Enhancing soil chemical properties at plantation riparian buffer zone using leguminous cover crops: A review

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Abstract. The construction of a reserved area known as riparian buffer zone (RBZ) in oil palm plantation is one of the conservation measures that helps to protect the nearest water sources from negative impact of adjacent land uses. Most of the plantation planted different types of leguminous cover crops (LCCs) at the RBZ area, considering the benefits and economical planting cost. However, little is known on the changes of soil properties sited in the RBZ which has been planted with different LCCs. As such, this paper intends to review the enhancement of soil chemical properties, specifically the soil pH, soil macronutrients and soil micronutrients at RBZ planted with different LCCs. The review encompasses the most common LCCs planted which are limited to Mucuna bracteate, Pueraria phaseoloides, Clitoria ternate, Calopogonium mucunoides and Centrosema pubescens. The effects of these LCCs on abovementioned soil properties were discussed and the issues on fertilizer run-off as well as the impact on the soil chemical properties at RBZ is critically reviewed. Findings showed that the planting of LCCs demonstrate a positive uptake of the run-off nutrients from adjacent land use, reflected by the amount of nutrients fixed by the LCCs as well as nutrients left in the soil. The findings also reveal that there is evidence on the enhancement of soil fertility in RBZ, due to the decomposition process followed by nutrient recycling of LCCs residues. This review suggested that the planting of LCCs in RBZ can enhance the soil chemical properties, reducing the fertilizer run-off through efficient nutrient uptake and act as the buffer zone to conserve the nearest water sources, leading to the sustainable environment in oil palm plantation.

Keywords: soil, riparian buffer zone, leguminous cover crops, sustainable

1. Introduction
Riparian buffer zone (RBZ) can be described as a vegetative strip of land that extends along the waterways with a unique transition area between terrestrial and aquatic environment ecosystems [1]. The waterways that are adjacent to RBZ are streams, rivers, lakes, and other waterways [2], [3]. The construction of RBZ is purposely to protect the aquatic ecosystem in nearest waterways as well as the soil against pollution and soil sedimentation due to surface runoff and landscape pollutants [2]. This RBZ will act as a filter for the run-off sediments and be able to control the erosion especially near the waterways [4]. Additionally, riparian buffer zones can control and protect watercourse from any inputs of any sediments, nutrients, and other contaminants by interrupting the surface runoff and groundwater from adjoining landscape [5]. Previous study found that riparian buffer zones can
control agricultural non-point sources of pollution due to fertilizer runoff and leaching [6]. In oil palm plantation, the fertilizer purposely applied to provide the palm with essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K). However, the over-application of fertilizer accompanied by the improper fertilizer schedule had resulted in negative effects to the plant and environment, specifically due to the accumulation of fertilizer in the soil. This has resulted in plant toxicity and environmental pollution, where the latter is commonly resulted from fertilizer runoff and leaching. As a result, the process led to the modification in soil chemical properties, specifically the soil-pH, soil-macro and micronutrients, soil-cation exchange capacity (CEC) as well as the soil physical and microbiological properties. In previous study, the findings showed that the long-term application of inorganic fertilizer had resulted in excessive enrichment of nutrients in soil [8] and to prevent this excess fertilizer being feed into waterways, the government agencies have been promoting riparian buffer zone as one of the means to minimize the pollutants and excess fertilizer from surface runoff [9]. The mean was succeeded by planting the selected riparian vegetation such as riparian forest and grasses [10] as well as cover crops [11] along the RBZ which suggested to help in filtering the polluted matters away from the water edge [12]. This paper intends to review the enhancement of soil chemical properties specifically the soil pH, soil macronutrients and soil micronutrients at RBZ planted with different LCCs, which limited to *Mucuna bracteate*, *Pueraria phaseoloides*, *Clitoria ternate*, *Calopogonium mucunoides* and *Centrosema pubescens*. The effects of these LCCs on abovementioned soil properties were discussed and the issues on fertilizer run-off as well as the impact on the soil chemical properties at RBZ is critically reviewed. The selection of article paper for this review was made using Scopus online database and Google Scholar.

2. **Riparian Buffer Zone (RBZ)**

Most of the agricultural area often has its own riparian buffer zone (RBZ) to reduce the undesirable effects of chemical-based activities conducted in the field. Previously, most of the agricultural fields created an RBZ using woody vegetation, which was planted surrounding the fields located near the waterways [1]. Recently, the planting of leguminous cover crops (LCCs) has become an extensive option in RBZ especially for oil palm plantation [13] due to their vigorous growth and additional benefits to the soil fertility. Cover crops can be defined as the crops that are used to cover the ground surface and protect soil from erosion and avoid loss of nutrients in deep layers by leaching and surface runoff [14]. The LCCs that are commonly used in plantation are *Mucuna bracteate*, *Pueraria phaseoloides*, *Centrosema pubescens*, *Calopogonium mucunoides*, *Clitoria ternate*, and *Calopogonium caerulum* [15]–[17], as shown in Figure 1.

![Common leguminous cover crops (LCCs) in oil palm plantation](image)

Figure 1: Common leguminous cover crops (LCCs) in oil palm plantation
By having different LCCs planted at riparian buffer zones, many benefits were obtained especially in conserving the soil. For example, the coverage of these legumes is able to protect the soil from the impact of raindrops, reduce runoff, wind, and water erosion [18]. Additionally, the nitrate leaching can be reduced [19] and the run-off of soil sediments will be reduced as the soil needs to pass through the LCCs rooting systems. Furthermore, the amount of dissolved nutrients benefited the plants before entering the water sources [20]. This course of action of conservation buffer zone indirectly improved the soil quality and reduced water pollution [21].

3. Fertilizer Run-Off from Adjacent Land Use

Fertilizer run-off phenomena from plantation has influenced soil chemical properties especially at RBZ. In the plantation, surface runoff may occur due to the rainfall, which swept the soil sediments and other contaminants. The fertilizer that commonly used in plantation such as urea, triple superphosphate, rock phosphate, ammonium sulphate and other [22], [23] able to affect the soil properties and water quality upon excessive application and may lead to major problem during oil palm plantation operation especially in deciding the effective fertilizer regime [24]. Additionally, the N-contamination has been reported due to excessive application of N-fertilizer [7]. In the soil, NO$_3^-$ which is negatively charged, was not attracted to negatively charged soil colloids. Therefore, it travels deeper into the soil and easily enters the groundwater following the gravitational-water movement [7]. It is estimated that approximately 81% of N-removal takes place in RBZ, depending on soil types and riparian vegetation [25]. It is previously reported that the buffer zone at Lakeside China has an average rate of total N- and P-removal of approximately 70% and 98%, respectively [26]. In addition, P in soil is highly immobile and binds tightly to soil particles, but due to surface runoff some amount may pass through the RBZ [7]. Other than that, fertilizer application has affected the soil pH by increasing the soil acidity [27], which is renowned whenever the chemical fertilizers were extensively applied.

4. Discussion

4.1 Effects of Leguminous Cover Crops (LCCs) on Soil Macronutrients and Soil pH

4.1.1 Nitrogen (N)

Nitrogen availability in the soil was affected by LCCs planted at riparian buffer zones. This is because of the ability of these LCCs to absorb low available nutrients in deeper soil profile and increased concentration of nutrients on the surface layer [11]. This statement was agreed by previous studies that cover crops have increased the N availability in the soil because cover crops can fix atmospheric N in the soil [28], [29] and retain excess N in soil [30]. These LCCs absorb the nutrients by exploring the nutrient pool in subsoil and take any available nutrient by using its extensive root system [11]. This act is able to reduce the impact of leaching and runoff of nutrients from adjacent plantations into water sources. According to the previous study, cover crops may reduce mass of N leached and NO$_3^-$ concentration by 20% to 80% compared with soil without cover crops [11]. This can be associated with the ability of cover crops to fix N$_2$ using their roots and prohibit nitrate leaching in groundwater and block downward movements to soil profile [14]. N being uptake by *Mucuna bracteata* were higher [31] compared to others, as studied by [32]. The data in Table 1 reveals the amount of N being fixed by different LCCs. Based on the findings, *Mucuna bracteata* is able to fix more atmospheric N compared to the *Pueraria phaseoloides*, *Clitoria ternate*, *Calopogonium mucunoides* and *Centrosema pubescens* [33]. This is probably due to the capability of *Mucuna bracteata* in fixing much N$_2$ whenever the percentage of ground cover is increased [34] and changing the fixed-N into the form that is available to plants [33].
Most of the time, the efficiency of LCCs to fix \( \text{N}_2 \) is usually affected by several factors such as soil pH, moisture content and soil temperature [11].

| Leguminous Cover Crops (LCCs) | \( \text{N}_2 \) Fixed by LCCs | References |
|-------------------------------|-------------------------------|------------|
| \textit{Pueraria phaseoloides} | 100 – 140 kg ha\(^{-1}\) crop\(^{-1}\) | [35]/[11]  |
|                               | 109.5(112) kg ha\(^{-1}\)      | [36]       |
|                               | 2.27 a %                       | [28]       |
|                               | 32 -130 ± 39 kg N ha\(^{-1}\)  | [13]       |
|                               | 58.1 kg N ha\(^{-1}\) year\(^{-1}\) | [33] |
| \textit{Clitoria ternatea}    | 1.76 x 10\(^7\) cfu/g         | [16]       |
| \textit{Mucuna bracteata}     | 69.7 kg N ha\(^{-1}\) year\(^{-1}\) | [33] |

4.1.2 Phosphorus (P)

Much of the P was found to be effectively being uptake by LCCs at riparian buffer zones to enhance their functions. The findings showed that dissolved P and total P loss were highly reduced with the use of cover crops [37]. For example, the planting of \textit{Pueraria phaseoloides} able to uptake approximately 4.3-6.0 kg ha\(^{-1}\) of P [36]. This finding is supported by the data obtained by [38], where they found that P uptake by \textit{Pueraria phaseoloides} was about 10 kg ha\(^{-1}\) year. The findings on P-uptake by \textit{Mucuna bracteata} reveals that the naturally grown \textit{Mucuna bracteata} took less P (6.81 mg/kg) compared to those purposely planted (10.92 mg/kg) [31]. In another study, the finding showed the potential of \textit{Mucuna bracteata} as soil conservation treatment as it can take much of P which loss via sediment run-off [39].

4.1.3 Potassium (K)

All the specified LCCs planted at riparian buffer zones in plantation areas capable of absorbing K in the soil sediment due to the fertilizer runoff from agricultural lands [28]. The findings in a study showed that much of K\(_2\)O was removed from the soil via plant uptake under different cover crops, ranging between 56 to 74 kg ha\(^{-1}\) [40]. The deep-rooted LCC such as \textit{Mucuna bracteata} allows the uptake of K+, adsorbed to soil colloid, in deeper soil profile [31]. The planting of \textit{Pueraria phaseoloides} on the other hand, is capable of increasing the amount of K (10.2 mg g\(^{-1}\)) compared to the area without legumes [13].

4.1.4 Soil pH

Various results have been reported on the relationship between LCCs and soil pH. The planting of \textit{Mucuna bracteata} was reported to be able to reduce the soil pH, compared to the fields without cover crops being planted [41]. In other findings, it was contrarily found that the soil pH is highly influenced by types of soil as well as the present soil conditions [42]. Other findings stated that the planting of \textit{Mucuna bracteata} in coconut plantation can improve the soil pH, near to neutral. As such, it is suggested that the planting of LCCs may affect the soil pH in RBZ, depending on types of nutrients available in the soil [34] as well as the soil types of the area [43]. This is reflected by the fundamental concept of soil pH, where the factors involve the parent materials of the soil, the climate, topography, and soil formation process.
5. Conclusion

Different LCCs demonstrate a positive uptake of nutrients from the soil and are able to reduce the leaching of nutrient substances into the water sources. Much of the findings reveals that the application of these LCCs as a crop planted in RBZ are able to enhance the soil fertility especially in N-fixation, conserve the water quality of nearest water sources and be able to recycle the nutrients back into soil through decomposition process of the residues. This review suggested that the planting of LCCs in RBZ can enhance the soil chemical properties, reducing the fertilizer run-off through efficient nutrient uptake and act as the buffer zone to conserve the nearest water sources, leading to the sustainable environment in oil palm plantation.

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