Effect of urban green biomass (pruning materials) compost on the growth of komatsuna (Brassica rapa L. var. perviridis LH Bailey) in different soils

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Abstract. Mineralization of organic matter in soil is affected by the total carbon (C) and nitrogen (N) contents and microbial activity. Therefore, we hypothesized that the application of compost made from pruning materials (PMs) would have different effects on plant growth depending on the properties of the soil. We grew komatsuna (Brassica rapa L. var. perviridis LH Bailey) plants for 1 month in different soils and found that there was a significant positive correlation between plant growth and the total C, N contents and microbial activity of the soil (p < 0.05). However, although PMs compost could be used as conditioners to increase the C and N contents and microbial activity of infertile soils, it was difficult to promote plant growth during the early stages of PMs compost application in these soils. Together, our results indicate that PMs compost is appropriate compost for sustaining or increasing the total C and N contents and microbial activity of the soil and increasing the yield of plants growing in fertile soil.

1. Introduction
The rapid development of urban green spaces has seen a consistent increase in the quantity of plant waste being produced [1], the disposal of which has become a major problem that affects both the environment and sustainable development [2]. Pruning materials (PMs) have traditionally been disposed of through burning. However, sustainable approaches that allow the PMs to be recycled, such as composting or mulching, can allow them to be fully used and effectively reduce CO₂ emissions [3-4].

The application of compost made from PMs compost to soil has been shown to effectively increase the soil porosity and water holding capacity [5]. PMs compost also have nearly the same capacity as conventional compost made from dung, leaves, and bark to improve soil chemical properties, such as fertility, as indicated by the cation exchange capacity (CEC), base cation saturation, and total carbon (C) and nitrogen (N) contents [6]. Furthermore, because PMs compost have a high content of cellulose and hemicellulose mixed with large amount of lignin, they have a high content of mineralizable C compared with conventional compost; thus, its application may have a priming effect on the organic matter mineralization that is present in the soil [7].

The priming of organic matter mineralization can have both positive and negative effects on soil properties [8]. For example, although it can improve the chemical, physical, and biological properties of the soil, it can also inhibit plant growth [9]. Thus, mixing PMs compost into the soil can effectively increase the soil organic matter content but a high content of mineralizable C can inhibit plant growth due to N immobilization [10], which results from the rapid increase in microbial activity [11]. Therefore, it is necessary to determine the growth of plants in soil to which PMs compost have been applied.
The C and N cycling dynamics in compost-supplemented soils can be affected by the compost feedstock, processing conditions, and time [11]. Furthermore, the mineralization of organic matter in the soil is affected by N availability and microbial activity [12-13], and the available N content is positively correlated with the total C and N contents of the soil [14]. Therefore, we hypothesized that the application of PMs compost would have different effects on plant growth depending on the total C and N contents and microbial activity of the soil.

The aim of this study was to evaluate the effect of PMs compost on plant growth in soils with different total C and N contents and microbial activities. In addition, we investigated whether PMs compost affect plant growth during the early stages of application. For this, we applied PMs compost to komatsuna (*Brassica rapa* L. var. *perviridis* LH Bailey) growing in different soils and used the dry weight of individual plants as an indicator of plant growth.

2. Materials and methods

2.1. Soil and compost

To investigate how the application of PMs compost affect plant growth in different soils, a planting experiment was conducted using forest soil, subsoil, and sand (Table 1). The forest soil (0–10 cm depth) was collected from evergreen broad-leaved forest growing on the Matsudo Campus of Chiba University (Matsudo, Chiba Prefecture, Japan) and the subsoil (>30 cm depth) was collected from an experimental field on the Matsudo Campus of Chiba University. The sand was purchased. Different types of soils were produced by mixing varying proportions of different soils (Table 2).

A (volume ratio of forest soil is 100%), B (volume ratio of forest soil : subsoil is 1:1), C (volume ratio of forest soil : subsoil is 1:2), D (volume subsoil is 100%), E (volume ratio of subsoil : sand is 1:1), F (volume ratio of subsoil : sand is 1:2) and G (volume ratio sand is 100%), with the resulting soil types A to G representing high to low total C and N contents and microbial activities as determined by fluorescein diacetate (FDA) hydrolysis [15] (Table 3).

The compost was made from PMs obtained from Agora Landscape Architecture Corporation (Tokyo, Japan). The PMs was consisted of leaves and branches from different species in urban green space. The composting process was divided into two stages. In the first stage, 30% volume of PMs compost as microorganism source was mixed with fresh wood chips (particle size < 25 mm) made from the PMs and was kept for 30 days, airing the mixture once per week. In the second stage, the wood chips mixed Table 1. Properties of the different soils and PMs compost used in this experiment.

| Soil/compost       | Water content (kg/kg) | Dry density (kg/L) | Fresh density (kg/L) | Total carbon content (g/kg) | Total nitrogen content (g/kg) | C/N ratio |
|--------------------|-----------------------|--------------------|----------------------|----------------------------|-------------------------------|-----------|
| Forest soil        | 0.28                  | 0.57               | 0.79                 | 110.4                      | 8.50                          | 12.98     |
| Subsoil            | 0.25                  | 0.74               | 0.98                 | 37.0                       | 2.10                          | 17.61     |
| Sand               | 0.09                  | 1.21               | 1.33                 | 2.6                        | 0.20                          | 13.00     |
| PMs compost        | 0.44                  | 0.17               | 0.3                  | 396.0                      | 16.30                         | 24.29     |

PMs: Pruning materials.
Table 2. Composition of the different soil types used.

| Soil  | Experimental materials | Volume ratio |
|-------|-------------------------|--------------|
| A     | Forest soil             | 1            |
| B     | Forest soil:subsoil     | 1:1          |
| C     | Forest soil:subsoil     | 1:2          |
| D     | Subsoil                 | 1            |
| E     | Subsoil:sand            | 1:1          |
| F     | Subsoil:sand            | 1:2          |
| G     | Sand                    | 1            |

Table 3. Total carbon (C) and nitrogen (N) contents and microbial activities of the different soils used in the experiment.

| Soil  | Total C (g/kg) | Total N (g/kg) | C/N ratio | FDA†         |
|-------|----------------|----------------|-----------|--------------|
| A     | 110.4 ± 9.01a  | 8.5 ± 0.73a    | 12.99     | 1.40 ± 0.044a|
| B     | 74.6 ± 6.09b   | 5.6 ± 0.49b    | 13.32     | 1.20 ± 0.04b |
| C     | 65.4 ± 5.34c   | 5 ± 0.43c      | 13.08     | 0.85 ± 0.028c|
| D     | 37 ± 3.02d     | 3.1 ± 0.24d    | 11.94     | 0.66 ± 0.022d|
| E     | 12 ± 0.98e     | 0.9 ± 0.08e    | 13.33     | 0.29 ± 0.01e |
| F     | 5.1 ± 0.42f    | 0.6 ± 0.03f    | 8.50      | 0.21 ± 0.007f|
| G     | 2.6 ± 0.21g    | 0.2 ± 0.01g    | 13.00     | 0.19 ± 0.009f|

Different lower-case letters within a column indicate significant differences among soil types ($p < 0.05$). Fluorescein diacetate (FDA) hydrolysis was used to indicate microbial activity. The values are absorbance values of the sample liquid at 490 nm [15].

Rectangular pots (volume: 2.2 L; length: 25 cm; width: 11 cm; depth: 8 cm) were filled with soils and PMs compost as treatments or only soils as a control. Each of the soil types were mixed with different ratios of PMs compost, as shown in Table 4.

2.2. Measurement of plant growth
Komatsuna was used as the test plant in this experiment. A total of 12 komatsuna seeds (Sakata Seed Corporation) were planted in each pot on August 20, 2016 and were watered once per day for 1 month. The plants were then harvested on September 20, 2016. After harvesting, the roots and leaves of each individual plant were washed with water, placed in a paper bag, and dried in an oven, to obtain the dry weight of the plant.

2.3. Total C and N contents, C/N ratio, and microbial activities in the soils and PMs compost
The total C and N contents and C/N ratio of the soils and compost were analyzed using a measured using a CN corder (YANACO Analytical Industry Co., Ltd.MT-700). Microbial activity was measured using the FDA hydrolysis method [7]. The FDA value used in this experiment was based on the amount of FDA hydrolyzed per 1 g dry weight of each sample.

2.4. Statistical analysis
To examine the difference in the parameters among the composts studied, one-way analysis of variance (ANOVA; multiple comparisons) was performed, followed by the least significant difference test. The results were considered significantly different at $p <0.05$. All the values were presented as the mean. SPSS 19.0 program was used to perform all statistical analyses.
Table 4. Details of the treatments used.

| Soil† | Volume of PM added to soil (%) | Treatment | Volume ratio |
|-------|-------------------------------|-----------|--------------|
|       |                               | A         |              |
|       | 0                             | Forest soil | 100%         |
|       | 7.5                           | Forest soil: PM | 70%:30%       |
|       | 15                            | Forest soil: PM | 85%:15%       |
|       | 30                            | Forest soil: PM | 92.5%:7.5%    |
|       | B                             | Forest soil: subsoil | 50%:50%         |
|       | 7.5                           | Forest soil: subsoil: PM | 35%:35%:30%       |
|       | 15                            | Forest soil: subsoil: PM | 42.5%:42.5%:15%       |
|       | 30                            | Forest soil: subsoil: PM | 46.25%:46.25%:7.5%       |
|       | C                             | Forest soil: subsoil | 33.3%:66.7%       |
|       | 7.5                           | Forest soil: subsoil: PM | 23.3%:46.7%:30%       |
|       | 15                            | Forest soil: subsoil: PM | 28.33:56.67:15%       |
|       | 30                            | Forest soil: subsoil: PM | 30.83:61.67:7.5%       |
|       | D                             | Subsoil | 100%         |
|       | 7.5                           | Subsoil: PM | 70%:30%       |
|       | 15                            | Subsoil: PM | 85%:15%       |
|       | 30                            | Subsoil: PM | 92.5%:7.5%    |
|       | E                             | Subsoil: sand: PM | 50%:50%       |
|       | 7.5                           | Subsoil: sand: PM | 35%:35%:30%       |
|       | 15                            | Subsoil: sand: PM | 42.5%:42.5%:15%       |
|       | 30                            | Subsoil: sand: PM | 46.25%:46.25%:7.5%       |
|       | F                             | Subsoil: sand | 33.3%:66.7%       |
|       | 7.5                           | Subsoil: sand: PM | 23.3%:46.7%:30%       |
|       | 15                            | Subsoil: sand: PM | 28.33:56.67:15%       |
|       | 30                            | Subsoil: sand: PM | 30.83:61.67:7.5%       |
|       | G                             | Sand | 100%         |
|       | 7.5                           | Sand: PM | 70%:30%       |
|       | 15                            | Sand: PM | 85%:15%       |
|       | 30                            | Sand: PM | 92.5%:7.5%    |

†A: forest soil alone; B: 1:1 ratio of forest soil: subsoil; C: 1:2 ratio of forest soil: subsoil; D: subsoil alone; E: 1:1 ratio of subsoil: sand; F: 1:2 ratio of subsoil: sand; G: sand alone. PM: compost made from pruning materials.

3. Results
The total C and N contents and microbial activities of the different treatments are shown in Table 5. In soils A, B, and C, which had the highest total C and N contents, the application of 7.5% PMs compost had no significant effect on the total C and N contents (p < 0.05), and in soils A and B, the application of 15% PMs compost also had no significant effect on the total C and N contents (p < 0.05). By contrast, the application of 7.5% and 15% PMs compost significantly increased the total C and N contents of soils D to G (p < 0.05), and the application of 30% PMs compost significantly increased the total C and N contents of all seven soil types (p < 0.05). The application of PMs compost significantly increased soil microbial activity in all seven soil types (p < 0.05), with larger amounts of PMs compost having greater effects.

Growth of the komatsuna plants, as indicated by the dry weights of individual plants, is shown in Table 6. In soils A and B, the application of 7.5% and 15% PMs compost significantly promoted plant growth (p < 0.05), while in soil C, only 7.5% PMs compost had a significant effect (p < 0.05), with 30% PMs compost inhibiting plant growth. In soils D to G, all levels of PMs compost significantly inhibited plant growth (p < 0.05).
Table 5. Total carbon (C) and nitrogen (N) contents, C/N ratios, and microbial activities in different soils after the addition of compost.

| Soil† | Volume of PM added to soil (%) | Total C (g/kg) | Total N (g/kg) | C/N ratio | FDA‡ |
|-------|--------------------------------|---------------|---------------|-----------|------|
| A     | 0                              | 110.4 ± 9.01a | 8.5 ± 0.73a   | 12.99     | 1.20 ± 0.044a |
|       | 7.5                            | 116.1 ± 9.63a | 8.7 ± 0.78a   | 13.34     | 1.59 ± 0.056b |
|       | 15                             | 124.4 ± 10.66ab | 9.0± 0.87a | 13.82     | 1.58 ± 0.055b |
|       | 30                             | 142.2 ± 11.72b | 9.6 ± 0.95b   | 14.81     | 1.70 ± 0.069c |
| B     | 0                              | 76.0 ± 6.09a  | 5.7 ± 0.49a   | 13.33     | 1.04 ± 0.040a |
|       | 7.5                            | 83.6 ± 6.34a  | 6.0 ± 0.51a   | 13.93     | 1.32 ± 0.044b |
|       | 15                             | 92.7 ± 6.75a  | 6.3 ± 0.55a   | 14.71     | 1.35 ± 0.053c |
|       | 30                             | 112.4 ± 8.69b | 7.2 ± 0.70b   | 15.61     | 1.60 ± 0.055d |
| C     | 0                              | 64.8 ± 5.34a  | 4.3 ± 0.43a   | 15.07     | 0.69 ± 0.028a |
|       | 7.5                            | 68.9 ± 5.32a  | 4.7 ± 0.43a   | 14.66     | 0.96 ± 0.036b |
|       | 15                             | 83.1 ± 6.27b  | 5.4 ± 0.51b   | 15.39     | 1.08 ± 0.044c |
|       | 30                             | 96.5 ± 7.06c  | 5.8 ± 0.57b   | 16.64     | 1.14 ± 0.048d |
| D     | 0                              | 43.3 ± 3.02a  | 3.1 ± 0.24a   | 13.97     | 0.42 ± 0.022a |
|       | 7.5                            | 49.4 ± 4.03b  | 3.4 ± 0.32a   | 14.53     | 0.86 ± 0.038b |
|       | 15                             | 61.4 ± 5.36c  | 3.9 ± 0.43b   | 15.74     | 1.03 ± 0.035c |
|       | 30                             | 83.9 ± 7.29d  | 4.9 ± 0.59b   | 17.12     | 1.06 ± 0.046c |
| E     | 0                              | 18.0 ± 0.98a  | 1.3 ± 0.08a   | 13.85     | 0.29 ± 0.011a |
|       | 7.5                            | 24.4 ± 1.01a  | 1.6 ± 0.08b   | 15.25     | 0.38 ± 0.012b |
|       | 15                             | 33.7 ± 1.45b  | 2.0 ± 0.11b   | 16.85     | 0.47 ± 0.018c |
|       | 30                             | 52.4 ± 3.18c  | 2.9 ± 0.25c   | 18.07     | 0.58 ± 0.022d |
| F     | 0                              | 11.9 ± 0.42a  | 0.8 ± 0.03a   | 14.88     | 0.20 ± 0.007a |
|       | 7.5                            | 18.8 ± 0.72b  | 1.1 ± 0.05b   | 17.09     | 0.32 ± 0.011b |
|       | 15                             | 26.4 ± 1.09c  | 1.5 ± 0.08b   | 17.60     | 0.38 ± 0.018b |
|       | 30                             | 44.8 ± 2.39d  | 2.4 ± 0.19c   | 18.67     | 0.46 ± 0.015c |
| G     | 0                              | 2.6 ± 0.21a   | 0.2 ± 0.01a   | 13.00     | 0.19 ± 0.009a |
|       | 7.5                            | 7.9 ± 0.61b   | 0.4 ± 0.04b   | 19.75     | 0.24 ± 0.007b |
|       | 15                             | 15.4 ± 0.82c  | 0.8 ± 0.06b   | 19.25     | 0.27 ± 0.009bc |
|       | 30                             | 32.1 ± 1.64d  | 1.6 ± 0.13c   | 20.63     | 0.32 ± 0.012c |

† A: forest soil alone; B: 1:1 ratio of forest soil: subsoil; C: 1:2 ratio of forest soil: subsoil; D: subsoil alone; E: 1:1 ratio of subsoil: sand; F: 1:2 ratio of subsoil: sand; G: sand alone.
‡ Fluorescein diacetate (FDA) hydrolysis was used to indicate microbial activity. The values are absorbances of the sample liquid at 490 nm [15].

Different lower-case letters in the same column indicate significant differences among treatments (p < 0.05).

Table 6. The mean (± SD) dry weight of the plants in each treatment group.

| Soil† | 0%† | 7.50%† | 15%† | 30%† |
|-------|-----|--------|------|------|
| A     | 0.83 ± 0.03 | 1.08 ± 0.04* | 1.10 ± 0.04* | 0.92 ± 0.06 |
| B     | 0.75 ± 0.04 | 0.89 ± 0.02* | 0.92 ± 0.04* | 0.72 ± 0.05 |
| C     | 0.64 ± 0.03 | 0.74 ± 0.02* | 0.65 ± 0.04 | 0.48 ± 0.01* |
| D     | 0.56 ± 0.05 | 0.49 ± 0.03* | 0.42 ± 0.02* | 0.27 ± 0.03* |
| E     | 0.51 ± 0.05 | 0.45 ± 0.01* | 0.36 ± 0.05* | 0.24 ± 0.1* |
| F     | 0.39 ± 0.05 | 0.33 ± 0.02* | 0.29 ± 0.01* | 0.21 ± 0.01* |
| G     | 0.31 ± 0.01 | 0.25 ± 0.01* | 0.21 ± 0.01* | 0.15 ± 0.04* |

† A: forest soil alone; B: 1:1 ratio of forest soil: subsoil; C: 1:2 ratio of forest soil: subsoil; D: subsoil alone; E: 1:1 ratio of subsoil: sand; F: 1:2 ratio of subsoil: sand; G: sand alone.
5th International Conference on Agricultural and Biological Sciences (ABS)  
IOP Conf. Series: Earth and Environmental Science 346 (2019) 012079  
doi:10.1088/1755-1315/346/1/012079

\[ \text{Percentage of compost made from pruning materials (PM) added to the soil.} \]

* Significantly different from the corresponding control group \((p \leq 0.05)\).

\[ \text{Figure 1. Relative growth of komatsuna (} \textit{Brassica rapa var. perviridis} \text{) plants in each treatment group compared with its corresponding control group. Four concentrations of compost made from pruning materials (PM) were applied to seven different soil types: (A) forest soil alone, (B) 1:1 ratio of forest soil: subsoil, (C) 1:2 ratio of forest soil: subsoil, (D) subsoil alone, (E) 1:1 ratio of subsoil: sand, (F) 1:2 ratio of subsoil: sand, and (G) sand alone. Relative plant growth was calculated as the ratio of the dry weight of an individual plant in a particular treatment group compared with the corresponding control group. * Significant difference compared with the control group \((p \leq 0.05)\).} \]

4. Discussion
The application of 7.5% PMs compost significantly promoted plant growth in soils A–C, and 15% PMs compost also significantly promoted plant growth in soils A and B (Figure 1). However, plant growth was significantly inhibited by the application of 7.5% and 15% PMs compost in soil types D–G and 30% PMs compost in all seven soil types. Compost contains a large number of microorganisms [17] and PMs compost contain a large amount of mineralizable carbon, which increases soil microbial activity. Consequently, the application of PMs compost increased microbial activity in the soil (Table 5), which resulted in the consumption of inorganic N in the soil [7] and N starvation.

The relationship between soil microbial activity and relative plant growth is shown in Figure 3. The was a positive correlation between the original soil microbial activity and relative plant growth. The application of PMs compost to soil that already had a relatively high microbial activity (soils A–C) had a greater effect on soil microbial activity because more microorganisms were present (Table 5).
is a positive relationship between net N mineralization and N uptake by plants [18] and the application of PMs compost enhances nutrient release [20]. Consequently, in soils A–C, the high original microorganism content in the soil contributed to the shortened process of organic matter mineralization and the reduced time until the net mineralized N was released from the applied PMs compost to the soil, thus increasing plant N uptake and enhancing nutrient release. Therefore, the application of 7.5% and 15% PMs compost increased net N mineralization and provided the necessary nutrients for plant growth, resulting in the immediate promotion of plant growth. However, the application of 30% PMs compost added excess mineralizable C and microorganisms to the soil, resulting in the consumption of N being higher than the amount supplied. Consequently, the application of 30% PMs compost did not significantly promote plant growth in soils A and B, and appeared to inhibit plant growth in soil C.

Figure 2. Relationship between the total nitrogen content and relative plant growth. Relative plant growth was calculated as the ratio of the dry weight of an individual plant in a particular treatment group to the corresponding control group.

Figure 3. Relationship between microbial activity and relative plant growth. The fluorescein diacetate (FDA) value is shown as the amount of FDA hydrolyzed per 1 g dry weight of sample. Relative plant growth was calculated as the ratio of the dry weight of an individual plant in a particular treatment group to the corresponding control group.
To improve the application of PMs compost in a wide range of soils with different microbial activities, future studies should determine the duration of the plant growth inhibition period to ascertain the best time to start planting after mixing PMs compost. In addition, the inorganic N dynamics that occur during the mineralization process after mixing PMs compost into the soil should be clarified to determine the amount and timing of PM addition that is required for various soil types.

5. Conclusion
Because PMs compost contain a large amount of mineralizable C, its application to the soil can readily cause N starvation due to the increased microbial activity. During the early stage of PMs compost application, the addition of 7.5% and 15% PMs compost effectively promoted plant growth in fertile soils (total N content > 4.6 g/kg). However, the application of 30% PMs compost to fertile soils led to an excessive consumption of N, resulting in no promotion, and even the inhibition, of plant growth. Furthermore, the application of any PM to infertile soil (total N < 4.6 g/kg) inhibited plant growth during the early stage, with this effect becoming more pronounced with increasing amounts of PMs compost. Therefore, further research is required to determine the duration of N starvation as a result of PMs compost application to determine the optimal amount and timing.

Acknowledgments
We would like to thank the Agora Landscape Architecture and Weihai Weinong Biotechnology Corporation for providing PMs compost and support. We would like to acknowledge the professional support of Professor Tatsuaki Kobayashi and Akira Kato of Chiba University for their advice. We are also thankful to Mr. Hitomi Takoya, for his assistance during the experiment. The experiments comply with the current laws of the country in which they were performed.

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