Impact of inorganic fertilizer to soil biological activity in an oil palm plantation

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Abstract. Oil palm can produce the highest quantity of vegetable oil per unit area. In order to reach this potential, as well as to maintain, and when necessary to improve the chemical fertility of soils, inorganic fertilizers are regularly applied in plantations. As it has been reported that the addition of inorganic fertilizers in agriculture, could negatively affect the biological characteristics of the soil, we have initiated a first research program to evaluate and confirm such possibility related to oil palm cultivation. This paper presents a study about the impact of inorganic fertilizer applications of soil biological activity in oil palm plantation located in the province of Riau in Sumatra, Indonesia. Observations have been conducted in a factorial NxPxK fertilizer trial, since 1995. For this study, our observations aimed to determine the short-term impact of these inorganic fertilizers, i.e. the impact during the following days after applications, as well as the long-term impact of similar fertilizers that have been applied repetitively, every six months since 1995. Bait lamina sticks were used to assess the biological soil activity (soil fauna feeding activity) from July to December 2017. Three types of fertilizer have been used for the study, Urea (as nitrogen source), Triple Super Phosphate (as phosphorus source) and Muriate of Potash (as potassium source) at various rates, and several combinations have been tested. The bait laminas were inserted in the palm circles, where fertilizers are commonly applied. The results show that in the short-term applications of inorganic fertilizers result in an increase of the soil fauna feeding activity: two days after urea applications, soil fauna feeding activity increased significantly compared the values before application. Phosphate and potassium fertilizer applications also increased the feeding activity, but this happened five days after the respective fertilizer applications. The intensity of the increase varied depending on the rate of applications. The long-term application of potassium fertilizer significantly increased the soil fauna feeding activity, while the application of phosphorus and nitrogen fertilizers did not show a significant increase.

1. Introduction

The use of inorganic fertilizers such as NPK fertilizers in oil palm plantation is a common standard practice [1]. About 50-70% of field operational costs are accounted for fertilizers [2]. The use of inorganic fertilizers as an agricultural intensification will create its own challenge, on the one hand, productivity will increase, but on the other hand, for example, the environment will face a serious threat. Some issues of soil degradation appeared in plantation such as reduction of ecosystem services, a decline in soil biological activity, and greenhouse gas emission, etc [3]. The conservation for soil quality in the plantation is a major because soil quality plays an essential role in ecosystem service [4]. In another hand, it is important to conserve the soil quality, because the soil is an investment for commercial plantation, for example, oil palm plantation [1].
The soil quality refers to the physical, chemical, and biological properties which provide the ecosystem function and give benefit to human [5]. Study about the impact of fertilizers application (long-term and short-term observation) in soil quality on chemical and physical aspect are largely explored [6], [7], [8]. However, to the best our knowledge, the information about the impact of inorganic fertilizers application to the soil biological activity focusing on soil fauna feeding activity using bait lamina method. This test was enabled to monitoring of biotic processes in the soil within a short period [9]. Feeding activity by soil fauna as one of the biological indicator of soil quality is sensitive to the changes of soil fertility and have a strong association with soil nutrient availability which affected by organic or inorganic fertilizers [7] The aim of this study is to determine the short-term impact of these inorganic fertilizers, i.e. the impact during the following days after applications, as well as the long-term impact of similar fertilizers that have been applied repetitively, every 6 months since 1995.

2. Materials and methods

2.1. Site description

The experiment was conducted on a mature oil palm plantation at Kandista estate, Siak, Riau, Indonesia. The study was carried out in July-December 2017 at mature (planted on 1993) oil palm plantation in Riau, Sumatera. This experiment was conducted in an experimental plot that previously used for NPK factorial trial that aimed to find the optimum rates and types of NPK fertilizers application to reach the optimum yield of oil palm. Fertilizer application started from January 1995 and continued until 2017. The fertilizers applied repetitively every six months in the circle for 22 years. The oil palm plantation’s age was 26 years old, with palm density 136 palms per hectare, planted in the equilateral triangular arrangement at a distance of 9 m.

2.2. Fertilizers application

The rate of NPK fertilizers application followed the table 1, and general fertilizer was applied at the same rate in all palms following table 2.

| Table 1. The rate of factorial NPK Fertilizer application (start from 1996 to 2017) |
|----------------------------------|----------------------------------|
| Fertilizers                     | Amount of fertilizer (kg/palm/year) |
| Urea (46 % N)                   | 0.375 | 1.75 | 3.125 |
| TSP (45 % P₂O₅)                 | 0.25  | 1.25 | 2.25  |
| MOP (60 % K₂O)                  | 0.5   | 2.5  | 4.5   |

| Table 2. The rate of General fertilizer application |
|---------------------------------|----------------------------------|
| Fertilizers                     | Dosage (kg/palm/year) |
| Kieserite (27 % MgO)            | 0.75 | 1.00 |
| HGFBorat                        | -    | 0.10 |

2.3. Bait lamina sampling

In this study, we used bait lamina method for assessing the soil fauna feeding activity in the impact of the long and short term of NPK fertilizer application in the soil. Bait lamina was first introduced by Törne in 1990 [9] to measure the soil biological activity. Bait lamina stick is a thin PVC strips (1 mm x 6 mm x 160 mm) with 16 apertures (1.5 mm diameter) bored at 3 mm intervals. The apertures were
filled with standard bait, containing cellulose powder, bran flakes and activated carbon (70:27:3). The test was based on visual assessment of feeding portion of laminated bait substrate exposed (empty holes indicate some biological activities in the soil).

The sampling took place from July to December 2017. Seven treatments were chosen to evaluate the impact of fertilizer application (treatments listed on table 3).

Table 3. The combination of NPK fertilizers

| No. | Treatments |
|-----|------------|
| 1   | NIP2K2     |
| 2   | N2P2K2     |
| 3   | N3P2K2     |
| 4   | N2P1K2     |
| 5   | N2P3K2     |
| 6   | N2P2K1     |
| 7   | N2P2K3     |

Three palms per treatment were chosen as replicate. Three groups of bait lamina each contain five baits were inserted in the circle of oil palm (see figure 1). The circle is an area which applied fertilizer. At each sampling time, a total of 315 sticks were inserted for six days of exposure (3 days before and harvested three days after time sequences).

The sticks were inserted until the top aperture was just bellow to the soil/EFB surface (±1mm). Each aperture was recorded as 0 (without perforation) and 1 (partial or complete perforation). To calculate the rate of feeding activity per bait, the number of holes (partial or complete hole) are counted then divided by 16 (the total number of holes per bait). Therefore the minimum score will be 0%, and the maximum will be 100%.

Figure 1. Scoring of bait lamina stick 0 (without perforation) and 1 (partial or complete perforation)

Additional observations such as the rainfall are recorded every time sequences during the period of the trial. Soil humidity data collected by use WET sensor, which rainfall is collected using automatic water station.

2.4. Observation

Long-term effect: Soil fauna feeding activity was observed after 22 years NPK fertilizers applied every six months since 1995.

Short-term effect: Soil fauna feeding activity was observed after NPK fertilizers application based on nine times sequence (table 4).

Table 4. Time sequences of observation

| No. | Days after fertilizer’s application |
|-----|------------------------------------|
| 1   | T0                                 |
| 2   | T2                                 |
| 3   | T5                                 |
| 4   | T10                                |
| 5   | T15                                |

Before
2 days
5 days
10 days
15 days
2.5. Statistical analysis
The average percentage of perforated holes of the 15 x 3 replicates bait lamina was used to represent the soil fauna feeding activity at each treatment. Repeated measure analysis was used to test the impact of fertilizer application on soil fauna feeding activity during 0-75 days. One way ANOVA was performed to test the difference in feeding activity between rates in each treatment. Significant differences in mean values were compared using the Turkey test. The Pearson correlation was used to see the correlation between soil fauna feeding activity and rainfall and other parameters that observed.

3. Results
The first trial was to study the long-term impact of NPK fertilizer to soil fauna feeding activity. Fertilizers have been applied since 22 years ago, regularly applied every semester (twice per year). The last fertilizer application was during March-June 2017. The long-term N fertilizers application in various rates (N1, N2, N3) gave an impact to soil fauna feeding activity. However, there was no statistically significant difference (P value: 0.769). The highest value showed by rate N1 (47%), and the lowest was showed by rate N2 (38%). The long-term application of P fertilizers in various rates (P1, P2, P3) tend to give a positive impact on soil fauna feeding activity. However, there was no statistically significant impact (P value: 0.245). The highest value showed by rate P2 (38%), and the lowest activity was by rate P1 (21%). The long-term K fertilizers application in various rates (K1, K2, K3) gave positive statistical significant impact to soil fauna feeding activity (P value: 0.021). The highest value of feeding activity showed by rate K3 (44%), and the lowest was by rate K1 (12%) (see figure 2).

![Figure 2](image-url)

**Figure 2.** The soil fauna feeding activity under Effect of various amount of N fertilizer (N1:N1P2K2, N2:N2P2K2, N3:N3P2K2), P fertilizer (P1:N2P1K2, P2:N2P2K2, P3:N2P3K2), and K fertilizer (K1:N2P2K1, K2:N2P2K2, K3:N2P2K3).

The short-term impact of NPK fertilizer was observed during the following days after fertilizer application based on time sequences (table 4). After 75 days of observation, the result showed that the application of N fertilizer has a statistically significant impact on soil fauna feeding activity (P value: 0.000). Two days after N fertilizer application, the soil fauna feeding activity on rates N1 and N3 increased significantly (P value: 0.012) compared to the soil feeding activity before fertilizers application (T0). Five days after N fertilizer application rates N2 and N3 remain stable. However, rate N1 has decreased. The feeding activity in all rates N fertilizers were decreased after ten days of application and increased gradually from 15 days until 60 days after application (see figure 3).
Figure 3. The soil fauna feeding activity under effect of various amount of N fertilizer (N1:N1P2K2, N2:N2P2K2, N3:N3P2K2) after 75 days of application.

The result showed that the application of P fertilizer has a statistically significant impact on soil fauna feeding activity (P value: 0.000). Five days after P fertilizer application, the feeding activity on rate P3 increased significantly compared to the soil fauna feeding activity on T0 (P value: 0.002), P1 also increased but not significant. The feeding activity in all rates P fertilizers were decreased after ten days of application and increased gradually from 15 days until 60 days after application. The feeding activity in all P rates were increased gradually; however, treatment P1 always showed the lowest feeding activity compared to the other P2 and P3 (see figure 4).

Figure 4. The soil fauna feeding activity under effect of various amount of P fertilizer (P1:N2P1K2, P2:N2P2K2, P3:N2P3K2) after 75 days of application.

The result showed that the application of K fertilizer application has a statistically significant impact on soil fauna feeding activity (P value: 0.005). Five days after K fertilizer application, the feeding activity on treatment K1 increased significantly compared to the feeding activity on T0 (P value: 0.007) while in rates K2 and K3 tend to decrease. The feeding activity in all rates K fertilizers were decreased after ten days of application and increased gradually from 15 days until 60 days after application. The feeding activity in all K rates was increased gradually, however rate K1 always showed the lowest feeding activity, and rate K3 always showed the highest between all K fertilizer rates. All treatments tend to decrease after 75 days of observation. However, the decreased was still not equal with the T0 (long-term effect) (figure 5). Rainfall during observation was varied between 0-73 mm per day. The highest cumulative rainfall during observation observed after ten days of fertilizer application (97.4 mm). Surprisingly the correlation between rainfall and soil fauna feeding activity showed no significant correlation.
Figure 5. The soil fauna feeding activity under Effect of various amount of K fertilizer (K1:N2P2K1, K2:N2P2K2, K3:N2P2K3) after 75 days of application.

4. Discussion
4.1. Long-term fertilization effect on soil fauna feeding activity
Result showed that treatment K fertilizer gave a significant impact on soil fauna feeding activity, however treatment N and P fertilizers did not show a significant impact, this result was related with observation made by reference [11] that found if the long-term PK and N fertilizers application had no statistically significant effect on soil biological indicator (bacterial biomass or fungal biomass). Feeding activity increased when N fertilizer rates were decreased, contrary to treatment K fertilizer which the value increased when the fertilizer rates were increased, while on treatment P fertilizer the highest feeding activity showed by the medium rate of P fertilizer. The possible reason may be the long-term NPK fertilization already could improve soil nutrient availability that can be used as a nutrient source by soil organism. Reference [12] found that NPK fertilization generally stimulated microbial and soil fauna growth, while [13] found that, the fertilizers application can increase the plant biomass production (above and below ground biomass) by providing an available nutrient for plant growth, the biomass may bring higher food sources or SOC for soil faunal populations and microbial activity through the decomposition process. Bait lamina observed in this trial has a significant correlation with soil humidity (p value: 0.000), average humidity recorded in this trial was 22.84%. Ideal humidity is the preferred habitat for soil fauna.

Figure 6. The correlation between soil humidity and soil fauna feeding activity after long-term application of inorganic fertilizer.
4.2. Short-term fertilization effect on soil fauna feeding activity
We found those two days after N fertilizer application; the feeding activity was increased significantly and then decreased until the minimum level on ten days after application, and then increased gradually until the end of observation. The NPK fertilizers application gave impact on soil fauna feeding activity. Treatment N fertilizer already showed a significantly different result on two days after fertilizer and then after two days until 75 days; there was no significant difference of feeding activity value. Treatment P fertilizer showed a significantly different result on five days after fertilizer application. Treatment P fertilizer showed a tendency started from five days until 75 days after application that the feeding activity value of rate P1 always showed the lowest value compared to P2 and P3 rates, and between P2 and P3 did not show a significant difference. This tendency also showed by treatment K, which K1 rate always showed the lowest value compared to K2 and K3. However, the significant different impact of K fertilizer application started after five days of fertilizer application. Ten days after fertilizer application the feeding activity was decreased, the possible reason may be the rainfall during the bait lamina installation was too high, the rainfall recorded on this period was about 113 mm. If the rainfall were too high, this situation would make soil pores saturated of water, thus limiting the movement of soil fauna and effected a low activity [14]. In this study, the long-term and short-term fertilizer application give impact to the soil fauna feeding activity. This might offer a chance for a scientist to find the effectiveness of inorganic fertilization rate that can give an optimal oil palm yield but still support the habitat of soil fauna (biological soil properties).

5. Conclusion
In our study, we found that after long-term inorganic fertilizers application there was no negative impact of the high rate of inorganic fertilizers application. Long-term K fertilizers gave a significant positive impact on soil fauna feeding activity. However, treatment N and P fertilizer did not show a statistically significant impact. The short-term applications of inorganic fertilizers increased the soil fauna feeding activity: two days after urea applications, soil fauna feeding activity increased significantly compared the values before application. Phosphate and potassium fertilizer applications also increased the feeding activity, but this happened five days after fertilizer applications.

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