Soil organic carbon and total nitrogen dynamics in paddy soils on the Java Island, Indonesia

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Abstract. Soil organic carbon is one of the soil quality parameters. Soil organic carbon and total nitrogen play an important role in soil physicochemical fertility. The purpose of this paper was to observe the dynamics of organic matter and nitrogen content in paddy soil in Java. Data is obtained from the collection of various research results since 1990, then to analyze the correlation between the chemical properties of the soil. Out of 860 data in five provinces in Java showed a strong correlation between soil organic carbon content and total nitrogen. More than 77% of the paddy soil in Java have low soil organic carbon content as well as more than 80% have a low total nitrogen content. The positive correlation between soil organic carbon content and total nitrogen is quite strong. Correlation coefficients were 0.842 in Banten, 0.900 in West Java, 0.895 in Central Java, 0.798 in East Java, and 0.898 in Yogyakarta. From this linear regression can be seen that the higher the soil organic carbon content, the ability of the soil to retain nitrogen will also be higher. We can manage soil fertility, especially the nitrogen availability in the soil by maintaining the soil organic matter content.

1. Introduction

Factors that affect the soil organic matter content such as include climate, land use, relief, landforms and human activities. Soil organic matter has an important role in soil fertility, both from its physical, chemical and biological characteristics. Physically, soil organic matter can improve soil permeability, increase soil resistance to erosion, increase water holding capacity and play a role in providing moisture, especially for sandy soils, can regulate heat absorption and release. Chemically, soil organic matter is a source of nutrients for plants. Apart from that, soil organic matter also contains substantial carbon, which provides a source of energy for soil macroflora and microflora. Soil organic matter can act as a contributor to the active nature of soil colloids and its physiological functions either as a growth hormone or otherwise are toxic [1,2].

Soil organic matter has a high specific surface (up to 800-900 m² g⁻¹) and Cation Exchange Capacity (CEC) value that ranges from 150 to 300 cmolc (+) kg⁻¹ [2]. Thus, it can be said that the soil surface CEC is caused by soil organic matter. Because of the high specific surface and CEC of soil organic matter, making it an important absorber of plant macro and micronutrients, heavy metal cations and organic materials such as pesticides [2].

Soil organic carbon plays a very important role in many soil functions and maintains a sustainable ecosystem. Soil organic carbon (SOC) is a carbon component of organic compounds. In general, soil organic matter (SOM) is difficult to measure directly, so it is approached by measuring soil organic carbon. Therefore, soil organic carbon is often said to represent the content of soil organic matter. Another indicator of soil fertility is the total nitrogen content. Nitrogen (N) is a soil nutrient that often
limits plant growth, which is needed by plants in large quantities. This nutrient does not exist as a constituent of minerals (rocks) but comes from the atmosphere (78% N) and soil organic matter. Soil is the main source of N for plants and most plants get 50% to 80% of their N requirement from the soil even in high doses of N fertilizer [3]. The main sources of N are added to the soil through inorganic fertilizers, other sources are biological fixation, precipitation, gas adsorption and organic fertilizers (manure, green manure and crop residues).

Java is an island with a densely populated area, which supplies Indonesian food production. Land management is needed to provide optimal agricultural productivity. The dynamics of soil organic carbon (SOC) and total nitrogen (TN) content can indicate the level of soil fertility, which can be used as a basis for land management. This paper aims to observe the dynamics of organic matter and nitrogen content in paddy soil in Java. This paper also shows the correlation of soil acidity (pH), clay content and CEC value with soil organic carbon and total nitrogen in paddy soil in Java.

2. Materials and methods
Soil analysis data were obtained from the collection of various research results from 1990 to 2018. Soil nitrogen content is the total nitrogen content using the Kjeldahl method [4]. Meanwhile, the soil organic carbon content is the result of analyses using the Walkey and Black method [4]. Other soil properties were soil acidity as pH (\(H_2O\)), CEC and soil texture.

The dynamics of soil nitrogen content in Java were obtained by making a correlation between the soil organic carbon (SOC) and total nitrogen content and making a linear regression between the two. The value of Coefficient determination (\(R^2\)) represents the closeness (value) of the relationship between the two parameters.

3. Results and discussion

3.1. Soil organic carbon and total nitrogen content
Soil organic carbon is one of the key attributes in assessing soil health, it is generally positively correlated with crop yield [5]. Important functional processes in soil are strongly influenced by the organic carbon content in the soil such as the ability to store nutrients especially nitrogen, water holding capacity and aggregate stability [6]. Total organic carbon is important for increased agricultural production because organic matter helps improve soil structure and cation exchange capacity and hold water, thus having a positive impact on soil fertility [7]. Soil organic carbon content also greatly affects soil microbial activity.

| Province       | Total area (%) of organic carbon status | Total area (%) of nitrogen carbon status |
|---------------|----------------------------------------|----------------------------------------|
|               | Low         | Moderate     | High       | Low         | Moderate     | High       |
| Banten        | 73.68       | 22.81        | 3.51       | 84.21       | 14.04        | 1.75       |
| West Java     | 58.82       | 33.69        | 7.49       | 62.03       | 37.97        | 0.00       |
| Central Java  | 79.75       | 14.43        | 5.82       | 82.83       | 17.17        | 0.00       |
| East Java     | 91.00       | 8.50         | 0.50       | 96.5        | 3.50         | 0.00       |
| Yogyakarta    | 86.36       | 13.64        | 0.00       | 90.91       | 9.09         | 0.00       |

Note: Based on Balai Penelitian Tanah [11]

Soil nitrogen is also important in maintaining soil quality, crop production and environmental protection [8]. Land use plays a major role in the distribution and amount of SOC and total nitrogen [9]. Chemical fertilizers with crop residues trigger an increase in SOC and TN compared to those without
chemical fertilizers plus a little organic fertilizer [10]. It is very important to know the relationship between soil organic carbon and total nitrogen its relation to other soil properties. The average content of organic C and soil nitrogen in five provinces in Java Island is presented in table 1, with a range of 58% to 91% having low soil organic carbon content and 62% to 96% having low total nitrogen content.

3.2. Soil organic carbon and total nitrogen correlation

The value of soil organic carbon content in the five provinces in Java is between 1.25% to 1.91% which is categorized as low content. Likewise, the average total nitrogen content in five provinces on the island of Java is categorized as low with a range of 0.11% to 0.17%. There is a direct relationship between soil organic carbon and total nitrogen content, an increase in soil organic carbon content will be followed by an increase in total nitrogen content [12]. That the correlation between soil organic carbon content and total nitrogen is positive and has a high enough correlation coefficient with a value of 0.80 to 0.90 [13] (table 2).

| Province      | Average content (%) | Correlation coefficient |
|---------------|---------------------|-------------------------|
|               | SOC                 | TN                      |                           |
| Banten        | 1.59 ± 0.66         | 0.15 ± 0.07             | 0.84                     |
| West Java     | 1.91 ± 0.68         | 0.17 ± 0.06             | 0.90                     |
| Central Java  | 1.55 ± 0.86         | 0.15 ± 0.08             | 0.89                     |
| East Java     | 1.25 ± 0.50         | 0.11 ± 0.04             | 0.80                     |
| Yogyakarta    | 1.54 ± 0.51         | 0.14 ± 0.04             | 0.90                     |

Soil organic carbon is strongly correlated with total nitrogen and this correlation was the terrestrial environment cycle of carbon and nitrogen [14]. Several factors have a bearing on soil organic carbon and total nitrogen content. These include the mean annual rainfall and mean annual temperature [15]. The correlation between soil organic carbon and total nitrogen among various land uses is positive. Land use plays a major role in the distribution and amount of soil organic carbon and total nitrogen [9]. Soil organic carbon and total nitrogen content were significantly correlated with the close combination in seasonally frozen soil [10].

Land use means a cultivation system that is closely related to what is given to the soil. Several factors influence the cultivation system, for example, the level of knowledge about fertilization, financial capacity. As an indicator of soil health, soil organic carbon has an important contribution to food production, as well as climate change mitigation and adaptation [16].

The relationship between soil organic carbon and total nitrogen can also be described using linear regression. It can be seen that the relationship between soil organic carbon and total nitrogen is very close, which can be seen from the relatively high R² value, ranging from 0.6 to 0.8 (figure 1).

3.3. Correlation of soil acidity (pH) with soil organic carbon and total nitrogen

Soil acidity can significantly influence soil organic carbon content, as it regulates soil nutrient bioavailability, organic matter turnover and various soil processes [17]. Soil carbon, nitrogen and C/N ratio are negatively correlated with soil pH, suggesting that a relatively low pH favors the accumulation of organic matter [18]. The collected data shows that Banten province is dominated by acid soils. Meanwhile, in other provinces (West Java, Central Java, East Java and Yogyakarta) the dominance of pH is above 5.5. The linear regression results between soil organic carbon and soil pH for the provinces of Banten, West Java, Central Java and East Java showed a negative correlation, while Yogyakarta Province showed a positive correlation. Meanwhile, linear regression between total nitrogen and soil pH has a negative correlation for the five provinces. Not a strong correlation value is indicated by the very low R² value, ranging from 0.0003 to 0.1 with correlation coefficient value below 0.3 for total nitrogen and 0.00004 to 0.21 for soil organic carbon with correlation coefficient value below 0.46 (figure 2). This
negative correlation shows that high pH values tend to have lower soil organic carbon content and total nitrogen, low pH tends to have higher soil organic carbon and total nitrogen content.

![Figure 1](image_url)  

**Figure 1**. Linear regression of soil organic carbon and total nitrogen in (a) Banten, (b) West Java, (c) Central Java, (d) East Java and (e) Yogyakarta

### 3.4. Correlation of clay content with soil organic carbon and total nitrogen

Soil texture, which is used to describe the particle size distribution of minerals, is said to be another important factor affecting the accumulation of soil organic matter [19]. Generally, clay and silt particles are better able to hold soil organic matter by stabilizing it from microbial mineralization [20]. The average soil organic carbon and total nitrogen content of soil samples containing more clay and silt were higher than that of other soil samples [18]. Linear regression between soil clay content and soil organic carbon for the provinces of Banten, West Java, East Java and DIY shows a positive relationship, but is different from Central Java which has a negative correlation. The same thing can be seen from the total nitrogen content, linear regression with clay content for the provinces of Banten, West Java, East Java and Yogyakarta shows a positive correlation, but in contrast to Central Java which has a negative
correlation. However, the correlation value is in the very weak to a moderate category which can be seen from the coefficient $R^2$ value which is very low, ranging from 0.00002 to 0.3 (correlation coefficient up to 5.5) for soil organic carbon and 0.004 to 0.38 for total nitrogen (correlation coefficient up to 6.2) (figure 3).

Figure 2. Linear regression between soil pH to soil organic carbon and total nitrogen of paddy soil in (a1, a2) Banten, (b1, b2) West Java, (c1, c2) Central Java, (d1, d2) East Java and (e1, e2) Yogyakarta
3.5. Correlation of CEC value with soil organic carbon and total nitrogen

One of the sources of soil CEC is soil organic matter, which is represented by the soil organic carbon value. Therefore, there is a very significant correlation between the soil organic carbon content and the CEC value [21]. Soil CEC and its exchangeable cations are closely related to their soil organic carbon content (organic matter, nutrient contents and cation exchange). Soil organic matter content (SOM) has a significant correlation with tropical soil attributes, especially cation exchange capacity (CEC) [22]. Theoretically, a high CEC value has a positive correlation with a high soil organic carbon content as well as total nitrogen. Linear regression between CEC value and soil organic carbon content for the provinces of Banten, West Java and East Java shows a positive correlation, but in contrast to Central Java and Yogyakarta which have a negative correlation. Meanwhile, the linear regression between the CEC value and total nitrogen content for the five provinces in Java shows a positive correlation. However, the correlation value varies from weak to moderate, which can be seen from the coefficient $R^2$ value which is very low, ranging from 0.004 to 0.138 (correlation coefficient below 0.5) for soil organic carbon and 0.014 to 0.183 (correlation coefficient below 0.4) or total nitrogen (figure 4).
Figure 3. Linear regression between soil clay content to soil organic carbon and total nitrogen of paddy soil in (a1, a2) Banten, (b1, b2) West Java, (c1, c2) Central Java, (d1, d2) East Java and (e1, e2) Yogyakarta
Figure 4. Linear regression between CEC value to soil organic carbon and total nitrogen of paddy soil in (a1, a2) Banten, (b1, b2) West Java, (c1, c2) Central Java, (d1, d2) East Java and (e1, e2) Yogyakarta

4. Conclusions
Soil organic carbon content of paddy soils in Java has decreased, more than 77% has low soil organic carbon content and more than 80% has low total nitrogen content. Most of them were of low status with an average content of between 1.25% to 1.91%, which indicates infertility. This should be a very serious concern to maintain the fertility of paddy soil in Java Island. Likewise, the total nitrogen content of paddy soils in Java Island is low with values ranging from 0.11% to 0.17%. Nitrogen has a very mobile character in the soil; therefore, it is necessary to minimize its loss in the soil. The soil organic carbon content and total nitrogen in the soil had a strong positive correlation with a high correlation value between 0.80 to 0.90. Soil acidity (pH), clay content and CEC values have a low correlation with soil organic C content and total nitrogen. This study implies that we have to manage soil fertility, especially nitrogen availability in the soil by maintaining the soil organic matter content.

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