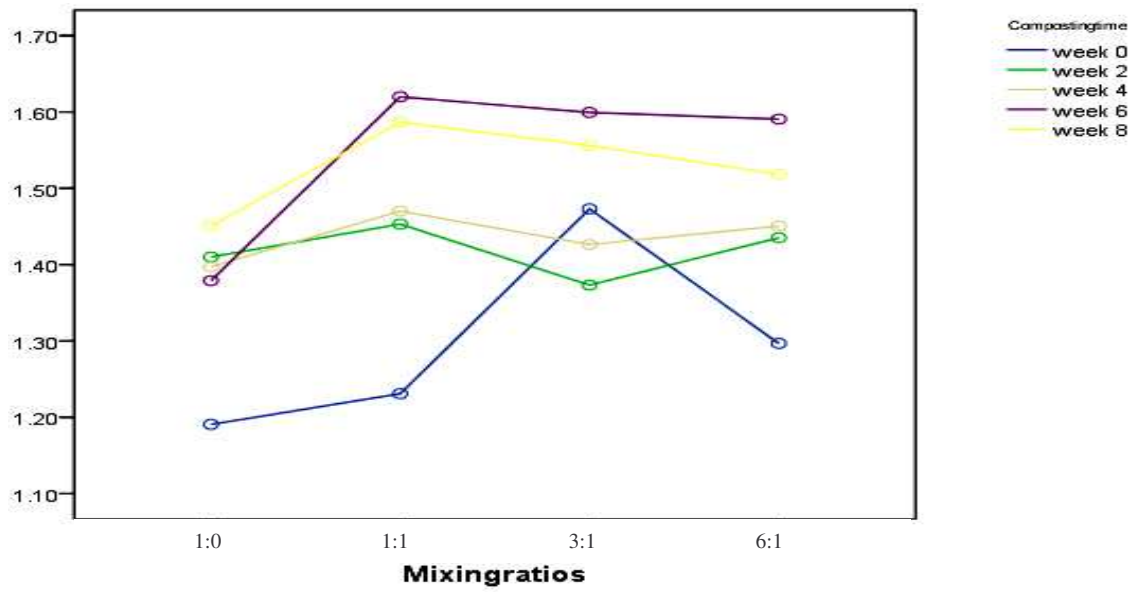


Figure 4.83 The simple main effect of composting time effect to total potassium classified by each level of mixing ratio at all of steam sterilization

### 4.3 Summary of the characteristic changes at the end of composting process

The aim of this study was sewage sludge utilization. At the end of experiment, the results of almost nutrients were in line with the organic fertilizer standard of the Department of Agriculture [44], except the organic matter and total phosphorus. The conclusion was described and compare with organic fertilizer standard as follow;

#### 4.3.1 The effects of mixing ratio to characteristic changes

- **Temperature:** The mixing ratio had the effect to temperature changes of all treatments ( $P = 0.005$ ).
- **Total solids:** The mixing ratio had the effect to total solids changes of all treatments ( $P < 0.001$ ).
- **Volatile solids:** The mixing ratio had the effect to volatile solids changes of all treatments ( $P < 0.001$ ).
- **pH:** The mixing ratio had the effect to pH changes of all treatments ( $P < 0.001$ ).
- **Organic matter:** The mixing ratio had the effect to organic matters changes of all treatments ( $P < 0.001$ ).
- **Organic nitrogen:** The mixing ratio had the effect to organic nitrogen changes of all treatments ( $P < 0.001$ ).
- **Inorganic nitrogen:** The mixing ratio had the effect to inorganic nitrogen changes of all treatments ( $P < 0.001$ ).
- **Carbon to nitrogen ratio:** The mixing ratio had the effect to carbon to nitrogen ratio changes of all treatments ( $P < 0.001$ ).
- **Total phosphorus:** The mixing ratio had the effect to total phosphorus changes of all treatments ( $P < 0.001$ ).
- **Available phosphorus:** The mixing ratio had the effect to available phosphorus changes of all treatments ( $P = 0.038$ ).
- **Total potassium:** The mixing ratio had the effect to available phosphorus changes of all treatments ( $P = 0.001$ ).

### 4.3.2 The effects of steam sterilization to characteristic changes

- **Temperature:** The steam sterilization had not the effect to temperature changes of all treatments ( $P = 0.121$ ).
- **Total solids:** The steam sterilization had the effect to total solids changes of all treatments ( $P < 0.001$ ).
- **Volatile solids:** The steam sterilization had the effect to volatile solids changes of all treatments ( $P < 0.001$ ).
- **pH:** The steam sterilization had the effect to pH changes of all treatments ( $P < 0.001$ ).
- **Organic matter:** The steam sterilization had not the effect to organic matters changes of all treatments ( $P = 0.149$ ).
- **Organic nitrogen:** The steam sterilization had the effect to organic nitrogen changes of all treatments ( $P < 0.001$ ).
- **Inorganic nitrogen:** The steam sterilization had the effect to inorganic nitrogen changes of all treatments ( $P < 0.001$ ).
- **Carbon to nitrogen ratio:** The steam sterilization had not the effect to carbon to nitrogen ratio changes of all treatments ( $P = 0.252$ ).
- **Total phosphorus:** The steam sterilization had not the effect to total phosphorus changes of all treatments ( $P = 0.107$ ).
- **Available phosphorus:** The steam sterilization had not the effect to available phosphorus changes of all treatments ( $P = 0.885$ ).
- **Total potassium:** The steam sterilization had not the effect to total potassium changes of all treatments ( $P = 0.790$ ).

### 4.3.3 The effects of composting time to characteristic changes

- **Temperature:** The composting time had the effect to temperature changes of all treatments ( $P < 0.001$ ).
- **Total solids:** The composting time had the effect to total solids changes of all treatments ( $P < 0.001$ ).
- **Volatile solids:** The composting time had the effect to volatile solids changes of all treatments ( $P < 0.001$ ).
- **pH:** The composting time had the effect to pH changes of all treatments ( $P < 0.001$ ).
- **Organic matter:** The composting time had the effect to organic matters changes of all treatments ( $P < 0.001$ ).
- **Organic nitrogen:** The composting time had the effect to organic nitrogen changes of all treatments ( $P < 0.001$ ).
- **Inorganic nitrogen:** The composting time had the effect to inorganic nitrogen changes of all treatments ( $P < 0.001$ ).
- **Carbon to nitrogen ratio:** The composting time had the effect to carbon to nitrogen ratio changes of all treatments ( $P < 0.001$ ).
- **Total phosphorus:** The composting time had the effect to total phosphorus changes of all treatments ( $P < 0.001$ ).
- **Available phosphorus:** The composting time had the effect to available phosphorus changes of all treatments ( $P < 0.001$ ).
- **Total potassium:** The composting time had the effect to total potassium changes of all treatments ( $P < 0.001$ ).

#### 4.3.4 The first and the second highest of characteristic changes

- **Temperature:** At the end of composting process, the first highest temperature was the treatment which had mixing ratio 1:0 and not covered by black plastic sheet. The second highest temperature was the treatment which had mixing ratio 3:1 and not covered by black plastic sheet.

- **Total solids:** At the end of composting process, the first highest total solids were the treatment which had mixing ratio 6:1 and not covered by black plastic sheet. The second highest total solids were the treatment which had mixing ratio 1:0 and not covered by black plastic sheet.

- **Volatile solids:** At the end of composting process, the first highest volatile solids was the treatment which had mixing ratio 1:1 and covered by black plastic sheet. The second highest volatile solids at the end of composting time was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet.

- **pH:** At the end of composting process, the first highest pH value was the treatment which had mixing ratio 1:0 and not covered by black plastic sheet. The second highest volatile solids at the end of composting time was the treatment which had mixing ratio 3:1 and not covered by black plastic sheet.

- **Organic matter:** At the end of composting process, the first highest organic matter were the treatment which had mixing ratio 1:1, both covered and not covered by black plastic sheet. The second highest organic matters were the treatment which had mixing ratio 3:1, both covered and not covered by black plastic sheet, the treatment which had mixing ratio 6:1, both covered and not covered by black plastic sheet.

- **Total nitrogen:** The results of total nitrogen of all treatments during week 8 of composting time had in the range 1.29-1.48%.

At the end of composting process, the first highest total nitrogen was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet. The second highest total nitrogen was the treatment which had mixing ratio 3:1, both covered and not covered by black plastic sheet, the treatment which had mixing ratio 6:1 and covered by black plastic sheet.

- **Carbon to nitrogen ratio:** At the end of composting process, the first highest carbon to nitrogen ratio was the treatment which had mixing ratio 1:1 and covered by black plastic sheet. The second highest carbon to nitrogen ratio was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet, the treatment which had mixing ratio 3:1, both covered and not covered by black plastic sheet, and the treatment which had mixing ratio 6:1, both covered and not covered by black plastic sheet.

- **Total phosphorus:** At the end of composting process, the first highest total phosphorus was the treatment which had mixing ratio 6:1 and not covered by black plastic sheet. The second highest total phosphorus was the treatment which had mixing ratio 1:0 and covered by black plastic sheet.

- **Available phosphorus:** At the end of composting process, the first highest available phosphorus was the treatment which had mixing ratio 6:1 and not covered by black plastic sheet. The second highest available phosphorus was the treatment which had mixing ratio 1:1 and covered by black plastic sheet, and the treatment which had mixing ratio 3:1 and not covered by black plastic sheet

- **Total potassium:** At the end of composting process, the first highest total potassium was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet. The second highest total potassium was the treatment which had mixing ratio 1:1 and covered by black plastic sheet.

Table 4.25 are shown the nutrient values in each treatment at the end of composting process and the organic fertilizer standard of Department of Agriculture [44].

Table 4.25 Compare nutrient values at the different conditions of composting with the organic fertilizer standard of the Department of Agriculture [44]

Nutrients	Treatments								organic fertilizer standard
	1:0	1:0	1:1	1:1	3:1	3:1	6:1	6:1	
	with PC	without PC	with PC	without PC	with PC	without PC	with PC	without PC	
pH	6.19	6.43	6.08	6.12	5.96	6.36	6.01	6.16	5.5-8.5
Organic matter*	15.18	14.88	18.44	18.13	16.10	16.70	16.40	16.45	> 30.0
Total nitrogen*	1.41	1.35	1.29	1.48	1.41	1.35	1.44	1.35	≥ 1.0
C/N ratio	6:1	6:1	8:1	7:1	7:1	7:1	7:1	7:1	≤ 20:1
Total phosphorus*	0.51	0.36	0.35	0.25	0.40	0.44	0.50	0.56	≥ 0.5
Total potassium*	1.45	1.45	1.58	1.59	1.56	1.55	1.51	1.53	≥ 0.5

Remark: \* is the unit of nutrients (%)

## CHAPTER V

### DISCUSSION

This chapter is conducted to discuss in term of initial chemical characteristics of sewage sludge and grass clippings, which used as raw materials for composting. In addition, the physical and chemical characteristics of the end product also have been discussed.

#### **5.1 Characteristics of sewage sludge and grass clippings**

The sewage sludge in this study contained moisture content 78.09%, pH 6.66, organic matter 19.01%, total nitrogen 2.17% and C/N ratio 5.08:1. Total nitrogen and pH of sewage sludge were resemble with the report from AIT (1995) and Eckhardt et al (1998) [9, 20], which contained total nitrogen in the range of 0.5-4.6% and pH in the range of 6.6-7.8. This was because of the sewage sludge of AIT and this study was from the same generated source. The sewage sludge which was collected by AIT (1995) was from Si Praya central wastewater treatment plant and Huay Kwang wastewater treatment plant, which the sewage sludge in this study was collected from wastewater treatment plants in Bangkok area. It implies that waste characteristics do not change much during the past fifteen years (1995-2010).

The grass clippings in this study contained moisture content 2.65%, pH 5.70, organic matter 28.87%, total nitrogen 0.98% and C/N ratio 17.08. Total nitrogen of grass clippings was resembled with the final report of compost demonstration project on the use of yard trimmings products: agriculture in partnership with San Jose [46], which had total nitrogen 1.2%. Besides this, the C/N ratio of grass clippings was in the range of 12-20:1 and similar to the United States environmental Protection Agency, 1994 [33]. pH of grass clippings was consistent with Craig Cogger et al [48], which had pH in the range of 5.0-6.0. The characteristic

of glass clippings in this study were resemble with other researches because the glass clippings were also collected from the mixture of 1-3 glass types [33].

The results of moisture content and chemical characteristics of sewage sludge and grass clippings were match with the organic fertilizer standard of Department of Agriculture (2005) [44].

## **5.2 Nutrients mineralization study**

### **5.2.1 Physical characteristics**

#### **5.2.1.1 Temperature**

The average temperatures of all treatments during 8 weeks of composting times were higher than the average of ambient temperature around 3-5 °C. The temperatures that enhance microbial activity are in the range of 28-55 °C. The highest oxygen consumption also occurs within this range [38]. The results of temperature in this study were in the range of 28-55 °C therefore they were suitable to microbial activities. The temperature has the direct effect on the chemical, physical, and soil microbial activities. Increasing temperature would increase the decomposition rate of organic matter [39], therefore it was resemble with the results in this study.

The initial temperatures in composting process of all treatments were resembled. In during the first week until the last week of composting times, the temperatures of all treatments were increased in the same trend.

The statistical analysis showed the mixing ratio had the effect to temperature at  $P = 0.005$ . Increasing sewage sludge to grass clippings ratio could increase carbon to nitrogen ratio which resulted in increasing composting temperature [40].

The statistical analysis showed the steam sterilization had no effect to temperature at  $P = 0.121$ . However, the result was found temperature in treatment which not covered by black plastic sheet was higher than that treatment which covered by black plastic sheet. Treatments which covered by black plastic sheet caused the accumulation of water in piles and some water could not evaporated during daylight therefore, these treatments had more moisture content and low temperature.

Expected, steam sterilization was not completely occurring because temperature ambient had influence to it.

The statistical analysis showed the composting time had the effect to temperature at  $P < 0.001$ . This was because of the temperature was increased during increasing composting times.

The different of temperature between initial and the end of composting process, the first highest different of temperature was the treatment which had mixing ratio 3:1 and not covered by black plastic sheet. The second highest different of temperature was the treatment which had mixing ratio 6:1 and covered by black plastic sheet.

In this study, the initial temperature was the most difference with the temperature at the end of composting process because of the ambient temperature had not changed much. Moreover, during composting, it was frequent rain and the weather was in the winter season.

#### **5.2.1.2 Total solids**

Total solid content comprises of suspended and dissolved solids which is usually expressed as a percentage of total solids in sewage sludge. The total solids in this study during 8 weeks of composting times were resembled with Metcalf and Eddy, which contained 12-40 % solids in dewatered sewage sludge [19].

The initial total solids in composting process of all treatments were similar. In during the first week until the last week of composting times, the total solids of all treatments had in the same trend.

The result of statistical analysis revealed that the mixing ratio had the effect to total solids at  $P < 0.001$ . This was because of the different of the initial carbon to nitrogen ratio had effected to total solids quantity.

The result of statistical analysis also found the steam sterilization had the effect to total solids at  $P < 0.001$ . The total solids of all treatments trended to increase according to increasing temperature. The treatments which covered by black plastic sheet had the total solids lower than treatments which not covered by black plastic sheet. As referred, steam sterilization had no effect to temperature change because of the treatments which covered by black plastic sheet were not difference

with the treatments which not covered by black plastic sheet. In this case, the temperature had no influence to decomposition rate but the air ventilation in composting pile was it. The treatments which covered by black plastic sheet had low oxygen from lease ventilation for the decomposition organic matter into total solids, therefore total solids in this treatments was lower than that of the treatments which not covered by black plastic sheet.

The result of statistical analysis found the composting time had the effect to total solids at  $P < 0.001$ . This was because of the total solids of all treatments trended to increase according to increasing composting time.

The different of total solids between initial and the end of composting process, the first highest different of total solids was the treatment which had mixing ratio 6:1 and not covered by black plastic sheet. The second highest different of total solids was the treatment which had mixing ratio 1:0 and not covered by black plastic sheet.

At the end of composting process, the first highest total solids were the treatment which had mixing ratio 6:1 and not covered by black plastic sheet. The second highest total solids were the treatment which had mixing ratio 1:0 and not covered by black plastic sheet.

### **5.2.1.3 Volatile solids**

Unstable sewage sludge can cause potential odor problems because it contains 75.80 % of volatile solid on a dry weight basis [19], but in during the first week until the last week of composting times of all treatments had 37-46% of volatile solids thus they had no odor problem. It was because of composting process and the sewage sludge in this study was random sampled from Nong Khaem wastewater treatment plant which has been treated by anaerobic digestion and dewatered by belt press therefore the initial volatile solids were reduced.

In during the first week until the last week of composting times, the volatile solids of all treatments had the same trend.

The result of statistical analysis revealed that the mixing ratio had the effect to volatile solids at  $P < 0.001$ . This was because of the different of the

initial carbon to nitrogen ratio had effected to microbial activities to change the organic matter into volatile solids.

The result of statistical analysis also found the steam sterilization had the effect to volatile solids at  $P < 0.001$ . The volatile solids of all treatments trended to decrease according to increasing temperature. The treatments which covered by black plastic sheet had the volatile solids higher than treatments which not covered by black plastic sheet. The temperature had the effect to change total solids into volatile solids but it were not the most difference in each treatment, therefore volatile solids quantity of treatments which covered by black plastic sheet were not much more than treatments which not covered by black plastic sheet.

The volatile solids of all treatments trended to decrease according to the increasing composting time. They were resembled with the result of statistical analysis that the composting time had the effect to volatile solids at  $P < 0.001$ . The results of volatile solids in this study were resemble with the research of Cabañas-Vargas [50] that found the majority of volatile solids reduction occurred during the first 6 to 8 weeks and little further decrease was detected during the maturation process.

The different of volatile solids between initial and the end of composting process, the first highest different of volatile solids was the treatment which had mixing ratio 3:1 and not covered by black plastic sheet. The second highest different of volatile solids was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet.

At the end of composting process, the first highest volatile solids were the treatment which had mixing ratio 1:1 and covered by black plastic sheet. The second highest volatile solids were the treatment which had mixing ratio 1:1 and not covered by black plastic sheet.

## 5.2.2 Chemical characteristics

### 5.2.2.1 pH

The optimum pH range in composting is quite broad that difficulties due to an excessively high or low pH level are rarely encountered. A pH range of organic materials from 3 to 11 can be composted. Composting can work effectively at the pH ranges 5.5-9.0. However, the process is most effective at 6.5-8.0 [38].

The pH in this study during week 8 of composting times was in the range of 5.24-6.68. They were resembled with a standby of John Pichtel [38].

The initial pH values in composting process of all treatments were resembled. In during the first week until the last week of composting times, the pH values of all treatments had the same trend.

The statistical analysis showed the mixing ratio had the effect to pH at  $P < 0.001$ . Increasing sewage sludge to grass clippings ratio could increase carbon to nitrogen ratio which resulted to decomposition reaction by microorganism, therefore pH trend had the similar with decomposition rate.

The statistical analysis showed the steam sterilization had the effect to pH at  $P < 0.001$ . The result was found temperature in treatment which not covered by black plastic sheet was higher than that of treatments which covered by black plastic sheet. The high rate of decomposition by microorganism had the affected from high temperature. At the fourth week of composting process, the pH of treatments which not covered by black plastic sheet were lower than pH of treatments which covered by black plastic sheet because of it had more the production rate of organic acids.

The result of statistical analysis showed that the composting time had the effect to pH at  $P < 0.001$ . It had the effect to pH because of the pH level normally decreases (perhaps to as low as 5.0) in during the early stages of composting because the production of organic acids (e.g., formic, acetic, and pyruvic). These acids serve as substrates for succeeding microbial populations. As the acids are decomposed, pH rises and often stabilizes at approximately neutral [38]. As referred, the pH trended in this study was resembled with them.

The different of pH between initial and the end of composting process, the first highest different of pH was the treatment which had mixing ratio 1:1 and covered by black plastic sheet. The second highest different of pH was the treatment which had mixing ratio 3:1 and not covered by black plastic sheet.

At the end of composting process, the first treatment that pH nearly the neutral was the treatment which had mixing ratio 1:0 and not covered by black plastic sheet. The second was the treatment which had mixing ratio 3:1 and not covered by black plastic sheet.

The final pH values of all treatments were in the line with organic fertilizer standard of Department of Agriculture [44].

#### **5.2.2.2 Organic matter**

Generally, microorganisms used the organic carbon as energy source and converted it into cell material and it has the effect to composting process. Organic matter help increases water holding capacity and hydraulic conductivity and organic matter also provides the adsorption sites for heavy metals [19].

In during the first week until the last week of composting times, the organic matters of all treatments had the same trend.

The statistical analysis showed the mixing ratio had the effect to organic matter at  $P < 0.001$ . Decreasing amount of sewage sludge (%) could increase organic matter. It had the effect to organic matter because of mixing ratio or C/N ratio is a factor used to control the rate of organic matter decomposition [39].

The statistical analysis showed the steam sterilization had no effect to organic matter at  $P = 0.149$ . The result was found temperature in treatments which not covered by black plastic sheet were not the most difference treatments with that of which covered by black plastic sheet, therefore steam sterilization was not influence to organic matter decomposition.

Composting time had the effect to organic matter at  $P < 0.001$ . It had the effect to organic matter because at the initial of composting process, all treatments had a large quantity of organic matter which non-biodegradable matters, after that organic matter degraded by microorganism and used it as energy sources for growth and then organic matter was degrading and decreasing [39].

The different of organic matter between initial and the end of composting process, the first highest different of organic matter was the treatment which had mixing ratio 1:0 and not covered by black plastic sheet. The second highest different of organic matter was the treatment which had mixing ratio 3:1 and covered by black plastic sheet.

At the end of composting process, the first highest organic matter was the treatment which had mixing ratio 1:1 and covered by black plastic sheet. The second highest organic matter was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet.

However, the organic matters of all treatments were not in the line with the organic fertilizer standard of Department of Agriculture. The standard value for organic matter should be more than 30 % by weight [44].

### **5.2.2.3 Total nitrogen**

Plants require nitrogen in relatively large amounts as compared with their need of other nutrients. The major source of natural nitrogen in the soil is provided by the decomposition of plant and animal residual added to the soil, and by the mineralization of soil organic matter [25]. The total nitrogen contains organic nitrogen and inorganic nitrogen. The organic nitrogen exists in materials formed from animal, human, and plant activities that produce manures, sewage waste, compost, and decomposing roots or leaves. These organic products transform into organic soil material called humus. Inorganic nitrogen comes from minerals, and is added to soil from precipitation, or as fertilizers. But the most of the nitrogen (N) in the environment is in forms that are unavailable for plant uptake.

Soil temperature has a strong effect on organic nitrogen which converted to inorganic nitrogen. Microbial activity is limited at soil temperature near freezing and increases with rising soil temperature and maximum N mineralization occurs when the soil temperature reaches 30-35 °C. It is resemble with the temperature of all treatments in this study.

- **Organic nitrogen:** The result of statistic analysis was showed the mixing ratio had the effect to organic nitrogen at  $P < 0.001$ . It had the effect to organic nitrogen because of carbon to nitrogen ratio had influences the rate of decomposition of organic matter and it had the effect in the released nitrogen.

The result of statistic analysis was showed the composting time had the effect to organic nitrogen at  $P < 0.001$ . It had the effect to organic nitrogen because of the organic nitrogen contained in soil organic matter is converted into plant-useable inorganic forms (ammonium,  $\text{NH}_4^+$ , and nitrate,  $\text{NO}_3^-$ ) as a result of the activities of soil microorganisms [24]. Therefore, the organic nitrogen of all treatments trended to decrease according to increasing composting time.

- **Inorganic nitrogen:** The result of statistic analysis was showed the mixing ratio had the effect to inorganic nitrogen at  $P < 0.001$ . It was resemble with W. O. Enwezor [51] which studied about the mineralization of nitrogen and phosphorus in organic materials of varying C/N and C/P ratios and that result was found nitrogen mineralization increased with decreasing C/N ratio because of the microorganisms decomposed total nitrogen to inorganic nitrogen.

The result of statistic analysis was showed the steam sterilization had the effect to inorganic nitrogen at  $P < 0.001$ . The treatments which not covered by black plastic sheet was the organic nitrogen lower than treatments which covered by black plastic sheet, in the other hand, the treatments which not covered by black plastic sheet had the inorganic nitrogen more than treatments which covered by black plastic sheet. As referred, steam sterilization had no effect to temperature change because of the treatments which covered by black plastic sheet were not the most difference with the treatments which not covered by black plastic sheet. Thus decomposition rate was depended on composting condition. The treatments which covered by black plastic sheet had lower ventilation and oxygen supply for the decomposition of organic nitrogen to inorganic nitrogen, therefore inorganic nitrogen in this treatments was lower than the treatments which not covered by black plastic sheet.

The result of statistic analysis was showed the composting time had the effect to inorganic nitrogen at  $P < 0.001$ . It had the effect to inorganic nitrogen because of the inorganic nitrogen of all treatments trended to increase according to increasing composting time. The rate of the decomposition proceeds depends on the temperature, at low temperature, total nitrogen release into inorganic nitrogen less than high temperature [24]. Therefore, it was resemble with the result of inorganic nitrogen of all treatments which had the trended to increase according to increasing temperature.

The decomposition of organic matter has the indirect effects on plant available because the organic acids is by product from the decomposition process can dissolve some element compounds and make them become plant available [39]. Therefore the treatments which had decreased organic matter leads to decreased organic nitrogen and increased inorganic nitrogen.

The results of total nitrogen of all treatments during week 8 of composting times were in the range of 1.29-1.48%. At the end of composting process, the first highest total nitrogen was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet. The second highest total nitrogen was the treatment which had mixing ratio 3:1, both covered and not covered by black plastic sheet, the treatment which had mixing ratio 6:1 and covered by black plastic sheet.

The total nitrogen of all treatments was in the line with organic fertilizer standard of Department of Agriculture [44].

#### **5.2.2.4 Carbon to nitrogen ratio**

Carbon to nitrogen ratio in the feedstock strongly affects to the rate of microbial activity. With few exceptions, all other nutrients are present in organic waste in adequate amounts and ratios [38].

The ideal ratio 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 and the optimum C/N ratio for soil and compost microorganisms has been established at approximately 25:1 [38].

The result of statistic analysis was showed the mixing ratio had the effect to carbon to nitrogen ratio at  $P < 0.001$ . It had the effect to carbon to nitrogen ratio because of the organic carbon content (%) and total nitrogen (%) in each ratio were difference. The percentage of total nitrogen had change more than the percentage of organic carbon content therefore, the carbon to nitrogen ratio which was calculated from organic carbon content (%) divided by amount of total nitrogen (%) could difference.

Composting time had the effect to carbon to nitrogen ratio at  $P < 0.001$ . The total nitrogen of all treatments trended to decrease according to increasing composting time because of it was due to conversion of organic nitrogen to ammonia by microorganisms. As mentioned above, carbon to nitrogen ratios increased would be a result from decreased total nitrogen [52].

In during the first week until the last week of composting times, the carbon to nitrogen ratio of all treatments had the same trend.

The different of carbon to nitrogen ratio between initial and the end of composting process, the first highest different of carbon to nitrogen ratio was the treatment which had mixing ratio 1:1 and covered by black plastic sheet. The second highest different of carbon to nitrogen ratio was the treatment which had mixing ratio 6:1 and not covered by black plastic sheet.

The carbon to nitrogen ratio of all treatments was in line with the organic fertilizer standard of the Department of Agriculture [44].

#### **5.2.2.5 Phosphorus**

Phosphorus is required as a small but vital ingredient in cell nuclei and it is essential for cell division and growth [25].

Phosphorus mineralization reactions in a way are similar to that nitrogen. Mineralization of organic phosphorus is enhanced by pH values that are conducive to general microbial actions. Generally, increasing the soil pH from acid to alkaline enhances phosphorus mineralization of phosphorus likes mineralization of nitrogen. They were rapid at higher soil temperature. Higher rates of biochemical reactions can be expected as the temperature increases [30].

In during the first week until the last week of composting times, the total phosphorus, and available phosphorus of all treatments had the same trend.

- **Total phosphorus:** The result of statistic analysis was showed the mixing ratio had the effect to total phosphorus at  $P < 0.001$ . Phosphorus exists in soils in organic and inorganic forms and organic forms of phosphorus are found in humus and other organic material [29]. Therefore, organic matter quantity in each mixing ratio had the effect to changed total phosphorus.

The result of statistic analysis was showed the composting time had the effect to total phosphorus at  $P < 0.001$ . It was resemble with the research of Vicente Espinosa Hernandez [53] that studied about effect of incubation period on phosphate sorption from three phosphorus sources in Morelos soil and it was found phosphorus is highest on the first day and it will gradually decrease with increasing duration.

The different of total phosphorus between initial and the end of composting process, the first highest different of total phosphorus was the treatment which had mixing ratio 1:0 and not covered by black plastic sheet. The second highest different of total phosphorus was the treatment which had mixing ratio 3:1 and covered by black plastic sheet.

At the end of composting process, the first highest total phosphorus was the treatment which had mixing ratio 6:1 and not covered by black plastic sheet. The second highest total nitrogen was the treatment which had mixing ratio 1:0 and covered by black plastic sheet.

The total phosphorus of all treatments were not in line with the organic fertilizer standard of the Department of Agriculture [44], except the treatment which had mixing ratio 1:0 and covered by black plastic sheet, the treatment which had mixing ratio 6:1, both covered and not covered by black plastic sheet. The standard value for total phosphorus should be more than 0.5% [44].

- **Available phosphorus:** The result of statistic analysis was showed the mixing ratio had the effect to available phosphorus at  $P = 0.038$ . Phosphorus can be rapidly fixed in from unavailable to plant and the reactions are depending on soil conditions and the mineral in soil [31]. Therefore, organic matter quantity in each mixing ratio had the effect to changed available phosphorus.

The result of statistic analysis was showed the composting time had the effect to available phosphorus at  $P < 0.001$ . It was resemble with Indiaty [54] that was found the available phosphorus to decrease according to increasing composting time. This was because of soluble phosphate ion reacted with calcium and free lime in soil, it was become to thee phosphate compounds and converted into insoluble compound that cause the soluble phosphate immobility in soil.

Reactions that reduce phosphorus availability occur in all ranges of soil pH but can be very pronounced in alkaline soils ( $\text{pH} > 7.3$ ) and in acidic soils ( $\text{pH} < 5.5$ ). Maintaining soil pH between 6 and 7 will generally result in the most efficient use of phosphate [31]. At second week, the available phosphorus and pH had highest values, which were resembled with theory that phosphates can highest dissolve at pH 6-7 [49].

As referred, the available phosphorus of all treatments were increased at the first two weeks, after that they trended to decrease until the composting process was finished at week 8.

The different of available phosphorus between initial and the end of composting process, the first highest different of total phosphorus was the treatment which had mixing ratio 6:1 and not covered by black plastic sheet. The second highest different of total phosphorus was the treatment which had mixing ratio 3:1 and not covered by black plastic sheet.

At the end of composting process, the first highest available phosphorus was the treatment which had mixing ratio 6:1 and not covered by black plastic sheet. The second highest total nitrogen was the treatment which had mixing ratio 3:1 and not covered by black plastic sheet.

### **5.2.2.6 Total potassium**

Potassium is an essential nutrient for plant growth. Almost of potassium is in the structural component of soil minerals and is not available for plant growth. The higher soil moisture usually means greater availability of K [32].

The results of statistic analyses were showed the mixing ratio had the effect to total potassium at  $P = 0.001$ . Increasing sewage sludge to grass clippings ratio could increase carbon to nitrogen ratio which resulted to decomposition reaction by microorganism and it changed organic matter to total potassium.

The results of statistic analyses were showed the composting time had the effect to total potassium at  $P < 0.001$ . The temperature of all treatments trended to increase according to increasing composting time. Therefore, the composting time had the effect to total potassium because of potassium uptake is reduced at low in soil temperatures [32].

In during the first week until the last week of composting times, the total potassium of all treatments was in the same trend.

The different of total potassium between initial and the end of composting process, the first highest different of total potassium was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet. The second highest different of total potassium was the treatment which had mixing ratio 1:1 and covered by black plastic sheet.

At the end of composting process, the first highest total potassium was the treatment which had mixing ratio 1:1 and not covered by black plastic sheet. The second highest total potassium was the treatment which had mixing ratio 1:1 and covered by black plastic sheet. The other treatments had nearly similar range of total potassium.

The total potassium of all treatments was in line with the organic fertilizer standard of the Department of Agriculture [44].

### 5.3 Selected suitable treatment for application

As a result, the determining of suitable treatment for mixed sewage sludge with grass clippings was considered from chemical characteristics such as pH, organic matter, total nitrogen, carbon to nitrogen ratio, total phosphorus and total potassium and sewage sludge management.

In this study, the mixing ratio, steam sterilization, and composting time in the composting process of all treatments were gave almost significantly difference to characteristic changes. However, the steam sterilization had no effect to temperature, organic matters, carbon to nitrogen ratio, total phosphorus, available phosphorus and total potassium.

At the end of experiment, the treatment which had the highest nutrients was the treatment which had mixing ratio 1:1. But it was not in line with the organic fertilizer standard of the Department of Agriculture [44]. The treatment which had the second highest nutrients was the treatment which had mixing ratio 6:1 and it also was in line with the organic fertilizer standard of the Department of Agriculture [44].

The sewage sludge should be optimized management and considered high benefit utilization, therefore the treatment which had optimized for soil amendment to agricultural utilization and can be reduced a large amount of sewage sludge was the treatment which had mixing ratio 6:1, both covered and not covered by black plastic sheet. Although, the steam sterilization was not significantly to the change of nutrients but it should be considered for actual implementation.

The treatment which had mixing ratio 6:1 and not covered by black plastic sheet is suitable for the area that has shade or roof and the ambient weather is not high such winter season.

The treatment which had mixing ratio 6:1 and covered by black plastic sheet is suitable for the area that has no shade or roof, frequent rain, and ambient weather is rather high such in the summer season. It should be controlled for moisture, external weather, and pests.

The characteristic and nutrient changes of the treatment which had mixing ratio 6:1 and covered by black plastic sheet is shown in Figure 5.1 and Figure 5.2.

The characteristic and nutrient change of the treatment which had mixing ratio 6:1 and not covered by black plastic sheet is shown in Figure 5.3 and Figure 5.4.

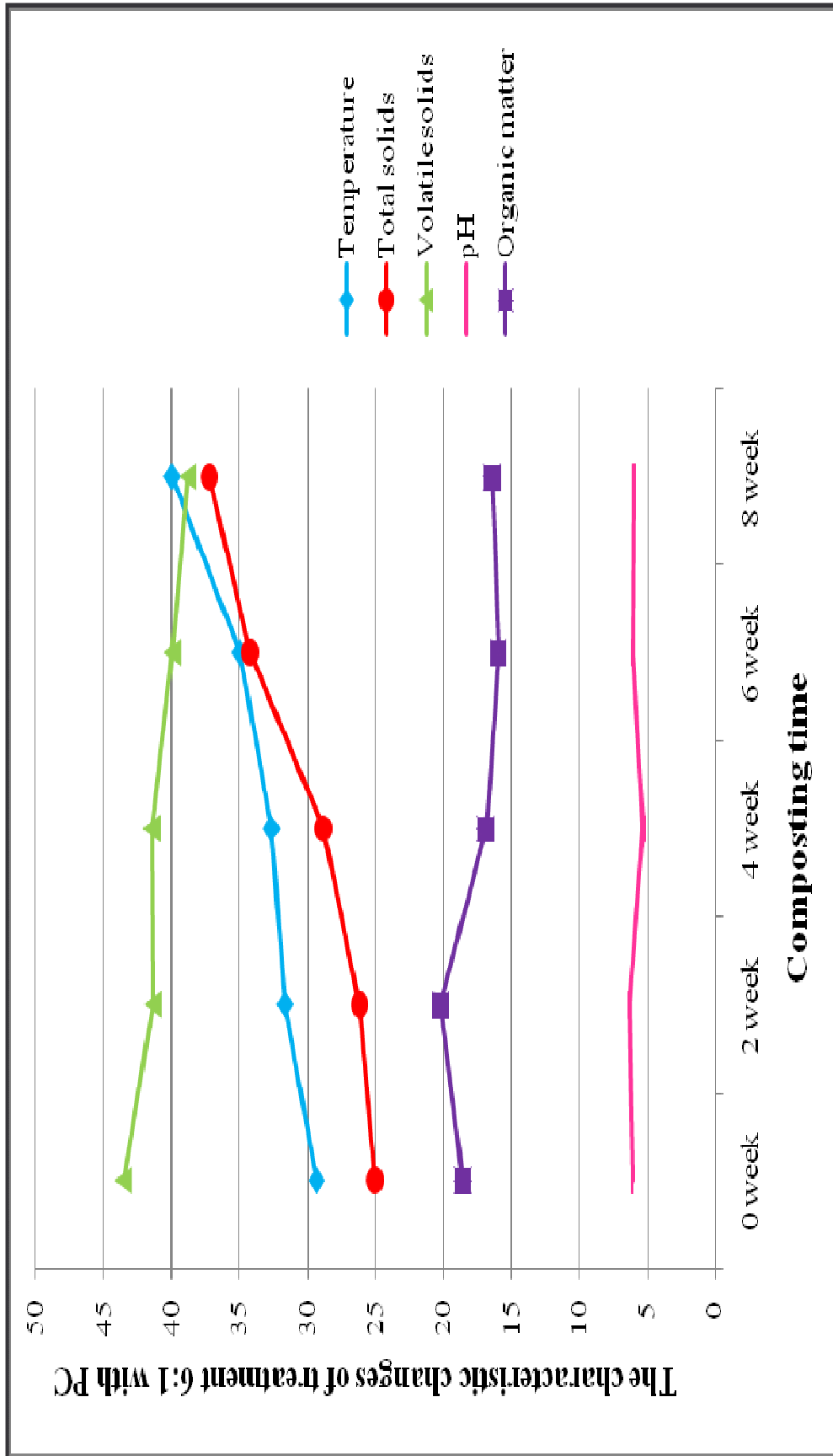


Figure 5.1 The characteristic changes of the treatment which had mixing ratio 6:1 and covered by black plastic sheet.

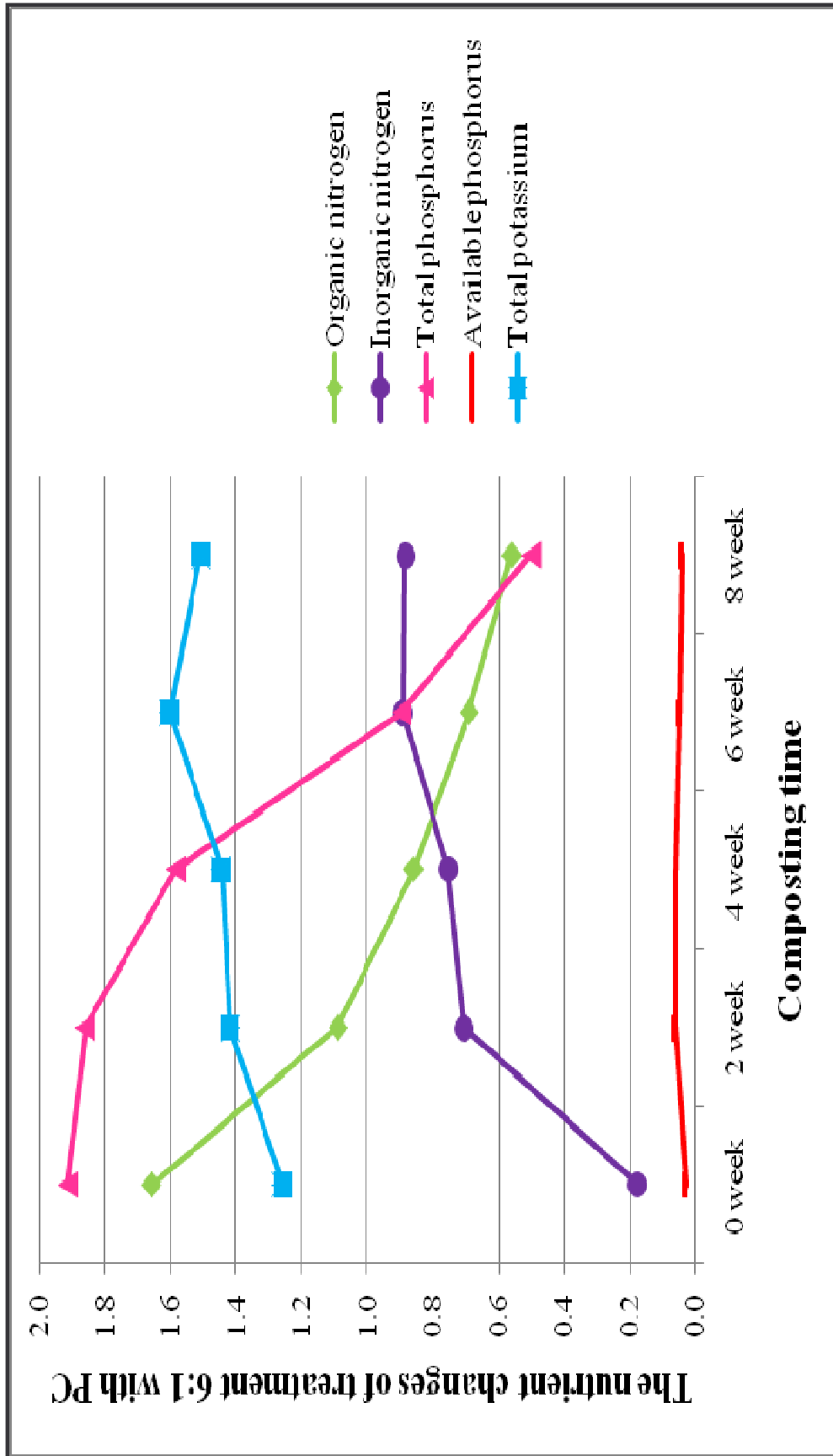


Figure 5.2 The nutrient changes of the treatment which had mixing ratio 6:1 and covered by black plastic sheet.

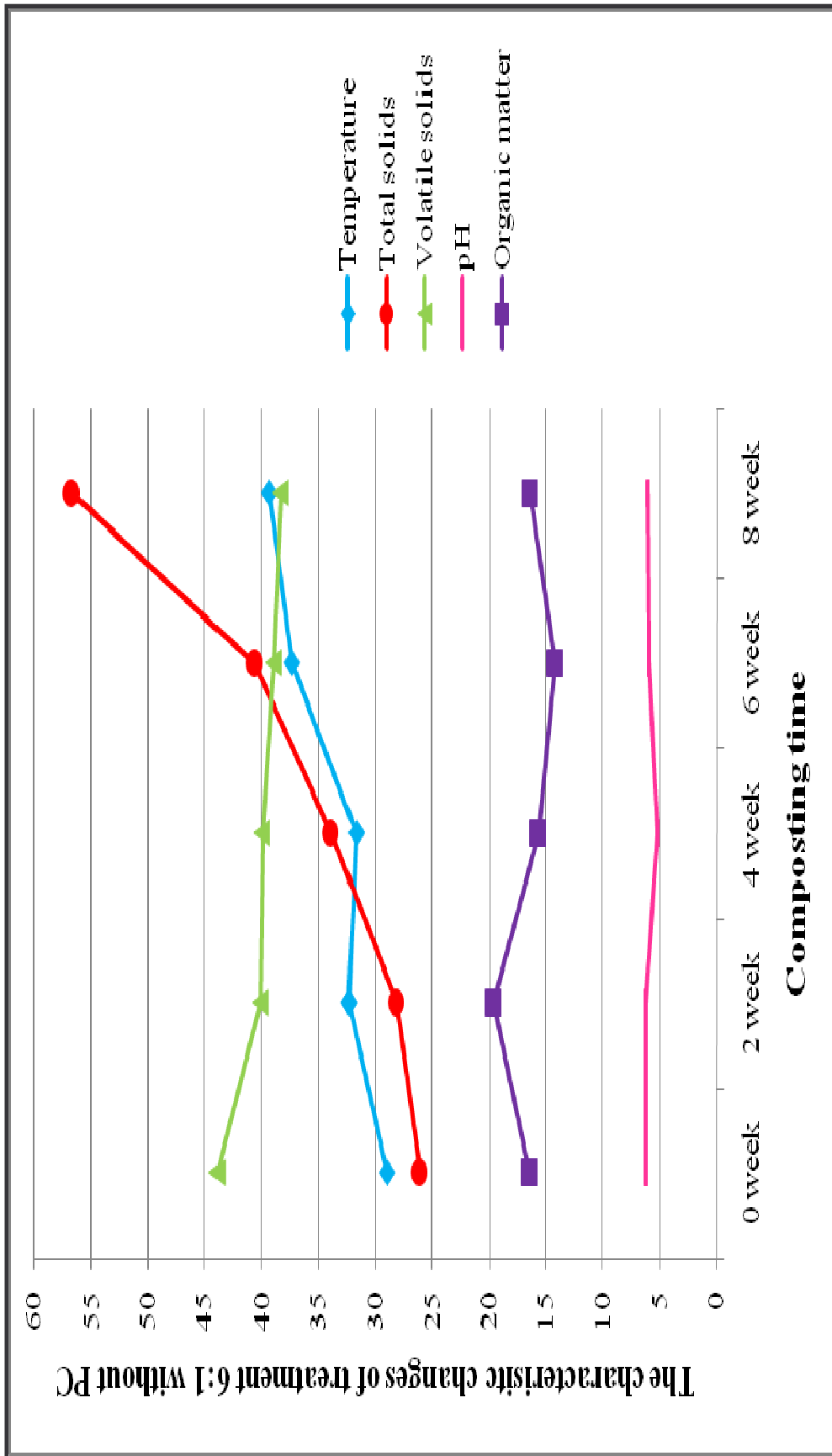


Figure 5.3 The characteristic changes of the treatment which had mixing ratio 6:1 and not covered by black plastic sheet.

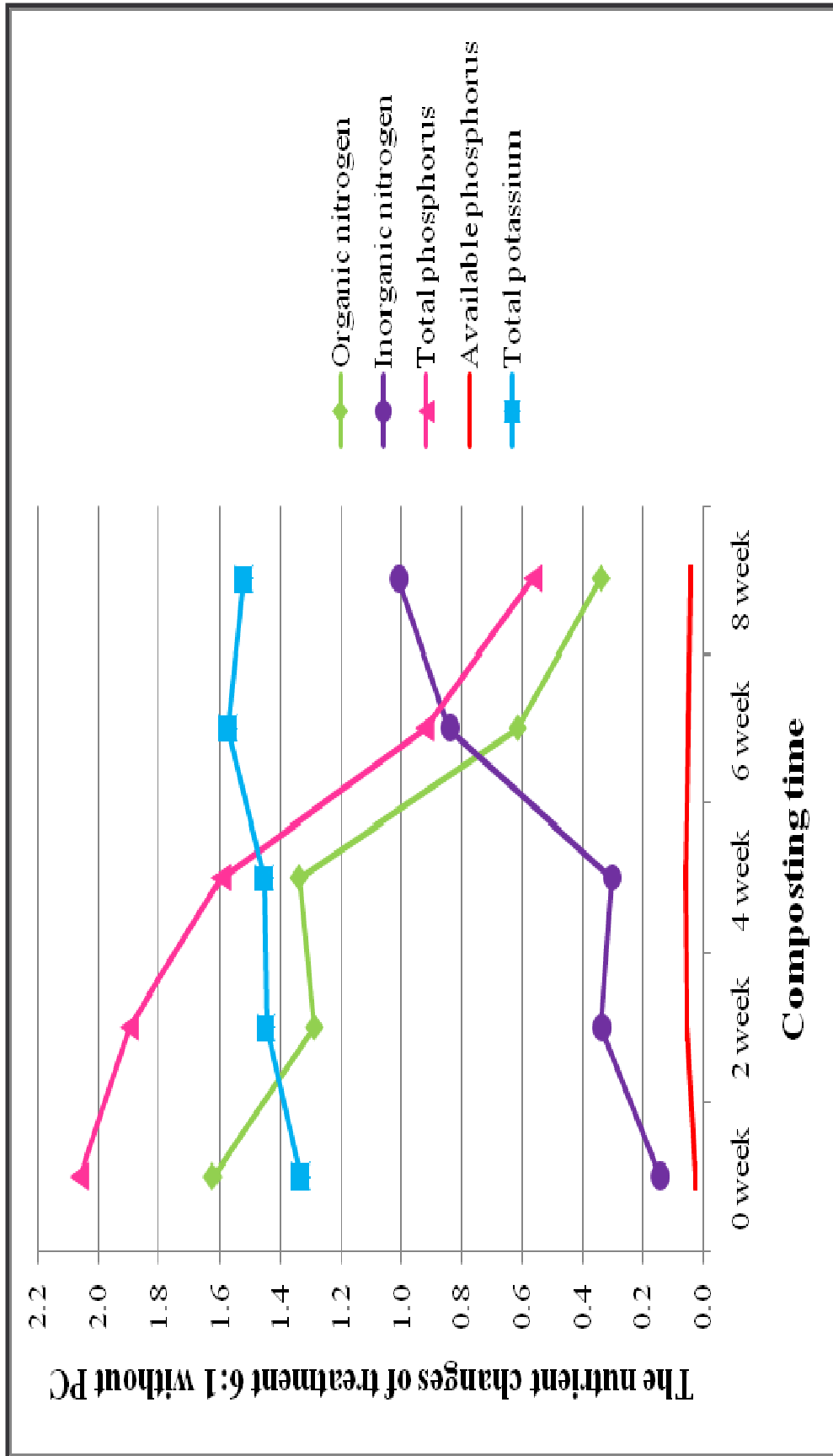


Figure 5.4 The nutrient changes of the treatment which had mixing ratio 6:1 and not covered by black plastic sheet.

## **CHAPTER VI**

### **CONCLUSION AND RECOMMENDATION**

This chapter is showed the conclusion and recommendation about different composting conditions to utilization sewage sludge mixed with grass clippings through the windrow composting.

#### **6.1 Conclusion**

##### **6.1.1 Physical and chemical characteristics of sewage sludge and grass clippings**

The initial chemical characteristics of sewage sludge were moisture content 78.09%, pH 6.66, organic matter 19.01%, total nitrogen 2.17% and C/N ratio 5.08:1.

The initial chemical characteristics of grass clippings were moisture content 2.65%, pH 5.70, organic matter 28.87%, total nitrogen 0.98% and C/N ratio 17.08:1.

Three out of five of the characteristics of sewage sludge were higher than that of the grass clippings. The characteristics of both nutrients can be the raw material for composting.

##### **6.1.2 Physical and chemical characteristic changes from sewage sludge mixed with grass clippings at different mixing ratios**

Mixing ratio was influenced to all of physical and chemical characteristic changes in sewage sludge mixed with grass clippings through the windrow composting technique because of it resulted to decomposition reaction by microorganism and others.

### **6.1.3 Physical and chemical characteristic changes from sewage sludge mixed with grass clippings at two steam sterilization conditions**

Steam sterilization was influenced to total solids, volatile solids, pH, organic nitrogen, and inorganic nitrogen changes but it was not influenced to temperature, organic matter, carbon to nitrogen ratio, total phosphorus, available phosphorus, and total potassium changes from sewage sludge mixed with grass clippings through the windrow composting technique.

The treatments which covered by black plastic sheet had low oxygen from lesser ventilation. Treatments which covered by black plastic sheet had the decomposition rate of organic matter to total solids, organic nitrogen to inorganic nitrogen and the production rate of organic acids lower than that of treatments which not covered by black plastic sheet.

### **6.1.4 Physical and chemical characteristic changes from sewage sludge mixed with grass clippings during different composting times**

Composting time was influenced to all of physical and chemical characteristic changes from sewage sludge mixed with grass clippings through the windrow composting technique. The physical and chemical characteristic were changed during increasing composting time because the decomposition reaction by microorganism and others.

### **6.1.5 Comparing physical and chemical characteristics from sewage sludge mixed with grass clippings at different conditions with guideline or standard**

At the end of the experiment, the results of almost nutrients were in the line with the organic fertilizer standard of Department of Agriculture [44], except, organic matters (the standard value for organic matter should be more than 30 % by weight) and total phosphorus (The standard value for total phosphorus should be more than 0.5%).

### **6.1.6 Selected suitable treatment for application**

The physical (temperature, total solids, and volatile solids) and chemical characteristics (pH, organic matter, organic nitrogen, inorganic nitrogen, carbon to nitrogen ratio, total phosphorus, available phosphorus, and total potassium) of all treatments at the end of composting process were similar.

- Temperature increased according to increasing of composting time.
- Total solids increased according to increasing of composting time.
- Volatile solids were slightly decreased.
- pH was slightly decreased at the first four weeks after that it was slightly increased. At the last week of composting times, the pH ranges were closed to the initial pH values.
- Organic matters were increased at first two weeks but during the second week until the sixth week they were decreased. The trends after that were increased until the composting process was finished at week 8 of composting times.
- Organic nitrogen was trended to decrease until the composting process was finished at week 8 of composting times.
- Inorganic nitrogen was trended to increase until the composting process was finished at week 8 of composting times.
- The carbon to nitrogen ratio of all treatments were increased at the first two weeks, but during the second week until forth week the carbon to nitrogen ratio were decreased. After that, the carbon to nitrogen ratio was increased until the composting process was finished at week 8 of composting times. Except the treatment which had mixing ratio 1:1 and not covered by black plastic sheet and mixing ratio 3:1 and covered by black plastic sheet, the carbon to nitrogen ratio of them were increased at the first two weeks and during the second week until forth week they were decreased. At the forth week until sixth week, they were increased again and after that decreased until the composting process was finished at week 8 of composting times. At sixth and eighth week, carbon to nitrogen ratios decreased would be a result from decreased organic carbon content and increased total nitrogen.
- Total phosphorus was continuously decreased until the composting process was finished at week 8 of composting times.

- Available phosphorus was increased at the first two weeks, after that they trended to decrease until the composting process was finished at week 8 of composting times.
- Total potassium was slightly increased until the composting process was finished at week 8 of composting times.

At the end of experiment, the treatment which had the highest nutrients was the treatment which had mixing ratio 1:1. But it was not in the line with the organic fertilizer standard of Department of Agriculture [44]. The treatment which had the second highest nutrients was the treatment which had mixing ratio 6:1 and it also was in the line with the organic fertilizer standard of Department of Agriculture [44].

In this study, the sewage sludge optimization management and high benefit on utilization were considered, therefore the treatment which had optimized for soil amendment to agricultural utilization and can be reduced a large amount of sewage sludge was the treatment which had mixing ratio 6:1, both covered and not covered by black plastic sheet. Although, the steam sterilization was not significantly to change of nutrients but it should be considered for actual implementation.

The treatment which had mixing ratio 6:1 and not covered by black plastic sheet is suitable for the area that has shade or roof and the ambient weather is low.

The treatment which had mixing ratio 6:1 and covered by black plastic sheet is suitable for the area that has no shade or roof, frequent rain, and weather is high because it could be control moisture, external weather, and pests.

## **6.2 Recommendation**

### **6.2.1 Recommendations for research application**

6.2.1.1 The result in this study proved that sewage sludge mixed with grass clippings can be used to the agricultural area as soil amendment. However, soil, plants, and ground water around the agricultural area should be investigated in term of nutrients, heavy metals, and pathogens.

6.2.1.2 The comparison of crop productions between soil amendments from this study with the chemical fertilizer or other soil conditioners should be done. It can help promoting the sustainable use of sewage sludge and recycling nutrients to the soil.

6.2.1.3 A guideline for sewage application on land from this study as follow;

- Sewage sludge and grass clippings are raw materials.
- Composting method is windrow composting.
- Mixing ratio between sewage sludge and grass clippings is 6:1.
- Composting time is  $\geq 8$  weeks.
- pH is 5.96-6.43.
- Organic matter (%) is  $> 16$ .
- Total nitrogen (%) is  $\geq 1.35$ .
- Carbon to nitrogen ratio is  $\geq 7:1$ .
- Total phosphorus (%) is  $\geq 0.5$ .
- Total potassium (%) is  $\geq 1.45$ .

### **6.2.3 Recommendation for the further study**

6.2.3.1. Grass clippings can be a bit increased carbon to nitrogen ratio and it cannot much help increasing porosity in soil and air ventilation of composting process. Therefore, other raw materials should be added to increasing efficiency of composting process.

6.2.3.2. Other raw materials should be mixed with sewage sludge and compost it with other method to suit with the area and existing raw materials.

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## **APPENDICES**

## APPENDIX A

### THE EXPERIMENT DATA

Table A.1 Temperature (°C) of sewage sludge mixing with grass clippings at different conditions during composting process

Composting time (day)	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
1	30.0	30.0	30.8	30.0	30.0	27.6	29.4	29.2
2	41.0	44.6	44.2	44.0	43.2	44.2	43.0	44.4
3	30.8	31.2	33.6	32.6	31.6	30.6	30.0	30.6
4	33.8	33.0	36.6	36.6	33.8	33.2	33.0	33.2
5	32.4	33.0	32.4	32.6	33.0	32.2	32.4	33.0
6	31.6	32.0	39.4	38.0	32.8	33.0	32.2	33.2
7	33.2	32.6	41.4	39.2	35.0	30.2	34.2	32.4
8	33.4	32.4	39.0	36.6	34.8	31.6	33.2	32.6
9	34.0	33.2	39.4	37.8	36.2	34.6	35.2	34.2
10	33.8	33.0	40.4	38.6	35.8	34.2	34.4	34.4
11	33.6	33.0	40.4	38.0	35.2	34.6	33.6	34.4
12	34.0	34.0	42.0	39.6	36.6	36.6	35.2	35.8
13	34.4	33.2	41.8	39.6	36.0	33.6	33.6	33.6
14	34.2	34.0	39.8	40.4	38.0	38.0	34.6	36.6
15	32.8	31.6	34.8	35.6	33.4	33.4	31.4	32.4
16	32.8	33.8	37.8	37.2	36.0	36.0	33.8	34.8
17	32.8	33.0	36.4	38.6	36.0	34.6	34.0	34.6
18	32.0	34.2	38.0	40.4	34.4	36.6	33.6	35.0
19	32.8	34.2	38.6	40.2	35.4	36.6	34.4	34.8
20	31.2	33.8	35.4	39.0	34.2	35.6	31.4	33.4
21	30.2	33.2	33.6	37.6	34.2	35.8	32.0	33.6
22	30.0	31.0	30.8	34.8	32.4	31.6	30.6	30.0
23	30.0	31.8	32.0	35.0	32.6	33.6	31.2	32.2
24	30.6	32.6	32.6	36.6	33.8	36.0	32.2	34.2
25	30.8	32.2	33.2	35.6	33.6	34.4	33.2	34.0
26	31.0	34.2	35.2	39.0	34.8	37.2	32.2	36.8
27	31.8	35.6	39.0	42.0	34.4	35.8	35.8	33.8
28	31.4	35.2	36.8	41.4	33.8	35.4	31.8	36.0
29	30.2	32.0	33.0	35.2	32.8	31.6	32.4	31.4
30	32.6	32.8	33.8	36.0	34.0	33.4	33.6	33.2
31	32.2	35.8	33.6	40.6	34.6	35.4	34.0	34.6
32	33.4	36.8	34.6	37.0	34.4	37.8	33.0	36.0
33	33.4	36.6	34.8	37.0	35.2	37.6	34.2	37.0
34	33.6	37.0	35.4	36.6	34.8	38.0	34.0	36.4
35	33.0	36.8	35.6	37.2	35.4	37.2	34.6	35.6

Table A.1 Temperature (°C) of sewage sludge mixing with grass clippings at different conditions during composting process (cont.)

Composting time (day)	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
36	32.4	35.8	33.4	36.2	33.2	36.4	33.0	33.6
37	33.0	37.6	35.8	41.8	36.0	40.0	33.2	39.0
38	32.4	37.4	33.4	39.6	35.4	39.0	33.8	37.4
39	33.8	37.8	36.2	41.2	37.0	39.6	34.2	39.6
40	33.4	38.2	37.0	40.8	37.0	40.6	34.4	39.6
41	34.0	39.4	36.6	39.6	35.0	36.4	34.2	36.0
42	33.8	40.4	39.0	40.8	35.6	37.8	35.4	39.0
43	34.6	37.8	36.4	37.6	36.4	37.2	35.0	36.8
44	36.8	39.8	37.6	39.8	37.6	39.8	36.4	40.4
45	37.6	42.0	38.4	40.4	37.6	44.0	38.0	42.0
46	38.2	42.4	39.2	40.6	38.2	43.6	39.4	42.4
47	38.2	42.4	39.2	40.2	38.8	43.0	39.2	42.4
48	37.0	44.0	39.2	40.6	39.6	46.2	37.0	44.8
49	35.8	41.2	38.0	41.6	37.8	43.4	37.0	42.2
50	35.8	40.6	37.2	37.6	36.8	40.2	37.0	38.2
51	34.0	42.2	37.6	37.6	38.8	38.8	37.2	43.0
52	36.0	42.8	37.6	38.2	37.2	40.6	36.2	40.2
53	36.6	42.8	38.4	39.0	40.6	36.6	37.2	41.0
54	37.6	43.8	40.2	38.4	38.4	40.8	39.2	41.2
55	39.6	46.0	40.0	39.6	41.2	42.2	40.8	44.2
56	39.8	47.4	42.2	41.8	40.4	43.4	40.2	40.2
57	39.4	43.0	38.0	37.6	38.8	41.4	40.0	39.2

Table A.2 Moisture content (%) of sewage sludge mixing with grass clippings at different conditions during composting process

Composting time (week)	Rep.	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
0	1	75.71	74.09	73.85	73.85	74.44	73.49	74.75	74.22
	2	75.27	75.21	73.17	73.51	74.63	73.18	75.07	73.33
	3	75.30	75.12	73.72	73.96	74.22	73.11	75.15	74.08
2	1	73.69	72.39	71.64	70.86	72.59	71.60	73.67	72.10
	2	73.97	72.88	70.47	74.19	72.49	71.49	73.61	71.74
	3	74.21	72.07	62.73	67.03	72.78	71.99	74.25	71.58
4	1	70.35	66.84	67.65	65.59	71.60	63.83	70.92	67.33
	2	70.31	67.62	66.83	63.53	71.77	62.60	71.68	65.05
	3	70.76	67.81	67.04	66.66	70.93	65.99	70.87	65.83
6	1	66.23	59.19	59.27	53.55	67.48	55.66	64.99	59.89
	2	67.35	59.02	60.35	51.41	67.50	53.97	66.38	58.65
	3	67.30	58.92	59.68	52.83	67.66	55.02	65.86	59.41
8	1	64.58	44.70	58.24	48.63	63.76	49.39	62.29	46.82
	2	64.66	47.57	57.50	47.65	62.68	49.85	63.24	41.66
	3	64.76	48.10	55.03	47.39	63.63	47.61	62.70	41.34

Table A.3 Total solids (%) of sewage sludge mixing with grass clippings at different conditions during composting process

Composting time (week)	Rep.	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
0	1	24.29	25.91	26.15	26.15	25.56	26.51	25.25	25.78
	2	24.73	24.79	26.83	26.49	25.37	26.82	24.93	26.67
	3	24.70	24.88	26.28	26.04	25.78	26.82	24.85	25.92
2	1	26.31	27.61	28.36	29.14	27.41	28.40	26.33	27.90
	2	26.03	27.12	29.53	25.81	27.51	28.51	26.39	28.26
	3	25.79	27.93	37.27	32.97	27.22	28.01	25.75	28.42
4	1	29.65	33.16	32.35	34.41	28.4	36.17	29.08	32.67
	2	29.69	32.38	33.17	36.47	28.23	37.40	28.32	34.95
	3	29.24	32.19	32.96	33.34	29.07	34.01	29.13	34.17
6	1	33.77	40.81	40.73	46.45	32.52	44.34	35.01	40.11
	2	32.65	40.98	39.65	48.59	32.50	46.03	33.62	41.35
	3	32.70	41.08	40.32	47.17	32.34	44.98	34.14	40.59
8	1	35.42	55.30	41.76	51.37	36.24	50.61	37.71	53.18
	2	35.34	52.43	42.50	52.35	37.32	50.15	36.76	58.34
	3	35.24	51.9	44.97	52.61	36.37	52.39	37.30	58.66

Table A.4 Volatile solids (%) of sewage sludge mixing with grass clippings at different conditions during composting process

Composting time (week)	Rep.	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
0	1	41.47	41.34	44.85	46.49	43.90	45.01	43.45	44.02
	2	45.22	41.49	46.11	46.95	44.18	44.42	43.59	43.98
	3	41.19	40.99	45.45	45.07	43.85	44.98	43.66	43.88
2	1	40.06	39.79	42.90	42.08	41.44	42.17	41.09	40.12
	2	40.22	39.80	42.89	42.37	42.19	42.31	41.50	39.99
	3	40.28	39.37	43.08	42.38	41.88	42.18	41.49	40.32
4	1	39.12	38.63	40.91	41.98	40.91	40.38	41.49	40.28
	2	39.41	38.73	40.97	43.44	41.41	40.97	41.68	39.99
	3	39.57	39.07	40.80	43.72	41.61	40.71	41.18	39.73
6	1	38.33	37.56	42.50	41.03	40.77	39.82	39.99	38.90
	2	38.30	37.57	42.40	41.48	41.33	39.91	39.80	38.98
	3	38.67	37.39	42.32	41.51	41.77	39.96	39.99	39.01
8	1	37.42	35.96	42.01	40.46	39.35	38.18	38.03	38.14
	2	37.75	36.25	41.91	40.40	39.46	38.84	39.00	38.04
	3	37.85	36.32	43.28	40.77	39.83	38.48	39.25	38.85

Table A.5 pH of sewage sludge mixing with grass clippings at different conditions during composting process

Composting time (week)	Rep.	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
0	1	6.17	6.13	6.39	6.20	6.38	6.66	6.13	6.26
	2	6.19	6.15	6.41	6.18	6.42	6.68	6.11	6.29
	3	6.20	6.13	6.43	6.19	6.42	6.69	6.10	6.30
2	1	6.27	6.24	6.56	6.30	6.35	6.28	6.32	6.32
	2	6.29	6.25	6.56	6.30	6.35	6.28	6.32	6.32
	3	6.29	6.23	6.57	6.30	6.35	6.30	6.34	6.32
4	1	5.39	5.29	5.57	5.52	5.26	5.31	5.28	5.25
	2	5.40	5.29	5.59	5.52	5.24	5.34	5.28	5.24
	3	5.39	5.29	5.61	5.53	5.23	5.31	5.29	5.25
6	1	6.13	6.31	5.99	5.94	5.88	6.39	6.08	6.00
	2	6.12	6.32	5.98	5.95	5.87	6.40	6.09	6.02
	3	6.12	6.32	5.97	5.96	5.86	6.40	6.10	6.03
8	1	6.20	6.42	6.09	6.12	5.95	6.35	6.02	6.16
	2	6.18	6.43	6.08	6.12	5.96	6.36	6.00	6.16
	3	6.19	6.44	6.06	6.11	5.96	6.37	6.00	6.16

Table A.6 Organic matter (%) of sewage sludge mixing with grass clippings at different conditions during composting process

Composting time (week)	Rep.	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
0	1	17.17	17.04	18.01	19.31	18.44	17.47	18.26	16.53
	2	17.38	18.46	18.04	20.20	18.24	17.84	19.15	16.17
	3	17.98	18.62	18.51	19.63	18.82	17.92	18.33	16.92
2	1	16.42	18.01	23.43	22.54	21.87	20.84	21.32	19.42
	2	18.15	18.69	22.07	22.16	21.94	20.92	19.96	19.57
	3	18.09	17.55	23.41	23.12	20.94	21.15	19.32	20.18
4	1	16.24	16.11	17.44	17.04	16.35	15.50	17.09	15.86
	2	16.17	16.36	17.18	15.84	16.64	16.55	17.35	15.67
	3	16.27	16.45	17.65	16.19	16.95	16.43	16.20	15.74
6	1	13.77	13.53	15.59	18.84	17.42	15.69	16.29	15.52
	2	13.84	14.33	17.58	18.73	18.22	16.65	16.66	11.56
	3	12.91	13.74	16.57	18.90	17.19	16.42	14.90	15.77
8	1	14.87	14.87	17.94	17.87	16.96	16.71	15.59	15.93
	2	14.73	15.04	18.67	18.67	17.04	16.87	16.78	16.20
	3	15.93	14.73	18.70	17.85	14.31	16.50	16.83	17.22

Table A.7 Organic nitrogen (%) of sewage sludge mixing with grass clippings at different conditions during composting process

Composting time (week)	Rep.	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
0	1	1.83	1.84	1.31	1.59	1.60	1.43	1.69	1.50
	2	1.82	1.67	1.30	1.34	1.42	1.38	1.56	1.84
	3	1.81	2.02	1.40	1.43	1.84	1.37	1.74	1.54
2	1	1.53	1.54	1.36	0.97	1.60	1.06	1.09	1.28
	2	1.51	1.58	1.41	1.02	1.62	1.07	1.04	1.29
	3	1.62	1.51	1.30	1.07	1.34	1.34	1.15	1.30
4	1	1.40	1.26	0.93	0.67	1.38	0.69	0.79	1.27
	2	0.92	1.57	0.74	0.78	1.36	0.61	0.74	1.46
	3	1.48	1.43	0.83	0.58	1.26	0.75	1.04	1.29
6	1	1.02	0.99	0.48	0.30	1.00	0.29	0.62	0.66
	2	1.07	0.81	0.57	0.40	1.27	0.29	0.73	0.57
	3	1.17	0.72	0.31	0.41	1.09	0.28	0.73	0.63
8	1	0.39	0.21	0.28	0.11	0.23	0.06	0.52	0.36
	2	0.19	0.04	0.38	0.05	0.35	0.07	0.72	0.40
	3	0.10	0.13	0.42	0.23	0.46	0.13	0.44	0.27

Table A.8 Inorganic nitrogen (%) of sewage sludge mixing with grass clippings at different conditions during composting process

Composting time (week)	Rep.	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
0	1	0.17	0.15	0.27	0.18	0.16	0.19	0.19	0.22
	2	0.15	0.15	0.28	0.15	0.16	0.20	0.16	0.02
	3	0.17	0.16	0.28	0.15	0.17	0.22	0.18	0.19
2	1	0.23	0.27	0.41	0.80	0.18	0.70	0.67	0.35
	2	0.26	0.23	0.41	0.75	0.20	0.70	0.73	0.34
	3	0.24	0.27	0.43	0.75	0.20	0.65	0.72	0.33
4	1	0.27	0.41	0.74	0.81	0.20	0.98	0.79	0.31
	2	0.29	0.38	0.75	0.80	0.23	0.98	0.75	0.31
	3	0.29	0.43	0.76	0.82	0.23	0.92	0.73	0.29
6	1	0.29	0.59	0.92	1.00	0.21	1.19	0.97	0.83
	2	0.33	0.59	0.83	1.00	0.22	1.21	0.85	0.83
	3	0.32	0.59	0.81	0.98	0.21	1.21	0.85	0.86
8	1	1.15	1.24	0.98	1.43	1.03	1.34	0.83	1.08
	2	1.16	1.22	0.88	1.30	1.09	1.28	0.82	0.96
	3	1.25	1.22	0.93	1.30	1.08	1.32	1.01	0.99

Table A.9 Carbon to nitrogen ratio of sewage sludge mixing with grass clippings at different conditions during composting process

Composting time (week)	Rep.	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
0	1	4.97	4.96	6.62	6.35	6.08	6.25	5.63	5.59
	2	5.11	5.88	6.61	7.85	6.72	6.56	6.49	5.04
	3	5.26	4.96	6.40	7.21	5.44	6.55	5.56	5.69
2	1	5.39	5.78	7.67	7.39	7.15	6.84	7.02	6.91
	2	5.94	6.00	7.04	7.26	7.01	6.87	6.54	6.98
	3	5.63	5.75	7.87	7.38	7.92	6.14	6.02	7.19
4	1	5.63	5.58	6.04	6.64	5.99	5.37	6.27	5.81
	2	7.75	4.85	6.70	5.81	6.09	6.06	6.76	5.14
	3	5.34	5.13	6.46	6.72	6.61	5.69	5.31	5.77
6	1	6.11	4.96	6.47	8.37	8.34	6.12	5.97	6.05
	2	5.74	5.95	7.29	7.77	7.09	6.47	6.11	4.80
	3	5.02	6.10	8.60	7.85	7.64	6.40	5.45	6.13
8	1	5.61	5.98	8.27	6.74	7.81	7.70	6.68	6.40
	2	6.32	6.92	8.60	8.01	6.84	7.25	6.34	6.94
	3	6.84	6.32	8.03	6.74	5.39	6.62	6.76	7.94

Table A.10 Total phosphorus (%) of sewage sludge mixing with grass clippings at different conditions during composting process

Composting time (week)	Rep.	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
0	1	2.01	2.13	1.63	1.61	1.97	1.71	1.92	2.08
	2	1.97	2.01	1.60	1.87	2.00	1.71	1.91	2.14
	3	1.95	2.05	1.56	1.79	1.80	1.71	1.92	1.97
2	1	2.24	2.27	1.68	1.89	1.80	1.71	1.86	1.92
	2	2.17	2.07	1.88	1.90	1.62	1.66	1.83	1.93
	3	2.18	2.06	1.77	1.75	1.61	1.68	1.90	1.84
4	1	1.80	1.72	1.61	1.52	1.52	1.56	1.57	1.59
	2	1.82	1.72	1.51	1.54	1.50	1.49	1.60	1.61
	3	1.89	1.71	1.52	1.56	1.52	1.64	1.59	1.59
6	1	1.00	0.92	0.72	0.98	0.82	0.80	0.91	0.90
	2	0.90	0.98	0.72	1.02	0.75	0.78	0.88	0.91
	3	0.93	0.95	0.65	1.01	0.81	0.81	0.91	0.96
8	1	0.50	0.36	0.37	0.30	0.43	0.43	0.42	0.56
	2	0.51	0.33	0.34	0.20	0.42	0.53	0.53	0.58
	3	0.53	0.40	0.35	0.25	0.35	0.37	0.55	0.56

Table A.11 Available phosphorus (%) of sewage sludge mixing with grass clippings at different conditions during composting process

Composting time (week)	Rep.	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
0	1	0.0371	0.0314	0.0263	0.0284	0.0267	0.0255	0.0284	0.0245
	2	0.0342	0.0308	0.0308	0.0309	0.0247	0.0247	0.0267	0.0257
	3	0.0324	0.0281	0.0200	0.0312	0.0242	0.0233	0.0268	0.0263
2	1	0.0579	0.0503	0.0625	0.0649	0.0500	0.0555	0.0550	0.0542
	2	0.0575	0.0585	0.0684	0.0575	0.0609	0.0545	0.0614	0.0538
	3	0.0576	0.0572	0.0658	0.0602	0.0604	0.0564	0.0584	0.0537
4	1	0.0420	0.0498	0.0503	0.0511	0.0582	0.0536	0.0538	0.0627
	2	0.0476	0.0475	0.0546	0.0533	0.0520	0.0529	0.0563	0.0559
	3	0.0478	0.0603	0.0529	0.0520	0.0505	0.0548	0.0626	0.0543
6	1	0.0393	0.0401	0.0501	0.0445	0.0436	0.0462	0.0494	0.0524
	2	0.0409	0.0411	0.0543	0.0446	0.0469	0.0478	0.0451	0.0484
	3	0.0411	0.0522	0.0441	0.0548	0.0455	0.0492	0.0481	0.0487
8	1	0.0332	0.0369	0.0455	0.0367	0.0383	0.0404	0.0385	0.0398
	2	0.0444	0.0435	0.0373	0.0386	0.0396	0.0406	0.0411	0.0434
	3	0.0348	0.0362	0.0362	0.0376	0.0395	0.0400	0.0375	0.0435

Table A.12 Total potassium (%) of sewage sludge mixing with grass clippings at different conditions during composting process

Composting time (week)	Rep.	1:0 with PC	1:0 without PC	1:1 with PC	1:1 without PC	3:1 with PC	3:1 without PC	6:1 with PC	6:1 without PC
0	1	1.198	1.046	1.027	1.05	1.635	1.262	1.196	1.352
	2	1.283	1.411	1.646	1.129	1.431	1.582	1.284	1.309
	3	1.189	1.017	1.021	1.512	1.413	1.515	1.297	1.342
2	1	1.436	1.440	1.435	1.455	1.315	1.273	1.483	1.435
	2	1.369	1.368	1.448	1.481	1.426	1.383	1.389	1.463
	3	1.335	1.512	1.450	1.449	1.417	1.425	1.390	1.451
4	1	1.445	1.300	1.581	1.451	1.487	1.461	1.461	1.416
	2	1.479	1.335	1.413	1.395	1.351	1.393	1.425	1.388
	3	1.415	1.409	1.546	1.435	1.430	1.436	1.451	1.562
6	1	1.493	1.304	1.503	1.640	1.593	1.661	1.585	1.511
	2	1.455	1.334	1.607	1.611	1.539	1.623	1.589	1.618
	3	1.309	1.379	1.672	1.686	1.577	1.603	1.638	1.603
8	1	1.427	1.388	1.535	1.565	1.541	1.543	1.525	1.479
	2	1.468	1.525	1.579	1.632	1.557	1.512	1.513	1.498
	3	1.452	1.443	1.632	1.578	1.58	1.603	1.496	1.599

## APPENDIX B

### THE ANALYTICAL STATISTICS

The three-way analyses of variance with one repeated measure was used to analyze main effects and interaction effects. When an interaction exists, main effects are ignore.

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

In case of double interaction, the F test of ANOVA was used to test a simple main effect of mixing ratio at each time period.

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.

Temperature was the example to use this analytical statistic method. Other characteristics and nutrients were used to same this analytical statistic method.

Table B.1 The tests of between-subject effects for temperature

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	141110.208	1	141110.208	1.568E5	.000
Mixingratio	16.758	3	5.586	6.207	.005
Streamsterilization	2.408	1	2.408	2.676	.121
Mixingratio * Streamsterilization	16.425	3	5.475	6.083	.006
Error	14.400	16	.900		

Table B.2 The tests of within-subject effects for temperature

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
compostingtimes	Sphericity Assumed	1653.667	4	413.417	668.148	.000
	Greenhouse-Geisser	1653.667	3.067	539.196	668.148	.000
	Huynh-Feldt	1653.667	4.000	413.417	668.148	.000
	Lower-bound	1653.667	1.000	1653.667	668.148	.000
compostingtimes * Mixzingratio	Sphericity Assumed	126.533	12	10.544	17.042	.000
	Greenhouse-Geisser	126.533	9.201	13.753	17.042	.000
	Huynh-Feldt	126.533	12.000	10.544	17.042	.000
	Lower-bound	126.533	3.000	42.178	17.042	.000
compostingtimes * Streamsterilization	Sphericity Assumed	25.467	4	6.367	10.290	.000
	Greenhouse-Geisser	25.467	3.067	8.304	10.290	.000
	Huynh-Feldt	25.467	4.000	6.367	10.290	.000
	Lower-bound	25.467	1.000	25.467	10.290	.005
compostingtimes * Mixzingratio * Streamsterilization	Sphericity Assumed	59.533	12	4.961	8.018	.000
	Greenhouse-Geisser	59.533	9.201	6.470	8.018	.000
	Huynh-Feldt	59.533	12.000	4.961	8.018	.000
	Lower-bound	59.533	3.000	19.844	8.018	.002
Error(compostingtimes)	Sphericity Assumed	39.600	64	.619		
	Greenhouse-Geisser	39.600	49.071	.807		
	Huynh-Feldt	39.600	64.000	.619		
	Lower-bound	39.600	16.000	2.475		

Table B.3 The simple main effect of mixing ratio classified by each level of steam sterilizations (with and without plastic cover) at each time period to temperature

Steam sterilizations	Composting times	F
With plastic cover	0	$F_{(0.95, 3, 8)} > F_{cal} = 1.286$ (p = 0.344)
	2	$F_{(0.95, 3, 8)} < F_{cal} = 6.476$ (p = 0.016)
	4	$F_{(0.95, 3, 8)} < F_{cal} = 35.167$ (p < 0.001)
	6	$F_{(0.95, 3, 8)} > F_{cal} = 4.000$ (p = 0.008)
	8	$F_{(0.95, 3, 8)} < F_{cal} = 8.143$ (p = 0.052)
Without plastic cover	0	$F_{(0.95, 3, 8)} < F_{cal} = 4.451$ (P = 0.041)
	2	$F_{(0.95, 3, 8)} < F_{cal} = 13.111$ (P = 0.002)
	4	$F_{(0.95, 3, 8)} < F_{cal} = 12.100$ (P = 0.002)
	6	$F_{(0.95, 3, 8)} < F_{cal} = 12.267$ (P = 0.002)
	8	$F_{(0.95, 3, 8)} < F_{cal} = 29.333$ (P < 0.001)

Table B.4 The simple main effect of steam sterilizations classified by each level of mixing ratios (1:0, 1:1, 3:1 and 6:1) at each time period to temperature

Mixing ratios	Composting times	F
1:0	0	$F_{(0.95, 1, 4)} > F_{cal} = 1.000$ (P = 0.374)
	2	$F_{(0.95, 1, 4)} > F_{cal} = 4.500$ (P = 0.101)
	4	$F_{(0.95, 1, 4)} < F_{cal} = 25.000$ (P = 0.007)
	6	$F_{(0.95, 1, 4)} < F_{cal} = 13.500$ (P = 0.021)
	8	$F_{(0.95, 1, 4)} < F_{cal} = 48.000$ (P = 0.002)
1:1	0	$F_{(0.95, 1, 4)} > F_{cal} = 1.000$ (P = 0.374)
	2	$F_{(0.95, 1, 4)} > F_{cal} = 0.571$ (P = 0.492)
	4	$F_{(0.95, 1, 4)} < F_{cal} = 12.250$ (P = 0.025)
	6	$F_{(0.95, 1, 4)} > F_{cal} = 4.500$ (P = 0.101)
	8	$F_{(0.95, 1, 4)} > F_{cal} = 0.250$ (P = 0.643)
3:1	0	$F_{(0.95, 1, 4)} < F_{cal} = 40.500$ (P = 0.003)
	2	$F_{(0.95, 1, 4)} > F_{cal} = 0.500$ (P = 0.519)
	4	$F_{(0.95, 1, 4)} > F_{cal} = 4.500$ (P = 0.101)
	6	$F_{(0.95, 1, 4)} < F_{cal} = 12.000$ (P = 0.026)
	8	$F_{(0.95, 1, 4)} < F_{cal} = 13.500$ (P = 0.021)
6:1	0	$F_{(0.95, 1, 4)} > F_{cal} = 1.250$ (P = 0.326).
	2	$F_{(0.95, 1, 4)} > F_{cal} = 2.000$ (P = 0.230).
	4	$F_{(0.95, 1, 4)} > F_{cal} = 1.800$ (P = 0.251).
	6	$F_{(0.95, 1, 4)} < F_{cal} = 49.000$ (P = 0.002).
	8	$F_{(0.95, 1, 4)} > F_{cal} = 0.571$ (P = 0.492).

Table B.5 The simple main effect of composting time at each interaction level of mixing ratios and steam sterilization conditions to temperature

Dependent Variable	(I) Compostingtime	(J) Compostingtime	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Mixingratio10_1	0	2	-2.33333 <sup>*</sup>	.59628	.029	-4.4689	-.1978
		4	.33333	.59628	1.000	-1.8022	2.4689
		6	-4.66667 <sup>*</sup>	.59628	.000	-6.8022	-2.5311
		8	-9.66667 <sup>*</sup>	.59628	.000	-11.8022	-7.5311
	2	0	2.33333 <sup>*</sup>	.59628	.029	.1978	4.4689
		4	2.66667 <sup>*</sup>	.59628	.012	.5311	4.8022
		6	-2.33333 <sup>*</sup>	.59628	.029	-4.4689	-.1978
		8	-7.33333 <sup>*</sup>	.59628	.000	-9.4689	-5.1978
	4	0	-.33333	.59628	1.000	-2.4689	1.8022
		2	-2.66667 <sup>*</sup>	.59628	.012	-4.8022	-.5311
		6	-5.00000 <sup>*</sup>	.59628	.000	-7.1355	-2.8645
		8	-10.00000 <sup>*</sup>	.59628	.000	-12.1355	-7.8645
	6	0	4.66667 <sup>*</sup>	.59628	.000	2.5311	6.8022
		2	2.33333 <sup>*</sup>	.59628	.029	.1978	4.4689
		4	5.00000 <sup>*</sup>	.59628	.000	2.8645	7.1355
		8	-5.00000 <sup>*</sup>	.59628	.000	-7.1355	-2.8645
8	0	9.66667 <sup>*</sup>	.59628	.000	7.5311	11.8022	
	2	7.33333 <sup>*</sup>	.59628	.000	5.1978	9.4689	
	4	10.00000 <sup>*</sup>	.59628	.000	7.8645	12.1355	
	6	5.00000 <sup>*</sup>	.59628	.000	2.8645	7.1355	

Table B.5 The simple main effect of composting time at each interaction level of mixing ratios and steam sterilization conditions to temperature (cont.)

Dependent Variable	(I) Compostingtime	(J) Compostingtime	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
Mixingratio10_2 0	0	2	-1.66667	.47140	.054	-3.3550	.0216
		4	-1.66667	.47140	.054	-3.3550	.0216
		6	-8.00000 <sup>*</sup>	.47140	.000	-9.6883	-6.3117
		8	-14.00000 <sup>*</sup>	.47140	.000	-15.6883	-12.3117
	2	0	1.66667	.47140	.054	-.0216	3.3550
		4	.00000	.47140	1.000	-1.6883	1.6883
		6	-6.33333 <sup>*</sup>	.47140	.000	-8.0216	-4.6450
		8	-12.33333 <sup>*</sup>	.47140	.000	-14.0216	-10.6450
	4	0	1.66667	.47140	.054	-.0216	3.3550
		2	.00000	.47140	1.000	-1.6883	1.6883
		6	-6.33333 <sup>*</sup>	.47140	.000	-8.0216	-4.6450
		8	-12.33333 <sup>*</sup>	.47140	.000	-14.0216	-10.6450
	6	0	8.00000 <sup>*</sup>	.47140	.000	6.3117	9.6883
		2	6.33333 <sup>*</sup>	.47140	.000	4.6450	8.0216
		4	6.33333 <sup>*</sup>	.47140	.000	4.6450	8.0216
		8	-6.00000 <sup>*</sup>	.47140	.000	-7.6883	-4.3117
8	0	14.00000 <sup>*</sup>	.47140	.000	12.3117	15.6883	
	2	12.33333 <sup>*</sup>	.47140	.000	10.6450	14.0216	
	4	12.33333 <sup>*</sup>	.47140	.000	10.6450	14.0216	
	6	6.00000 <sup>*</sup>	.47140	.000	4.3117	7.6883	

Table B.5 The simple main effect of composting time at each interaction level of mixing ratios and steam sterilization conditions to temperature (cont.)

Dependent Variable	(I) Compostingtime	(J) Compostingtime	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
Mixingratio11_1	0	2	-4.00000 <sup>*</sup>	.63246	.001	-6.2651	-1.7349
		4	-2.66667 <sup>†</sup>	.63246	.018	-4.9317	-.4016
		6	-7.00000 <sup>*</sup>	.63246	.000	-9.2651	-4.7349
		8	-7.66667 <sup>†</sup>	.63246	.000	-9.9317	-5.4016
	2	0	4.00000 <sup>*</sup>	.63246	.001	1.7349	6.2651
		4	1.33333	.63246	.612	-.9317	3.5984
		6	-3.00000 <sup>*</sup>	.63246	.008	-5.2651	-.7349
		8	-3.66667 <sup>†</sup>	.63246	.002	-5.9317	-1.4016
	4	0	2.66667 <sup>†</sup>	.63246	.018	.4016	4.9317
		2	-1.33333	.63246	.612	-3.5984	.9317
		6	-4.33333 <sup>†</sup>	.63246	.000	-6.5984	-2.0683
		8	-5.00000 <sup>*</sup>	.63246	.000	-7.2651	-2.7349
	6	0	7.00000 <sup>*</sup>	.63246	.000	4.7349	9.2651
		2	3.00000 <sup>†</sup>	.63246	.008	.7349	5.2651
		4	4.33333 <sup>†</sup>	.63246	.000	2.0683	6.5984
		8	-.66667	.63246	1.000	-2.9317	1.5984
8	0	7.66667 <sup>†</sup>	.63246	.000	5.4016	9.9317	
	2	3.66667 <sup>†</sup>	.63246	.002	1.4016	5.9317	
	4	5.00000 <sup>*</sup>	.63246	.000	2.7349	7.2651	
	6	.66667	.63246	1.000	-1.5984	2.9317	

Table B.5 The simple main effect of composting time at each interaction level of mixing ratios and steam sterilization conditions to temperature (cont.)

Dependent Variable	(I) Compostingtime	(J) Compostingtime	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
Mixingratio11_2	0	2	-5.00000 <sup>*</sup>	.63246	.000	-7.2651	-2.7349
		4	-5.33333 <sup>*</sup>	.63246	.000	-7.5984	-3.0683
		6	-6.33333 <sup>*</sup>	.63246	.000	-8.5984	-4.0683
		8	-7.66667 <sup>*</sup>	.63246	.000	-9.9317	-5.4016
	2	0	5.00000 <sup>*</sup>	.63246	.000	2.7349	7.2651
		4	-.33333	.63246	1.000	-2.5984	1.9317
		6	-1.33333	.63246	.612	-3.5984	.9317
		8	-2.66667 <sup>*</sup>	.63246	.018	-4.9317	-.4016
	4	0	5.33333 <sup>*</sup>	.63246	.000	3.0683	7.5984
		2	.33333	.63246	1.000	-1.9317	2.5984
		6	-1.00000	.63246	1.000	-3.2651	1.2651
		8	-2.33333 <sup>*</sup>	.63246	.042	-4.5984	-.0683
	6	0	6.33333 <sup>*</sup>	.63246	.000	4.0683	8.5984
		2	1.33333	.63246	.612	-.9317	3.5984
		4	1.00000	.63246	1.000	-1.2651	3.2651
		8	-1.33333	.63246	.612	-3.5984	.9317
8	0	7.66667 <sup>*</sup>	.63246	.000	5.4016	9.9317	
	2	2.66667 <sup>*</sup>	.63246	.018	.4016	4.9317	
	4	2.33333 <sup>*</sup>	.63246	.042	.0683	4.5984	
	6	1.33333	.63246	.612	-.9317	3.5984	

Table B.5 The simple main effect of composting time at each interaction level of mixing ratios and steam sterilization conditions to temperature (cont.)

Dependent Variable	(I) Compostingtime	(J) Compostingtime	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
Mixingratio31_1	0	2	-3.00000 <sup>*</sup>	.63246	.008	-5.2651	-.7349
		4	-2.33333 <sup>†</sup>	.63246	.042	-4.5984	-.0683
		6	-6.66667 <sup>‡</sup>	.63246	.000	-8.9317	-4.4016
		8	-9.66667 <sup>‡</sup>	.63246	.000	-11.9317	-7.4016
	2	0	3.00000 <sup>*</sup>	.63246	.008	.7349	5.2651
		4	.66667	.63246	1.000	-1.5984	2.9317
		6	-3.66667 <sup>‡</sup>	.63246	.002	-5.9317	-1.4016
		8	-6.66667 <sup>‡</sup>	.63246	.000	-8.9317	-4.4016
	4	0	2.33333 <sup>†</sup>	.63246	.042	.0683	4.5984
		2	-.66667	.63246	1.000	-2.9317	1.5984
		6	-4.33333 <sup>‡</sup>	.63246	.000	-6.5984	-2.0683
		8	-7.33333 <sup>‡</sup>	.63246	.000	-9.5984	-5.0683
	6	0	6.66667 <sup>‡</sup>	.63246	.000	4.4016	8.9317
		2	3.66667 <sup>†</sup>	.63246	.002	1.4016	5.9317
		4	4.33333 <sup>†</sup>	.63246	.000	2.0683	6.5984
		8	-3.00000 <sup>*</sup>	.63246	.008	-5.2651	-.7349
8	0	9.66667 <sup>‡</sup>	.63246	.000	7.4016	11.9317	
	2	6.66667 <sup>‡</sup>	.63246	.000	4.4016	8.9317	
	4	7.33333 <sup>†</sup>	.63246	.000	5.0683	9.5984	
	6	3.00000 <sup>*</sup>	.63246	.008	.7349	5.2651	

Table B.5 The simple main effect of composting time at each interaction level of mixing ratios and steam sterilization conditions to temperature (cont.)

Dependent Variable	(I) Compostingtime	(J) Compostingtime	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
Mixingratio31_2	0	2	-6.33333 <sup>*</sup>	.51640	.000	-8.1828	-4.4839
		4	-4.33333 <sup>*</sup>	.51640	.000	-6.1828	-2.4839
		6	-7.66667 <sup>*</sup>	.51640	.000	-9.5161	-5.8172
		8	-15.66667 <sup>*</sup>	.51640	.000	-17.5161	-13.8172
	2	0	6.33333 <sup>*</sup>	.51640	.000	4.4839	8.1828
		4	2.00000 <sup>*</sup>	.51640	.031	.1506	3.8494
		6	-1.33333	.51640	.273	-3.1828	.5161
		8	-9.33333 <sup>*</sup>	.51640	.000	-11.1828	-7.4839
	4	0	4.33333 <sup>*</sup>	.51640	.000	2.4839	6.1828
		2	-2.00000 <sup>*</sup>	.51640	.031	-3.8494	-.1506
		6	-3.33333 <sup>*</sup>	.51640	.001	-5.1828	-1.4839
		8	-11.33333 <sup>*</sup>	.51640	.000	-13.1828	-9.4839
	6	0	7.66667 <sup>*</sup>	.51640	.000	5.8172	9.5161
		2	1.33333	.51640	.273	-.5161	3.1828
		4	3.33333 <sup>*</sup>	.51640	.001	1.4839	5.1828
		8	-8.00000 <sup>*</sup>	.51640	.000	-9.8494	-6.1506
8	0	15.66667 <sup>*</sup>	.51640	.000	13.8172	17.5161	
	2	9.33333 <sup>*</sup>	.51640	.000	7.4839	11.1828	
	4	11.33333 <sup>*</sup>	.51640	.000	9.4839	13.1828	
	6	8.00000 <sup>*</sup>	.51640	.000	6.1506	9.8494	

Table B.5 The simple main effect of composting time at each interaction level of mixing ratios and steam sterilization conditions to temperature (cont.)

Dependent Variable	(I) Compostingtime	(J) Compostingtime	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
Mixingratio61_1	0	2	-2.33333 <sup>*</sup>	.51640	.011	-4.1828	-.4839
		4	-3.33333 <sup>*</sup>	.51640	.001	-5.1828	-1.4839
		6	-5.66667 <sup>*</sup>	.51640	.000	-7.5161	-3.8172
		8	-10.66667 <sup>*</sup>	.51640	.000	-12.5161	-8.8172
	2	0	2.33333 <sup>*</sup>	.51640	.011	.4839	4.1828
		4	-1.00000	.51640	.816	-2.8494	.8494
		6	-3.33333 <sup>*</sup>	.51640	.001	-5.1828	-1.4839
		8	-8.33333 <sup>*</sup>	.51640	.000	-10.1828	-6.4839
	4	0	3.33333 <sup>*</sup>	.51640	.001	1.4839	5.1828
		2	1.00000	.51640	.816	-.8494	2.8494
		6	-2.33333 <sup>*</sup>	.51640	.011	-4.1828	-.4839
		8	-7.33333 <sup>*</sup>	.51640	.000	-9.1828	-5.4839
	6	0	5.66667 <sup>*</sup>	.51640	.000	3.8172	7.5161
		2	3.33333 <sup>*</sup>	.51640	.001	1.4839	5.1828
		4	2.33333 <sup>*</sup>	.51640	.011	.4839	4.1828
		8	-5.00000 <sup>*</sup>	.51640	.000	-6.8494	-3.1506
8	0	10.66667 <sup>*</sup>	.51640	.000	8.8172	12.5161	
	2	8.33333 <sup>*</sup>	.51640	.000	6.4839	10.1828	
	4	7.33333 <sup>*</sup>	.51640	.000	5.4839	9.1828	
	6	5.00000 <sup>*</sup>	.51640	.000	3.1506	6.8494	

Table B.5 The simple main effect of composting time at each interaction level of mixing ratios and steam sterilization conditions to temperature (cont.)

Dependent Variable	(I) Compostingtime	(J) Compostingtime	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
Mixingratio61_2	0	2	-4.66667 <sup>*</sup>	1.13529	.021	-8.7326	-.6007
		4	-4.00000	1.13529	.055	-8.0659	.0659
		6	-9.66667 <sup>*</sup>	1.13529	.000	-13.7326	-5.6007
		8	-11.66667 <sup>*</sup>	1.13529	.000	-15.7326	-7.6007
	2	0	4.66667 <sup>*</sup>	1.13529	.021	.6007	8.7326
		4	.66667	1.13529	1.000	-3.3993	4.7326
		6	-5.00000 <sup>*</sup>	1.13529	.013	-9.0659	-.9341
		8	-7.00000 <sup>*</sup>	1.13529	.001	-11.0659	-2.9341
	4	0	4.00000	1.13529	.055	-.0659	8.0659
		2	-.66667	1.13529	1.000	-4.7326	3.3993
		6	-5.66667 <sup>*</sup>	1.13529	.005	-9.7326	-1.6007
		8	-7.66667 <sup>*</sup>	1.13529	.001	-11.7326	-3.6007
	6	0	9.66667 <sup>*</sup>	1.13529	.000	5.6007	13.7326
		2	5.00000 <sup>*</sup>	1.13529	.013	.9341	9.0659
		4	5.66667 <sup>*</sup>	1.13529	.005	1.6007	9.7326
		8	-2.00000	1.13529	1.000	-6.0659	2.0659
8	0	11.66667 <sup>*</sup>	1.13529	.000	7.6007	15.7326	
	2	7.00000 <sup>*</sup>	1.13529	.001	2.9341	11.0659	
	4	7.66667 <sup>*</sup>	1.13529	.001	3.6007	11.7326	
	6	2.00000	1.13529	1.000	-2.0659	6.0659	

\*. The mean difference is significant at the 0.05 level.

## APPENDIX C PHOTOGRAPHS OF EXPERIMENT



Figure C.1 The treatments which covered by black plastic sheet



Figure C.2 The treatments which not covered by black plastic sheet

## **BIOGRAPHY**

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