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Effects of Soil Moisture and Temperature on Decomposition Rates of Some Waste Materials from Agriculture and Agro-industry

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Abstract : The effect of soil moisture and temperature on decomposition of waste materials, bagasse, coir dust, rice chaff and rice straw, in soil were examined by measuring the decrease in weight of and CO_2 generation from each waste material. The rate of the decrease in weight increased as temperature rose, and was highest in rice straw followed by bagasse, rice chaff and coir dust in this order, irrespective of soil moisture and temperature level. In all waste materials, the rate of decrease in weight was highest in the soil holding the water equivalent to field capacity (saturated soil) followed by submerged soil and dry soil in this order. CO_2 generation rate was also highest in rice straw followed by bagasse, rice chaff and coir dust. It was highest in saturated soil followed by half-saturated or submerged soil and dry soil in this order. The rate of CO_2 generation from rice straw in saturated soil was highest at the initial period of incubation and it decreased thereafter, but the rate in submerged soil was highest at 40 and 20 days after the start of incubation at 20 and 35°C, respectively. The rate of CO_2 generation from coir dust and rice chaff was very low at all soil moisture levels at either 20 or 35°C. The content of total N in the waste materials was positively and significantly correlated with the rate of decrease in weight in saturated and submerged soils at a moderate temperature (Oct. - Dec.), and in submerged soil at a high temperature (Aug. - Oct.). It was also significantly correlated with CO_2 generation rate in submerged soil at 20°C. Holocellulose and hemicellulose contents were negatively and significantly correlated with CO_2 generation rate in dry soil at 20°C. Lignin content was also significantly and negatively correlated with CO_2 generation in dry soil at 35°C.

Key words : CO_2 generation, Decomposition rate, Soil moisture, Soil temperature, Waste materials.

Currently, waste materials from agriculture and agro-industry are increasing in most countries, including Thailand. The volume of rice straw (31 million tons) is the biggest among the wastes from crop production, and bagasse (6.5 million tons) and rice chaff (5 million tons) are very large waste materials as compared with other agro-industrial wastes in Thailand (Office of Agricultural Economic, 1994; Sartsanarakkit, 1988; Thongjoo, 1995). Some kinds of waste materials, which have high nutritional value or are easily decomposed, i.e., rice bran and castor meal have been used for agriculture (Pintukanok et al., 1988). However, most of the other waste materials have been left unused and are causing environmental problems.

Soils in the tropical area contain less organic matter than those in the temperate region because high moisture and temperature of the tropical soils accelerate the decomposition of organic substances (Jenkinson, 1988; Kirschbaum, 1995; Azmal et al., 1996; Tenge et al., 1998; Devevre and Horwath, 2000). According to the Department of Land Development, Thailand (2000) Thailand is a tropical country, in which low organic matter is a serious problem covering a vast area of 30.56 million hectares or 59.5% of the total area in Thailand. To solve this problem, farmers in the tropical area are advised to apply organic substances or wastes from crop production into soil. It is not only to add more organic matter but also to maintain crop productivity and soil fertility in the long term (Naklang et al., 1999).

There have been several studies on the utilization of waste materials from agriculture and factories to improve the physical and chemical properties of soil (May et al., 1973; Sabey et al., 1977; Epstein et al., 1978; Liang, 1982; Cheung and Wong, 1983; Kawaguchi et al., 1983; Pagliai et al., 1983; Yonebayashi, 1983; Wei et al., 1985; Sartsanarakkit, 1988; Thongjoo, 1995; Bernal et al., 1998; Tenge et al., 1998). Generally, these waste materials are easily decomposed. However, the studies on the decomposition of waste materials that are difficult to be decomposed are limited.

In addition there have been only a few studies on the decomposition of waste materials in the soil at different moisture and temperature levels. Thus, it is necessary to investigate the use of hard-to-decompose waste materials in the tropical countries. In this study, the decomposition rates of some waste materials were estimated from the weight decrease of the waste materials packed in mesh bags, and buried in the soil. However, it is difficult to know the change of the decomposition rate in the soil. Then the rate of decomposition was estimated from the rate of CO_2 generation from the waste materials mixed with soil under different moisture and temperature conditions.

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Table 1. Chemical and physical properties of waste materials used in this study.

Properties	Bagasse	Coir dust	Rice straw	Rice chaff
Total N (%)	0.16	0.09	1.34	0.28
Total C (%)	47.32	48.94	39.47	43.25
C/N ratio	312	572	30	156
Holocellulose (%)	72.45	66.28	54.76	72.41
Cellulose (%)	33.34	30.70	27.89	31.12
Hemicellulose (%)	39.11	35.58	26.87	41.30
Lignin (%)	27.96	63.53	30.87	46.96
Ash (%)	2.03	2.90	14.31	9.40
Water content (%)	8.75	9.08	8.67	8.45

This method is usually used for assessment of soil microorganism activity (Bekku et al., 1995). It is well known that the chemical property of materials affect their decomposition rate in soil (Swift et al., 1981; Palm and Sanchez, 1991; Tian et al., 1995; Moritsuka et al., 2000; Riberiro et al., 2002). So we analyzed the chemical properties of the waste materials and discussed the relationship among them. The results of this study should be useful for further studies on the use of waste materials to improve physical and chemical property of soil.

Materials and Methods

Four waste materials bagasse from Tanegashima, coir dust from Thailand and rice chaff and rice straw from Gifu. Table 1 shows the physical and chemical properties of these waste materials. Total N and total C were analysed with an NC analyser (NC－95A), cellulose and holocellulose by JIS method, and lignin by the sulfuric acid method. Soil samples collected from the field at the Faculty of Applied Biological Sciences, Gifu University, were air-dried and passed through a 2- mm mesh sieve. The pH of the soil sample was 6.12. The electrical conductivity was 0.017 mS/cm, and the total N was 0.039 %, the total C 0.532 % and the C/N ratio was 13.63. The soil texture was sandy loam (Horiuchi et al., 1989).

Weight decrease of waste materials:

Table 2. Water content of the soil at various moisture levels.

Soil moistures	Water content (%)
Dry	1.39
Half-saturated*	14.90
Saturated	26.59
Submerged	42.39

* saturated soil: the soil holding water equivalent to field capacity.

Each waste material (5.6 g) was put in a mesh bag and buried in the soil for 2 months at 3 levels of soil moisture: dry, saturated (holding water equivalent to field capacity), and submerged (Table 2). This experiment was conducted during three periods under natural conditions: a) August－October 2002 (high temperature); b) October－December 2002 (moderate temperature); and c) January－February 2003 (low temperature). Table 3 shows the average temperatures during each period. Each treatment had 3 replications. Decomposition rates were estimated from the percentage of decrease in weight of each waste material after a 2-month incubation.

CO_2 generation from waste materials:

One kilogram of soil and four grams of each waste material were mixed and put into a one-liter plastic bottle. Soil without waste materials was also prepared

Table 3. Average soil temperature during Aug.－Oct. (high temperature), Oct.－Dec. (moderate temperature) and Jan.－Feb. (low temperature).

Seasons	Soil moistures	Average temp. (°C)
Aug.- Oct.	Dry	35.1
(High temperature)	Saturated	30.9
	Submerged	31.2
Oct.- Dec.	Dry	21.5
(Moderate temperature)	Saturated	18.9
	Submerged	19.8
Jan.- Feb.	Dry	13.3
(Low temperature)	Saturated	11.8
	Submerged	12.6

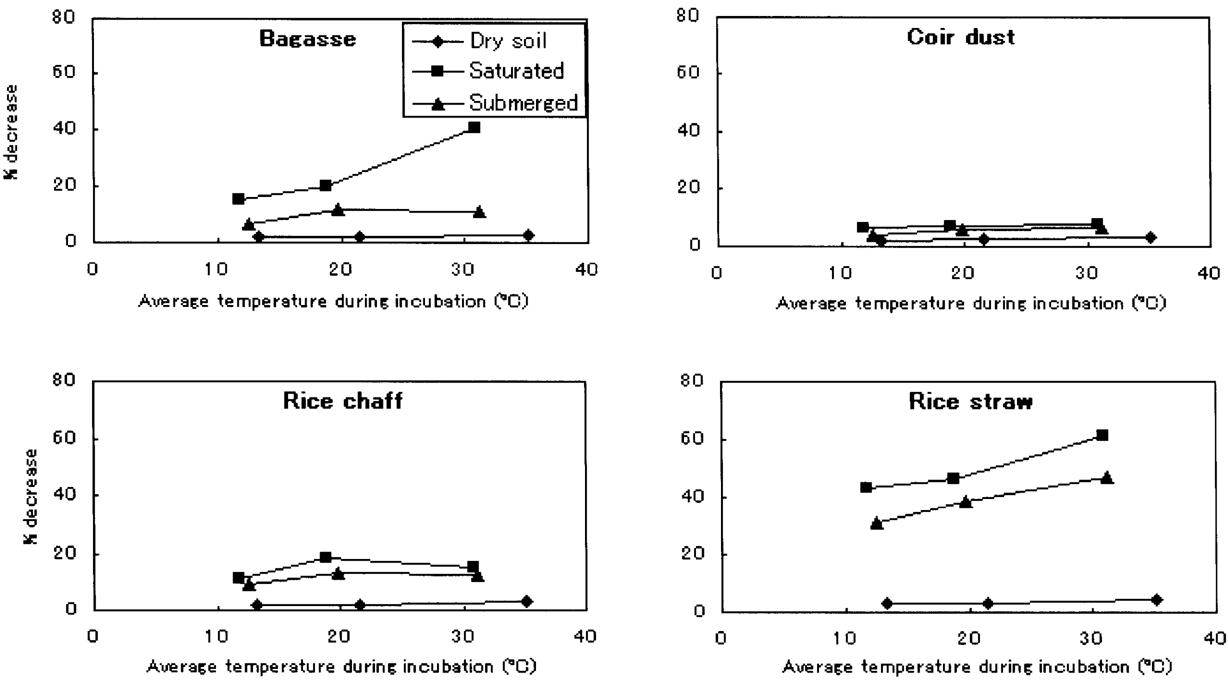

Fig. 1. Percentage of the decrease in weight of four waste materials after a 2 – month incubation in the soil at various moisture and temperature levels.

as a blank. The soil mixed with each waste material was moistened at 4 levels (dry, half-saturated, saturated, and submerged), and kept at 20 or 35°C. These temperatures were selected referring to the climate data of cool and hot seasons in Thailand (Department of Agriculture, 1982; Thiraphorn, 1990), and Table 2 shows the water contents of the soil samples at each moisture level. Each treatment had 3 replications. Bottles were kept in a thermo-regulated incubator and moisture was regulated during incubation. The CO_2 generation rate was measured by gas chromatography (GC-14B), at 1, 10, 20, 30, 40 and 50 days after the start of incubation. Air samples taken from the upper part of the sealed bottles were analyzed three times each for 5 minutes at the measuring date, and CO_2 generation rate per minute was calculated from the difference between the initial and final of CO_2 concentration/5. Values shown in this paper are the differences between the rate of mixed sample and that of the blank.

Results

Decrease in weight of waste materials:

Fig. 1 shows the percentage of decrease in weight of the waste materials after a 2-month incubation in the soils at various water holding levels and temperatures. At all temperatures (all seasons tested) the rate of decrease in weight was the highest in rice straw followed by bagasse, rice chaff and coir dust in this order. It was higher in saturated soil than in submerged soil, but was very low in dry soil. The higher the soil temperature and the higher the soil moisture, the higher was the rate of decrease in weight in rice straw and bagasse, although the rate of decrease in weight of bagasse in submerged soil and that of coir dust and rice chaff at all soil-moisture levels were scarcely influenced by temperature (Fig.1).

There were significant positive correlations between the average total N content and the average rate of decrease in weight of the four waste materials, in the saturated soil and submerged soil at a moderate temperature, and in the submerged soil at a high temperature (Table 4). In addition, the average rate of decrease in weight of the four waste materials in dry soil at moderate temperature was negatively and significantly correlated with the hemicellulose content, and that in dry soil at a high temperature with cellulose content of the materials. The rate of decrease in weight positively correlated with the total N content, and negatively with the contents of total C, holocellulose, hemicellulose and lignin, at all soil moisture and temperature levels (Table 4).

CO_2 generation from waste materials:

Fig. 2 shows the rate of CO_2 generation from the waste materials during incubation in the soil at various water-holding levels at 20 and 35°C.

At 20°C in the saturated soil, the rate of CO_2 generation was highest in rice straw followed by bagasse, and was very low in coir dust and rice chaff. The rate of CO_2 generation from rice straw and bagasse was highest at the 1st day of incubation and decreased thereafter. In the half-water-saturated soil (half-saturated water), the CO_2 generation rate was

Table 4. Coefficients of correlation between the average rate of decrease in weight in the four waste materials and the chemical components of the waste materials.

	Low temperature			Moderate temperature			High temperature		
Factors	Dry	Saturated	Submerged	Dry	Saturated	Submerged	Dry	Saturated	Submerged
Total N	0.999**	0.977*	0.999**	0.698	0.967*	0.993**	0.921	0.810	0.998**
Total C	-0.900	-0.842	-0.905	-0.334	-0.904	-0.900	-0.818	-0.659	-0.885
C/N ratio	-0.767	-0.763	-0.793	-0.077	-0.859	-0.808	-0.588	-0.695	-0.768
Holocellulose	-0.893	-0.846	-0.870	-0.940	-0.767	-0.846	-0.930	-0.627	-0.884
Cellulose	-0.859	-0.727	-0.822	-0.779	-0.688	-0.779	-0.987*	-0.395	-0.820
Hemicellulose	-0.869	-0.854	-0.852	-0.959*	-0.764	-0.835	-0.873	-0.683	-0.871
Lignin	-0.482	-0.651	-0.541	-0.024	-0.701	-0.600	-0.127	-0.874	-0.542

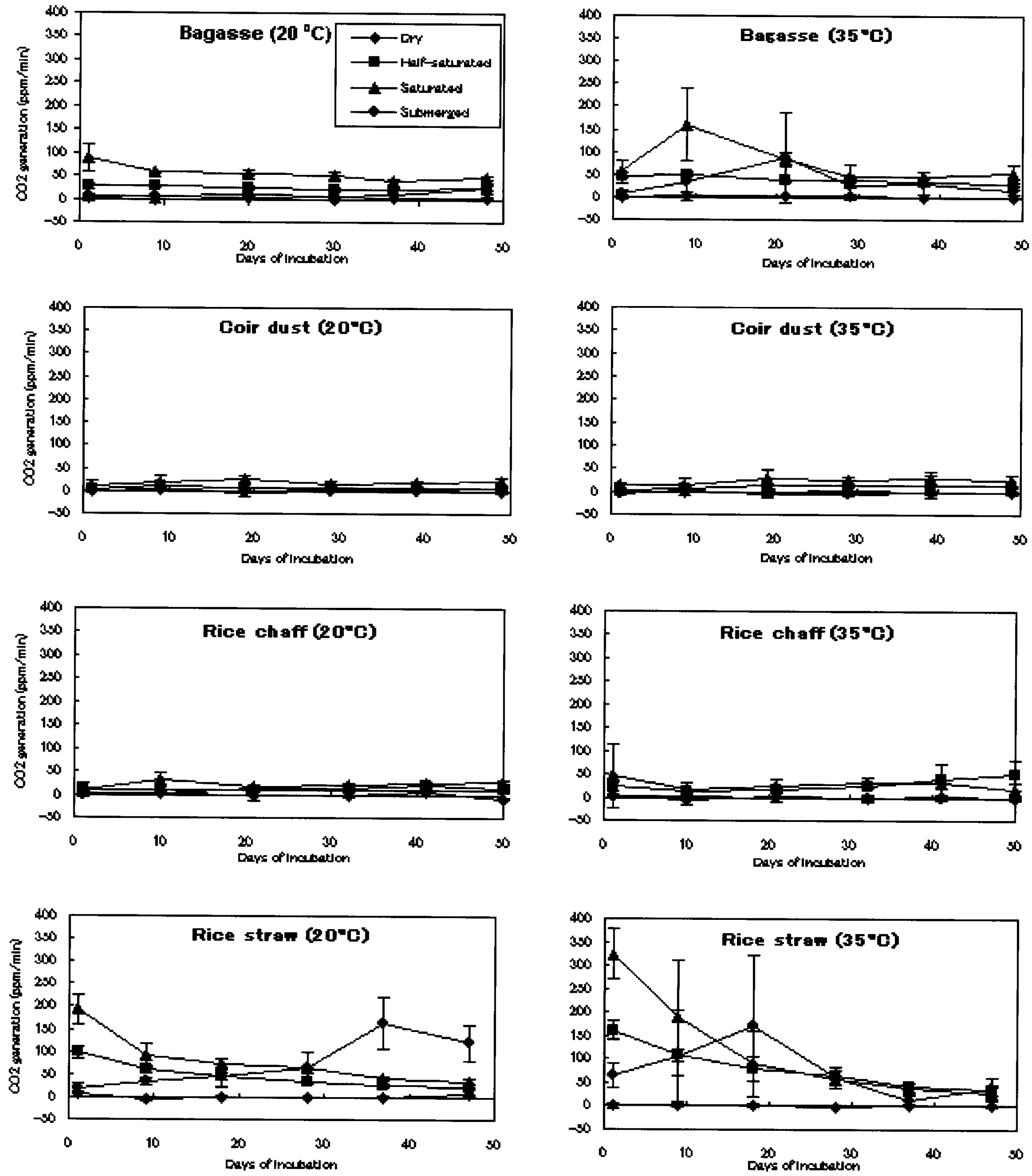

Fig. 2. Change in the rate of CO_2 generation from the four waste materials incubated in the soil at various moisture and temperature levels.

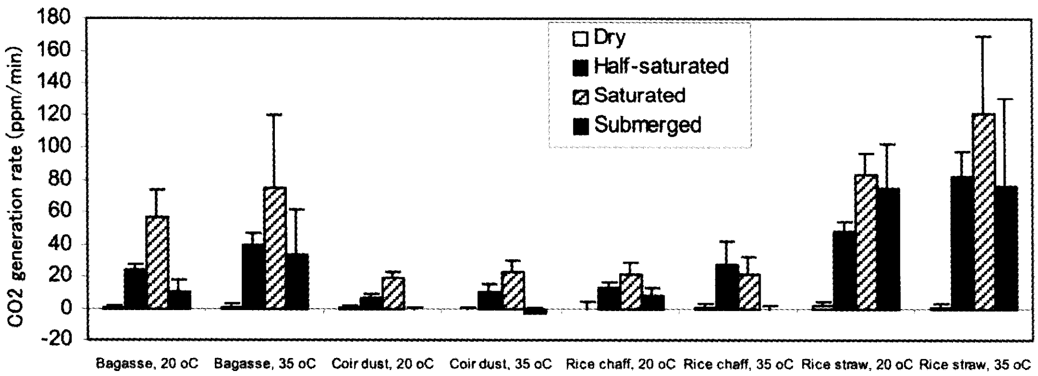

Fig. 3. Average rate of CO_2 generation during incubation in the soil at various moisture and temperature levels, in the four waste materials.

Table 5. Coefficients of correlation between CO_2 generation rate and the chemical components of the waste materials.

	20°C				35°C			
Factors	Dry	Half-saturated	Saturated	Submerged	Dry	Half-saturated	Saturated	Submerged
Total N	0.823	0.916	0.818	0.993**	0.482	0.939	0.851	0.877
Total C	-0.492	-0.776	-0.638	-0.857	-0.550	-0.845	-0.674	-0.690
C/N ratio	-0.274	-0.755	-0.655	-0.748	-0.759	-0.823	-0.676	-0.671
Holocellulose	-0.973*	-0.750	-0.667	-0.885	-0.112	-0.742	-0.703	-0.748
Cellulose	-0.802	-0.576	-0.424	-0.793	0.046	-0.613	-0.475	-0.529
Hemicellulose	-0.995**	-0.781	-0.727	-0.882	-0.163	-0.758	-0.755	-0.799
Lignin	-0.222	-0.780	-0.841	-0.573	-0.989*	-0.767	-0.819	-0.781

similar to that in the saturated soil, although the rate was lower. At 20°C in dry soil and submerged soil, bagasse, coir dust and rice chaff generated CO_2 only slightly if at all throughout the incubation period, but rice straw generated CO_2, increasing the generation rate from the 1st to 40th day of incubation. After the 40th day it decreased again.

At 35°C in saturated soil, rice straw generated CO_2 at the highest rate (300 ppm / min) at the 1st day of incubation, and the rate decreased during the incubation period. Under the same condition, bagasse generated CO_2 at a low rate (50 ppm/min) at the 1st day, but the rate was increased to 150 ppm/min at 10 days and decreased thereafter. The rate after the 10th day was similar to that from rice straw. At 35°C in the half-saturated soil, rice straw generated CO_2 at a rate of 150 ppm/min at the 1st day and the rate decreased thereafter, but bagasse generated CO_2 at about 50 ppm/min at the 1st day and the rate did not change thereafter during the incubation period. At 35 °C in submerged soil, the rate of CO_2 generation in rice straw and bagasse was highest at 20 days after the start of incubation, though the rate of CO_2 generation in rice straw was higher than that in bagasse. Coir dust and rice chaff generated only a small amount of CO_2 in the saturated, half-saturated and submerged soils even at 35°C, but rice chaff generated slightly more CO_2 than coir dust. In dry soil, all waste materials generated CO_2 at a very low rate in all soils at all water-holding levels examined.

Fig. 3 shows the average rates of CO_2 generation during the 50-day incubation period. As a whole, rice straw generated CO_2 at the highest rate followed by bagasse, rice chaff and coir dust in this order, and the CO_2 generation rate was higher at 35°C than at 20°C. All waste materials examined generated CO_2 at a higher rate in the saturated soil than in other soil samples at both 20 and 35°C, except for rice chaff incubated at 35°C, which generated more CO_2 in half-saturated soil than in the saturated soil. The rate of CO_2 generation from bagasse, coir dust and rice chaff in submerged soil was lower than that in saturated and half-saturated soils, but that from rice straw was comparable to that in saturated and half-saturated soils at both 20 and 35°C (Fig. 3). Interestingly, however, the rate of CO_2 generation from rice straw incubated in submerged soil had a peak at 40 and 20 days after the start of incubation at 20 and 35°C, respectively. This means that rice straw in submerged soil decomposed more rapidly at 35°C than at 20°C.

Table 5 shows the coefficient of correlation of CO_2 generation rate with the chemical components of waste materials. A significantly high positive correlation was observed between the rate of CO_2 generation from waste materials in submerged soil and total N content of the waste materials. Although the rate of CO_2 generation from waste material in dry soil was very low, the CO_2 generation at 20°C was negatively and significantly correlated with the content of holocellulose and hemicellulose in the waste materials, and that at 35°C was also negatively correlated with the content of lignin.

Discussion

The decomposition rate of waste materials in soil measured by decrease in weight was closely correlated with that measured by CO_2 generation (r = 0.920** at 35°C (high temperature) and r = 0.815** at 20°C (moderate temperature)). The decomposition rate was enhanced by the high temperature, and was highest in saturated soil followed by half-saturated or submerged soil and dry soil. Irrespective of temperature and soil moisture level, the decomposition rate was highest in rice straw followed by baggase. Correlation analysis showed that the higher content of total N and the lower contents of holocellulose, hemicellulose and lignin enhanced the decomposition of materials. Generally, C/N ratio is used as an index of the decomposition rate of organic matters, but it was not significantly correlated with the decomposition rate of the waste materials in this study. The lignin content may be a more important factor for decomposition (Abad et al., 2002). Decomposition (decrease in weight) was hastened by raising the temperature only in the waste materials with a low lignin content, rice straw and bagasse. In addition, only rice straw was easily decomposed in submerged soil.

The decomposition rate (CO_2 generation) of rice straw was highest at the initial stage of incubation in the saturated or half-saturated soil. However, it increased during the incubation period in submerged soil reaching a peak at 20 and 40 days after the start of incubation at 35 and 20°C, respectively. This is probably because microbial activity was higher in saturated soil than in submerged soil (highly anaerobic condition), and microbial activity under submerged conditions increased more rapidly at 35°C than at 20 °C. Devevre and Horwath (2000) also reported that under non-flooded conditions, the release of CO_2 from rice straw was higher than under a flooded condition, since microbial activity in soil was decreased under the flooded condition. Decomposition of coir dust and rice chaff in the soil was very slow even at a high temperature in saturated soil, which means that these materials are kept in the soil for a long time. This study showed that the decomposition rate of the four waste materials was differently influenced by temperature and soil moisture levels. The effects of each waste material after decomposition on the soil chemical property as well as on crop production should be examined further.

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