Status of soil organic carbon and its management recommendation for rice plants at four experiment stations of the Indonesian Centre for Rice Research

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Abstract. A survey, mapping, and compilation of recommendations for paddy field had been carried out in four Experimental Station of Indonesian Center for Rice Research in 2015-2016. The objective of detailed scale nutrient status mapping (<1:5,000) was to obtain information about the different variations in the diversity of organic matter status and its management. The results showed that C-organic content of paddy soils, of the 318.44 ha of paddy fields area at Sukamandi was low for 314.37 ha or 98.72% and moderate for 4.07 ha (1.28%). Pusakanagara experimental station, with 37.50 ha of paddy fields area, had low and moderate levels of soil C-organic contents on 8.68 ha (41.75%), and 12.12 ha (58.25%) area respectively. About 20.80 ha rice field area at the Kuningan research station contained low and medium C-organic on 8.68 ha (41.75%) and 12.12 ha (58.25%) area respectively. At Muara experimental station, soil C-organic was classified as low and moderate for 8.14 ha (40.72%), and 11.86 ha (59.28%) area respectively. To increase the C-organic status of this soil, it must be carried out to return harvested straw and or apply manure from outside at least 4 t ha\textsuperscript{-1}.

1. Introduction

Paddy soil has specific characteristics, because it has been heavily influenced by the activities of flora, fauna and especially humans both in the past and present. Lowland soils are unique because they are cultivated in predominantly under anaerobic (inundated) conditions, with soil conditions that are slushed at a depth of 0-10 cm [1]. At first glance, paddy soil looks homogeneous because it has a narrow area limited by bunds, but the narrow soil condition can cause differences in soil morphology, especially texture and nutrient status, depending on the method of processing and management of the soil given. These variations in conditions are generally always present and are commonly referred to as soil heterogeneity [2].

The ability of lowland soil to produce optimally is influenced by the soil parent material, its management level, climate related to water availability and solar intensity. Soil chemical properties are largely determined by the interaction of various soil-forming factors, namely: parent material, climate
(rainfall and temperature), topography, vegetation and human intervention. The interaction of several factors mentioned above results in different soil chemical properties and soil fertility which cause to the productivity of paddy fields.

The productivity of paddy fields that have been managed intensively for a long period has also caused problems, including in terms of nutrient balance. There are indications on the declining of rice production in intensive rice cultivation, which is might be due to the limited primary macro nutrient, like C-organic. It is known that straw compost may increase soil C, N, P and K and plant growth (plant height and number of tillers) [3,4].

Soil carbon content reflects the content of organic matter in the soil which is an important measure for soil management. Even organic materials are believed to be the key to drought resistance and the sustainability of food production [5]. Provision of organic fertilizers is a management activity that is expected to improve soil fertility through improving the physical, chemical and biological properties of the soil [6]. Rice straw contains 0.71% N; K 1.27%; P 0.50%; and C-organic 25.98%. One of the functions of organic matter is to increase the availability of N, P, K, and S elements, and the cation exchange capacity (CEC), which in turn increases plant production. Organic matter added into the paddy soil, it is an essential source of energy for soil biota, as well.

The nutrient balance of the paddy soil nutrient status at each location can be determined by taking soil samples and analyzing its nutrient levels in the laboratory according to what nutrient levels are needed and delineation or limit drawing can be carried out if there are differences, so that differences in the nutrient status of the rice fields at each the location can be known. This activity is a mapping of the soil nutrient status of the rice fields.

Accuracy in mapping soil nutrient status depends on the scale of the intended map. Smaller map scale contains more accurate information, so that even though in narrow variation contents in soil, the nutrient status can still be identified on how to cultivate and manage the soil, especially fertilization in accordance with condition of soil nutrient status and plant needs which in the end fulfillment of balanced fertilization, increase productivity, save fertilizer use and are environmentally friendly.

2. Materials and methods

2.1. Materials

The materials used for this activity were field map of each research station, soil drill, Global Positioning System. Mapping of paddy soil nutrient status was carried out from 2015 to 2016 at four research stations of the Indonesian Center for Rice Research, namely Sukamandi, Pusakagara, Kuningan and Muara.

2.2. Methods

The nutrient status mapping activity had been carried out in 4 stages of activities, namely: 1) Producing field maps of 1:2,000 scale compiled from overlaying between google, topographical, administrative and rice fields maps from each station; 2) Soil sampling. Soil samples were taken at a depth of 20 cm composited from 5 to 10 individual samples (sub samples), with a distance of 25-50 m for each sub sample in the field. The individual samples were homogenized and then sampled 0.5 kg composite soil representing 2 ha of rice field; 3) Soil samples were analyzed their C-organic contents at the Laboratory of the Indonesian Soil Research Institute; 4) Producing map of nutrient status. The results of the analysis of nutrient content were grouped into status classes with predefined standard criteria and plotted onto a base map (each status class was assigned a different color), for deliniating each nutrient status. As materials for making a nutrient status map, were the 200 soil samples composites (based on area and target map scale) consisting of 155, 15, 15, and 15 samples each from the research station of Sukamandi, Pusakagara,
Kuningan, and Muara, respectively. The basis for calculating the number of samples is derived from calculating the total area multiplied by the map scale.

Classification of nutrient status based on the following criteria:
1. Low nutrient status (R) class indicates that the plant is very responsive to fertilizer application. Without the addition of fertilizer, the production will decrease and the plants will show signs of scaling, abnormal, and miserably growths.
2. Medium nutrient status (S) class indicates moderate nutrient requirements, without fertilizer, less than normal plant growth, no deficiency symptoms and medium production.
3. The high nutrient status (T) class indicates that the plant does not need fertilizer and low response to fertilization. Fertilizer is needed to replace the loss of nutrients transported by harvest (grain and straw) or called the maintenance dose.

3. Results and discussion

3.1. C-organic performance of paddy soil at Sukamandi Research Station
Sukamandi research station with alluvial soil types is located in the center of rice production in the pantura (north seashore) area at an elevation less than 200 m above sea level. From the 318.44 ha rice fields area at the Sukamandi research station, an area of 314.37 ha (98.72%) and the remaining 4.07 ha (4.07%) contained low and medium organic C (table 1). Continuous rice planting without returning the straw to the land causes the soil organic C content to be low (<2% C-organic). Low levels of C-organic indicate that this soil has a limited carrying capacity, so if the addition of inorganic fertilizers continuously increase, but plants do not respond to the input, it is called the leveling off phenomenon [7].

Map of C-organic nutrient status of Sukamandi research station scale 1:5,000 shows that the medium levels were found in only 3 sites (figure 1). Previous researcher found that the intensified lowlands and highlands areas in Indonesia have low soil organic matter content (<2%) [8]. However, in contrary there are some highland areas cultivated by planting economically valuable vegetables have moderate to high levels of organic matter.

![Figure 1. Map of soil organic C content of soil in Sukamandi experiment station.](image-url)
Table 1. C-organic content of Sukamandi research station.

| C-organic (%) | Potassium dichromate solution | Sukamandi |
|---------------|-------------------------------|-----------|
| Low           | <2                            | 314.37    | 98.72 |
| Medium        | 2-4                           | 4.07      | 1.28  |
| High          | >4                            | -         | -     |
| Total         |                               | 318.44    | 100   |

3.2. C-organic performance of paddy soil of Pusakanegara research station

Pusakanegara research station, composed of alluvial soil types, is located in the center of rice production in the pantura area at an elevation less than 200 m above sea level. All the 37.50 ha of rice fields area in the research station, contained low C-organic (table 2). This C-organic condition is the same as the low value (1.40%) in paddy fields in the surrounding areas [9]. The low level of C-organic is a reflection of previous land management that the amount of added organic matter has not been able to raise the C-organic content to a value above 2%.

Table 2. C-organic content of Pusakanegara research station.

| Org-C content | Potassium dichromate solution | Pusakanegara |
|---------------|-------------------------------|--------------|
| Low           | <2                            | 37.50        | 100 |
| Medium        | 2-4                           | -            | -   |
| High          | >4                            | -            | -   |
| Total         |                               | 37.50        | 100 |

Figure 2. Map of soil organic C content of soil in Pusakanegara research station.
3.3. C-organic performance of paddy soil of Kuningan Research Station
Kuningan research station composed of Inceptisol soil types is located in intensify of rice production area at an elevation about 500 m above sea level. From the 20.80 ha rice fields area at the Kuningan research station, areas of 8.68 ha (41.75%) and 12.12 ha (58.25%) contained low and moderate organic C content (table 3). Kuningan is one of the areas in West Java which is often planted with rice. The content of C-organic in brass is in a low category (1.88%) [9]. Kuningan research station having organic C content >2% in more than 50% area indicates that the station is better than Sukamandi and Pusakagara in management of organic matter. It would be wise to maintaining it.

The distribution of soil organic C content at the Kuningan experimental station was grouped into two classes, namely low and medium levels. The differences in C-organic levels are possibly caused the different histories of land clearing or management.

| Org-C content | Potassium dichromate solution organic C (%) | Kuningan |
|---------------|--------------------------------------------|----------|
| Low           | <2                                         | 8.68     |
| Medium        | 2-4                                        | 12.12    |
| High          | ≥4                                         |          |
| **Total**     |                                            | 20.80    |

Figure 3. Map of soil organic C content of soil in Kuningan experiment station.

3.4. C-organic performance of paddy soil of Muara Research Station
Muara research station composed of Inceptisols soil types is located in urban area at an elevation about 250 m above sea level. From the 20.00 ha rice fields area at Muara research station, areas of 8.14 ha (40.72%) and 11.86 ha (59.28%) contained low and moderate organic C contents (table 4 and figure 4).
This proportion is better than the paddy fields in the surrounding area, because according to Ikhwani et al. [10] the soil organic C content in the Muara area is low so it is recommended to add organic matter to increase soil C-organic. Muara and Kuningan research stations have the areas with low and medium organic C contents and the proportion is almost equal.

| Org-C content | Potassium dichromate solution organic C (%) | Muara ha | % |
|---------------|------------------------------------------|---------|---|
| Low           | <2                                       | 8.14    | 40.72 |
| Medium        | 2-4                                      | 11.86   | 59.28 |
| High          | >4                                       | -       | -     |
| **Total**     | **20.00**                                | **100** |

Figure 4. Map of soil organic C content of soil in Muara experiment station.

3.5. Organic fertilizer management recommendations

The C-organic content of the four experimental stations varied widely, but it was dominated by moderate to low soil organic C-status. To increase soil productivity, the management of organic matter from straw and manure is required 4 t ha⁻¹ at a low C status level (tables 5 and 6) as a complement to inorganic
fertilization. Given the very important role of organic matter, the policy on the use of organic materials for paddy fields has been listed in MOA 40 of 2007 [11], and then updated in 2020 by the IAARD [12].

Single and compound inorganic fertilizers recommendations (NPK 15-15-15) are prepared for four research stations combined with straw compost or manure of 4 and t ha\(^{-1}\) season\(^{-1}\) for low to medium, and high C content. The recommendations are targeted to reach production of 6 to 7 t ha\(^{-1}\) (tables 5 and 6). In the long term fertilizing straw compost or manure at these rates every season continuously can improve C-organic content and other soil properties.

**Table 5.** Single fertilizer recommendation with straw or organic matter for low to medium soil organic C content.

| Soil nutrient status | Single fertilizer + 4 t ha\(^{-1}\) straw | Single + organic fertilizer t ha\(^{-1}\) |
|----------------------|------------------------------------------|----------------------------------------|
|                      | Urea| SP-36| KCl | Urea| SP-36| KCl |
|                      | kg ha\(^{-1}\)| | | kg ha\(^{-1}\)| | |
| Low                  | 230 | 100  | 50  | 225 | 50  | 80  |
| Low                  | 230 | 100  | 0   | 225 | 50  | 30  |
| Low                  | 230 | 100  | 0   | 225 | 50  | 30  |
| Low                  | 230 | 75   | 50  | 225 | 25  | 80  |
| Medium               | 230 | 75   | 0   | 225 | 25  | 30  |
| Medium               | 230 | 75   | 0   | 225 | 25  | 30  |
| Medium               | 230 | 50   | 50  | 225 | 0   | 80  |
| High                 | 230 | 50   | 0   | 225 | 0   | 30  |
| High                 | 230 | 50   | 0   | 225 | 0   | 30  |

**Table 6.** Compound NPK fertilizer recommendation with straw or organic matter for low to medium soil organic C content.

| Soil nutrient status | NPK + 4 t ha\(^{-1}\) Straw | NPK + 4 t ha\(^{-1}\) Organic fertilizer |
|----------------------|-----------------------------|----------------------------------------|
|                      | Urea| NPK | Urea | NPK | Urea |
|                      | kg ha\(^{-1}\)| | | kg ha\(^{-1}\)| | |
| Low                  | 300 | 150 | 300 | 150 |
| Low                  | 225 | 175 | 150 | 200 |
| Low                  | 225 | 175 | 150 | 200 |
| Medium               | 250 | 150 | 300 | 150 |
| Medium               | 225 | 175 | 150 | 200 |
| Medium               | 225 | 175 | 150 | 200 |
| High                 | 200 | 200 | 250 | 150 |
| High                 | 200 | 150 | 150 | 200 |
| High                 | 200 | 150 | 150 | 200 |

The residue of rice or straw can improve and enhance the physical, chemical and biological properties of the soil. In paddy fields, each planting season produces 2 to 9 t ha\(^{-1}\) of straw which has the potential to be used as organic material after composting [13] or according to Grednera and Tippkotera [14], the potential for rice straw is approximately 1.4 times the yield. This straw compost contains nutrients and organic acids that can be utilized by microorganisms for metabolic activity in their role in the nutrient
cycle [15]. Application of 5 t ha$^{-1}$ season$^{-1}$ of straw for 4 seasons can contribute as much as 1.7 t C-organic [16]. Utilization of straw in paddy fields increases soil C-organic and exchangeable K [17].

4. Conclusions

The survey results showed that C-organic contents in the soil of paddy field areas at the four experimental stations were categorized into low to moderate status and none of them had high level of soil C-organic. Sukamandi experimental station, with total paddy field area 318.44 ha showed that 314.37 ha or 98.72% (almost entire area) and only 4.07 ha or 1.28% areas contained low and moderate soil C-organic, respectively. The Pusakanagara station with total paddy field area of 37.50 ha had almost equal in low and medium levels of soil C-organic contents namely 8.68 ha (41.75%) and 12.12 ha (58.25%) areas respectively. The Kuningan research station, with total rice field area of 20.80 ha had 8.68 ha (41.75%) and 12.12 ha (58.25%) areas containing low and medium soil C-organic contents, respectively. While the Muara station with 20.00 ha paddy fields area had 8.14 ha (40.72%) and 11.86 ha (59.28%) areas containing low and moderate levels of soil C-organic contents.

In an effort to maintain low soil C-organic to reach moderate status, it is recommended that application of harvested straw and or manure from outside must be carried out at least 4 t ha$^{-1}$ for straw and 2 t ha$^{-1}$ for others source of organic fertilizer. The application of composted straw and organic fertilizer serves as an ameliorant and complements to mineral fertilizers according to the soil nutrient status.

Acknowledgments

Authors acknowledgement to the survey and mapping team from both Indonesian Soil Research Institute and ICRR.

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