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# Soil Productivity after Decomposition of Waste Materials under Different Soil Moisture and Temperature

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**Abstract** : Productivity of the soil with waste material (WM), i.e., bagasse, coir dust, rice chaff and rice straw decomposed for two months at various temperatures and soil moisture were investigated by analyzing the chemical properties and growth of maize cultured on the soil for 45 days. The soil with decomposed WM (WM soil), tended to show lower pH values than the soil without WM soil (control) as a whole. The values of electric conductance were higher in WM soil, especially in the soil with decomposed rice chaff and rice straw referred to as rice-chaff and rice-straw soils, respectively. The total N content tended to be higher in the WM soil except for coir dust soil. The total C content tended to be higher in all WM soils. The difference in the content of total N and total C between WM and control soils was remarkable in bagasse soil. The change of the chemical properties of the soil did not apparently correlate with the rate of $CO_2$ generation during incubation of WM soils, but pH, electric conductance, content of total N and total C contents were higher in the soils generating $CO_2$ at a rate of 40 to 80 ppm $min^{-1}$, in bagasse or rice straw soils. The dry matter production of maize on WM soils was positively correlated with the rate of $CO_2$ generation. It was suggested that the WM soils generating little $CO_2$, such as the soil with bagasse or rice straw decomposed in a dry condition, tended to inhibit maize growth owing to low pH and shortage of available nitrogen by rapid decomposition just after the start of maize growth. The wet WM soils generating $CO_2$ format a rate of 40 to 80 ppm $min^{-1}$, e.g., bagasse and rice straw soils might be favorable for dry matter production of maize.

**Key words** : Decomposition rate, Maize, Soil productivity, Waste materials.

There is an increasing interest in using waste materials (WMs) to improve soil productivity in agricultural systems in tropical areas (Tian et al., 1992). Application of WM to soil is known to have beneficial effects on soil nutrients, soil physical conditions, soil biological activity and crop performance (Wade and Sanchez, 1983; Bernal et al., 1998; Hadas et al., 2004). The effects of WM on soils and crops differ with their decomposition rate and nutrient release rate. Furthermore, rapidly decomposing WM provides crops with a lot of nutrients in the early stage of crop growth, but may not affect the soil physical conditions while slowly decomposing WM have opposite effects to the above (Tian et al., 1993). In Thailand, WM is sometimes used after crop harvesting, since a lot of WM is left in the field after harvest. Furthermore, government and private sectors have tried to promote the utilization of those wastes, e.g., applying them as compost or soil amendment, but most farmers do not use these WM. The residue material is usually burnt after harvest (Ongprasert, 1991).

In previous studies, low quality WM with a high C/N ratio (e.g. coir dust or rice chaff) was used for preparing soil-less growing media for containerized crop production (Reynolds, 1974; Chweya et al., 1978), or for container-grown ornamental plants (Handreck, 1993; Stamps and Evans, 1997). Currently, the studies on the use of low-quality WM to improve soil or to increase soil productivity have been limited. Thus, the studies on the use of low-quality WM to improve the physical properties and also to improve the chemical properties of the soil are needed.

Studies on the environmental factors focusing on decomposition of WM in tropical areas including Thailand have been neglected. Most studies on WM management aim at application of WM for improving soil fertility or increasing plant productivity without considering the process of the decomposition of those WMs. However, in 2002-2003, we examined the effects of soil moisture and temperature on the decomposition rates of low quality WMs measuring the decreased in weight and the rate of $CO_2$ generation from each WM (Thongjoo et al., 2005). The rate of the decrease in weight of WM 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 WMs, 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. The average rates of $CO_2$ generation from each WM during the 2-month incubation at various temperatures and soil moisture coincided with the measured decreased in weight of each WM. In this study, we

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Table 1. pH of soils (soil to water ratio, 1:1) after incubation with waste materials at 20 and 35°C for 2 months.

| | | Bagasse | | | Coir dust | | |
|---|---|---|---|---|---|---|---|
| Temperature | Soil moisture | Control | Mixed | Difference from control | Control | Mixed | Difference from control |
| 20°C | Dry | 6.3 | 6.1 | –0.2 | 6.2 | 6.0 | –0.2* |
| | Half-saturated | 6.2 | 5.9 | –0.3** | 6.1 | 5.8 | –0.3 |
| | Saturated | 6.2 | 6.1 | –0.1 | 6.2 | 5.8 | –0.4 |
| | Submerged | 6.8 | 6.6 | –0.2** | 6.8 | 6.5 | –0.3 |
| | Average | 6.4 | 6.2 | –0.2 | 6.3 | 6.0 | –0.3 |
| 35°C | Dry | 6.3 | 6.1 | –0.2* | 6.2 | 6.1 | –0.1 |
| | Half-saturated | 6.1 | 6.0 | –0.1 | 6.0 | 6.0 | 0.0 |
| | Saturated | 6.3 | 6.2 | –0.1 | 6.1 | 6.1 | 0.0 |
| | Submerged | 6.8 | 6.8 | 0.0 | 6.6 | 6.5 | –0.1 |
| | Average | 6.4 | 6.3 | –0.1 | 6.2 | 6.2 | 0.0 |

| | | Rice chaff | | | Rice straw | | |
|---|---|---|---|---|---|---|---|
| Temperature | Soil moisture | Control | Mixed | Difference from control | Control | Mixed | Difference from control |
| 20°C | Dry | 5.9 | 5.8 | –0.1 | 5.9 | 5.8 | –0.1* |
| | Half-saturated | 5.4 | 5.2 | –0.2 | 5.8 | 5.7 | –0.1* |
| | Saturated | 5.6 | 5.6 | 0.0 | 6.0 | 5.7 | –0.3 |
| | Submerged | 5.7 | 5.6 | –0.1 | 6.7 | 6.8 | 0.1 |
| | Average | 5.7 | 5.5 | –0.2 | 6.1 | 6.0 | –0.1 |
| 35°C | Dry | 5.8 | 5.8 | 0.0 | 5.9 | 6.0 | 0.1 |
| | Half-saturated | 5.4 | 5.3 | –0.1 | 5.7 | 5.5 | –0.2 |
| | Saturated | 5.6 | 5.5 | –0.1 | 6.0 | 6.0 | 0.0 |
| | Submerged | 5.5 | 5.1 | –0.4 | 6.5 | 6.5 | 0.0 |
| | Average | 5.6 | 5.4 | –0.2 | 6.0 | 6.0 | 0.0 |

* and ** show significance at the 0.05 and 0.01 probability level, respectively.

focused on the effects of the decomposed WM on the chemical properties of the soil, soil productivity, and the relationship between the soil productivity and decomposition process. We examined the physical and chemical properties of the soil and plant growth on it for 1-2 months. The results of this study may serve as the basis for determining the methods of applying WM to soil, and to increase the value and potential of low-quality WM.

## Materials and Methods

### 1. Decomposition process of waste materials (WMs)

Four kinds of waste materials (WM), namely bagasse from Tanegashima, coir dust from Thailand, and rice chaff and rice straw from Gifu, were used in this study. Soil samples were collected from the field at Faculty of Applied Biological Sciences, Gifu University. They were air-dried and passed through a 2-mm mesh sieve. The physical and chemical properties of these WMs and soils have been described previously (Thongjoo et al., 2005). One kilogram of soil and four grams of WM were mixed and put into a one-liter plastic bottle. This was the average amount of waste material generally applied to improve soil properties in Thailand. The used average was about 10 tons per hectare (Vacharotayan et al., 1983; Sornsawaphark and Im-erb, 1984; Rattanarak et al., 1992). Simultaneously, the bottles of soil without materials were also prepared as a control. Each treatment had 3 replications. Each bottle was investigated at 4 levels of soil moisture: dry, half-saturated, saturated, and submerged. Bottles were kept at 20 or 35°C in a thermo-regulated incubator and moisture was regulated during the 2 months of 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 (Thongjoo et al., 2005).

### 2. Measurement of chemical properties of soil

After the incubation, 20 grams of soil was taken from each bottle for analysis of chemical property, e.g. pH, electrical conductivity (EC), total N and total C contents. pH and EC were measured with a by pH/conductivity meter (CyberScan PC 10) and total N and total C were analyzed by NC analyzer (NC-95A).

Table 2. Electrical conductivity of soil (1:5, $\mu$s cm$^{-1}$) after incubation with waste materials at 20 and 35°C for 2 months.

| Temperature | Soil moisture | Bagasse Control | Bagasse Mixed | Bagasse Difference from control | Coir dust Control | Coir dust Mixed | Coir dust Difference from control |
|---|---|---|---|---|---|---|---|
| 20°C | Dry | 18.4 | 20.2 | 1.8 | 15.3 | 24.9 | 9.6* |
| | Half-saturated | 21.4 | 25.4 | 4.0* | 33.2 | 39.1 | 5.9 |
| | Saturated | 23.4 | 24.1 | 0.7 | 28.4 | 34.4 | 6.0 |
| | Submerged | 30.8 | 42.0 | 11.2 | 25.5 | 32.4 | 6.9 |
| | Average | 23.5 | 27.9 | 4.4 | 25.6 | 32.7 | 7.1 |
| 35°C | Dry | 23.8 | 24.5 | 0.7 | 27.5 | 32.6 | 5.1 |
| | Half-saturated | 40.1 | 44.4 | 4.3 | 41.1 | 43.5 | 2.4 |
| | Saturated | 25.5 | 29.6 | 4.1 | 48.5 | 50.4 | 1.9 |
| | Submerged | 37.3 | 43.0 | 5.7 | 37.3 | 44.5 | 7.2 |
| | Average | 31.7 | 35.4 | 3.7 | 38.6 | 42.8 | 4.2 |

| Temperature | Soil moisture | Rice chaff Control | Rice chaff Mixed | Rice chaff Difference from control | Rice straw Control | Rice straw Mixed | Rice straw Difference from control |
|---|---|---|---|---|---|---|---|
| 20°C | Dry | 16.1 | 20.5 | 4.4** | 16.6 | 18.9 | 2.3 |
| | Half-saturated | 24.1 | 19.9 | –4.2 | 31.8 | 53.8 | 22.0** |
| | Saturated | 20.2 | 21.0 | 0.8 | 29.5 | 52.4 | 22.9** |
| | Submerged | 26.4 | 34.9 | 8.5* | 19.8 | 46.4 | 26.6** |
| | Average | 21.7 | 24.1 | 2.4 | 24.4 | 42.9 | 18.5 |
| 35°C | Dry | 17.7 | 20.0 | 2.3* | 16.8 | 17.3 | 0.5 |
| | Half-saturated | 25.7 | 45.3 | 19.6** | 54.9 | 82.9 | 28.0** |
| | Saturated | 23.1 | 40.1 | 17.0* | 45.1 | 43.8 | –1.3 |
| | Submerged | 39.1 | 66.5 | 27.4** | 26.3 | 46.0 | 19.7** |
| | Average | 26.4 | 43.0 | 16.6 | 35.8 | 47.5 | 11.7 |

* and ** show significance at the 0.05 and 0.01 probability level, respectively.

### 3. Layout of pot experiment and measurement of plant growth

Soil samples (980 grams) after incubation with WM were put into a black plastic pot (15 cm in diameter and 12 cm in height). After the soil was saturated with water, four seeds of maize (cv. Snow dent 125) were sown at a 2 cm depth on 1 June, 2003. Fifteen days after seeding (DAS), the seedlings were thinned out for 2 maize plants per pot. No fertilizer was applied. The experiment was conducted with 3 replications. At 45 days after seeding (1 June-15 July, 2003), two maize plants from each pot were tested by growing maize, e.g. number of leaves (visible leaf blade were counted), chlorophyll content of the second fully expanded leaves from the top and dry weight (oven dried at 70°C for 2 days). The chlorophyll content was measured non-destructively using the Minolta SPAD-502 model manufactured by Minolta Co., Ltd., Japan (the SPAD value was read 3 times per leaf per plant).

## Results

### 1. Changes of chemical property of soils

The pH of the soil mixed with WM tended to decrease during the incubation in all temperature and soil moisture treatments (Table 1). It decreased significantly in half-saturated and submerged soil with bagasse, in dry and half-saturated soil with rice straw at 20°C and in dry soil with bagasse at 35°C. On the contrary, the EC of soil tended to increase during the incubation in all treatments (Table 2). It increased significantly in half-saturated soil with bagasse, in dry soil with coir dust, in dry soil with rice chaff and in submerged soil with rice straw in half-saturated, saturated and submerged soil at 20° C. It increased significantly in all soils with different moisture conditions, and in half-saturated and submerged soil with rice straw at 35°C. In general, the increase in EC of soil was obvious in all soils with different moisture conditions in particular in those with rice chaff at 35°C and in those with rice straw both at 20 and 35°C. The total N content tended to increase in the soil with bagasse, rice chaff and rice straw (Table 3). It increased significantly in half-saturated, saturated and submerged soils with bagasse at 20°C and in soils with bagasse all soil moistures, and rice chaff in half-saturated soil at 35°C. Generally, the total N content of soil increased in all soil moisture conditions, particularly in the soil with bagasse both at 20 and 35°C. In the soils with coir dust, the results

Table 3. Total N content of soil (%) after incubation with waste materials at 20 and 35°C for 2 months.

| | | Bagasse | | | Coir dust | | |
|---|---|---|---|---|---|---|---|
| Temperature | Soil moisture | Control | Mixed | Difference from control | Control | Mixed | Difference from control |
| 20°C | Dry | 0.034 | 0.042 | 0.008 | 0.032 | 0.029 | –0.003 |
| | Half-saturated | 0.036 | 0.049 | 0.013** | 0.032 | 0.029 | –0.003 |
| | Saturated | 0.036 | 0.048 | 0.012** | 0.030 | 0.030 | 0.000 |
| | Submerged | 0.036 | 0.048 | 0.012** | 0.031 | 0.031 | 0.000 |
| | Average | 0.036 | 0.047 | 0.011** | 0.031 | 0.030 | –0.001 |
| 35°C | Dry | 0.031 | 0.037 | 0.006* | 0.027 | 0.028 | 0.001 |
| | Half-saturated | 0.031 | 0.038 | 0.007** | 0.028 | 0.027 | –0.001 |
| | Saturated | 0.032 | 0.042 | 0.010** | 0.029 | 0.028 | –0.001 |
| | Submerged | 0.033 | 0.040 | 0.007* | 0.036 | 0.028 | –0.008 |
| | Average | 0.032 | 0.039 | 0.007** | 0.030 | 0.028 | –0.002 |

| | | Rice chaff | | | Rice straw | | |
|---|---|---|---|---|---|---|---|
| Temperature | Soil moisture | Control | Mixed | Difference from control | Control | Mixed | Difference from control |
| 20°C | Dry | 0.045 | 0.047 | 0.002 | 0.044 | 0.044 | 0.000 |
| | Half-saturated | 0.043 | 0.045 | 0.002 | 0.044 | 0.046 | 0.002 |
| | Saturated | 0.044 | 0.045 | 0.001 | 0.050 | 0.052 | 0.002 |
| | Submerged | 0.045 | 0.047 | 0.002 | 0.049 | 0.050 | 0.001 |
| | Average | 0.044 | 0.046 | 0.002 | 0.047 | 0.048 | 0.001 |
| 35°C | Dry | 0.046 | 0.049 | 0.003 | 0.042 | 0.042 | 0.000 |
| | Half-saturated | 0.044 | 0.050 | 0.006* | 0.043 | 0.045 | 0.002 |
| | Saturated | 0.046 | 0.052 | 0.006 | 0.047 | 0.048 | 0.001 |
| | Submerged | 0.046 | 0.049 | 0.003 | 0.047 | 0.047 | 0.000 |
| | Average | 0.046 | 0.050 | 0.004** | 0.045 | 0.046 | 0.001 |

* and ** show significance at the 0.05 and 0.01 probability level, respectively.

were opposite those of other WMs. On the other hand, the content of total C of soil tended to increase in all treatments (Table 4). At 20°C, it increased significantly in all soils with bagasse, in dry soil with rice chaff, and in saturated and submerged soil with rice straw; and at 35°C, it increased significantly in all soils with bagasse, and in dry, half-saturated and saturated soils with rice chaff. In general, the increase of total C content of soil was obvious in all soils with different moisture conditions, particularly in the soils with bagasse both at 20 and 35°C, with rice chaff at 35°C, and with rice straw at 20°C.

## 2. Growth of maize

Maize plants were grown in the pots filled with the soil with decomposed WM (WM soil) for 45 days. Generally, maize growth was affected by the presence of WM only slightly. The number of leaves was increased significantly by bagasse decomposed in dry soil both at 20 and 35°C and by rice straw decomposed in submerged soil at 20°C (Table 5). Generally, the increase in the number of leaves was more obvious on the soil with decomposed bagasse (referred to as bagasse soil hereafter) than on either rice straw or rice chaff soil. The increase was the least on coir dust soil. On the other hand, the dry weight of the maize plant decreased significantly on the soil with coir dust in saturated soil at 20°C (Table 6). However, the increase of dry weight of maize plant was more obvious on the rice straw soil than on the bagasse soil. Furthermore, the chlorophyll content of maize increased significantly on the soil with rice straw decomposed in half-saturated soil at 35°C (Table 7). Generally, it tended to increase on almost all bagasse, rice straw and rice-chaff soils, but decrease on coir dust soil, especially on the soil with coir dust decomposed at 35°C.

# Discussion

## 1. Relationship between $CO_2$ generation rate during incubation and changes of chemical properties of soil

There was no significant correlation between the $CO_2$ generation rate and change in any properties of soil mixed with each WM (Fig.1). The pH value decreased in submerged soil with rice chaff at 35°C, where the $CO_2$ generation rate was very small (Fig.1-a). It also decreased greatly in saturated soil with coir dust at 20°C where the $CO_2$ rate was the highest among all treatments. On the other hand, soil pH correlated

Table 4. Total C content of soil (%) after incubation with waste materials at 20 and 35°C for 2 months.

| | | Bagasse | | | Coir dust | | |
|---|---|---|---|---|---|---|---|
| Temperature | Soil moisture | Control | Mixed | Difference from control | Control | Mixed | Difference from control |
| 20°C | Dry | 0.36 | 0.47 | 0.11* | 0.40 | 0.43 | 0.03 |
| | Half-saturated | 0.37 | 0.55 | 0.18** | 0.42 | 0.43 | 0.01 |
| | Saturated | 0.38 | 0.54 | 0.16** | 0.43 | 0.44 | 0.01 |
| | Submerged | 0.38 | 0.53 | 0.15** | 0.44 | 0.44 | 0.00 |
| | Average | 0.37 | 0.52 | 0.15** | 0.42 | 0.44 | 0.02 |
| 35°C | Dry | 0.35 | 0.41 | 0.06* | 0.36 | 0.37 | 0.01 |
| | Half-saturated | 0.34 | 0.42 | 0.08** | 0.36 | 0.37 | 0.01 |
| | Saturated | 0.35 | 0.49 | 0.14** | 0.36 | 0.37 | 0.01 |
| | Submerged | 0.37 | 0.44 | 0.07* | 0.37 | 0.37 | 0.00 |
| | Average | 0.35 | 0.44 | 0.09** | 0.36 | 0.37 | 0.01** |

| | | Rice chaff | | | Rice straw | | |
|---|---|---|---|---|---|---|---|
| Temperature | Soil moisture | Control | Mixed | Difference from control | Control | Mixed | Difference from control |
| 20°C | Dry | 0.55 | 0.59 | 0.04* | 0.55 | 0.57 | 0.02 |
| | Half-saturated | 0.57 | 0.58 | 0.01 | 0.54 | 0.59 | 0.05 |
| | Saturated | 0.56 | 0.59 | 0.03 | 0.54 | 0.66 | 0.12** |
| | Submerged | 0.56 | 0.59 | 0.03 | 0.54 | 0.61 | 0.07** |
| | Average | 0.56 | 0.59 | 0.03** | 0.54 | 0.61 | 0.07* |
| 35°C | Dry | 0.55 | 0.60 | 0.05* | 0.55 | 0.52 | −0.03 |
| | Half-saturated | 0.55 | 0.62 | 0.07* | 0.55 | 0.53 | −0.02 |
| | Saturated | 0.55 | 0.64 | 0.09* | 0.53 | 0.56 | 0.03 |
| | Submerged | 0.56 | 0.59 | 0.03 | 0.49 | 0.54 | 0.05 |
| | Average | 0.55 | 0.61 | 0.06** | 0.53 | 0.54 | 0.01 |

* and ** show significance at the 0.05 and 0.01 probability level, respectively.

with total C contents of WM (r = −0.726, $p<0.05$) in dry condition, where the $CO_2$ generation rate was very low. The decrease of soil pH might be caused by some kind of organic acids released from WM and accumulated in the soil under such conditions (Rao and Mikkelson, 1976; Killham, 1994; Gudmundsson et al., 2004; Meunchang et al., 2005). However, the pH did not decrease in the soil, where the $CO_2$ generation rate was 40 to 80 ppm $min^{-1}$.

In the saturated soil with rice straw incubated at 35°C, EC was nearly equal to that in the control though the $CO_2$ generation rate was the highest (Fig.1-b). Ions released from the decomposition process, i.e., $NH_4^+$, $NO_3^-$, $H_2PO_4^-$, $HPO_4^{2-}$, $K^+$, etc., might be absorbed by microorganisms (Killham, 1994; Sanchez-Monedero et al., 2001). On the other hand, higher values of EC were observed in the soil with rice straw when the $CO_2$ generation rate was 40-80 ppm $min^{-1}$, although the values of EC of soil with bagasse were lower than that in the soil with rice straw, when the $CO_2$ generation rate was in the same range. Furthermore, submerged soil incubated with rice chaff at 35°C showed a very high EC value though the average $CO_2$ generation rate was almost zero, i.e., the rate was only 2.3-2.9 ppm $min^{-1}$ at 1 and 10 days of incubation period. At a $CO_2$ generation rate in this range, the decrease of pH was largest. This might also have been the result of the accumulation of organic acids.

The total N content of soil with rice straw was nearly the same as that of the control in spite of its high $CO_2$ generation rate (Fig.1-c). Nitrogen volatilization from WM soil might be expected when $CO_2$ was actively generated. Bagasse soil generating $CO_2$ in a range of 20 to 80 ppm $min^{-1}$ contained more N than other soils. The sugars remaining in the bagasse soil might activate soil microorganisms and induce nitrogen fixation by free living microorganisms (Brady, 1990; Killham, 1994; Soil Staff, 1998). Furthermore, the correlation of the $CO_2$-generation rate with the total C content of WM was similar to that with the total N content (Fig.1-d). Not only the total N content, but also the total C content was higher in the bagasse soil than other soils. It was noticeable that soils mixed with WM generating $CO_2$ at a medium rate tended to contain more total C. It could be possible that these WM were promptly incorporated into the microorganisms after decomposition (Takahashi, 1978; Kanthawivorn, 1990). In the soil generating $CO_2$ more actively, like a rice-straw soil, total C might be decreased. As a whole, it was difficult to find a simple relationship between

Table 5. Number of leaves of maize after growing 30 days on the soil after incubation with waste materials at 20 and 35°C for 2 months.

| Temperature | Soil moisture | Bagasse Control | Bagasse Mixed | Bagasse Difference from control | Coir dust Control | Coir dust Mixed | Coir dust Difference from control |
|---|---|---|---|---|---|---|---|
| 20°C | Dry | 6.3 | 7.3 | 1.0** | 6.0 | 6.2 | 0.2 |
| | Half-saturated | 6.5 | 7.0 | 0.5 | 6.2 | 6.2 | 0.0 |
| | Saturated | 6.6 | 7.0 | 0.4 | 6.2 | 6.0 | –0.2 |
| | Submerged | 6.8 | 7.7 | 0.9 | 6.3 | 7.0 | 0.7 |
| | Average | 6.6 | 7.3 | 0.7* | 6.2 | 6.3 | 0.1 |
| 35°C | Dry | 6.4 | 7.0 | 0.6** | 6.1 | 6.3 | 0.2 |
| | Half-saturated | 6.3 | 7.3 | 1.0 | 6.0 | 5.8 | –0.2 |
| | Saturated | 6.5 | 7.0 | 0.5 | 6.0 | 6.0 | 0.0 |
| | Submerged | 6.5 | 7.3 | 0.8 | 6.2 | 6.5 | 0.3 |
| | Average | 6.4 | 7.2 | 0.8** | 6.1 | 6.2 | 0.1 |

| Temperature | Soil moisture | Rice chaff Control | Rice chaff Mixed | Rice chaff Difference from control | Rice straw Control | Rice straw Mixed | Rice straw Difference from control |
|---|---|---|---|---|---|---|---|
| 20°C | Dry | 6.2 | 6.5 | 0.3 | 6.2 | 6.2 | 0.0 |
| | Half-saturated | 6.2 | 6.3 | 0.1 | 6.3 | 6.8 | 0.5 |
| | Saturated | 6.1 | 6.0 | -0.1 | 6.2 | 6.3 | 0.1 |
| | Submerged | 6.3 | 6.5 | 0.2 | 6.4 | 7.2 | 0.8* |
| | Average | 6.2 | 6.3 | 0.1 | 6.3 | 6.6 | 0.3 |
| 35°C | Dry | 6.0 | 6.5 | 0.5 | 6.1 | 6.7 | 0.6 |
| | Half-saturated | 6.2 | 6.8 | 0.6 | 6.1 | 6.5 | 0.4 |
| | Saturated | 6.0 | 6.5 | 0.5 | 6.1 | 7.0 | 0.9 |
| | Submerged | 6.0 | 6.2 | 0.2 | 6.1 | 6.2 | 0.1 |
| | Average | 6.1 | 6.5 | 0.4* | 6.1 | 6.6 | 0.5* |

* and ** show significance at the 0.05 and 0.01 probability level, respectively.

changes of soil chemical properties and the rate of $CO_2$ generation, partly because of buffering capacity of soil and the small amount of materials.

**2. Relationship between $CO_2$-generation rate during incubation and maize growth**

Soils generating $CO_2$ at a higher rate tended to increase the dry weight of maize ($r = 0.583$, $p < 0.01$), (Fig.2). However, the soil generating $CO_2$ at the maximum rate did not increase the dry weight of maize so much (Fig.2). It was noticeable that the soil generating $CO_2$ at a medium rate (40 to 80 ppm $min^{-1}$) was the best for the dry-weight increase of maize. This was related with a high pH, EC, total N content and total C content of the soils. Cultivation of maize plants on the soil with bagasse decomposed in dry soil at 35°C, which generated $CO_2$ at a very small rate, did not increase the dry-weight growth, and that on the soil with bagasse decomposed in dry, half saturated and submerged soil at 20°C, which also generated $CO_2$ at a very small rate decreased the dry-weight growth compared with the control. The chlorophyll content of maize was also decreased on the soil with bagasse decomposed in dry soil at 35°C. In the plants grown on the soil with rice straw decomposed in dry soil at 20°C, both the chlorophyll content and dry weight decreased. Because rice straw and bagasse decomposed at a higher rate than the other two WMs in half-saturated and saturated soil (Thongjoo et al., 2005), such WM might induce a competition for nitrogen between maize and soil microorganisms by decomposing the remaining WMs (Mary et al., 1996; Chapman, 1997; Khalil et al., 2005).

In conclusion, incubation of rice straw or bagasse in half-saturated and saturated soil at either 20 or 35°C, was most effective for improving soil productivity. Incubation of coir dust 2 months at either soil moisture or temperature did not improve soil productivity. In the next study, we will study the effects of other factors, e.g. chemical fertilizers, on the decomposition of waste materials and physical and chemical properties of soil as well as plant growth on the soil with decomposed waste materials in the field.

## References

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Table 6. Dry weight of maize (g/plant) after growing 30 days on the soil after incubation with waste materials at 20 and 35°C for 2 months.

| | | Bagasse | | | Coir dust | | |
|---|---|---|---|---|---|---|---|
| Temperature | Soil moisture | Control | Mixed | Difference from control | Control | Mixed | Difference from control |
| 20°C | Dry | 0.51 | 0.48 | −0.03 | 0.60 | 0.54 | −0.06 |
| | Half-saturated | 0.53 | 0.51 | −0.02 | 0.50 | 0.46 | −0.04 |
| | Saturated | 0.57 | 0.62 | 0.05 | 0.48 | 0.38 | −0.10* |
| | Submerged | 0.56 | 0.47 | −0.09 | 0.55 | 0.60 | 0.05 |
| | Average | 0.54 | 0.52 | −0.02 | 0.53 | 0.50 | −0.03 |
| 35°C | Dry | 0.52 | 0.52 | 0.00 | 0.54 | 0.51 | −0.03 |
| | Half-saturated | 0.54 | 0.64 | 0.10 | 0.52 | 0.42 | −0.10 |
| | Saturated | 0.55 | 0.59 | 0.04 | 0.45 | 0.48 | 0.03 |
| | Submerged | 0.52 | 0.68 | 0.16 | 0.63 | 0.56 | −0.07 |
| | Average | 0.53 | 0.61 | 0.08 | 0.54 | 0.49 | −0.05 |
| | | Rice chaff | | | Rice straw | | |
| Temperature | Soil moisture | Control | Mixed | Difference from control | Control | Mixed | Difference from control |
| 20°C | Dry | 0.62 | 0.62 | 0.00 | 0.64 | 0.60 | −0.04 |
| | Half-saturated | 0.59 | 0.53 | -0.06 | 0.62 | 0.77 | 0.15 |
| | Saturated | 0.59 | 0.58 | -0.01 | 0.60 | 0.63 | 0.03 |
| | Submerged | 0.64 | 0.69 | 0.05 | 0.64 | 0.75 | 0.11 |
| | Average | 0.61 | 0.61 | 0.00 | 0.63 | 0.69 | 0.06 |
| 35°C | Dry | 0.61 | 0.62 | 0.01 | 0.62 | 0.68 | 0.06 |
| | Half-saturated | 0.62 | 0.59 | −0.03 | 0.60 | 0.70 | 0.10 |
| | Saturated | 0.58 | 0.61 | 0.03 | 0.59 | 0.67 | 0.08 |
| | Submerged | 0.61 | 0.61 | 0.00 | 0.63 | 0.74 | 0.11 |
| | Average | 0.61 | 0.61 | 0.00 | 0.61 | 0.70 | 0.09** |

* and ** show significance at the 0.05 and 0.01 probability level, respectively.


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Table 7. Chlorophyll content of maize (SPAD reading) after growing 30 days on the soil after incubation with waste materials at 20 and 35°C for 2 months.

| Temperature | Soil moisture | Bagasse | | | Coir dust | | |
|---|---|---|---|---|---|---|---|
| | | Control | Mixed | Difference from control | Control | Mixed | Difference from control |
| 20°C | Dry | 12.10 | 13.37 | 1.27 | 11.90 | 12.40 | 0.50 |
| | Half-saturated | 9.87 | 12.53 | 2.66 | 10.07 | 9.95 | –0.12 |
| | Saturated | 11.93 | 12.53 | 0.60 | 11.98 | 10.97 | –1.01 |
| | Submerged | 12.57 | 13.27 | 0.70 | 12.00 | 12.65 | 0.65 |
| | Average | 11.62 | 12.93 | 1.31 | 11.49 | 11.49 | 0.00 |
| 35°C | Dry | 12.67 | 12.47 | –0.20 | 12.35 | 11.58 | –0.77 |
| | Half-saturated | 11.53 | 12.80 | 1.27 | 11.35 | 10.50 | –0.85 |
| | Saturated | 12.37 | 12.50 | 0.13 | 11.40 | 11.02 | –0.38 |
| | Submerged | 12.17 | 12.90 | 0.73 | 12.07 | 11.05 | –1.02 |
| | Average | 12.19 | 12.67 | 0.48 | 11.79 | 11.04 | –0.75 |

| Temperature | Soil moisture | Rice chaff | | | Rice straw | | |
|---|---|---|---|---|---|---|---|
| | | Control | Mixed | Difference from control | Control | Mixed | Difference from control |
| 20°C | Dry | 12.23 | 14.52 | 2.29 | 13.22 | 12.50 | –0.72 |
| | Half-saturated | 10.90 | 11.70 | 0.80 | 10.63 | 12.80 | 2.17 |
| | Saturated | 12.62 | 11.70 | –0.92 | 11.57 | 10.45 | –1.12 |
| | Submerged | 11.82 | 12.77 | 0.95 | 13.68 | 15.00 | 1.32 |
| | Average | 11.89 | 12.67 | 0.78 | 12.28 | 12.69 | 0.41 |
| 35°C | Dry | 12.53 | 14.75 | 2.22 | 13.08 | 13.45 | 0.37 |
| | Half-saturated | 11.83 | 11.93 | 0.10 | 9.28 | 11.50 | 2.22* |
| | Saturated | 11.75 | 10.73 | –1.02 | 10.57 | 11.38 | 0.81 |
| | Submerged | 11.22 | 12.90 | 1.68 | 11.02 | 13.35 | 2.33 |
| | Average | 11.83 | 12.58 | 0.75 | 10.99 | 12.42 | 1.43 |

* show significance at the 0.05 probability level.


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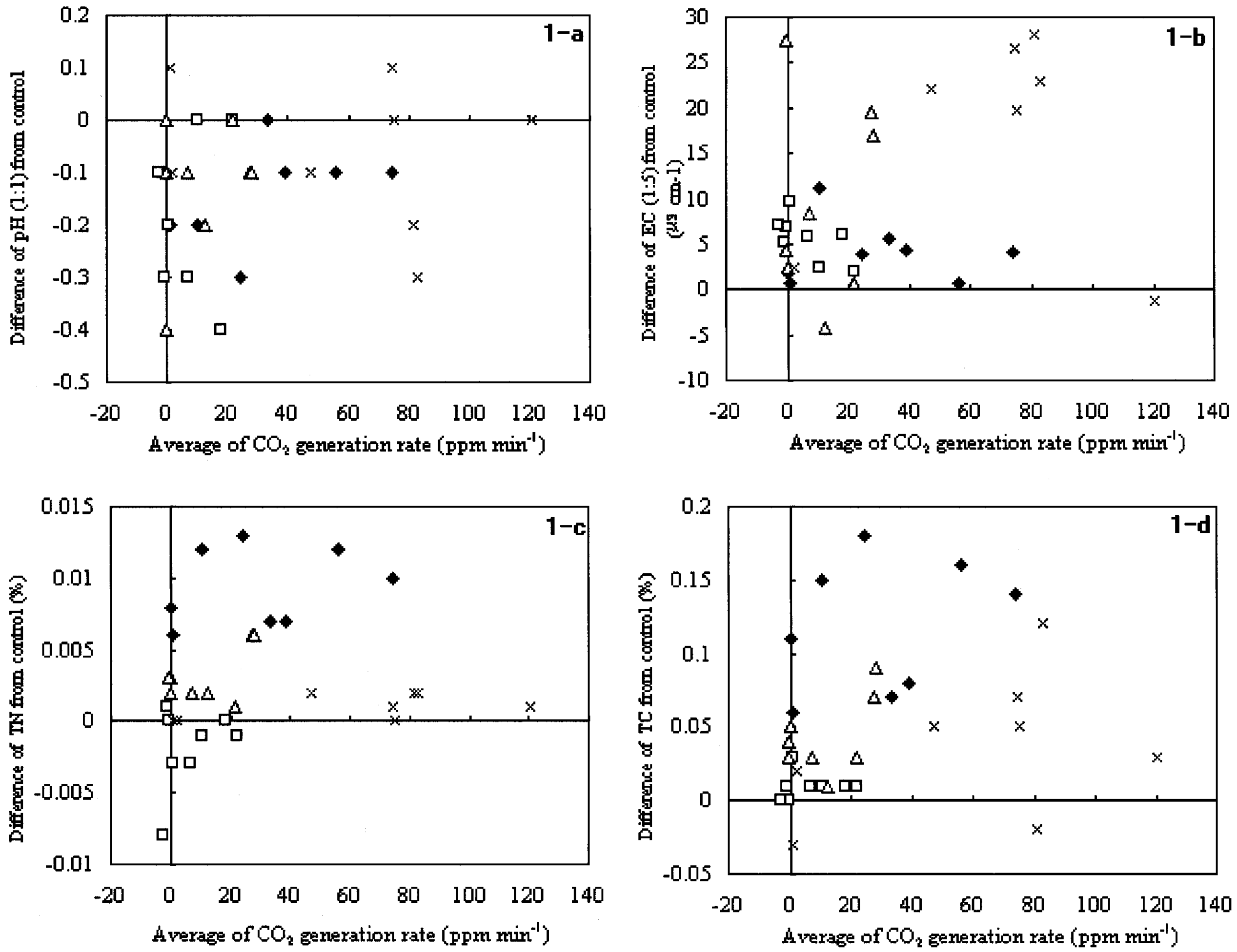


Fig. 1. Relationship between $CO_2$ generation rate during incubation and changes in the chemical properties of soil ( ◆ ; Bagasse, □ ; coir dust, △ ; rice chaff and × ; rice straw).

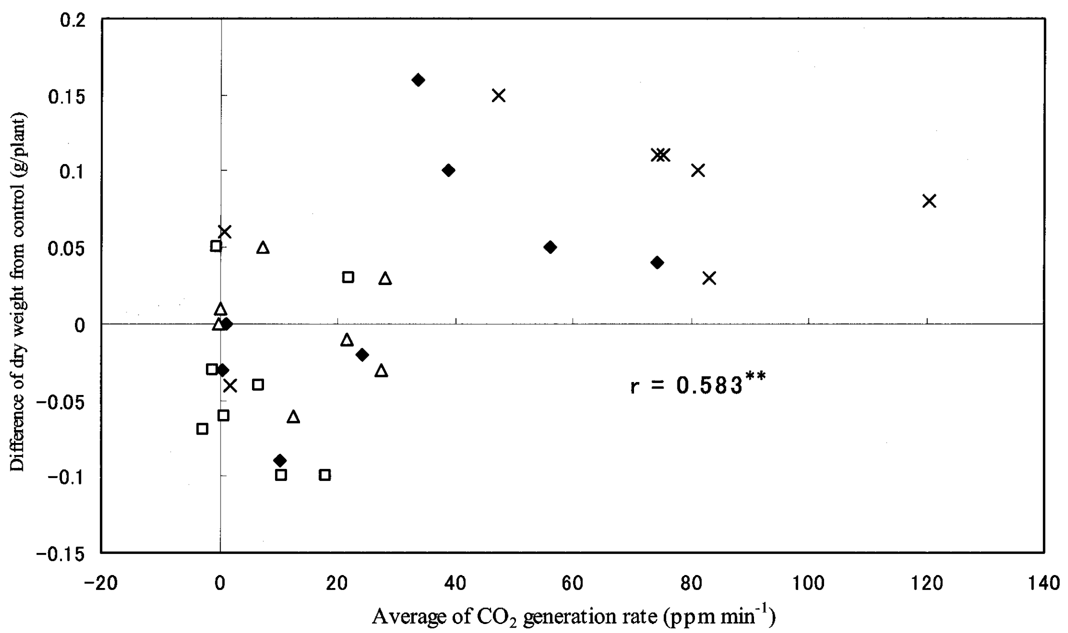


Fig. 2 Relationship between $CO_2$ generation rate during incubation and maize growth (◆; Bagasse, □; coir dust, △; rice chaff and ×; rice straw).