

## CHAPTER 4

### RUSULTS

#### 4.1 Isolation and selection of effective cellulase-, amylase-, protease- and lipase-producing microorganisms

In this study, 32 samples were collected from Northern Thailand (Table 9). They consisted of 20 soil samples from many sites, 5 samples of commercial soil culture from compost stores, 5 samples of bio-fertilizer and 2 samples of liquid fertilizer from home-made fertilizer. Microorganisms from different sources were isolated and many of cellulose-, protein-, starch- and lipid-degrading microorganisms were found. There were 100, 73, 67 and 87 isolates of microorganisms that could produce cellulase, amylase, protease and lipase, respectively.

Screening each isolates on corresponding media (Table 10), twenty isolates i.e. CMB 20, CMB 24, CMG 8, CMG 10, EM 9, EM 11, KL 3, KL 10, LHE 1, LHE 3, LHE 10, LHE 12, LHF 2, LHF 5, LPA 14, LPA 15, LPA 7, LPE 2, LPE 10 and MT 4 could produce cellulase enzyme on carboxy methyl cellulose agar which all of them have clear zone more than 15 mm in diameter. Twelve isolates i.e. CMD 3, CMD 7, CMD 17, GB 12, GB 15, HM 1, KL 9, LHB 3, LPD 9, LPD 10, LPF 8 and MG 4 could produce amylase enzyme on starch agar which all of them have clear zone more than 25 mm in diameter. Ten isolates i.e. BS 1, BT 5, CMA 9, EA 10, EM 2, EM 21, IL 2, KL 5, LPA 15 and LPB 4 could produce protease enzyme on skim milk agar which all of them have clear zone more than 25 mm in diameter.

**Table 9** Number of microorganisms producing cellulose, amylase, protease and lipase from different sources

Sample sources (code)	Number of microorganisms
<b>Soil</b>	
Thambon Soun-Dok, Chiang Mai (CMA)	16
Chiang Mai Zoo I, Chiang Mai (CMB)	24
Chiang Mai Zoo II, Chiang Mai (CMC)	27
Doi Suthep I, Chiang Mai (CMD)	19
Doi Suthep II, Chiang Mai (CME)	21
Thambon Mae-Hia, Chiang Mai (CMF)	12
Amphor Prow, Chiang Mai (CMG)	11
Amphor Ban-Thi, Lamphun (LHA)	10
Amphor Muang I, Lamphun (LHB)	6
Amphor Muang II, Lamphun (LHC)	15
Tambon Doi-Ti, Lamphun (LHD)	12
Ban-Tha, Lamphun (LHE)	14
Ban-Jamkaemod, Lamphun (LHF)	11
Amphor Muang I, Lampang (LPA)	16
Amphor Muang II, Lampang (LPB)	15
Amphor Maetha I, Lampang (LPC)	12
Amphor Maetha II, Lampang (LPD)	17
Amphor Turn I, Lampang (LPE)	12
Amphor Turn II, Lampang (LPF)	10
Amphor Sob-Prap, Lampang (LPG)	11
<b>Soil culture</b>	
Ear-Arthron Brand (EA)	12
Kae-Lang (KL)	12
Mai-Gham brand (MG)	9
Mai-Long Mai-Ru Brand (ML)	10
Mai-Thai Brand (MT)	7
<b>Compost</b>	
Bai-Zon Brand (BZ)	5
Bou-Tawan Brand (BT)	8
Humose Brand (HM)	4
Ilo Brand (Ilo)	7
Prayanak Brand (PN)	10
<b>Liquid fertilizer</b>	
EM (EM)	24
Green Blossom Brand (GB)	15
<b>Total</b>	<b>554</b>

Eleven isolates i.e. CMC 26, CMD 6, GB 11, GB 14, KL 1, KL 12, LPA 7, LPC 2, LPD 4, LPD 12 and PN 8 could produce lipase enzyme on tributyrin agar which all of them have clear zone more than 25 mm in diameter.

**Table 10** The diameter of hydrolytic zone of cellulase-, amylase-, protease- and lipase- producing microorganisms on corresponding solid media

Medium	Enzyme activity	Microorganism (isolate)	Diameter of hydrolytic zone (mm)
Carboxy methyl cellulose agar	Cellulase	CMB 24, EM11, KL10, LHF2, LHF 5	15
		CMG 10, EM 9	16
		CMG 8, LPE 2, MT 4	17
		CMB 20, KL 3, LPE 10	18
		LHE 1, LHE 12, LPA 14, LPA 15	19
		LPA 7	20
		LPE 10	21
		LHE 3	22
		Starch agar	Amylase
CMD 17	26		
KL 9	27		
HM 1	29		
CMD 3, CMD 7, LPD 10	31		
GB 15, LPF 8	32		
GB 12	35		
Skim milk agar	Protease	CMA 9	21
		EA 10, LPB 4	25
		IL 2	28
		KL 5	30
		BT 5, EM 2	31
		LPA 15	32
		BS 1	35
EM 21	35		
Tributyrin agar	Lipase	GB 11	20
		KL 1	21
		KL 12	23
		PN 8	25
		GB 14	29
		CMC 26	35
		LPA 7	35
		CMD 6	32
LPD 12	52		
LPD 4	45		
LPC 2	55		

## 4.2 Enzyme Activity

The enzyme activity of effective cellulase-, amylase-, protease- and lipase-producing microorganisms were shown in Table 11. Four isolates of cellulose-degrading

microorganisms i.e. LHE 10, LHE 3, LHE 12 and LPA 15 were selected due to their interesting activity which the isolate of LHE 10 showed the highest activity with the value of  $0.1277 \text{ U mL}^{-1}$ , followed by isolates of LHE 3, LHE 12 and LPA 15 with the value of  $0.1152 \text{ U mL}^{-1}$ ,  $0.0784 \text{ U mL}^{-1}$  and  $0.0775 \text{ U mL}^{-1}$ , respectively. The highest amylase, protease and lipase activity were found in the starch-degrading isolates of GB 12 with the value of  $0.2559 \times 10^{-3} \text{ U mL}^{-1}$ , protein-degrading BS 1 with the value of  $0.2508 \text{ U mL}^{-1}$  and lipid-degrading LPC 2 with the value of  $97.765 \text{ U mL}^{-1}$ , respectively

**Table 11** Enzyme activity of isolated microorganisms

Enzyme	Isolate	Enzyme activity*	Enzyme	Isolate	Enzyme activity*
<b>Cellulase</b>	CMB 20	0.0548	<b>Protease</b>	BS 1	0.2508**
	CMB 24	0.0500		BT 5	0.1112
	CMG 8	0.0559		CMA 9	0.0602
	CMG 10	0.0507		EA 10	0.0602
	EM 9	0.0523		EM 2	0.0983
	EM 11	0.0506		EM 21	0.2242
	KL 3	0.0453		IL 2	0.0900
	KL 10	0.0508		KL 5	0.2153
	LHE 1	0.0693		LPA 15	0.2207
	LHE 3	0.1152**		LPB 4	0.1544
	LHE 10	0.1277**	<b>Lipase</b>	CMC 26	75.568
	LHE 12	0.0784**		CMD 6	74.463
	LHF 2	0.0495		GB 11	60.787
	LHF 5	0.0487		GB 14	75.509
	LPA 14	0.0763		KL 1	61.101
	LPA 15	0.0775**		KL 12	69.709
	LPA 7	0.0104		LPA 7	76.667
	LPE 2	0.0404		LPC 2	97.765**
	LPE 10	0.0553		LPD 4	95.508
MT 4	0.0493	LPD 12	97.653		
<b>Amylase</b>	CMD 3	0.1704	PN 8	72.653	
	CMD 7	0.1829			
	CMD 17	0.0753			
	GB 12	0.2559**			
	GB 15	0.1807			
	HM 1	0.0859			
	KL 9	0.0701			
	LHB 3	0.0606			
	LPD 9	0.0614			
	LPD 10	0.2100			
	LPF 8	0.2177			
	MG 4	0.0665			

\* Unit of enzyme activity: cellulase ( $\text{U mL}^{-1}$ ), protease ( $\text{U mL}^{-1}$ ), amylase ( $\times 10^{-3} \text{ U mL}^{-1}$ ) and lipase ( $\text{U mL}^{-1}$ ).

\*\* Selected microorganisms giving high enzyme activity.

### 4.3 Identification of effective microorganisms

#### 4.3.1 Morphological and biochemical characteristics of bacterial isolates GB 12, LPC 2, LHE 3 and BS 1

The isolates of GB 12, LPC 2, LHE 3 and BS 1 were aerobic Gram-positive, spore-forming, rod-shaped bacterium (Figure C6 – C9 of Appendix C) which produced cream-white colonies (0.5 - 1 cm in diameter) on nutrient agar. The details of morphological and biochemical characteristics of the isolates of GB 12, LPC 2, LHE 3 and BS 1 are shown in Table 12. The characteristics have been classified as a strain belonging to genus *Bacillus* sp. according to Sneath *et al.* (1986).

**Table 12** Characterization of bacterial isolates GB 12, LPC 2, LHE 3 and BS 1

Tests	Isolates			
	LHE 3	BS 1	GB 12	LPC 2
Rod-shaped in young cultures	+	+	+	+
Endospore produced	+	+	+	+
Gram stain	+	+	+	+
Strict aerobes	-	-	-	-
Facultative anaerobes or microaerophiles	+	+	+	+
Strict anaerobes	-	-	-	-
Sulphate to sulfide	-	-	-	-
Catalase	+	+	+	+
Oxidase	-	+	+	+
Glucose (acid)	+	+	+	+
Nitrate to nitrite	+	+	+	+

+ indicate positive result; - indicate negative result.

#### 4.3.2 Morphological characteristics of fungal isolates of LHE 12 and LHE 10

Rapid growth colonies of fungal isolate of LHE 12 on potato dextrose agar at 30°C were olive green with a cream reverse. Colonial texture was woolly to cottony to somewhat granular. Sclerotia, when present, were dark brown. Hyphae were septate

and hyaline. Conidial heads were radiate to loosely columnar with age. Conidiophores were coarsely roughened and uncolored. Conidia were smooth and globose (Figure C10 of appendix C). These characters were identified in genus *Aspergillus* sp. according to Barnett (1998), Ellis (1993) and Sutton (1980). While fungal isolate of LHE 10 was unknown species because it had only hyphae, no sporulation, then it could not be identified by morphological character (Figure C11 of appendix C).

### **4.3.3 Morphological characteristics of actinomycete isolate LPA 15**

Colonies of actinomycete isolate LPA 15 were white and can be produced soluble brown pigment on starch-casein agar at 45°C (Figure C12 of appendix C). This isolate produced aerial mycelium with long chain of spores on the same medium. The spore shape was circular and it formed spiral. These characters were identified in genus *Streptomyces* sp. according to Holt *et al.* (1994).

### **4.3.4 Identification of bacteria, actinomycetes and fungi by DNA sequencing**

From the DNA extraction of selected isolates by using the isoplant DNA extraction kit, the result showed that the selected isolates i.e. GB 12, LPC 2, LHE 3, BS 1, LPA 15, LHE 12 and LHE 10 had the genomic DNA concentrations at 22.1, 10.9, 20.1, 15.2, 20.1, 18.3 and 15.9 ng  $\mu\text{L}^{-1}$ , respectively. Then, the genomic DNA were tested for PCR-amplifiable DNA with 16S rRNA-universal primers by using primers 27F, 520R and 357F for bacteria and actinomycete, for fungi using primers ITS I and ITS 4. The DNA sequence of each primers and each isolates were shown in Figure B1 to B14 of appendix B. After that,

the DNA sizes were measured by gel electrophoresis and found that bacteria and actinomycete had DNA size at 500 base pairs (Figure 4) while fungi had 700 base pairs (Figure 5). The PCR products were purified by using TaKaRa SUPREC<sup>TM</sup>-PCR and then, the DNA in pure PCR products were sequenced using 16S rRNA for bacteria and actinomycete, and 18s rRNA for fungi. The DNA sequences were shown in Figure B15 to B21 of appendix B The DNA sequence from each primers of each isolates was connected by using BioEdit program. The output of DNA sequence from BioEdit program of each isolates were shown in Figure B22 to B28 of appendix B The sequences were compared to 16S rRNA gene sequences in the GenBank using the Blast program. The sequence of isolate GB 12, LPC 2, BS 1, LHE 3, LPA 15, and LHE 12 involved the closest match to that of *Bacillus subtilis* isolate with a homology of 100%, *Bacillus subtilis* 99%, *Bacillus subtilis* 100%, *Bacillus subtilis* 99% , *Streptomyces regensis* 98 % and *Aspergillus flavus* 100 %, respectively (Table 13). Then, isolates GB 12, LPC 2, BS 1, LHE 3, LPA 15 and LHE 12 should be *Bacillus subtilis* GB 12, *Bacillus subtilis* LPC 2, *Bacillus subtilis* BS 1, *Bacillus subtilis* LHE 3, *Streptomyces regensis* LPA15 and *Aspergillus flavus* LHE 12, respectively. Having homology percentage below 91%, fungal isolate LHE 10 could not be identified and it might be a new species.

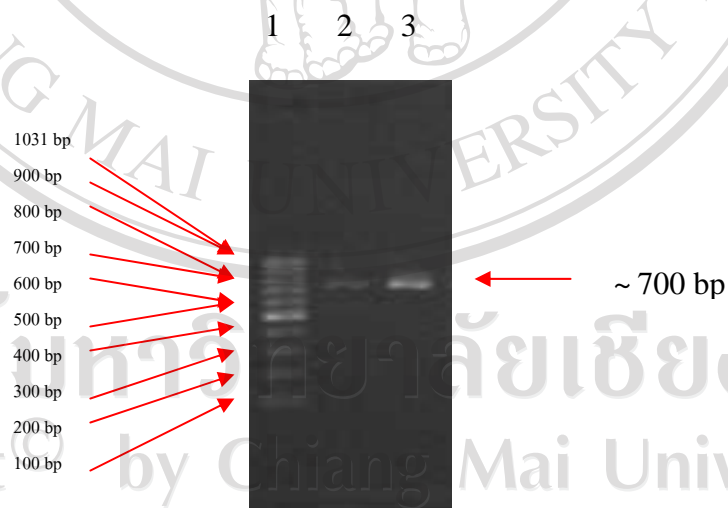
**Table 13** Identification of isolates GB 12, LPC 2, BS 1, LHE 3, LPA 15, LHE 12 and LHE 10 by using DNA sequence

Isolates	Reference species	Accession number	Identities	% Homology
GB 12	<i>Bacillus subtilis</i>	FJ595878.1	471/471	100
LPC 2	<i>Bacillus subtilis</i>	FJ595878.1	479/480	99
BS 1	<i>Bacillus subtilis</i>	FJ208798.1	476/476	100
LHE 3	<i>Bacillus subtilis</i>	DQ659146.1	470/471	99
LPA15	<i>Streptomyces lilaceus</i>	DQ026649.1	457/465	98
LHE 12	<i>Aspergillus flavus</i>	EF661566.1	510/510	100
LHE 10	<i>Fungal sp.</i>	AM231362.1	439/478	91



**Figure 4** DNA size of isolates GB 12, LPC 2, BS 1, LHE 3 and LPA 15

Lane 1: DNA marker;  
Lane 2: DNA size of isolate GB 12;  
Lane 3: DNA size of isolate LPC 2;  
Lane 4: DNA size of isolate BS 1;  
Lane 5: DNA size of isolate LHE 3;  
Lane 6: DNA size of isolate LPA 15.



**Figure 5** DNA size of isolates LHE 10 and LHE 12

Lane 1: DNA marker;  
Lane 2: DNA size of isolate LHE 12;  
Lane 3: DNA size of isolate LHE 10

## 4.4 Compost activator development for composting in Laboratory and field experiment

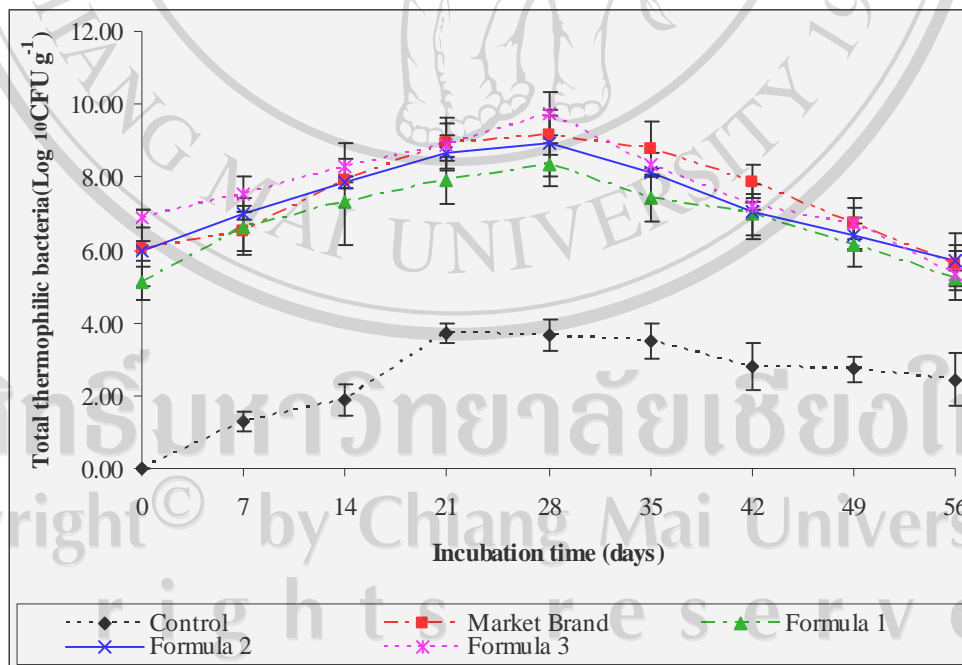
### 4.4.1 Growth of thermophilic bacteria

The changes of thermophilic bacteria during decomposing rice straw in laboratory experiment was shown in Table 14 and Figure 6. The growth of thermophilic bacteria of treatments with Market brand, Formula 1, Formula 2 and Formula 3 were similar and not significantly different ( $p > 0.05$ ) throughout the decomposition period, the initial amount of thermophilic bacteria of treatment with Market brand, Formula 1, Formula 2 and Formula 3 inoculums were  $6.05 \pm 1.06$ ,  $5.10 \pm 0.45$ ,  $5.95 \pm 0.27$  and  $6.87 \pm 0.23 \log_{10} \text{CFU g}^{-1}$ , respectively at the onset of the composting period while control treatment had a few number of thermophilic bacteria. The growth of treatments with Market brand, Formula 1, Formula 2 and Formula 3 inoculums increased and reached a maximum peak, with  $\log_{10} \text{CFU g}^{-1}$  equal to  $9.14 \pm 0.55$ ,  $8.34 \pm 0.57$ ,  $8.93 \pm 0.92$  and  $9.75 \pm 0.58$ , respectively after 28 days of incubation time. Thereafter, decreased to a level of  $5.60 \pm 0.56$ ,  $5.22 \pm 0.23$ ,  $5.69 \pm 0.77$  and  $5.32 \pm 0.68 \log_{10} \text{CFUg}^{-1}$  at the end of incubation time. However, decomposing process with formular 3 inoculum preceded the other ones. In case of control, the amount of thermophilic bacteria was significantly lower ( $p < 0.05$ ) than other treatments all over the time of decomposition. The growth of thermophilic bacteria took place within lower level from 3.70 to  $2.44 \log_{10} \text{CFU g}^{-1}$ .

**Table 14** Changes in the thermophilic bacteria biomass ( $\log_{10}$  CFU  $g^{-1}$ ) during decomposition of rice straw

Days	Treatment				
	control	Market brand	Formular 1	Formular 2	Formular 3
0	0.00±0.00 <sup>a*</sup>	6.05±1.06 <sup>bc</sup>	5.10±0.45 <sup>b</sup>	5.95±0.27 <sup>bc</sup>	6.87±0.23 <sup>c</sup>
7	1.29±0.27 <sup>a</sup>	6.51±0.52 <sup>b</sup>	6.63±0.78 <sup>b</sup>	7.01±0.20 <sup>bc</sup>	7.54±0.50 <sup>c</sup>
14	1.88±0.43 <sup>a</sup>	7.93±0.09 <sup>b</sup>	7.32±1.17 <sup>b</sup>	7.86±0.16 <sup>b</sup>	8.31±0.64 <sup>b</sup>
21	3.70±0.26 <sup>a</sup>	8.95±0.51 <sup>c</sup>	7.92±0.64 <sup>b</sup>	8.68±0.45 <sup>bc</sup>	8.89±0.73 <sup>bc</sup>
28	3.66±0.41 <sup>a</sup>	9.14±0.55 <sup>bc</sup>	8.34±0.57 <sup>b</sup>	8.93±0.92 <sup>bc</sup>	9.75±0.58 <sup>c</sup>
35	3.51±0.49 <sup>a</sup>	8.76±0.74 <sup>c</sup>	7.42±0.65 <sup>b</sup>	8.11±0.11 <sup>bc</sup>	8.32±0.32 <sup>bc</sup>
42	2.81±0.64 <sup>a</sup>	7.87±0.45 <sup>b</sup>	6.98±0.55 <sup>b</sup>	7.03±0.76 <sup>b</sup>	7.23±0.10 <sup>b</sup>
49	2.74±0.35 <sup>a</sup>	6.73±0.42 <sup>b</sup>	6.14±0.60 <sup>b</sup>	6.41±0.46 <sup>b</sup>	6.74±0.70 <sup>b</sup>
56	2.44±0.74 <sup>a</sup>	5.60±0.56 <sup>b</sup>	5.22±0.23 <sup>b</sup>	5.69±0.77 <sup>b</sup>	5.32±0.68 <sup>b</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 6** Changes of thermophilic bacteria growth during decomposition of rice straw

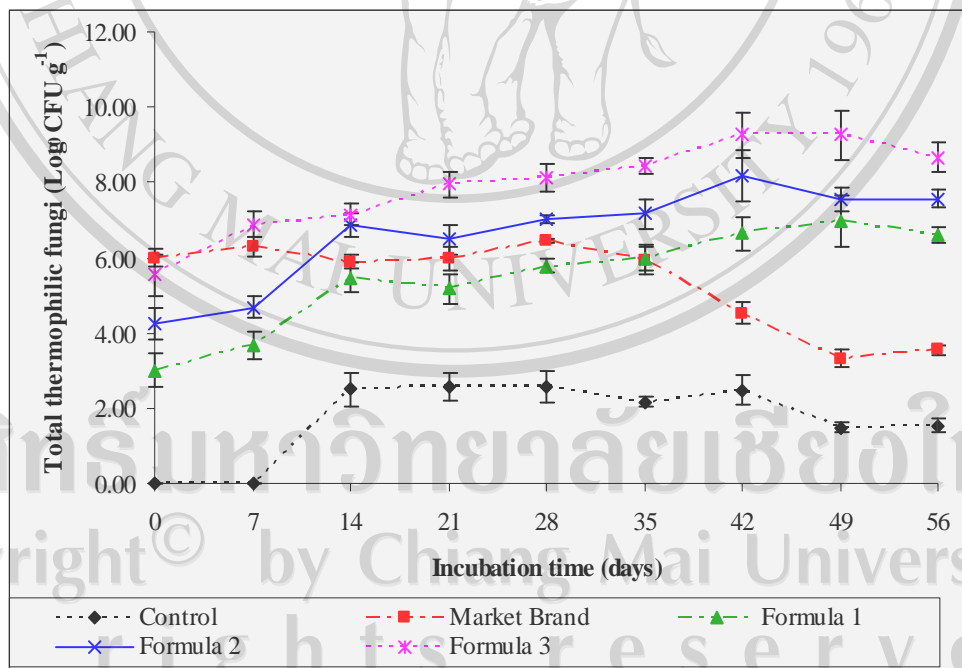
#### 4.4.2 Growth of thermophilic fungi

Table 15 and Figure 7, present the growth of thermophilic fungi of the composting rice straw. The initial amount of thermophilic fungi of Market brand, Formula 1, Formula 2, and Formula 3 were  $5.98 \pm 0.24$ ,  $3.00 \pm 0.44$ ,  $4.23 \pm 0.41$  and  $5.54 \pm 0.54 \log_{10} \text{CFU g}^{-1}$ , respectively, while control had a few number of fungi. The growing thermophilic fungi of Formula 1, Formula 2 and Formula 3 simultaneously increased and reached its high peak of growth, with  $6.96 \pm 0.67$ ,  $8.16 \pm 0.69$ ,  $9.25 \pm 0.58 \log_{10} \text{CFU g}^{-1}$ , respectively near 42-49 days of incubation time, followed by slow decline. Among these decomposing process, the treatment with formular 3 inoculum rose above those of the other ones. Conversely, in the case of Market brand the growth of thermophilic fungi biomass showed a long term of a few growing period (4 weeks), after that it at once decrease to the end of the experimental period with  $3.54 \pm 0.15 \log_{10} \text{CFU g}^{-1}$ . For the control, it was found that the growth of thermophilic fungi took place after 14 days of incubation time with  $2.50 \pm 0.46 \log_{10} \text{CFU g}^{-1}$  and then kept their growth around 2.58 to  $1.47 \log_{10} \text{CFU g}^{-1}$  until the end of decomposition period. All of these treatment the growth of thermophilic fungi of control treatment was at the lowest level.

**Table 15** Changes in the thermophilic fungi biomass ( $\log_{10}$  CFU  $g^{-1}$ ) during decomposition of rice straw

Days	Treatment				
	control	Market brand	Formular 1	Formular 2	Formular 3
0	0.00±0.00 <sup>a*</sup>	5.98±0.24 <sup>d</sup>	3.00±0.44 <sup>b</sup>	4.23±0.41 <sup>c</sup>	5.54±0.54 <sup>d</sup>
7	0.00±0.00 <sup>a</sup>	6.29±0.28 <sup>d</sup>	3.67±0.38 <sup>b</sup>	4.68±0.29 <sup>c</sup>	6.89±0.36 <sup>e</sup>
14	2.50±0.46 <sup>a</sup>	5.89±0.20 <sup>b</sup>	5.47±0.38 <sup>b</sup>	6.87±0.30 <sup>c</sup>	7.15±0.30 <sup>d</sup>
21	2.58±0.38 <sup>a</sup>	5.97±0.30 <sup>c</sup>	5.17±0.40 <sup>b</sup>	6.48±0.39 <sup>c</sup>	7.95±0.33 <sup>d</sup>
28	2.57±0.40 <sup>a</sup>	6.43±0.06 <sup>c</sup>	5.78±0.19 <sup>b</sup>	7.02±0.11 <sup>d</sup>	8.13±0.36 <sup>e</sup>
35	2.17±0.15 <sup>a</sup>	5.92±0.37 <sup>b</sup>	5.98±0.34 <sup>b</sup>	7.17±0.40 <sup>c</sup>	8.46±0.21 <sup>d</sup>
42	2.48±0.39 <sup>a</sup>	4.53±0.30 <sup>b</sup>	6.63±0.45 <sup>c</sup>	8.16±0.69 <sup>d</sup>	9.25±0.58 <sup>e</sup>
49	1.47±0.14 <sup>a</sup>	3.31±0.23 <sup>b</sup>	6.96±0.67 <sup>c</sup>	7.54±0.31 <sup>c</sup>	9.25±0.64 <sup>d</sup>
56	1.53±0.18 <sup>a</sup>	3.54±0.15 <sup>b</sup>	6.60±0.20 <sup>c</sup>	7.56±0.24 <sup>d</sup>	8.67±0.39 <sup>e</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 7** Changes of thermophilic fungi growth during decomposition of rice straw

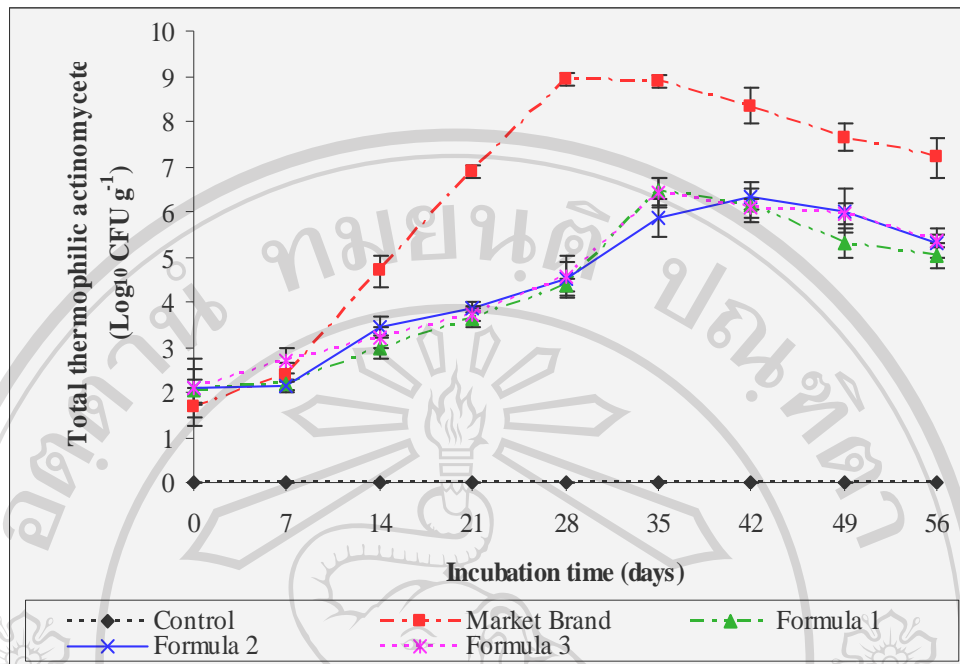
#### 4.4.3 Growth of thermophilic actinomycetes

As shown in Table 16 and Figure 8, the initial amount of thermophilic actinomycetes biomass of treatments with Market brand, Formula 1, Formula 2 and Formula 3 inocula were  $1.67 \pm 0.42$ ,  $2.03 \pm 0.26$ ,  $2.11 \pm 0.39$  and  $2.09 \pm 0.16$   $\text{Log}_{10}$  CFU  $\text{g}^{-1}$ , respectively. The thermophilic actinomycetes count of treatment with Market brand inoculum increased to the highest peak at day 28 with  $8.93 \pm 0.16$   $\text{log}_{10}$  CFU  $\text{g}^{-1}$ , followed by decline till to the final of decomposition period and it significantly had higher amount of thermophilic actinomycetes than those of other treatments during the decomposing process. For the thermophilic actinomycetes growth of the treatments with Formula 1, Formula 2 and Formula 3 inoculum, they proceeded in the same pattern and nearly increased all over the time of experimental period. Whereas, the control could not detected any growth of thermophilic actinomycetes during the decomposing process.

**Table 16** Changes in the thermophilic actinomycetes biomass ( $\text{log}_{10}$  CFU  $\text{g}^{-1}$ ) during decomposition of rice straw

Days	Treatment				
	control	Market brand	Formular 1	Formular 2	Formular 3
0	$0.00 \pm 0.00$ <sup>a*</sup>	$1.67 \pm 0.42$ <sup>b</sup>	$2.03 \pm 0.26$ <sup>b</sup>	$2.11 \pm 0.39$ <sup>b</sup>	$2.09 \pm 0.16$ <sup>b</sup>
7	$0.00 \pm 0.00$ <sup>a</sup>	$2.35 \pm 0.31$ <sup>bc</sup>	$2.17 \pm 0.13$ <sup>b</sup>	$2.12 \pm 0.10$ <sup>b</sup>	$2.70 \pm 0.26$ <sup>c</sup>
14	$0.00 \pm 0.00$ <sup>a</sup>	$4.68 \pm 0.36$ <sup>d</sup>	$2.98 \pm 0.23$ <sup>b</sup>	$3.46 \pm 0.22$ <sup>c</sup>	$3.21 \pm 0.24$ <sup>bc</sup>
21	$0.00 \pm 0.00$ <sup>a</sup>	$6.87 \pm 0.14$ <sup>c</sup>	$3.65 \pm 0.23$ <sup>b</sup>	$3.87 \pm 0.12$ <sup>b</sup>	$3.74 \pm 0.15$ <sup>b</sup>
28	$0.00 \pm 0.00$ <sup>a</sup>	$8.93 \pm 0.16$ <sup>c</sup>	$4.36 \pm 0.13$ <sup>b</sup>	$4.52 \pm 0.37$ <sup>b</sup>	$4.54 \pm 0.47$ <sup>b</sup>
35	$0.00 \pm 0.00$ <sup>a</sup>	$8.88 \pm 0.15$ <sup>d</sup>	$6.45 \pm 0.29$ <sup>c</sup>	$5.86 \pm 0.45$ <sup>b</sup>	$6.41 \pm 0.33$ <sup>c</sup>
42	$0.00 \pm 0.00$ <sup>a</sup>	$8.34 \pm 0.40$ <sup>c</sup>	$6.12 \pm 0.37$ <sup>b</sup>	$6.34 \pm 0.29$ <sup>b</sup>	$6.08 \pm 0.22$ <sup>b</sup>
49	$0.00 \pm 0.00$ <sup>a</sup>	$7.64 \pm 0.30$ <sup>d</sup>	$5.32 \pm 0.33$ <sup>b</sup>	$6.01 \pm 0.49$ <sup>c</sup>	$5.95 \pm 0.25$ <sup>c</sup>
56	$0.00 \pm 0.00$ <sup>a</sup>	$7.19 \pm 0.43$ <sup>c</sup>	$5.01 \pm 0.27$ <sup>b</sup>	$5.32 \pm 0.33$ <sup>b</sup>	$5.35 \pm 0.13$ <sup>b</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 8** Changes of thermophilic actinomycetes growth during decomposition of rice straw

#### 4.4.4 Growth of cellulose-degrading thermophiles

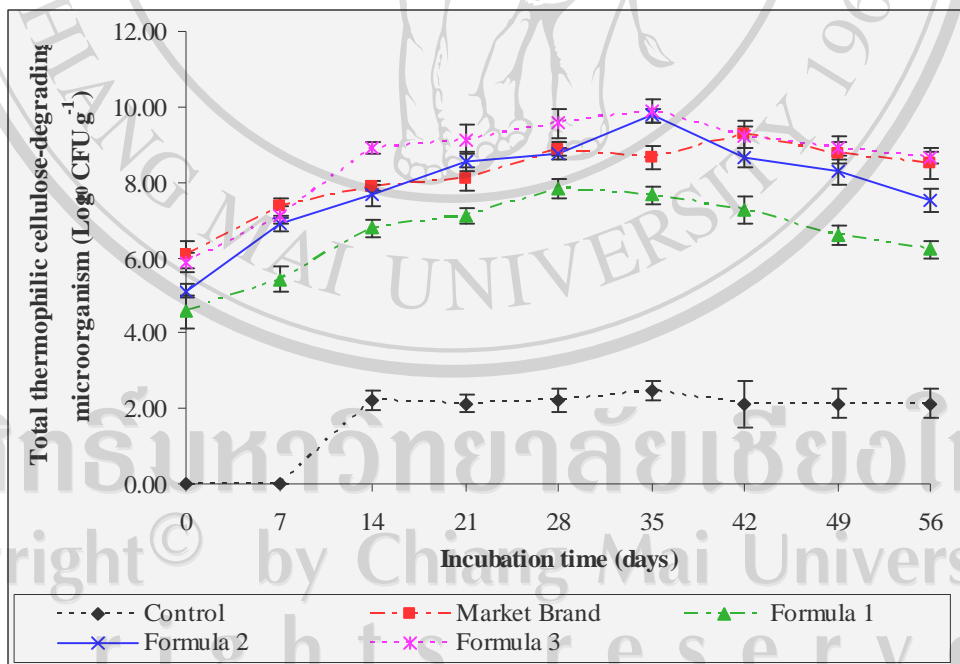
In Table 17 and Figure 9, the amount of cellulose-degrading thermophiles of treatments with Market brand, Formula 1, Formula 2 and Formula 3 inocula began at  $6.10 \pm 0.36$ ,  $4.57 \pm 0.43$ ,  $5.12 \pm 0.16$  and  $5.87 \pm 0.24 \log_{10} \text{CFU g}^{-1}$ , respectively.

During the decomposition period the growth of cellulose-degrading thermophiles of all treatments were found in the same direction. They increased in number with the increasing time and reached a highest peak after 35 or 42 days of incubation time, followed by a marginal decrease. However, cellulose-degrading thermophiles of treatment with Formular 3 could quickly grow up and predominated those of other treatments. The growth of cellulose-degrading thermophiles in case of control had a slightly increasing number with narrow range between  $2.20 \pm 0.26$  and  $2.48 \pm 0.27 \log_{10} \text{CFU g}^{-1}$  only.

**Table 17** Changes in the cellulose-degrading thermophiles biomass ( $\log_{10}$  CFU  $g^{-1}$ ) during decomposition of rice straw

Days	Treatment				
	control	Market brand	Formular 1	Formular 2	Formular 3
0	0.00±0.00 <sup>a*</sup>	6.10±0.36 <sup>d</sup>	4.57±0.43 <sup>b</sup>	5.12±0.16 <sup>c</sup>	5.87±0.24 <sup>d</sup>
7	0.00±0.00 <sup>a</sup>	7.34±0.25 <sup>d</sup>	5.43±0.32 <sup>b</sup>	6.89±0.19 <sup>c</sup>	7.13±0.24 <sup>cd</sup>
14	2.20±0.26 <sup>a</sup>	7.89±0.13 <sup>c</sup>	6.78±0.23 <sup>b</sup>	7.65±0.28 <sup>c</sup>	8.90±0.16 <sup>d</sup>
21	2.13±0.24 <sup>a</sup>	8.10±0.31 <sup>c</sup>	7.09±0.20 <sup>b</sup>	8.56±0.27 <sup>c</sup>	9.14±0.38 <sup>d</sup>
28	2.22±0.31 <sup>a</sup>	8.87±0.18 <sup>c</sup>	7.84±0.27 <sup>b</sup>	8.76±0.17 <sup>c</sup>	9.56±0.40 <sup>d</sup>
35	2.48±0.27 <sup>a</sup>	8.65±0.29 <sup>c</sup>	7.67±0.23 <sup>b</sup>	9.76±0.18 <sup>d</sup>	9.90±0.31 <sup>d</sup>
42	2.11±0.60 <sup>a</sup>	9.27±0.35 <sup>c</sup>	7.24±0.36 <sup>b</sup>	8.65±0.27 <sup>c</sup>	9.21±0.29 <sup>c</sup>
49	2.13±0.40 <sup>a</sup>	8.76±0.28 <sup>c</sup>	6.58±0.27 <sup>b</sup>	8.31±0.40 <sup>c</sup>	8.91±0.32 <sup>c</sup>
56	2.13±0.40 <sup>a</sup>	8.52±0.41 <sup>d</sup>	6.21±0.24 <sup>b</sup>	7.52±0.32 <sup>c</sup>	8.65±0.15 <sup>d</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 9** Changes of cellulose-degrading thermophiles growth during decomposition of rice straw

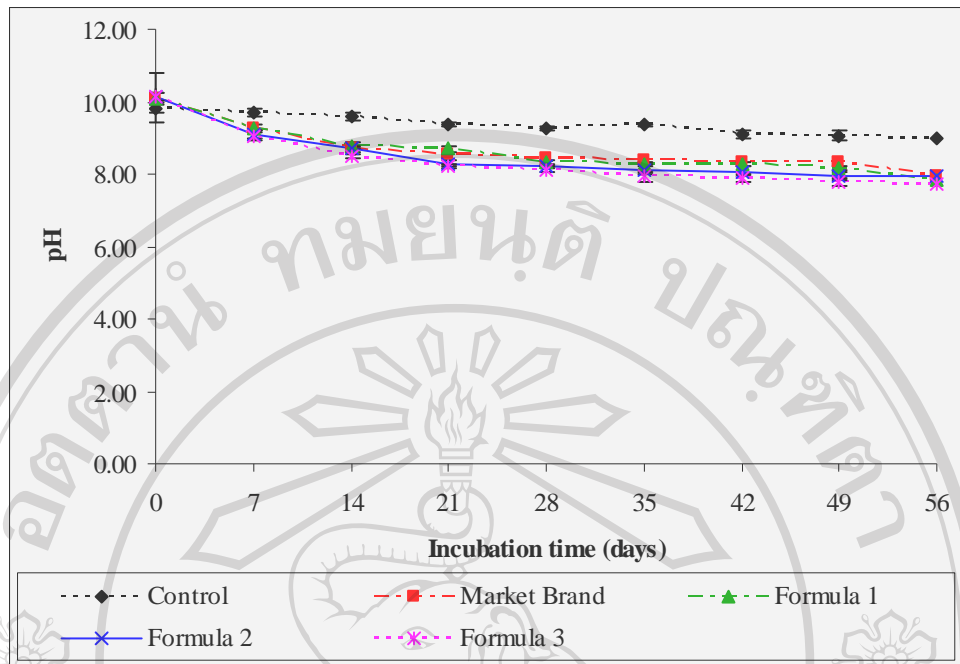
#### 4.4.5 Changes of pH

Table 18 and Figure 10, present pH of rice straw decomposition. All the pH variation conducted in the same trend. The initial pH values of all treatments were in rang of 9.80 to 10.10. Thereafter, they decreased till the end of decomposition period at the level range of 7.70 to 8.98 for treatments with inoculums and control treatment. However, decreasing pH values of treatment with inoculum Formular 3 predominantly took place, whereas these of control slowly went down.

**Table 18** Changes of the pH during decomposition of rice straw

Days	Treatment				
	control	Market brand	Formular 1	Formular 2	Formular 3
0	9.80±0.10 <sup>a*</sup>	10.10±0.26 <sup>a</sup>	10.10±0.69 <sup>a</sup>	10.10±0.11 <sup>a</sup>	10.10±0.13 <sup>a</sup>
7	9.70±0.17 <sup>b</sup>	9.25±0.16 <sup>a</sup>	9.25±0.07 <sup>a</sup>	9.10±0.09 <sup>a</sup>	9.05±0.09 <sup>a</sup>
14	9.60±0.10 <sup>c</sup>	8.70±0.10 <sup>b</sup>	8.78±0.10 <sup>b</sup>	8.70±0.10 <sup>b</sup>	8.50±0.13 <sup>a</sup>
21	9.35±0.10 <sup>c</sup>	8.55±0.10 <sup>b</sup>	8.69±0.07 <sup>b</sup>	8.30±0.08 <sup>a</sup>	8.20±0.07 <sup>a</sup>
28	9.25±0.06 <sup>c</sup>	8.45±0.05 <sup>b</sup>	8.35±0.07 <sup>b</sup>	8.20±0.08 <sup>a</sup>	8.12±0.05 <sup>a</sup>
35	9.35±0.06 <sup>d</sup>	8.40±0.06 <sup>c</sup>	8.30±0.06 <sup>c</sup>	8.10±0.04 <sup>b</sup>	7.94±0.08 <sup>a</sup>
42	9.10±0.04 <sup>d</sup>	8.34±0.07 <sup>c</sup>	8.28±0.03 <sup>c</sup>	8.08±0.10 <sup>b</sup>	7.89±0.14 <sup>a</sup>
49	9.05±0.10 <sup>d</sup>	8.31±0.06 <sup>c</sup>	8.15±0.05 <sup>c</sup>	7.97±0.12 <sup>b</sup>	7.76±0.12 <sup>a</sup>
56	8.98±0.14 <sup>c</sup>	7.96±0.12 <sup>b</sup>	7.83±0.06 <sup>ab</sup>	7.95±0.10 <sup>b</sup>	7.70±0.07 <sup>a</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 10** Changes of pH during decomposition of rice straw

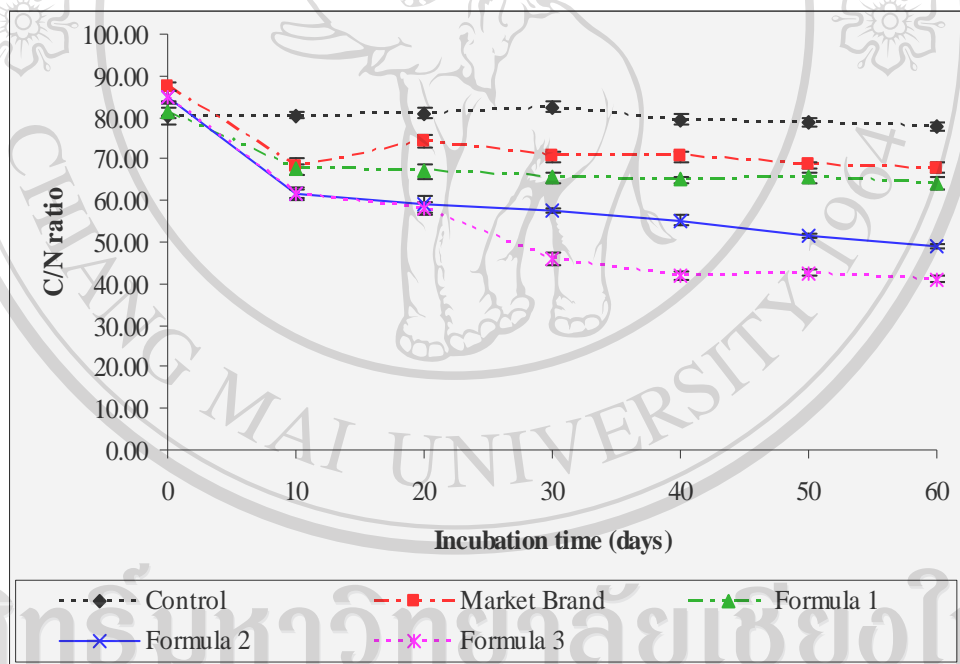
#### 4.4.6 Changes of C/N ratio

Table 19 and Figure 11, present change of C/N ratio during decomposing rice straw. The initial C/N ratio of treatments with Market brand, Formula 1, Formula 2, Formula 3 inocula and control began with  $80.50 \pm 1.99$ ,  $87.50 \pm 0.92$ ,  $81.50 \pm 1.66$ ,  $85.00 \pm 1.43$  and  $85.00 \pm 1.18$ , respectively. All the C/N ratio of treatment with inoculums promptly decreased after 10 days of decomposing time and then slowly decline to the end of experiment. However, decreasing C/N ratio of treatment with Formula 3 significantly predominate with  $41.01 \pm 0.75$  at the end of experiment, followed by treatment with Formula 2 to  $49.01 \pm 0.58$ . As for the control treatment, the C/N ratio took place a few change from  $80.50 \pm 1.99$  to  $77.67 \pm 0.95$ .

**Table 19** Changes in the C/N ratio during decomposition of rice straw

Days	Treatment				
	control	Market brand	Formular 1	Formular 2	Formular 3
0	80.50±1.99 <sup>a*</sup>	87.50±0.92 <sup>b</sup>	81.50±1.66 <sup>a</sup>	85.00±1.43 <sup>b</sup>	85.00±1.18 <sup>b</sup>
10	80.50±0.95 <sup>c</sup>	68.00±2.01 <sup>b</sup>	67.50±1.22 <sup>b</sup>	61.50±1.58 <sup>a</sup>	61.50±0.99 <sup>a</sup>
20	81.00±1.29 <sup>d</sup>	74.00±1.52 <sup>c</sup>	67.00±1.80 <sup>b</sup>	59.00±2.04 <sup>a</sup>	58.00±1.46 <sup>a</sup>
30	82.50±1.15 <sup>e</sup>	70.50±1.21 <sup>d</sup>	65.50±1.33 <sup>c</sup>	57.50±0.44 <sup>b</sup>	46.00±1.44 <sup>a</sup>
40	79.50±1.21 <sup>e</sup>	70.50±1.13 <sup>d</sup>	65.00±0.79 <sup>c</sup>	55.30±1.32 <sup>b</sup>	42.00±1.01 <sup>a</sup>
50	78.90±1.02 <sup>e</sup>	68.50±0.82 <sup>d</sup>	65.50±1.19 <sup>c</sup>	51.50±0.71 <sup>b</sup>	42.50±0.73 <sup>a</sup>
60	77.67±0.95 <sup>e</sup>	67.80±1.19 <sup>d</sup>	64.15±1.54 <sup>c</sup>	49.01±0.58 <sup>b</sup>	41.01±0.75 <sup>a</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .

**Figure 11** Changes of C/N ratio during decomposition of rice straw

## 4.5 Composting process in laboratory experiment

### 4.5.1 Growth of thermophilic bacteria

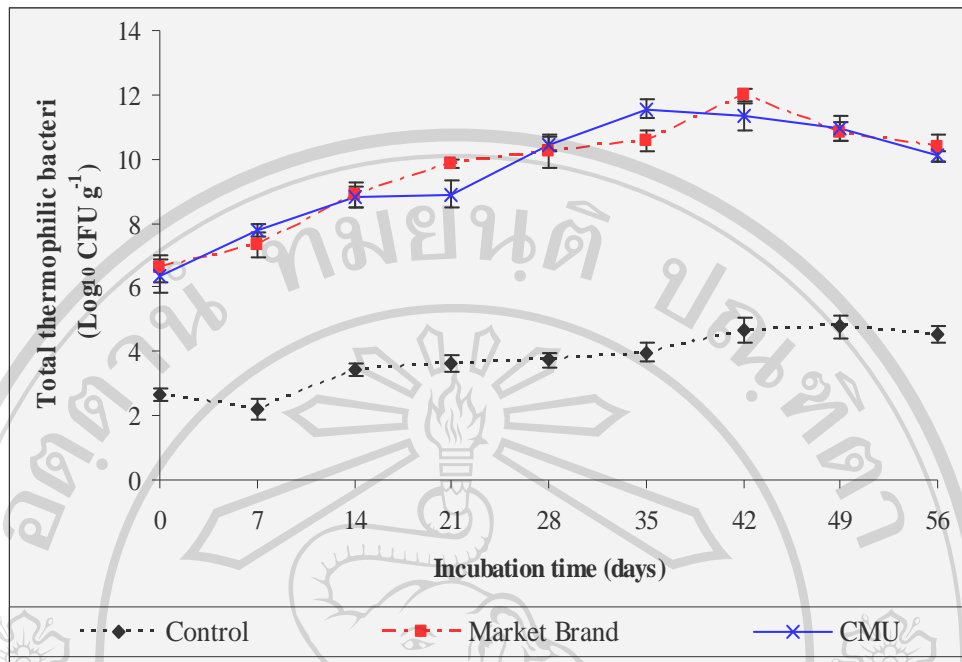
The growth of thermophilic bacteria during composting in laboratory was shown in Table 20 and Figure 12. The growth of thermophilic bacteria in both

decomposition mixing with Market brand and CMU inoculums were found in the same trend. At the beginning day, the amount of thermophilic bacteria of treatments with Market brand and CMU inoculum were  $6.58 \pm 0.44$  and  $6.36 \pm 0.51 \log_{10} \text{CFU g}^{-1}$ , respectively. The growth of thermophilic bacteria of treatment with Market brand and CMU inoculums increased with time and reached the maximum growth of  $11.98 \pm 0.20$  and  $11.54 \pm 0.38 \log_{10} \text{CFU g}^{-1}$  after 42 and 59 days of incubation time respectively, followed by decreasing in number  $\log_{10} \text{CFU g}^{-1}$   $10.34 \pm 0.44$  and  $10.08 \pm 0.18$  at the end of incubation period. In case of control treatment, the growth of thermophilic bacteria slightly increased in amount of  $2.68 \pm 0.20$  to  $4.54 \pm 0.28 \log_{10} \text{CFU g}^{-1}$  from the first to the end of incubation time.

**Table 20** Changes in thermophilic bacteria biomass ( $\log_{10} \text{CFU g}^{-1}$ ) during composting in laboratory

Days	Treatment		
	control	Market brand	CMU
0	$2.68 \pm 0.20^{a+*}$	$6.58 \pm 0.44^b$	$6.36 \pm 0.51^b$
7	$2.18 \pm 0.33^a$	$7.32 \pm 0.38^b$	$7.79 \pm 0.21^b$
14	$3.44 \pm 0.20^a$	$8.9 \pm 0.40^b$	$8.8 \pm 0.33^b$
21	$3.65 \pm 0.27^a$	$9.87 \pm 0.13^c$	$8.9 \pm 0.43^b$
28	$3.73 \pm 0.21^a$	$10.23 \pm 0.53^b$	$10.45 \pm 0.24^b$
35	$3.97 \pm 0.29^a$	$10.56 \pm 0.31^b$	$11.54 \pm 0.29^c$
42	$4.65 \pm 0.39^a$	$11.98 \pm 0.20^b$	$11.32 \pm 0.40^b$
49	$4.77 \pm 0.37^a$	$10.85 \pm 0.27^b$	$10.95 \pm 0.38^b$
56	$4.54 \pm 0.28^a$	$10.34 \pm 0.44^b$	$10.08 \pm 0.18^b$

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 12** Changes of thermophilic bacteria growth during composting rice straw in laboratory experiment

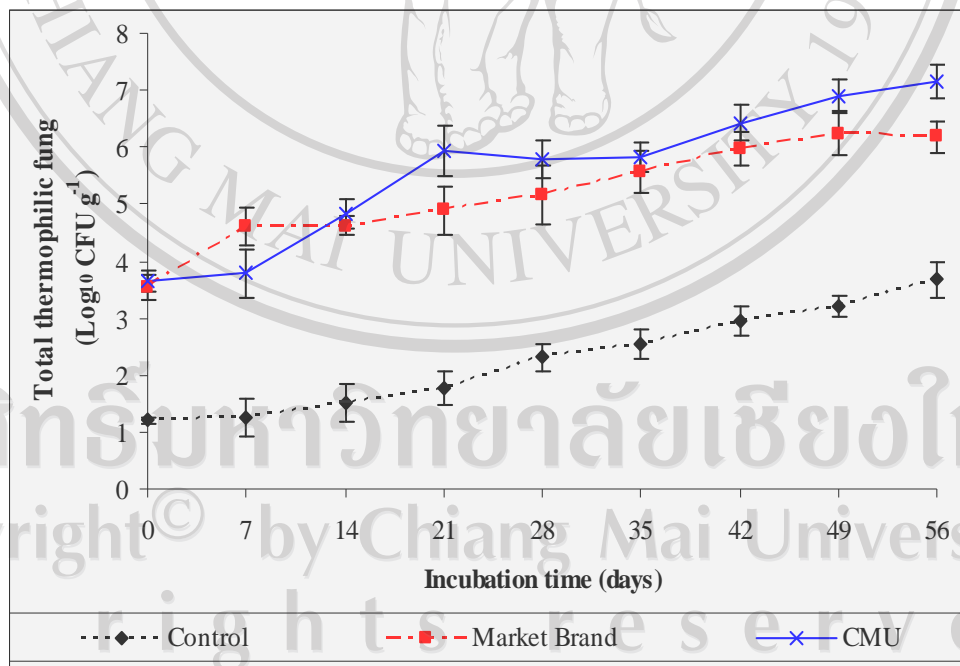
#### 4.5.2 Growth of thermophilic fungi

The growth of thermophilic fungi during composting in laboratory was shown in Table 21 and Figure 13. The initial amount of thermophilic fungi in composting with Market brand and CMU inoculums were  $3.54 \pm 0.23$  and  $3.65 \pm 0.18 \log_{10} \text{CFU g}^{-1}$ , respectively. At the first week of incubation period, the growth of thermophilic fungi of treatment with Market brand inoculum significantly increased ( $p < 0.05$ ) in number more than those of treatment with CMU inoculum (Table 21). However, the thermophilic fungi of the treatment with CMU inoculum rose above those of the treatment with Market brand from the week after to the end of incubation time. For the thermophilic fungi growth of control treatment, it was similar to that of treatment of Market brand with the exception of lower amount between  $1.20 \pm 0.06$  and  $3.67 \pm 0.32 \log_{10} \text{CFU g}^{-1}$  during incubation period.

**Table 21** Changes in thermophilic fungi biomass ( $\log_{10}$  CFU  $g^{-1}$ ) during composting in laboratory

Days	Treatment		
	control	Market brand	CMU
0	1.20±0.06 <sup>a*</sup>	3.54±0.23 <sup>b</sup>	3.65±0.18 <sup>b</sup>
7	1.26±0.33 <sup>a</sup>	4.61±0.32 <sup>c</sup>	3.78±0.42 <sup>b</sup>
14	1.5±0.33 <sup>a</sup>	4.62±0.16 <sup>b</sup>	4.83±0.25 <sup>b</sup>
21	1.76±0.29 <sup>a</sup>	4.89±0.42 <sup>b</sup>	5.93±0.45 <sup>c</sup>
28	2.31±0.25 <sup>a</sup>	5.17±0.52 <sup>b</sup>	5.78±0.33 <sup>b</sup>
35	2.54±0.26 <sup>a</sup>	5.57±0.36 <sup>b</sup>	5.82±0.25 <sup>b</sup>
42	2.95±0.27 <sup>a</sup>	5.98±0.30 <sup>b</sup>	6.43±0.31 <sup>b</sup>
49	3.2±0.19 <sup>a</sup>	6.23±0.37 <sup>b</sup>	6.91±0.28 <sup>c</sup>
56	3.67±0.32 <sup>a</sup>	6.18±0.28 <sup>b</sup>	7.15±0.27 <sup>c</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 13** Changes of thermophilic fungi growth during composting in laboratory

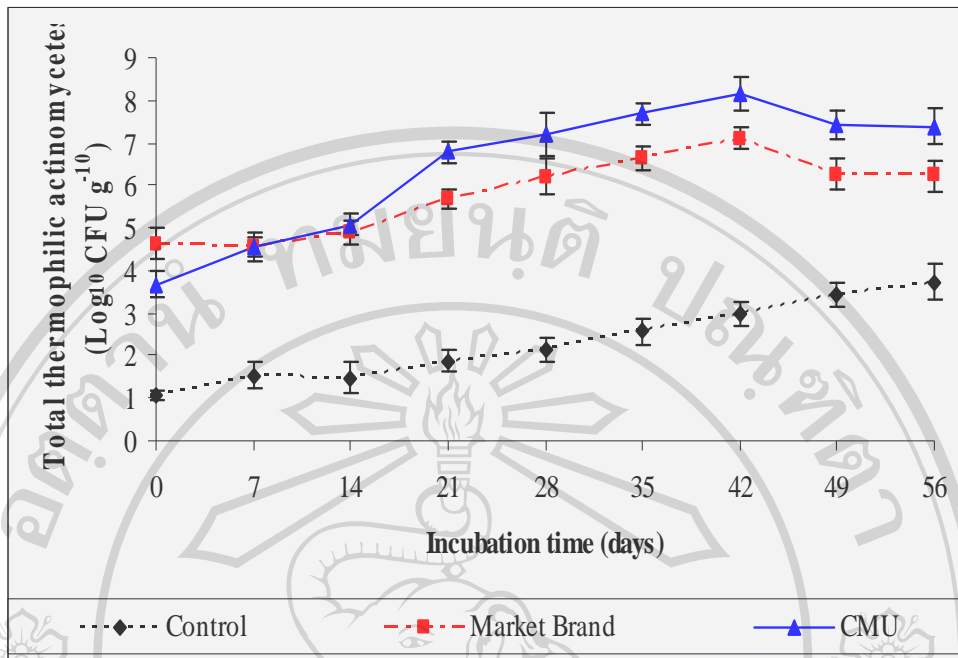
### 4.5.3 Growth of thermophilic actinomycetes

The growth of thermophilic actinomycetes during composting in laboratory was shown in Table 22 and Figure 14. The initial number of thermophilic actinomycetes of decomposition with Market brand and CMU inoculums were  $4.63 \pm 0.35$  and  $3.66 \pm 0.31$   $\log_{10}$  CFU  $g^{-1}$ , respectively. The thermophilic actinomycetes growth of both treatments with Market brand and CMU inocula were mostly parallel from 14 days to end of incubation time, nevertheless the actinomycetes growth of treatment with CMU inoculum always significantly rose ( $p < 0.05$ ) over. The thermophilic actinomycetes from CMU inoculum could reach the maximum growth of  $8.15 \pm 0.40$   $\log_{10}$  CFU  $g^{-1}$  after 42 days of incubation time, while the other one arose  $7.11 \pm 0.24$   $\log_{10}$  CFU  $g^{-1}$  at the same time. Subsequently, both of them decreased a few Log no. to the end of incubation time. For the control treatment, the thermophilic actinomycetes increased slightly with a few amount of  $1.08 \pm 0.09$  to  $3.74 \pm 0.43$   $\log_{10}$  CFU  $g^{-1}$ .

**Table 22** Changes in thermophilic actinomycetes biomass ( $\log_{10}$  CFU  $g^{-1}$ ) during composting in laboratory

Days	Treatment		
	control	Market brand	CMU
0	$1.08 \pm 0.09^{a*}$	$4.63 \pm 0.35^c$	$3.66 \pm 0.31^b$
7	$1.53 \pm 0.30^a$	$4.56 \pm 0.32^b$	$4.56 \pm 0.22^b$
14	$1.48 \pm 0.38^a$	$4.89 \pm 0.30^b$	$5.09 \pm 0.28^c$
21	$1.88 \pm 0.26^a$	$5.67 \pm 0.23^b$	$6.78 \pm 0.26^c$
28	$2.12 \pm 0.29^a$	$6.21 \pm 0.42^b$	$7.2 \pm 0.53^c$
35	$2.56 \pm 0.33^a$	$6.66 \pm 0.28^b$	$7.69 \pm 0.26^c$
42	$2.98 \pm 0.29^a$	$7.11 \pm 0.24^b$	$8.15 \pm 0.40^c$
49	$3.44 \pm 0.29^a$	$6.25 \pm 0.36^b$	$7.42 \pm 0.36^c$
56	$3.74 \pm 0.43^a$	$6.22 \pm 0.37^b$	$7.39 \pm 0.41^c$

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 14** Changes of thermophilic actinomycetes growth during composting in laboratory

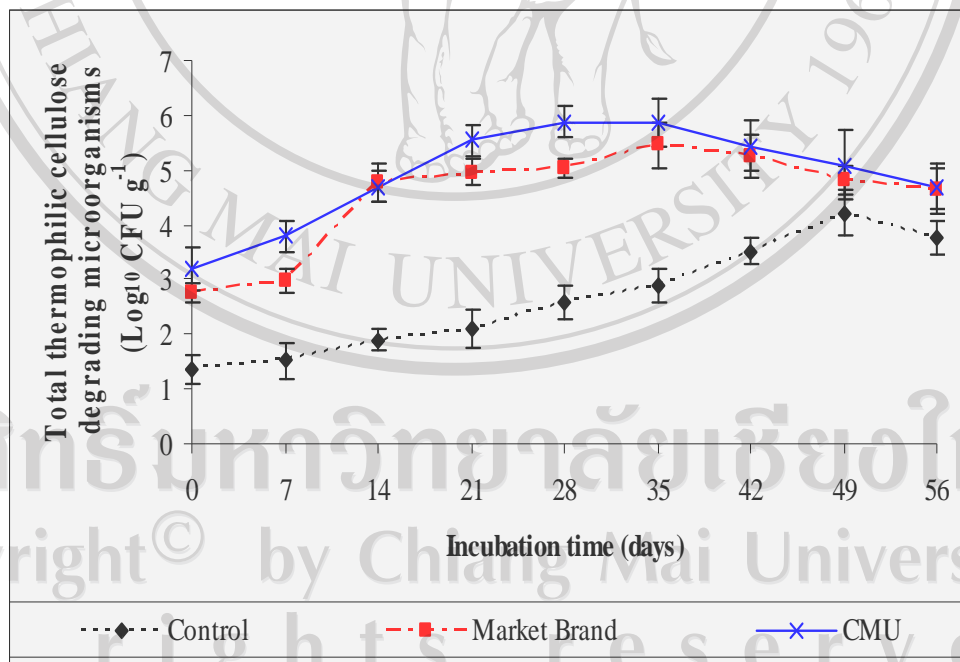
#### 4.5.4 Growth of cellulose-degrading thermophiles

The growth of cellulose-degrading thermophiles during composting in laboratory was shown in Table 23 and Figure 15. The initial amount of total cellulose-degrading thermophiles of composting with CMU inoculum began with  $3.20 \pm 0.39$   $\log_{10}$  CFU  $g^{-1}$ . The growth of them regularly increased with time and reached the maximum growth of  $5.88 \pm 0.44$   $\log_{10}$  CFU  $g^{-1}$  after 35 days of incubation time, followed by decreasing to  $4.66 \pm 0.44$   $\log_{10}$  CFU  $g^{-1}$  at the end of experiment. The growth of cellulose-degrading thermophiles of composting with Market brand varied up and down with the incubation time. However, most of amount of their growth was underneath the growth with CMU inoculum. In case of the control treatment, it allowed cellulose-degrading thermophiles to grow slowly with  $1.34 \pm 0.26$  and  $3.76 \pm 0.29$   $\log_{10}$  CFU  $g^{-1}$  from beginning to end of incubation time.

**Table 23** Changes in thermophilic bacteria biomass ( $\log_{10}$  CFU  $g^{-1}$ ) during composting in laboratory

Days	Treatment		
	control	Market brand	CMU
0	1.34±0.26 <sup>a*</sup>	2.76±0.17 <sup>b</sup>	3.2±0.39 <sup>b</sup>
7	1.52±0.32 <sup>a</sup>	2.98±0.21 <sup>b</sup>	3.79±0.27 <sup>c</sup>
14	1.89±0.20 <sup>a</sup>	4.78±0.35 <sup>b</sup>	4.69±0.28 <sup>b</sup>
21	2.12±0.35 <sup>a</sup>	4.96±0.23 <sup>b</sup>	5.54±0.29 <sup>b</sup>
28	2.59±0.31 <sup>a</sup>	5.03±0.16 <sup>b</sup>	5.87±0.29 <sup>c</sup>
35	2.88±0.30 <sup>a</sup>	5.45±0.42 <sup>b</sup>	5.88±0.44 <sup>b</sup>
42	3.51±0.24 <sup>a</sup>	5.26±0.39 <sup>b</sup>	5.43±0.46 <sup>b</sup>
49	4.22±0.43 <sup>a</sup>	4.8±0.27 <sup>a</sup>	5.09±0.62 <sup>a</sup>
56	3.76±0.29 <sup>a</sup>	4.65±0.36 <sup>b</sup>	4.66±0.44 <sup>b</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 15** Changes of cellulose-degrading thermophiles growth during composting in laboratory

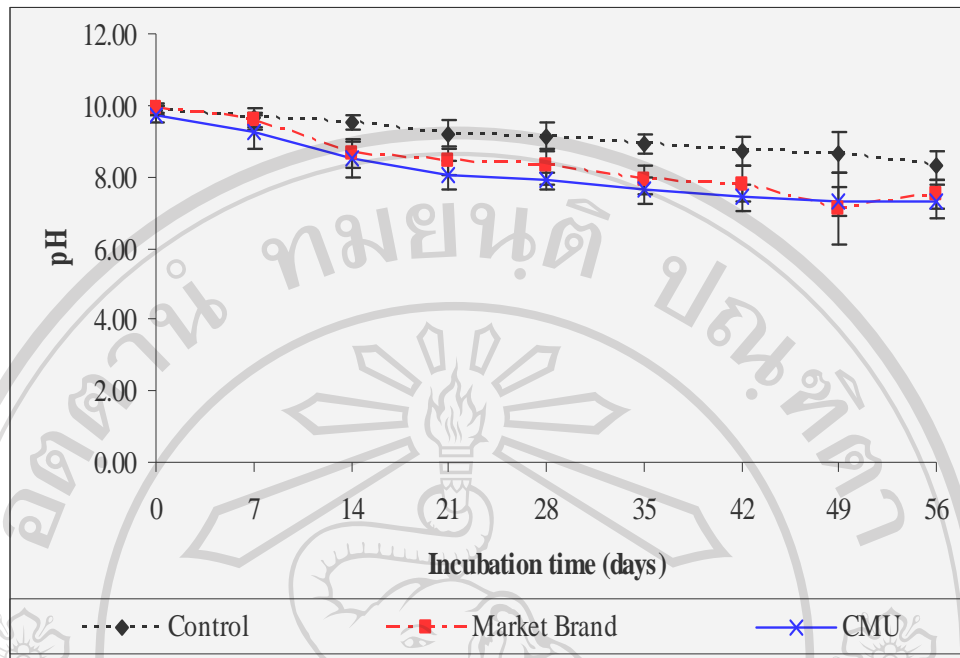
#### 4.5.5 Change of pH

The onset pH of all treatments (Market brand, CMU inocula and control) were nearly the same pH value of 10 (Table 24 and Figure 16). During the composting process, the pH of both treatments with Market brand and CMU inoculums were similar. They slightly dropped from alkaline to rather neutral at  $7.52 \pm 0.41$  and  $7.32 \pm 0.49$ , respectively at the end of experiment. In case of control treatment, decreasing in pH was slower than the others. The pH dropped to  $8.32 \pm 0.38$  at the end of experiment.

**Table 24** Changes of pH during composting in laboratory

Days	Treatment		
	control	Market brand	CMU
0	9.88±0.19 <sup>a*</sup>	9.89±0.13 <sup>a</sup>	9.75±0.22 <sup>a</sup>
7	9.65±0.24 <sup>a</sup>	9.57±0.22 <sup>a</sup>	9.26±0.46 <sup>a</sup>
14	9.52±0.19 <sup>b</sup>	8.63±0.38 <sup>a</sup>	8.51±0.56 <sup>a</sup>
21	9.21±0.39 <sup>b</sup>	8.42±0.35 <sup>a</sup>	8.02±0.41 <sup>a</sup>
28	9.12±0.42 <sup>b</sup>	8.29±0.49 <sup>a</sup>	7.88±0.25 <sup>a</sup>
35	8.90±0.27 <sup>b</sup>	7.92±0.38 <sup>a</sup>	7.61±0.35 <sup>a</sup>
42	8.73±0.42 <sup>b</sup>	7.80±0.48 <sup>a</sup>	7.41±0.39 <sup>a</sup>
49	8.68±0.56 <sup>b</sup>	7.11±0.98 <sup>a</sup>	7.31±0.42 <sup>ab</sup>
56	8.32±0.38 <sup>b</sup>	7.52±0.41 <sup>ab</sup>	7.32±0.49 <sup>a</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 16** Changes of pH during composting in laboratory

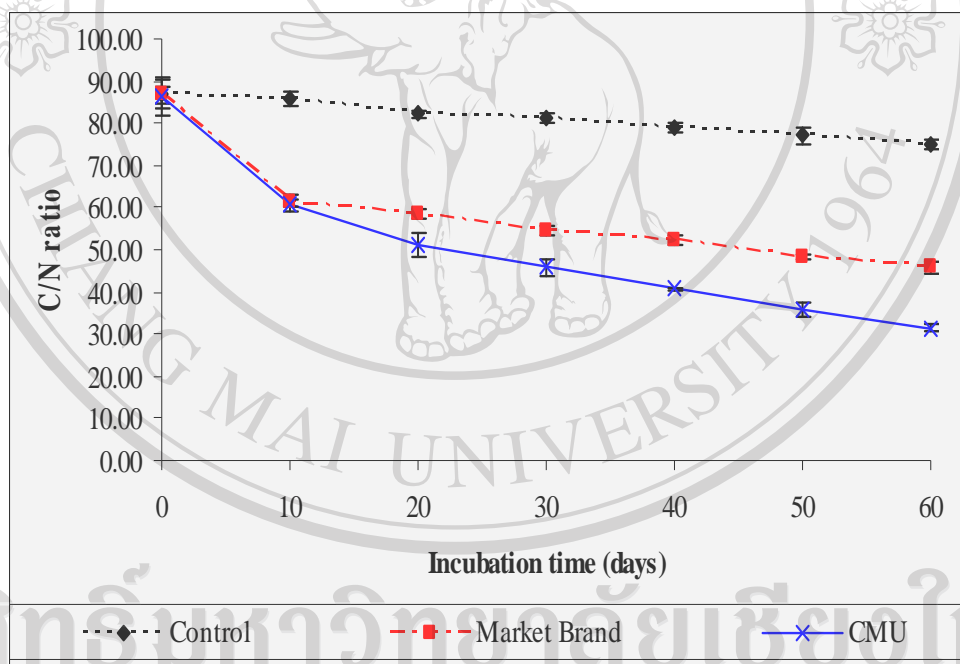
#### 4.5.6 Change of C/N ratio

The initial C/N ratio of composting rice straw with Market brand, and CMU inoculum and control were shown in Table 25 and Figure 17 with the value of  $86.65 \pm 3.47$ ,  $86.32 \pm 4.63$  and  $86.71 \pm 1.89$ , respectively. The C/N ratio of treatment with CMU and Market brand inoculum rapidly decreased during the first 10 days of incubation time. After that, both of two treatments continuously dropped in C/N ratio of  $31.51 \pm 1.07$  and  $45.79 \pm 1.60$ , respectively. However, the falling in C/N ratio of the treatment decomposition with CMU inoculum was somewhat significantly faster ( $p < 0.05$ ) than that of Market brand inoculum. For the control treatment, a retarded C/N ratio took place slowly dropping to  $74.98 \pm 1.03$  at the end of incubation time.

**Table 25** Changes of C/N ratio during composting in laboratory

Days	Treatment		
	control	Market brand	CMU
0	86.71±1.89 <sup>a*</sup>	86.65±3.47 <sup>a</sup>	86.32±4.63 <sup>a</sup>
10	85.76±1.82 <sup>b</sup>	61.09±1.78 <sup>a</sup>	60.98±0.74 <sup>a</sup>
20	82.15±0.78 <sup>c</sup>	58.43±1.25 <sup>b</sup>	51.09±2.74 <sup>a</sup>
30	81.32±1.30 <sup>c</sup>	54.41±1.19 <sup>b</sup>	45.98±1.99 <sup>a</sup>
40	79.17±1.05 <sup>c</sup>	52.09±1.07 <sup>b</sup>	40.87±1.29 <sup>a</sup>
50	77.09±2.12 <sup>c</sup>	48.27±0.79 <sup>b</sup>	35.98±1.75 <sup>a</sup>
60	74.98±1.03 <sup>c</sup>	45.79±1.60 <sup>b</sup>	31.51±1.07 <sup>a</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .

**Figure 17** Changes of C/N ratio during decomposting in laboratory

## 4.6 Composting process in field experiment

### 4.6.1 Growth of thermophilic bacteria

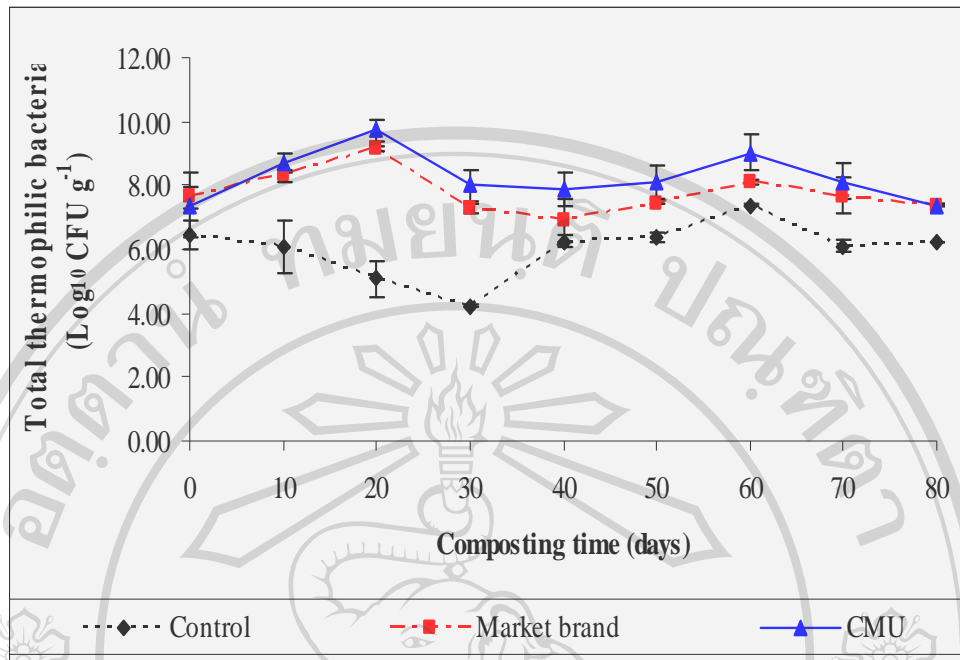
The result of the growth of thermophilic bacteria during composting process was shown in Table 26 and Figure 18. The initial amount of thermophilic bacteria in

composting pile with Market brand and CMU inocula were  $7.62 \pm 0.31$  and  $7.38 \pm 0.98 \log_{10} \text{CFU g}^{-1}$  followed by increasing in number up to  $9.16 \pm 0.09$  and  $9.73 \pm 0.34 \log_{10} \text{CFU g}^{-1}$  after 20 days of composting time. After that, they slowly declined until the end of experiment. Mostly, the growth of both the thermophiles was similar. However, thermophiles in compost with CMU inoculum were above the other one. For the control treatment, the amount of thermophiles just began to grow up after 40 days of incubation time and they could only get more about one log number.

**Table 26** Changes of thermophilic bacteria biomass ( $\log_{10} \text{CFU g}^{-1}$ ) during composting process in the field experiment

Days	Treatment		
	control	Market brand	CMU
0	$6.48 \pm 0.45^{a*}$	$7.62 \pm 0.31^a$	$7.38 \pm 0.98^a$
10	$6.08 \pm 0.85^a$	$8.30 \pm 0.20^b$	$8.70 \pm 0.28^b$
20	$5.08 \pm 0.58^a$	$9.16 \pm 0.09^b$	$9.73 \pm 0.34^b$
30	$4.24 \pm 0.04^a$	$7.30 \pm 0.15^b$	$8.00 \pm 0.51^c$
40	$6.26 \pm 0.17^a$	$6.92 \pm 0.67^{ab}$	$7.89 \pm 0.53^b$
50	$6.37 \pm 0.12^a$	$7.43 \pm 0.00^b$	$8.07 \pm 0.52^c$
60	$7.37 \pm 0.03^a$	$8.11 \pm 0.07^b$	$9.03 \pm 0.54^c$
70	$6.10 \pm 0.17^a$	$7.67 \pm 0.58^b$	$8.11 \pm 0.56^b$
80	$6.23 \pm 0.01^a$	$7.36 \pm 0.05^b$	$7.39 \pm 0.07^b$

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 18** Changes of thermophilic bacteria growth during composting process in the field experiment

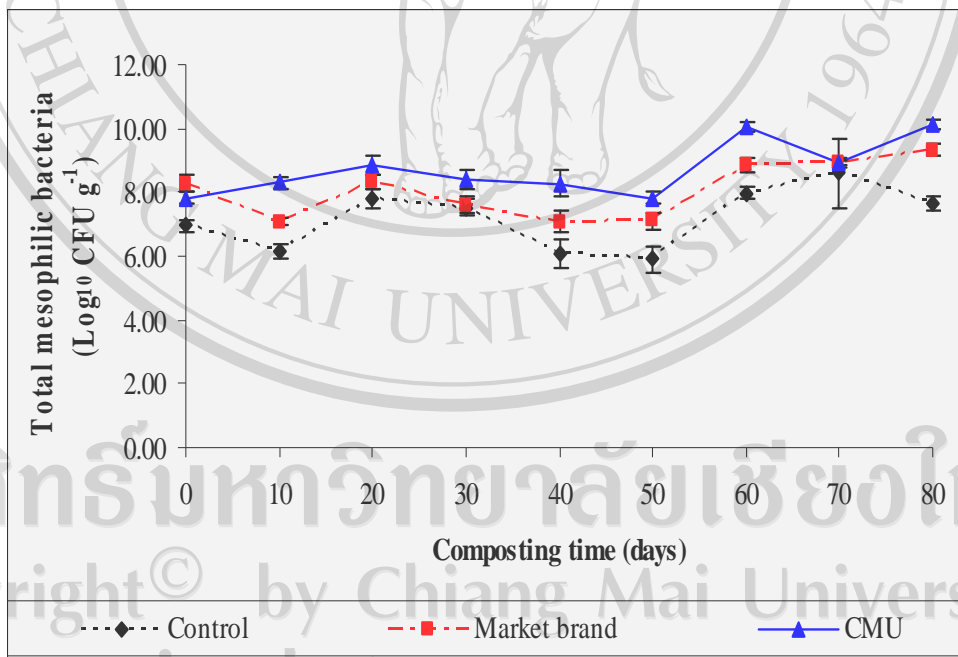
#### 4.6.2 Growth of mesophilic bacteria

The growth of mesophilic bacteria during composting process was shown in Table 27 and Figure 19. The mesophilic bacteria in composts with Market brand, CMU inocula and control treatment were found in the same direction. At the beginning day, the amount of mesophilic bacteria in composts with Market brand inoculum and control were  $8.27 \pm 0.26$  and  $6.96 \pm 0.19 \log_{10} \text{CFU g}^{-1}$ , respectively. During the composting process, the growth of both mesophilic bacteria varied up and down. The amount of mesophilic bacteria of treatment with CMU inoculum began with  $7.83 \pm 0.19 \log_{10} \text{CFU g}^{-1}$  and then significantly arose above ( $p < 0.05$ ) the other treatments throughout the composting period.

**Table 27** Changes of mesophilic bacteria biomass ( $\log_{10}$  CFU  $g^{-1}$ ) during composting process in the field experiment

Days	Treatment		
	control	Market brand	CMU
0	6.96±0.19 <sup>a*</sup>	8.27±0.26 <sup>c</sup>	7.83±0.19 <sup>b</sup>
10	6.17±0.25 <sup>a</sup>	7.08±0.14 <sup>b</sup>	8.30±0.20 <sup>c</sup>
20	7.78±0.30 <sup>a</sup>	8.33±0.22 <sup>b</sup>	8.85±0.29 <sup>b</sup>
30	7.53±0.27 <sup>a</sup>	7.61±0.24 <sup>a</sup>	8.39±0.32 <sup>b</sup>
40	6.07±0.44 <sup>a</sup>	7.08±0.33 <sup>b</sup>	8.28±0.39 <sup>c</sup>
50	5.89±0.41 <sup>a</sup>	7.11±0.25 <sup>b</sup>	7.84±0.20 <sup>c</sup>
60	7.98±0.19 <sup>a</sup>	8.87±0.21 <sup>b</sup>	10.06±0.16 <sup>c</sup>
70	8.62±1.09 <sup>a</sup>	8.91±0.17 <sup>a</sup>	8.95±0.09 <sup>a</sup>
80	7.62±0.22 <sup>a</sup>	9.34±0.21 <sup>b</sup>	10.12±0.17 <sup>c</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 19** Changes of mesophilic bacteria growth during composting process in the field experiment

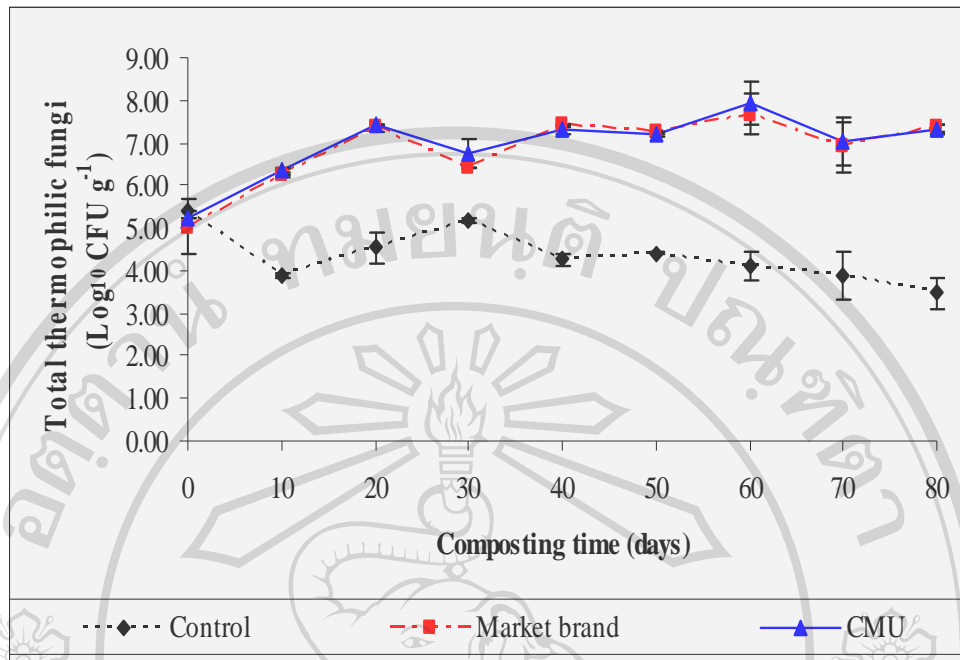
### 4.6.3 Changes of thermophilic fungi growth

The growth of thermophilic fungi during composting process in field experiment was shown in Table 28 and Figure 20. The growth of thermophilic fungi in both of composts with Market brand and CMU inocula were found in the same manner. Both of thermophile fungi increased in number with the time together. Consecutive increasing in number began from  $5.02 \pm 0.65$  and  $5.24 \pm 0.01 \log_{10} \text{CFU g}^{-1}$  to  $7.36 \pm 0.09$  and  $7.31 \pm 0.11 \log_{10} \text{CFU g}^{-1}$ , respectively. In case of control treatment, the growth of thermophilic fungi performed in the opposite way, decreasing from  $5.39 \pm 0.01 \log_{10} \text{CFU g}^{-1}$  at the beginning day to  $3.47 \pm 0.38 \log_{10} \text{CFU g}^{-1}$  at the end of composting period.

**Table 28** Changes of thermophilic fungi biomass ( $\log_{10} \text{CFU g}^{-1}$ ) during composting process in the field experiment

Days	Treatment		
	control	Market brand	CMU
0	$5.39 \pm 0.01^{\text{a}*}$	$5.02 \pm 0.65^{\text{a}}$	$5.24 \pm 0.01^{\text{a}}$
10	$3.89 \pm 0.07^{\text{a}}$	$6.26 \pm 0.05^{\text{b}}$	$6.34 \pm 0.07^{\text{b}}$
20	$4.53 \pm 0.36^{\text{a}}$	$7.34 \pm 0.08^{\text{b}}$	$7.43 \pm 0.02^{\text{b}}$
30	$5.18 \pm 0.07^{\text{a}}$	$6.42 \pm 0.01^{\text{b}}$	$6.74 \pm 0.35^{\text{b}}$
40	$4.25 \pm 0.15^{\text{a}}$	$7.42 \pm 0.02^{\text{b}}$	$7.30 \pm 0.09^{\text{b}}$
50	$4.41 \pm 0.02^{\text{a}}$	$7.25 \pm 0.03^{\text{b}}$	$7.19 \pm 0.05^{\text{b}}$
60	$4.11 \pm 0.32^{\text{a}}$	$7.67 \pm 0.46^{\text{b}}$	$7.93 \pm 0.51^{\text{b}}$
70	$3.87 \pm 0.56^{\text{a}}$	$6.90 \pm 0.58^{\text{b}}$	$7.04 \pm 0.58^{\text{b}}$
80	$3.47 \pm 0.38^{\text{a}}$	$7.36 \pm 0.09^{\text{b}}$	$7.31 \pm 0.11^{\text{b}}$

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 20** Changes of thermophilic fungi growth during composting process in the field experiment

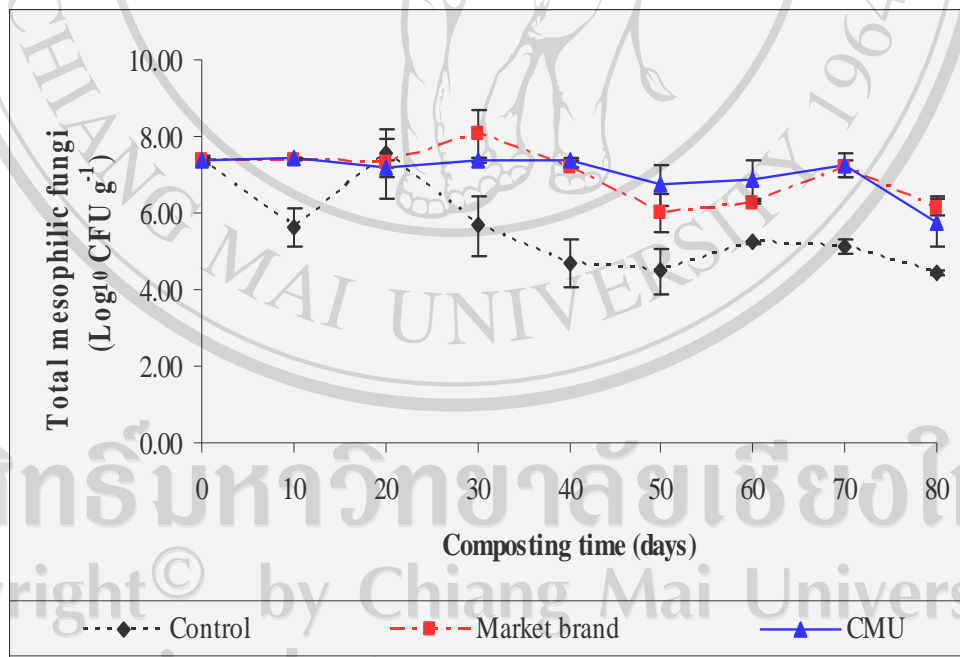
#### 4.6.4 Growth of mesophilic fungi

The growth of mesophilic fungi throughout the composting period was shown in Table 29 and Figure 21. The initial amount of mesophilic fungi in composts with Market brand, CMU inocula and control treatment were  $7.37 \pm 0.08$ ,  $7.37 \pm 0.12$  and  $7.39 \pm 0.04 \log_{10} \text{CFU g}^{-1}$ , respectively. The growth of mesophilic fungi in composts with Market brand was rather close to those in compost with CMU inoculum all over the time of experiment. For the control treatment, mesophilic fungi grew up within a short time and quickly decreased in lower number from the 20<sup>th</sup> days to end of composting time.

**Table 29** Changes of mesophilic fungi biomass ( $\log_{10}$  CFU  $g^{-1}$ ) during composting process in the field experiment

Days	Treatment		
	control	Market brand	CMU
0	7.39±0.04 <sup>a*</sup>	7.37±0.08 <sup>a</sup>	7.37±0.12 <sup>a</sup>
10	5.62±0.52 <sup>a</sup>	7.39±0.03 <sup>b</sup>	7.44±0.02 <sup>b</sup>
20	7.56±0.63 <sup>a</sup>	7.31±0.09 <sup>a</sup>	7.17±0.77 <sup>a</sup>
30	5.66±0.80 <sup>a</sup>	8.07±0.60 <sup>b</sup>	7.37±0.04 <sup>b</sup>
40	4.68±0.61 <sup>a</sup>	7.18±0.02 <sup>b</sup>	7.40±0.02 <sup>b</sup>
50	4.48±0.61 <sup>a</sup>	5.99±0.50 <sup>b</sup>	6.74±0.54 <sup>b</sup>
60	5.25±0.03 <sup>a</sup>	6.26±0.03 <sup>b</sup>	6.91±0.50 <sup>c</sup>
70	5.14±0.19 <sup>a</sup>	7.18±0.21 <sup>b</sup>	7.24±0.30 <sup>b</sup>
80	4.43±0.04 <sup>a</sup>	6.15±0.22 <sup>b</sup>	5.78±0.63 <sup>b</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 21** Changes of mesophilic fungi growth during composting process in the field experiment

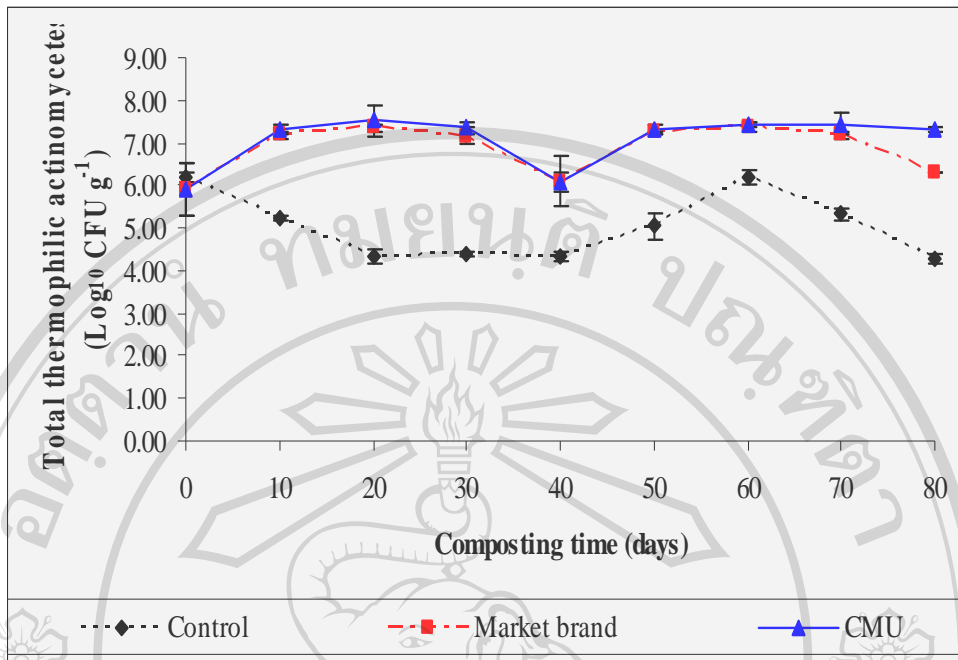
#### 4.6.5 Growth of thermophilic actinomycetes

The growth of thermophilic actinomycetes throughout the composting period was shown in Table 30 and Figure 22. The initial amount of total thermophilic actinomycetes in composts with Market brand, CMU inocula and control were  $5.89 \pm 0.61$ ,  $5.90 \pm 0.60$  and  $6.19 \pm 0.09 \log_{10} \text{CFU g}^{-1}$ , respectively. It was found that the growth of thermophilic actinomycetes in the piles with Market brand and CMU inocula were the very similar pattern. They grew up and down with the range around 6 to  $7 \log_{10} \text{CFU g}^{-1}$ . For control piles, the growth of thermophilic actinomycetes lately took place after 40 days of composting period. They only reached a high peak of near  $6 \log_{10} \text{CFU g}^{-1}$  and then again declined to the former level at  $4.30 \pm 0.11 \log_{10} \text{CFU g}^{-1}$ .

**Table 30** Changes of thermophilic actinomycetes biomass ( $\log_{10} \text{CFU g}^{-1}$ ) during composting process in the field experiment

Days	Treatment		
	control	Market brand	CMU
0	$6.19 \pm 0.09^{a*}$	$5.89 \pm 0.61^a$	$5.90 \pm 0.60^a$
10	$5.22 \pm 0.06^a$	$7.17 \pm 0.09^b$	$7.31 \pm 0.09^b$
20	$4.34 \pm 0.15^a$	$7.36 \pm 0.09^b$	$7.51 \pm 0.38^b$
30	$4.39 \pm 0.07^a$	$7.17 \pm 0.20^b$	$7.34 \pm 0.15^b$
40	$4.31 \pm 0.12^a$	$6.08 \pm 0.24^b$	$6.10 \pm 0.60^b$
50	$5.05 \pm 0.31^a$	$7.24 \pm 0.03^b$	$7.30 \pm 0.13^b$
60	$6.18 \pm 0.16^a$	$7.36 \pm 0.10^b$	$7.42 \pm 0.08^b$
70	$5.32 \pm 0.12^a$	$7.22 \pm 0.02^b$	$7.41 \pm 0.31^b$
80	$4.30 \pm 0.11^a$	$6.33 \pm 0.00^b$	$7.30 \pm 0.05^c$

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 22** Changes of thermophilic actinomycetes growth during composting process in the field experiment

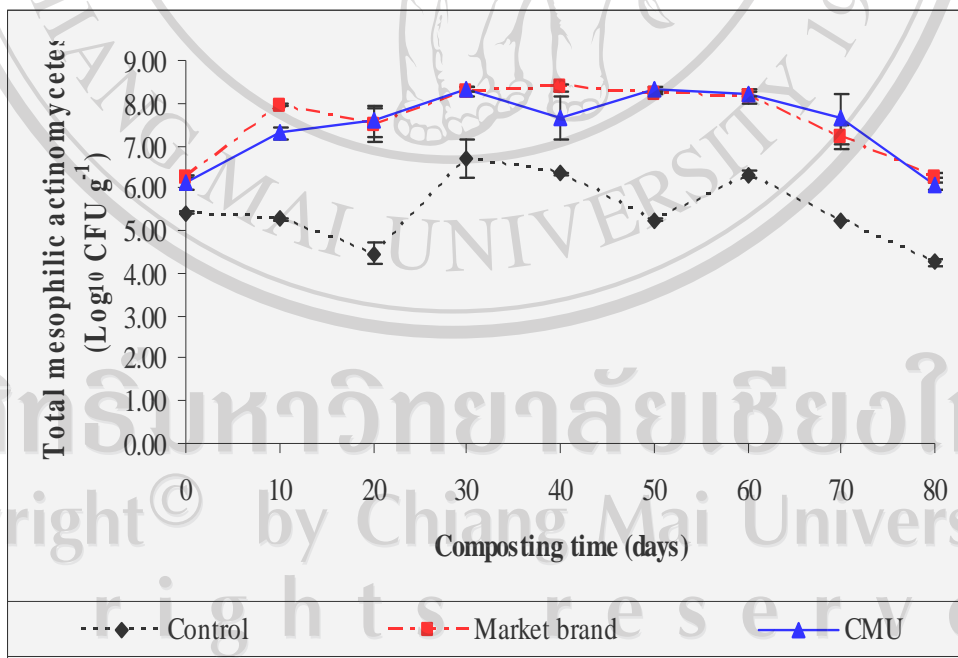
#### 4.6.6 Growth of mesophilic actinomycetes

The most of growth of the mesophilic actinomycetes profiles were similar for both of composting piles with Market brand and CMU inocula which shown in Table 31 and Figure 23. The initial amount of mesophilic actinomycetes in composting piles with Market brand and CMU inocula were  $6.25 \pm 0.02$  and  $6.12 \pm 0.18 \log_{10} \text{CFU g}^{-1}$ , respectively. The mesophilic actinomycetes growth of compost piles with Market brand and CMU inoculum were at highest peak of  $8.36 \pm 0.10$  and  $8.33 \pm 0.05 \log_{10} \text{CFU g}^{-1}$  on day 40<sup>th</sup> and 50<sup>th</sup>, respectively followed by steady decreasing to  $6.25 \pm 0.12$  and  $6.09 \pm 0.15 \log_{10} \text{CFU g}^{-1}$  at the end of experiment. The growth of mesophilic actinomycetes in the control treatment alternately fluctuated between  $5.41 \pm 0.03$  and  $4.25 \pm 0.07 \log_{10} \text{CFU g}^{-1}$  during the composting period.

**Table 31** Changes of mesophilic actinomycetes biomass ( $\log_{10}$  CFU  $g^{-1}$ ) during composting process in the field experiment

Days	Treatment		
	control	Market brand	CMU
0	5.41±0.03 <sup>a*</sup>	6.25±0.02 <sup>b</sup>	6.12±0.18 <sup>b</sup>
10	5.28±0.03 <sup>a</sup>	7.95±0.03 <sup>c</sup>	7.29±0.13 <sup>b</sup>
20	4.46±0.27 <sup>a</sup>	7.49±0.40 <sup>b</sup>	7.57±0.37 <sup>b</sup>
30	6.71±0.45 <sup>a</sup>	8.27±0.14 <sup>b</sup>	8.32±0.08 <sup>b</sup>
40	6.34±0.03 <sup>a</sup>	8.36±0.10 <sup>c</sup>	7.65±0.51 <sup>b</sup>
50	5.26±0.03 <sup>a</sup>	8.23±0.03 <sup>b</sup>	8.33±0.05 <sup>c</sup>
60	6.32±0.08 <sup>a</sup>	8.16±0.19 <sup>b</sup>	8.21±0.05 <sup>b</sup>
70	5.23±0.02 <sup>a</sup>	7.20±0.26 <sup>b</sup>	7.63±0.60 <sup>b</sup>
80	4.25±0.07 <sup>a</sup>	6.25±0.12 <sup>b</sup>	6.09±0.15 <sup>b</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 23** Changes of mesophilic actinomycetes growth during composting process in the field experiment

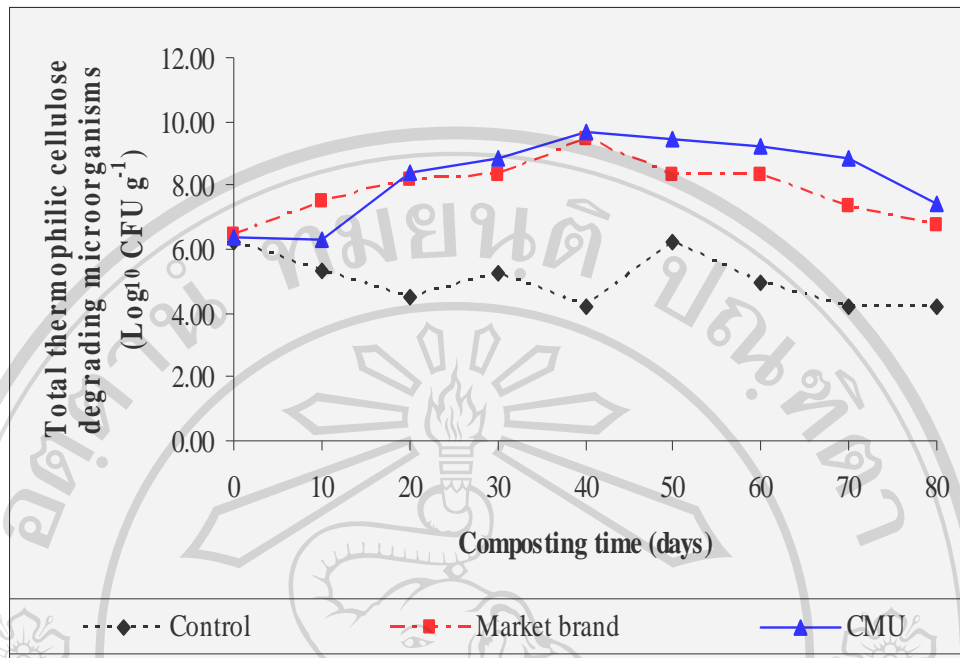
#### 4.6.7 Growth of cellulose-degrading thermophiles

The growth of cellulose-degrading thermophiles for Market brand and CMU inoculum during composting period in field experiment was in the same manner as showed in Table 32 and Figure 24. At the beginning day, the amount of these thermophiles in composts with Market brand and CMU inocula were  $6.43 \pm 0.03$  and  $6.39 \pm 0.06 \log_{10} \text{CFU g}^{-1}$ , respectively. It was found that both the cellulose degrading therophiles of treatment with Market brand and CMU inocula increased the highest peak of  $9.45 \pm 0.04$  and  $9.70 \pm 0.26 \log_{10} \text{CFU g}^{-1}$  after 40 days of incubation time, respectively followed by decreasing in number of  $6.71 \pm 0.55$  and  $7.42 \pm 0.07 \log_{10} \text{CFU g}^{-1}$  at the end of experiment. In case of control piles, cellulose-degrading thermophiles had long lag phase of growth and could shortly grow up after 40 days of incubation time. The growth of them varied in narrow range from  $6.22 \pm 0.04$  to  $4.23 \pm 0.10 \log_{10} \text{CFU g}^{-1}$ .

**Table 32** Changes of cellulose-degrading thermophiles biomass ( $\log_{10} \text{CFU g}^{-1}$ ) during composting process in the field experiment

Days	Treatment		
	control	Market brand	CMU
0	$6.22 \pm 0.04^{a*}$	$6.43 \pm 0.03^b$	$6.39 \pm 0.06^b$
10	$5.29 \pm 0.10^a$	$7.53 \pm 0.16^c$	$6.31 \pm 0.09^b$
20	$4.50 \pm 0.55^a$	$8.21 \pm 0.12^b$	$8.41 \pm 0.08^b$
30	$5.23 \pm 0.02^a$	$8.30 \pm 0.11^b$	$8.82 \pm 0.04^c$
40	$4.19 \pm 0.06^a$	$9.45 \pm 0.04^b$	$9.70 \pm 0.26^b$
50	$6.25 \pm 0.02^a$	$8.35 \pm 0.10^b$	$9.48 \pm 0.23^c$
60	$4.94 \pm 0.75^a$	$8.35 \pm 0.06^b$	$9.25 \pm 0.17^c$
70	$4.23 \pm 0.13^a$	$7.36 \pm 0.12^b$	$8.82 \pm 0.04^c$
80	$4.23 \pm 0.10^a$	$6.71 \pm 0.55^b$	$7.42 \pm 0.07^c$

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$



**Figure 24** Changes of cellulose-degrading thermophiles during composting process in the field experiment

#### 4.6.8 Growth of cellulose-degrading mesophiles

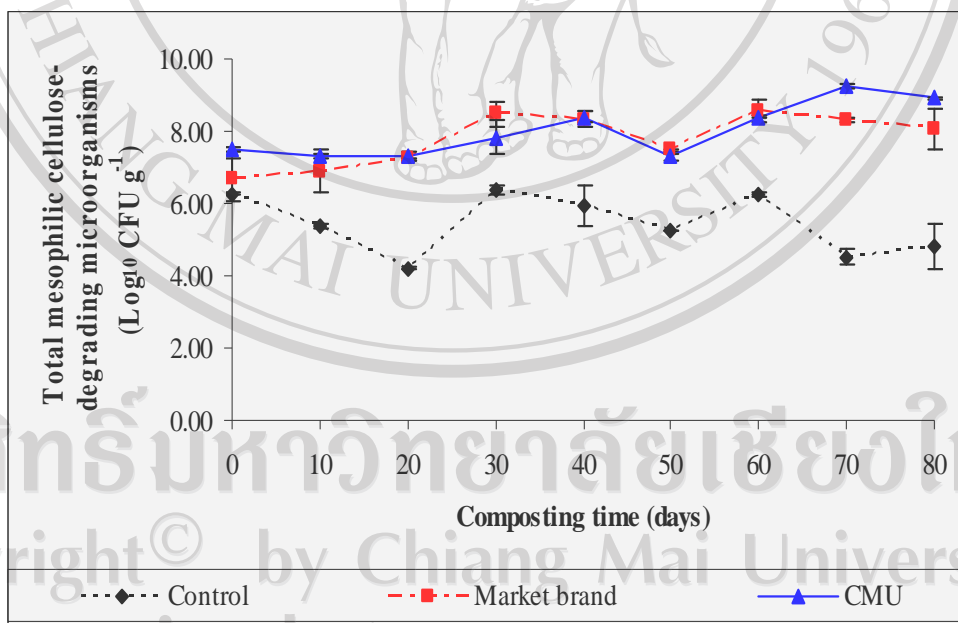
The growth of cellulose-degrading mesophiles during composting process was shown in Table 33 and Figure 25. The change of the growth of the cellulose-degrading mesophiles in both of composts with Market brand and CMU inocula were found in the same direction. The amount of cellulose-degrading mesophiles in composts with Market brand and CMU inoculum at the beginning day were  $6.66 \pm 0.59$  and  $7.48 \pm 0.06 \log_{10} \text{CFU g}^{-1}$ , respectively. They conducted their growth up and down during composting process. Most of the number of colony forming units were much the same and reached  $8.06 \pm 0.55$  and  $8.93 \pm 0.04 \log_{10} \text{CFU g}^{-1}$ , respectively at the end of composting period.

In case of control treatment, the change of cellulose-degrading mesophiles performed like the above composting with CMU inoculum but the amount of growth varied with lower number between  $6.28 \pm 0.04$  and  $4.82 \pm 0.61 \log_{10} \text{CFU g}^{-1}$ .

**Table 33** Changes of cellulose-degrading mesophiles biomass ( $\log_{10}$  CFU  $g^{-1}$ ) during composting process in the field experiment

Days	Treatment		
	control	Market brand	CMU
0	6.28±0.04 <sup>a*</sup>	6.66±0.59 <sup>a</sup>	7.48±0.06 <sup>b</sup>
10	5.40±0.07 <sup>a</sup>	6.90±0.58 <sup>b</sup>	7.31±0.08 <sup>b</sup>
20	4.20±0.02 <sup>a</sup>	7.23±0.02 <sup>b</sup>	7.32±0.12 <sup>b</sup>
30	6.37±0.11 <sup>a</sup>	8.47±0.34 <sup>b</sup>	7.84±0.44 <sup>b</sup>
40	5.94±0.56 <sup>a</sup>	8.32±0.23 <sup>b</sup>	8.38±0.16 <sup>b</sup>
50	5.25±0.02 <sup>a</sup>	7.47±0.03 <sup>c</sup>	7.30±0.08 <sup>b</sup>
60	6.23±0.06 <sup>a</sup>	8.58±0.31 <sup>b</sup>	8.40±0.03 <sup>b</sup>
70	4.52±0.01 <sup>a</sup>	8.31±0.07 <sup>b</sup>	9.25±0.06 <sup>c</sup>
80	4.82±0.61 <sup>a</sup>	8.06±0.55 <sup>b</sup>	8.93±0.04 <sup>b</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 25** Changes of cellulose-degrading mesophiles during composting process in the field experiment

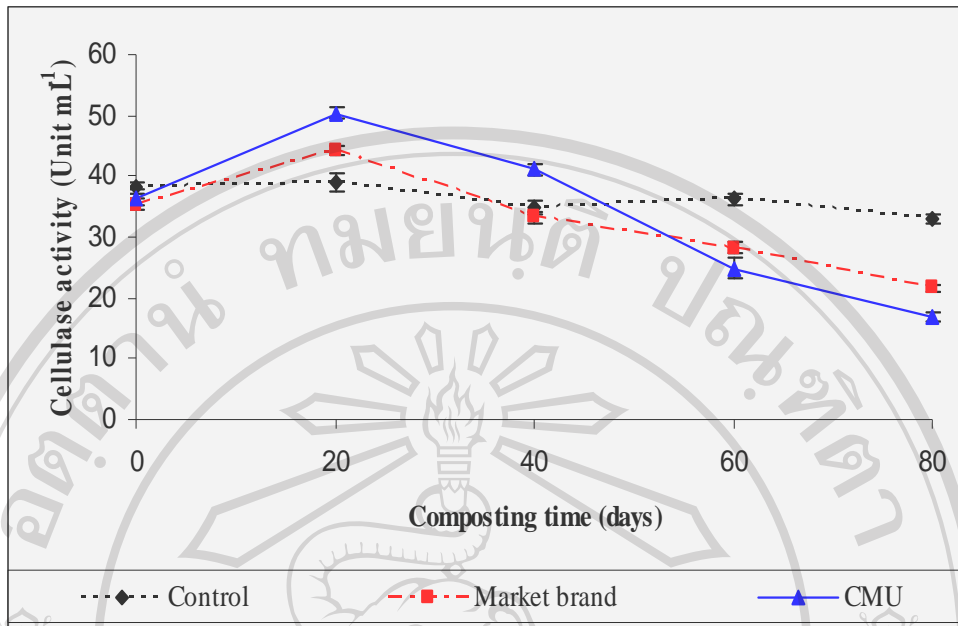
#### 4.6.9 Cellulase activity

The activity of cellulase from microorganisms in composting piles during the composting process was given in Table 34 and Figure 26. The cellulase activity of composting piles with Market brand and CMU inoculum decreased from  $44.16 \pm 0.74$ ,  $50.42 \pm 1.03 \text{ U mL}^{-1}$  to  $21.61 \pm 0.54$ ,  $16.87 \pm 0.70 \text{ U mL}^{-1}$  at the end of composting process, respectively. It was evident that cellulase activity in composting piles with CMU inoculum significantly preceded ( $p < 0.05$ ) that from Market brand inoculum throughout the process. In case of the control treatment, the cellulase activity was steadily changed during processing period.

**Table 34** Changes of cellulase activity ( $\text{U mL}^{-1}$ ) during composting process in the field experiment

Days	Treatment		
	control	Market brand	CMU
0	$38.22 \pm 0.92^{b+*}$	$35.33 \pm 0.92^a$	$36.55 \pm 1.33^{ab}$
20	$38.95 \pm 1.49^a$	$44.16 \pm 0.74^b$	$50.42 \pm 1.03^c$
40	$34.88 \pm 1.02^a$	$33.32 \pm 0.93^a$	$41.16 \pm 0.91^b$
60	$36.24 \pm 1.02^c$	$28.25 \pm 0.87^b$	$24.90 \pm 1.55^a$
80	$33.07 \pm 0.75^c$	$21.61 \pm 0.54^b$	$16.87 \pm 0.70^a$

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 26** Changes of cellulase activity during composting process in the field experiment

#### 4.6.10 Temperature

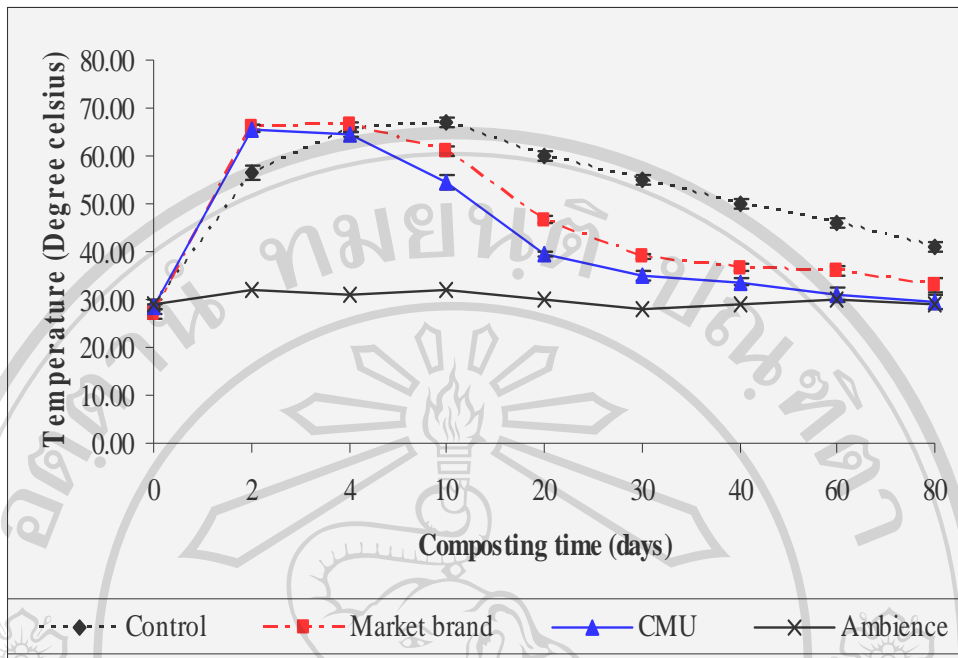
Composting piles with Market brand, CMU inoculums and control treatment reached 50°C and entered the thermophilic phase on second day of composting time as showed in Table 35 and Figure 27. The maximum temperature of composting piles with Market brand inoculum in the thermophilic phase was  $66.75 \pm 0.50$  °C as for those with CMU inoculum it was  $65.75 \pm 0.96$ °C. Such temperature in control treatment took place after 10 days of composting time. The thermophilic phase of composting piles with Market brand inoculum continued for 18 days. In case of compost piles with CMU inoculum, this stage had lasted only for a short time of 8 days while the durable thermophilic phase of control treatment had taken time late for 40 days. The temperature of compost piles with Market brand inoculum sharply decreased after thermophilic phase and entered a cooling phase after 40 days of

composting time, while the compost piles with CMU inoculum entered the cooling phase after 30 days of composting time. Otherwise, the temperature of composting piles with CMU inoculum was equal to ambience temperature after 60 days of composting time. But both of compost piles with market brand inoculum and control piles still gave the more temperature than the ambience temperature at the end of experimental time.

**Table 35** Changes of temperature (°C) during composting process in the field experiment

Days	Treatment		
	control	Market brand	CMU
0	28.50±1.29 <sup>b*</sup>	27.00±0.82 <sup>a</sup>	28.50±0.50 <sup>ab</sup>
2	56.50±1.29 <sup>a</sup>	66.25±0.50 <sup>b</sup>	65.75±0.96 <sup>b</sup>
4	65.50±0.58 <sup>a</sup>	66.75±0.50 <sup>b</sup>	64.75±0.50 <sup>a</sup>
10	67.00±0.82 <sup>c</sup>	61.00±0.82 <sup>b</sup>	54.50±1.73 <sup>a</sup>
20	60.00±0.82 <sup>c</sup>	46.75±0.96 <sup>b</sup>	39.75±0.50 <sup>a</sup>
30	55.00±0.82 <sup>c</sup>	39.25±0.50 <sup>b</sup>	35.00±0.82 <sup>a</sup>
40	50.00±0.82 <sup>c</sup>	36.75±0.96 <sup>b</sup>	33.75±0.96 <sup>a</sup>
60	46.00±0.82 <sup>c</sup>	36.00±0.82 <sup>b</sup>	31.00±1.41 <sup>a</sup>
80	41.00±1.15 <sup>c</sup>	33.00±1.63 <sup>b</sup>	29.50±1.29 <sup>a</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 27** Changes of temperature during composting process in the field experiment

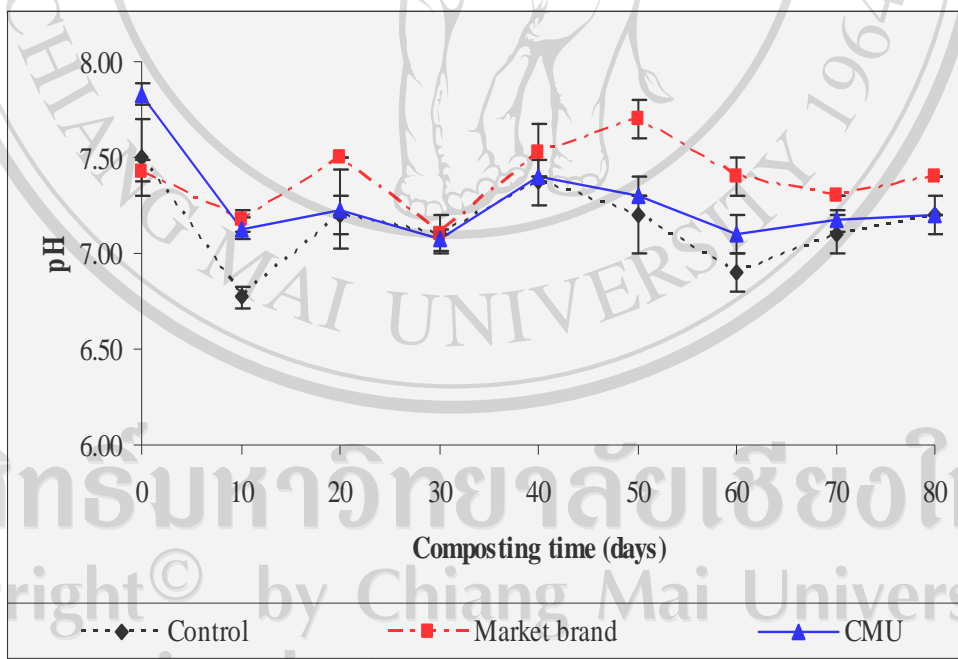
#### 4.6.11 pH

pH of compost piles with Market brand, CMU inoculums and control treatment slightly changed from beginning day at levels  $7.43 \pm 0.06$ ,  $7.83 \pm 0.06$  and  $7.50 \pm 0.20$  to the end of experiment at levels  $7.40 \pm 0.00$ ,  $7.20 \pm 0.00$  and  $7.20 \pm 0.10$ , respectively (as shown in Table 36 and Figure 28). They varied up and down and kept their composting activities close to neutral (near pH 7). However, pH change of treatment with CMU had a wider pH range from more alkaline close to neutral level.

**Table 36** Changes of pH during composting process in the field experiment

Days	Treatment		
	control	Market brand	CMU
0	7.50±0.20 <sup>a*</sup>	7.43±0.06 <sup>a</sup>	7.83±0.06 <sup>b</sup>
10	6.77±0.06 <sup>a</sup>	7.17±0.06 <sup>b</sup>	7.13±0.06 <sup>b</sup>
20	7.20±0.10 <sup>a</sup>	7.50±0.00 <sup>b</sup>	7.23±0.21 <sup>a</sup>
30	7.10±0.00 <sup>a</sup>	7.10±0.10 <sup>a</sup>	7.07±0.06 <sup>a</sup>
40	7.37±0.12 <sup>a</sup>	7.53±0.15 <sup>a</sup>	7.40±0.00 <sup>a</sup>
50	7.20±0.20 <sup>a</sup>	7.70±0.10 <sup>b</sup>	7.30±0.00 <sup>a</sup>
60	6.90±0.10 <sup>a</sup>	7.40±0.10 <sup>c</sup>	7.10±0.10 <sup>b</sup>
70	7.10±0.10 <sup>a</sup>	7.30±0.00 <sup>b</sup>	7.17±0.06 <sup>a</sup>
80	7.20±0.10 <sup>a</sup>	7.40±0.00 <sup>b</sup>	7.20±0.00 <sup>a</sup>

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .

**Figure 28** Changes of pH during composting process in the field experiment

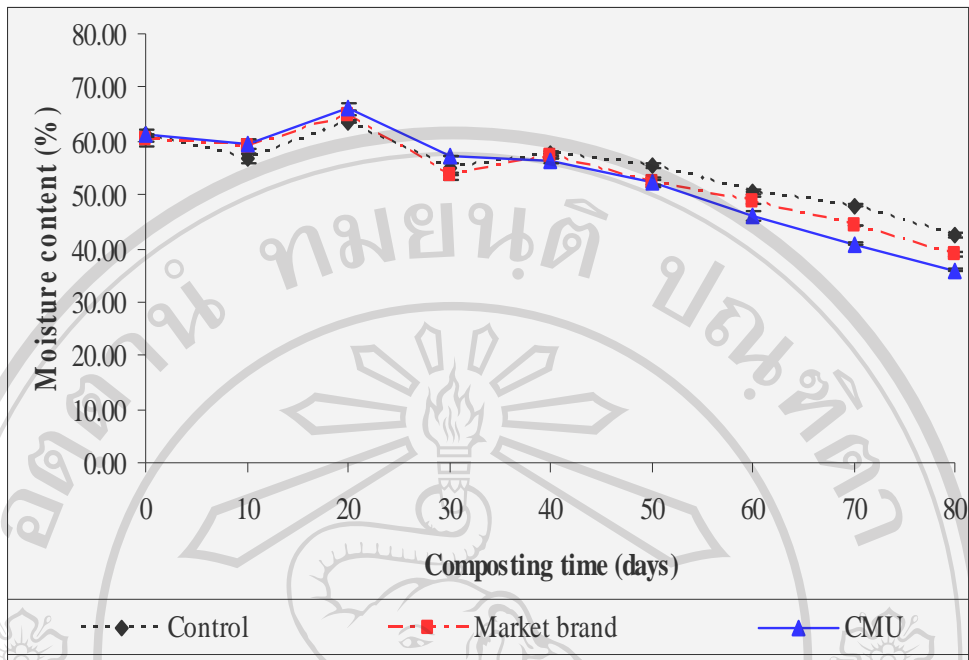
#### 4.6.12 Moisture content

Moisture content of all treatments were attempted to adjust to 60 % at intervals of turning pile. At the initial stage of composting, the percentage of moisture content of control piles, compost piles with Market brand and CMU inocula were  $61.03 \pm 1.00$  %,  $60.13 \pm 0.95$  % and  $61.20 \pm 1.23$  %, respectively and then gradually dropped during composting time (Figure 29). The moisture contents of all piles dropped to  $42.57 \pm 0.39$  %,  $38.85 \pm 0.40$  % and  $35.85 \pm 0.25$  %, respectively. All treatment conducted in the same manner. The decreasing in moisture content of treatment with CMU inoculum significantly preceded ( $p < 0.05$ ) over the other ones, followed by the treatment with Market brand inoculum (Table 37).

**Table 37** Changes of moisture content (%) during composting process in the field experiment

Days	Treatment		
	control	Market brand	CMU
0	$61.03 \pm 1.00^{a*}$	$56.75 \pm 1.03^a$	$61.20 \pm 1.23^a$
10	$60.13 \pm 0.95^a$	$58.90 \pm 1.08^b$	$59.40 \pm 0.98^b$
20	$63.59 \pm 0.07^a$	$64.76 \pm 1.00^{ab}$	$65.98 \pm 1.01^b$
30	$54.76 \pm 1.00^a$	$53.43 \pm 0.58^a$	$57.21 \pm 0.13^b$
40	$57.65 \pm 0.49^b$	$57.27 \pm 0.33^b$	$56.27 \pm 0.41^a$
50	$55.59 \pm 0.43^b$	$52.26 \pm 0.96^a$	$52.43 \pm 0.48^a$
60	$50.67 \pm 0.48^c$	$48.81 \pm 0.75^b$	$46.04 \pm 0.79^a$
70	$47.92 \pm 0.13^c$	$44.11 \pm 0.07^b$	$40.82 \pm 0.23^a$
80	$42.57 \pm 0.39^c$	$38.85 \pm 0.40^b$	$35.85 \pm 0.25^a$

\* Means followed by different letters within row indicated significant differences at  $p < 0.05$ .



**Figure 29** Changes of moisture content during composting process in the field experiment

#### 4.7 Adequacy of the composting process in field experiment

Compost characteristics after process i.e. pH, moisture content, C/N ratio, total organic carbon, total nitrogen, total phosphorus, total potassium, total calcium, total magnesium, electrical conductivity (EC) values, and germination index were presented in Table 38 with reference to compost standard specified by Land Development Department, Ministry of Agriculture and cooperative, Thailand. All measuring parameters of compost treatments with Market brand, CMU inoculum and control approached to the regulation of complete compost. Certainly, they could be acceptable and used as fertilizer.

**Table 38** Compost feature treated with Market brand, and CMU inoculum in field experiment

Parameter	Unit	Treatment			Compost standard *
		Control	Market brand	CMU	
pH	-	7.20±0.10 <sup>+a</sup>	7.40±0.00 <sup>b</sup>	7.20±0.00 <sup>a</sup>	5.5-8.5
Moisture content	%	42.57±0.39 <sup>c</sup>	38.85±0.40 <sup>b</sup>	35.85±0.25 <sup>a</sup>	35
C/N ratio	-	13.09±4.27 <sup>a</sup>	9.97±1.51 <sup>a</sup>	9.71±0.61 <sup>a</sup>	<20
Total organic carbon (C)	%	18.94±3.05 <sup>b</sup>	14.93±1.72 <sup>ab</sup>	12.47±1.88 <sup>a</sup>	25-50
Total nitrogen (N)	%	1.50±0.26 <sup>a</sup>	1.53±0.34 <sup>a</sup>	1.28±0.11 <sup>a</sup>	>1.0
Total Phosphorus (P)	%	1.6±0.24 <sup>a</sup>	1.37±0.02 <sup>a</sup>	1.26±0.28 <sup>a</sup>	>0.5
Total potassium (K)	%	0.82±0.20 <sup>a</sup>	1.52±0.09 <sup>b</sup>	1.71±0.03 <sup>b</sup>	>0.5
Total calcium (Ca)	%	2.98±0.19 <sup>a</sup>	2.73±0.14 <sup>a</sup>	2.61±0.48 <sup>a</sup>	>2.0
Total magnesium (Mg)	%	0.81±0.13 <sup>a</sup>	0.76±0.02 <sup>a</sup>	0.71±0.16 <sup>a</sup>	>0.3
Electrical conductivity (EC)	dS/m	1.37±0.06 <sup>a</sup>	1.27±0.06 <sup>a</sup>	1.40±0.17 <sup>a</sup>	<6.0
Germination index (GI)	-	104.13±6.34 <sup>a</sup>	97.30±2.95 <sup>a</sup>	104.80±18.5 <sup>a</sup>	>90

\*Compost standard according to Land Development Department, Ministry of Agriculture and Corporatives, Thailand (2005)

<sup>+</sup> Means followed by different letters within row indicated significant differences at  $p < 0.05$ .

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