Changes in chemical properties of soil in an organic agriculture system

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Abstract. Organic agriculture has been associated with the change in soil characteristic and capability of supporting crop growth. The objective of this study was to determine the fluctuation of selected soil chemical properties as managed under organic agriculture system with different kinds of crop for eight years. Observations were carried out during 2013 to 2016 on soil samples collected for total organic carbon, total nitrogen, available phosphate, exchangeable K, exchangeable Al and pH, and crops yield. Total soil organic carbon ranged from 1.97 to 3.46%. Similar patterns were also exhibited by total N and exchangeable K in the range from 0.19 to 0.33 % and 0.22 to 0.44 cmol·kg⁻¹, respectively. Available P tended to increase linearly from 5.54 to 10.72 mg·kg⁻¹ as observed on exchangeable K. Soil pH increased in 2014 but tended to steady in the following years. In contrast, the exchangeable Al declined from 1.47 to 0.10 mg·kg⁻¹. In all cases, the yield of crops in organic agriculture system was lower than that of conventional cropping system. Increasing rate of cow manure application was suggested.

1. Introduction

The reemergence of organic agriculture is demanded by the increasing appreciation in the healthy food and environmental issues. Organic foods have been convincingly demonstrated to expose consumers to fewer synthetic pesticides associated with human health [1, 2, 3,4]. Similarly, organic farming has been deemed to have less environmental impact than conventional approaches [5, 6, 7, 8]. Although organic agriculture is pessimistically perceived unable to feed the world [9], it has potentially provide substantial contribution to the global food supply, while preserving the environment [10]. Such as notion was supported by the fact that organic agriculture has expanded rapidly in recent years. In 2015, there were 50.9 million hectares of organically managed farmland, or 6.5 million hectares increment over 2014 [11]. Likewise, the world’s food organic market tends to expand continuously. The sales of global organic food reached 80 billion US dollars in 2014 [12] and increased to 81.6 billion US dollars in 2015 [11].

The motivations of conventional crop producers to convert their land into organic production system can arise from variety of reasons [13]. Nevertheless, to market crop products labeled as “organic”, the producer should abide by stringent regulations in the crop production. The exact production methods may be varied across countries, but the exclusion of most synthetic pesticides and fertilizers, the management of soils through addition of organic materials and use of crop rotation are adopted as the general principles in the crop production [14]. Moreover, before being qualified as an
organic agriculture, a production area must undergo at least three years transition without synthetic chemical fertilizers and synthetic pesticides [15].

Lower crop yields are the most common features reported during the transition from conventional to organic agriculture. However, the yield will gradually increase over time along with the improved soil quality and management skill [16, 17, 18, 19]. Under organically managed system, the nutrients availability for the plant uptake is largely dependent upon microbial activities mediated decomposition and mineralization processes of the organic materials added to the soil. These processes occurred very slowly but progressively throughout a period of time [20]. Initially, the plant growth obtains nutrients mostly from the priming effect in the decomposition and mineralization of the organic materials applied to the soil [21]. A repeated organic amendment to soil, however, will lead to the creation of a long-term nutrient pool for plant uptake [22, 23]. The rate of nutrients build-up in the nutrient pools can be fluctuated across time as determined by a number of factors [24]. This study was undertaken to determine the fluctuation of selected chemical properties of soil as managed under organic agriculture system for eight years as a guidance for designing the best crop production strategies.

2. Materials and Methods

2.1. Description of the experimental site
The study was conducted during period of 2013–2016 on 20 m × 30 m paddock at the organic research station, Faculty of Agriculture, University of Bengkulu located at Air Duku, RejangLebong Regency, Bengkulu Province, Indonesia (3°27’34″S and 102°36’54″E, 1054 m above sea level). The site is characterized by sandy loam soil suborder Andept. The average annual rainfall for the last 10 years was 2,965.5 mm with the monthly average 247.12 mm. Throughout the growing season, mean air temperature and relative humidity were 20 °C and 87.8%, respectively. Prior to present study, organic cropping management and crop rotation were implemented successively since 2009 with sweet corn as the main crop. Table 1 presents the soil chemical properties recorded in 2009.

| Chemical Properties | Soil depth (cm) |
|---------------------|-----------------|
|                     | 0–25 | 25–53 | 53–78 | >78  |
| BD (g·cm⁻³)         | 1.98  | 1.66  | 2.24  | 2.05 |
| pH (H₂O)            | 5.50  | 5.00  | 4.80  | 4.30 |
| C--org (%)          | 2.31  | 1.15  | 1.43  | 1.19 |
| N-total (%)         | 0.27  | 0.25  | 0.12  | 0.13 |
| C/N Ratio           | 8.56  | 4.60  | 11.92 | 9.15 |
| P-Bray (mg·kg⁻¹)    | 4.95  | 3.61  | 3.63  | 2.55 |
| K (cmol·kg⁻¹)       | 0.19  | 0.26  | 0.16  | 0.23 |
| K (mg·kg⁻¹)         | 74.10 | 101.40| 62.40 | 89.70|
| Ca (cmol·kg⁻¹)      | 1.10  | 0.98  | 0.50  | 0.60 |
| Ca (mg·kg⁻¹)        | 220.00| 196.00| 100.00| 120.00|
| Mg (cmol·kg⁻¹)      | 0.23  | 0.27  | 0.25  | 0.40 |
| Mg (mg·kg⁻¹)        | 27.60 | 32.40 | 30.00 | 48.00|

2.2. Cropping system
Since 2009 different sweet corn based crop rotations were raised. Table 2 lists the cropping pattern adopted during period of 2013 to 2016. In each growing season, the soil was manually tilled using hoes to the depth of 14 cm and amended with cow manure at 15 ton·ha⁻¹ as the basal fertilizer. Moreover, a locally made organic liquid fertilizer [25] was side-dressed as the supplemental nutrients for the crop. Except sweet corn, all the crop residues following harvest were returned to the paddock. The sweet corn residue was taken for the cows feed.
Table 2. Sweet corn based crop rotations adopted in two growing seasons during the period of 2013–2016.

| Year | 1st growing season (February–April) | 2nd growing season (June–September) |
|------|-------------------------------------|-------------------------------------|
| 2013 | Sweet corn                          | Carrot                              |
| 2014 | Peanut                              | Sweet corn                          |
| 2015 | Sweet corn                          | Fallow                              |
| 2016 | Sweet corn                          | Soybean                             |

2.3. Soil sampling

For sampling purpose, the site was equally divided into three sections (two ends and middle) and from each section five random soil sample cores were taken at plow layer (20 cm depth). The collection of soil samples was performed at the end of second growing season (October) in each year. The soil samples from each section were composited, air-dried, ground, and sieved through a 0.5 mm sieve prior to chemical analysis. The laboratory procedures for soil analysis as described by [26] were adopted to determine total organic carbon (Walky and Black method), soil total nitrogen (Kjeldahl method), available P (Bray-2 method), exchangeable K, exchangeable Al and pH. Descriptive statistics was employed for the data analysis.

3. Results and Discussion

3.1. Total soil organic carbon (TSOC)

The observed TSOC at tillage depth over four years of experimentation is presented on figure 1. As pointed out by [27] that organic carbon in the soil can serve as a good indicator for soil quality to warrant a sustainable agroecosystem. In this study, the overall values of TSOC were greater than 1%, indicating that the soil could maintain a sustainable crop production, but the soil aggregate in 2013 and 2015 might be unstable for having TSOC less than 2% [28].

Although the removal of sweet corn biomass from the paddock to some extent has reduced the annual TSOC [29], no notable change was observed in TSOC from the initial state in 2009, due to the crop rotation implemented ever since. Notable TSOC increase in 2014 and 2016 indicated that the involvement of legumes had played important role in soil organic turnover and improvement, as also reported by [30, 31]. In addition, the higher contribution of soybean on TSOC over peanut was in disagreement to the report published by [32]. This possibly was resulted from the poor growth performances of soybean during experimentation.

![Figure 1. Total soil organic carbon (TSOC) observed in the period between 2013 and 2016.](image)

3.2. Soil total nitrogen (STN)
Figure 2 illustrates the fluctuation of the STN in the period of four years. STN is also used as the indicator of soil quality for sustainable land use management [33]. It measures the total amount of nitrogen present in the soil, which is mostly held in organic matter and is not readily available to the plant [34]. N in soil mainly originated from organic matter and higher N content contained in the organic matter leads to higher soil N content [35]. In this study, the observed STN were ranged from medium-level (0.19% in 2013) to high-level (0.33% in 2014) [36]. Similar to TSOC, the involvement of legume in the crop rotation provided a meaningful contribution to STN. Figure 2 also shows that fallowing had contributed a comparable STN to the legumes. Billygoat weed (Ageratum conyzoides) exhibited the most dominant weed during fallowing period and in earlier study, billygoat weed had high N content and comparable to Gliricidia (tree legume) and L. leucocephala (shrub legume) [37].

![Figure 2: Soil total nitrogen (STN) observed in the period between 2013 and 2016.](image)

3.3. Soil available P

While soil nitrogen is dynamic in nature and continuously recycled between atmosphere, soil solution, soil organic matter, plant material and soil organisms [38], soil P is held tightly by the surface of soil particles to make it more stable in the soil [39]. In a long term, therefore, the soil P would gradually build up as the organic materials from fertilizer and crop residues are added to the soil and made available as the organic materials are decomposed and mineralized [40, 41]. The annual evaluation on soil available P has confirmed such phenomenon, where soil available P at tillage depth was increased in a linear fashion (figure 3). A similar pattern can also be inferred from the initial status of available P in 2009.

![Figure 3: Available P observed in the period between 2013 and 2016.](image)
3.4. Exchangeable K
Plant nutrient availability in organic agriculture system heavily relies on organic matter supply to the soil. Seasonal cow manure amendment at a rate of 15 ton·ha⁻¹ and crop residues have led to increasing soil organic matter as indicated by TSOC. Mineralization of soil organic matter released a significant amount of plant nutrients, including K [35]. During the course of the evaluation, exchangeable K in soil had similar fashion to that of available P, except in 2015. The high rainfall occurred in 2015 might have leached much K from the soil. As it has been pointed out by [42], that K is susceptible to leaching under excessive rainfall, particularly on very sandy soils.

![Figure 4](image_url)  
**Figure 4.** Exchangeable K observed in the period between 2013 and 2016.

3.5. Exchangeable Al
In contrast to other soil chemical properties, seasonal cow manure application and crop rotation resulted in considerable reduction on exchangeable Al. Exchangeable Al declined drastically from 1.47 cmol·kg⁻¹ in 2013 to 0.1 cmol·kg⁻¹ in 2016 (Figure 5). This might have been related to the increase in humic substance released during the soil organic matter mineralization. Functional groups from humic substance bond Al forming an organo-metallic complex [43, 44], leading to the reduction of exchangeable Al. Previous studies also pointed out that soil amended with organic fertilizer exhibited lower exchangeable Al in soils [25, 45, 46]. Nevertheless, the remarkable decline in exchangeable Al from 2014 to 2015 remains unexplained as no specific identification of humic fraction was carried out in this study.

![Figure 5](image_url)  
**Figure 5.** Exchangeable Al observed in the period between 2013 and 2016.

3.6. Soil pH
Soil pH increased slightly in 2015 but tended to steady at the following years (Figure 6). The increase in soil pH is due to the reduction of exchangeable Al, as also pointed out by some researchers.
Figure 6. Soil pH observed in the period between 2013 and 2016.

Formation of Al-organic complex pronouncedly reduces Al hydrolysis in the soil solution, leading to the lower proton production and increases soil pH. Acid soil treated with organic acids i.e. citric, oxalic, and humic acids caused the decrease in the solubility of Al and increased soil pH [47, 48]. Even though, the increase in soil pH is associated with exchangeable Al, mainly at soil pH lower than 5.5, a number of factors also influence soil pH. The increase in soil pH in 2015 might have been associated with higher rainfall in the particular year. Dilution effect of higher soil moisture will raise soil pH [49].

4. Conclusion

Four year evaluation demonstrated that soil chemical properties in organic farming environment had been dynamic over the years. Application of cow manure at a rate of 15 ton·ha⁻¹ and crop rotation brought about a fluctuation of TSOC, TSN, exchangeable K and soil pH while available P steadily increased. Different trend was observed on exchangeable Al, declining sharply in 2015 and 2016. At the end of evaluation, soil chemical properties evaluated in this study had slight improvement but available P and exchangeable Al with substantial improvement when compared to that in 2009. This study suggests that the soil quality of organic soil could be preserved by regular application cow manure and crop rotation.

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