Physical deterioration of soil and rice productivity in rural Java

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Abstract. Soil degradation is one of the world’s most serious ecological and environmental problems affected agricultural productions. The agricultural sector defines land degradation as a process of decreasing land productivity that is temporary or permanent, characterized by a decrease in physical, chemical, and biological properties. This study aims to investigate the impact physical deterioration of which occurs in the form of structure fertilizer application on rice productivity. This study applied Autoregressive model to analyse the primary data collected from 4 main rice producer areas in Central Java and East Java, namely Cilacap, Grobogan, Lamongan and Jember. The results show that previous chemical fertilizer use has negative impacts on rice productivity. Inorganic chemical fertilizers have an important role in increasing productivity, but at the same time the uncontrolled use of it is one of the causes of the decline in the quality of biological, physical, and chemical fertility of the soil.

Key words: soil degradation, rice productivity, autoregressive, chemical fertilizers

1. Introduction

Rice is the staple food of most Indonesian people. Therefore, rice production has a very important role to meet the rice demand. Indonesian Government attempts to increase rice production in Indonesia by setting the supporting policies, including through increasing rice productivity. Rice Production must be adapted to ecological conditions and economic needs [1], however, Indonesian rice sector still faces the soil degradation due to some factors such as deforestation, policy direction, erosion, climate change and uncontrolled use of inorganic chemical fertilizer [2], [3]. In addition, most of the rice farming in Indonesia, are small scale, less efficient, and have low productivity, resulting in low income in the agricultural sector. Farmers have lack of knowledge and skills how to balance the land ecosystem to maintain nutrition and soil fertility quality.

Soil degradation is a serious problem for the ecology, environment and agricultural production [4], [5]. The agricultural sector defines land degradation as a process of decreasing land productivity that is temporary or permanent, characterized by a decrease in physical, chemical, and biological properties [6]. Physical deterioration occurs in the form of compaction, movement or displacement, water imbalance, obstruction of drainage, and damage to the application of soil structure fertilization which significantly reduces soil fertility, quality and productivity [7]–[9].

The uncontrolled use of synthetic chemical fertilizers is further aggravated by intensive agricultural activities, it has been estimated that about 70% agricultural input is lost due to the intensive
agriculture, and only remaining 30% being brought into production [10], while the return of nutrients to agricultural land is only in the form of chemical fertilizers such as Urea, TSP, and KCl which only contain elements N, P, and K. Inorganic chemical fertilizers have an important role in increasing productivity, providing a large amount of macro essential nutrient supply for plants and improving crop yield in the short-term, but having environmental effects [11]–[13]. Large amounts of external N inputs with decreasing N use efficiency have contributed to severe environmental degradation since the 1990s [14]. Furthermore diffuse nitrogen (N) and phosphorus (P) pollutions are identified as the main drivers of eutrophication aggravation [15]. This situation occurs in many agricultural field, especially in Java. Therefore, this study aimed to examine the impact physical deterioration of which occurs in the form of structure fertilizer application on rice productivity.

2. Research methods

This study was conducted in Central Java and East Java Provinces, which are well known as the biggest rice producer in Indonesia. From those provinces, 4 districts were selected as study areas, namely Cilacap, Grobogan, Lamongan and Jember districts. Those districts are the largest producer of rice in Central Java and East Java until present. Then, 325 plots of paddy field selected through random sampling method. We recalled the data in 2 season of planting, season 1 and season 2 in 2018. This study applied autoregressive model to estimate the effect of inorganic chemical fertilizer use on rice productivity in term of season in the study areas. In this regression model as depicted in the equation (1), the response variable in the previous time has become the predictor and the errors have our usual assumptions about errors in a simple linear regression model [16].

\[ P_t = C + \beta_1 P_{t-1} + \beta_2 S_t + \beta_3 S_{t-1} + \beta_4 U_t + \beta_5 U_{t-1} + \beta_6 N_t + \beta_7 N_{t-1} + \beta_8 Z_t + \beta_9 Z_{t-1} + \beta_{10} Or_{gt} + \beta_{11} Or_{gt-1} + \beta_{12} Pe_{st} + \beta_{13} Pe_{st-1} + \varepsilon_t \]  

Here,

- \( P_t \) = Productivity of rice at \( t \) (kg/m²)
- \( P_{t-1} \) = Productivity of rice at \( t-1 \) (kg/m²)
- \( S_t \) = Quantity of seed at \( t \) (kg)
- \( S_{t-1} \) = Quantity of seed at \( t-1 \) (kg)
- \( U_t \) = Quantity of urea fertilizer at \( t \) (kg)
- \( U_{t-1} \) = Quantity of urea fertilizer at \( t-1 \) (kg)
- \( N_t \) = Quantity of NPK fertilizer at \( t \) (kg)
- \( N_{t-1} \) = Quantity of NPK fertilizer at \( t-1 \) (kg)
- \( Z_t \) = Quantity of ZA fertilizer at \( t \) (kg)
- \( Z_{t-1} \) = Quantity of ZA fertilizer at \( t-1 \) (kg)
- \( Or_{gt} \) = Quantity of Organic fertilizer at \( t \) (ml)
- \( Or_{gt-1} \) = Quantity of Organic fertilizer at \( t-1 \) (ml)
- \( P_{est} \) = Quantity of pesticide at \( t \) (ml)
- \( P_{est-1} \) = Quantity of pesticide at \( t-1 \) (ml)
- \( \varepsilon_t \) = Random disturbance
- \( t \) = Season
- \( t-1 \) = Previous season
- \( C \) = Constant
- \( \beta_{1-13} \) = Estimated regression coefficient

3. Result

As a center of rice production, the districts of Cilacap, Grobogan, Lamongan and Jember always try to increase their rice production, including by increasing the factors of rice production. However, the results of the study showed that rice productivity in 4 main rice producing district of Central Java and East Java provinces actually experienced a decline in the second season (see Figure 1).
Rice farmers in the study areas used inorganic chemical fertilizer such as Urea, TSP, NPK, Phonska and ZA fertilizers (Figure 2). In season 2, farmers slightly reduced the use of Urea, Phonska and ZA fertilizers, but the use of TSP and NPK fertilizers was the same as for season 1. The average use of chemical fertilizers in Lamongan was the highest compared to other districts. Some farmers also used manure and organic fertilizer (Figure 3). However, very few farmers use organic fertilizer and manure. The farmer respondents in East Java did not use manure for their rice cultivation. The quantity of organic fertilizer and manure used in season 1 and 2 was the same. Farmers in East Java did not apply manure for their rice farming. Urea, NPK and ZA fertilizer are the most widely used by farmers to give nutrient to the paddy plant. In addition, most farmers also use chemical pesticides to eradicate and prevent pests and plant hopper attacks (Figure 4). The use of pesticides in Cilacap and Jember in seasons 1 and 2, the quantity was the same. However, in Grobogan district, the use of pesticides in season 2 was greater than that in season 1, while farmers in Lamongan preferred to reduce the use of pesticides in season 2. This situation shows that respondent farmers still depend a lot on inorganic chemical fertilizers and pesticides, resulted physical deterioration of soil. The use of seeds in both seasons at the study area was the same amount, except in Lamongan where farmers reduced the quantity of seeds in the second season (Figure 6). The use of seeds could affect rice production [17]. However, the results in this study showed that with the same quantity of seeds, rice productivity at the study area declined.
Table 1 illustrates that the estimation results show different results for each district. The estimation models omit some variables due to collinearity problem. In general, previous productivity, urea fertilizer, and organic fertilizer influence rice productivity in all districts. The previous season of rice productivity has positive influence on the current rice productivity in the study area at 1% significance level. The result indicates that a rice farming that has higher, productivity in the previous season can result rice farming more productively in the following season. Urea fertilizer at current season also has positive influence to the current rice productivity, but urea fertilizer use in the previous season has negative influence. These findings indicate that the higher quantity of urea fertilizer use will imply the decline of rice productivity in the next season. This is in accordance with Khanif [18] and Hartati et al [13]. The use of organic fertilizer in the previous season has positive effect to the current rice productivity in all districts. This means the use of organic fertilizer will improve rice productivity in the next season. This finding is linier with the previous studies [19][20]. NPK fertilizer use in the previous season is negatively significant to the rice productivity in all districts, except Jember. It might be due to the rice farmer in Jember applied mixing organic and inorganic fertilizer more appropriate than other districts. The quantity of organic use in Jember is the largest. ZA fertilizer at current season is positively significant at productivity only in Lamongan, but it is not significant for previous season. Pesticide use in the current season has positive effect to the rice productivity, but the use of it in the previous season has negative impact to the production only happens in Lamongan. This is due to the quantity of pesticide in Lamongan is the largest.

Table 1. Estimation Result of Rice Productivity in Study Area

| Variable                  | Cilacap          | Grobogan       | Lamongan     | Jember          |
|---------------------------|------------------|----------------|--------------|-----------------|
| Productivity, 1           | 0.74956*** (0.0549) | 0.60381*** (0.0642) | 0.51826*** (0.1142) | 0.77527*** (0.0612) |
| Seed, 1                   | (omitted)        | (omitted)      | (omitted)    | (omitted)       |
| Seed, 1                   | 0.00139 (0.0016)  | -0.00389 (0.0045)  | 0.00213 (0.0037)  | -0.00111** (0.0005) |
| Urea, 1                   | 0.00166*** (0.0005) | 0.00069** (0.0001)  | 0.00409** (0.0016)  | 0.00111** (0.0005) |
| Urea, 1                   | -0.00167*** (0.0008) | -0.00091** (0.0003)  | -0.00060* (0.0003)  | -0.00093* (0.0005) |
| NPK, 1                    | -0.003312** (0.0017) | -0.002942 (0.0028)  | -0.000242 (0.0028)  | 0.000388 (0.0010) |
| NPK, 1                    | -0.000185** (0.0011) | -0.000034* (0.0001)  | -0.000169* (0.0009)  | -0.00059 (0.0012) |
| ZA, 1                     | (omitted)        | (omitted)      | (omitted)    | (omitted)       |
| ZA, 1                     | 0.00011 (0.0009)  | 0.00147 (0.0018)   | -0.00058 (0.0008)  | (omitted)       |
| Organic, 1                | (omitted)        | (omitted)      | (omitted)    | (omitted)       |
| Organic, 1                | 0.00011* (0.0009) | 0.00009** (0.0004)  | 0.00035* (0.0039)  | (omitted)       |
| Pesticide, 1              | -0.00022 (0.0003) | -0.00011 (0.0014)  | 0.00033** (0.0002)  | 0.00022 (0.0004) |
| Pesticide, 1              | 0.00024 (0.0003)  | 0.000007 (0.0014)  | -0.00018* (0.0001)  | -0.00019 (0.0003) |
| Constant                  | 0.03853* (0.0085) | 0.07402* (0.0177)  | -0.24240** (0.0977) | 0.20728* (0.0052) |
| F-stat                    | 27.14***         | 12.83***        | 10.18***     | 51.72***        |
| R-squared                 | 0.7903           | 0.5789          | 0.7140       | 0.8808          |
| Number of observations    | 83               | 94             | 67           | 81              |

Note: *Significant at 10% level; **Significant at 5% level; ***Significant at 1% level; standard error in parentheses.
From the estimated parameter of constant, the rice productivity in Lamongan is the worst. The quantity of seed, inorganic chemical fertilizer and pesticide in Lamongan is the largest. These findings indicate that the higher quantity of seed, urea and NPK fertilizer and pesticide use will imply the decline of rice productivity in the next season. The use of inorganic chemical fertilizers and chemical pesticides will decrease plant productivity [13][18]. The high content of synthetic chemicals stored in the soil will be toxic to plant roots and cause the physical deterioration so that soil fertility continues to decline. As a result, agricultural productivity will be lower than before. Furthermore, intensive paddy field monoculture system in long term application also decline soil fertility [21] This is the reason why the rice productivity in the second season in the study areas was lower than that in the first season. On the other hand, application of organic fertilizer may increase the rice productivity because organic fertilizer improves physical and biological activities of soil [19][20]. Also organic fertilizer has higher organic matter content, it can enhance soil physical properties mainly by improving aggregate stability and decreasing soil bulk density [22]. Organic fertilizer is more eco-friendly and effective way to increase N, P and other nutrients availability for plant than inorganic fertilizer [23][24][25][26]. In addition, in long term application of inorganic chemical fertilizer can cause physical deterioration, decrease important micronutrient, and certainly reduce crop productivity [22][26].

4. Conclusion
The uncontrolled application of inorganic chemical fertilizer can cause physical deterioration of soil which is one of the world’s most serious ecological and environmental problems affected agricultural productions. The results show that previous chemical fertilizer use has negative impacts on rice productivity. The productivity in Lamongan is the lowest compared to other districts, because the use of inorganic chemical fertilizers and pesticides is the highest. Inorganic chemical fertilizers have an important role in increasing productivity, but at the same time causes of the decline in the quality of biological, physical, and chemical fertility of the soil.

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