Universal Journal of Agricultural Research 12(1): 188-194, 2024 http://www.hrpub.org
DOI: 10.13189/ujar.2024.120118

Improvement of Soil Chemical Properties in Mature Oil Palm Plantations by Pruning and Immersing of Weeds as Cover Crops

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Received November 13, 2023; Revised January 2, 2024; Accepted February 17, 2024

Cite This Paper in the Following Citation Styles

(a): *[1] Asbur Y, PurwaningrumY , "Improvement of Soil Chemical Properties in Mature Oil Palm Plantations by Pruning and Immersing of Weeds as Cover Crops," Universal Journal of Agricultural Research, Vol. 12, No. 1, pp. 188 - 194, 2024. DOI: 10.13189/ujar.2024.120118.*

(b): *Asbur Y, Purwaningrum Y (2024). Improvement of Soil Chemical Properties in Mature Oil Palm Plantations by Pruning and Immersing of Weeds as Cover Crops. Universal Journal of Agricultural Research, 12(1), 188 - 194. DOI: 10.13189/ujar.2024.120118.*

Abstract The use of *Asystasia gangetica* weed as a cover crop in oil palm plantations can produce changes in soil's chemical properties, which allows for the sustainable development of oil palm plantations. The aim of this research is to evaluate how pruning and immersing *A. gangetica* as a cover crop (CC) can improve soil chemical properties in mature oil palm plantations. The experimental design used was a non-factorial randomized block design with four replications. The treatment was structured in five levels of pruning and immersing of the *A. gangetica* cover crop. Planting *A. gangetica* without pruning and immersing only increases the total P content of the soil. However, pruning and immersing CC *A. gangetica* was able to reduce pH and increase organic C, total P and available K content of the soil. Pruning CC *A. gangetica* at 60 days after planting (DAP) and immersed increased pH, organic C, total P, and soil available K. These results indicate that pruning *A. gangetica* at 60 HST and then immersed can improve the chemical properties of the soil in mature oil palm plantations.

Keywords *Asystasia gangetica*, Increasing, Organic C, Planting

1. Introduction

Indonesia is the largest producer of palm oil (*Elaeis guineensis* Jacq.) in the world with Crude Palm Oil (CPO) production of 45.1 million tones and North Sumatra is the fourth largest CPO producing province in Indonesia, with an average yield of 4.21 tones/ha and a yield of 5.3 tons in 2021 [1]. In North Sumatra, especially Naga Rejo Village, Deli Serdang Regency, oil palm plantations only use cover crops when the oil palm plants are immature, but after the plants mature cover crops are not used, resulting in a decrease in physical, chemical and biological properties of the soil [2], increased loss of water and nutrients due to erosion [3,4] and decreased activity of soil microorganisms [2]. This happens because oil palm farmers in smallholder oil palm plantations in Naga Rejo Village did not comply with the guidelines outlined in the Indonesian Sustainable Palm Oil (ISPO), such as the use of cover crops in mature oil palm plantations. When oil palms are mature, cover crops such as *Mucuna bracteata*, which are usually planted in immature oil palm plantations, will die naturally because they cannot tolerate shade. In this situation, the vegetation under mature oil palm stands will naturally be replaced by various types of weeds [5] which can be used as cover crops, including the broad-leaved perennial weed *Asystasia gangetica* (L.) T. Anderson. According to many research findings, using weeds as a cover crop can increase soil fertility [6,7], control weeds [8], encourage nutrient cycles [9,2], increase total organic carbon and total nitrogen, and prevent soil erosion [8].

The use of cover crops has been recognized as one of the activities in realizing sustainable oil palm plantations because it can reduce CO_2 emissions [10], restore the physical properties of the soil [8], maintain soil moisture and increase the soil's ability to grow. They absorb water [7], and increase the content of organic C, total N and soil organic matter [6]. Soil organic matter (organic N) is a source of energy for soil microorganism populations and increases soil N content through mineralization of cover crop biomass [11]. Cover crops absorb nutrients such as N, P, and K from deep soil layers and then store them in their shoots. By pruning and immersing the shoots, the absorbed nutrients will be deposited on the soil surface where the pruning will decompose and release the nutrients through mineralization, making them available in the top layer of soil, where most of the oil palm roots develop [12].

Although the use of cover crops is a common practice in oil palm plantations, its use is still limited to when the oil palm is not yet mature, whereas once the oil palm is mature, cover crops are not used. There are several studies that have studied the use of *A. gangetica* weed as a cover crop in mature oil palm plantations, but have not yet carried out pruning and burying the cuttings to improve soil chemical properties. Although Saha et al., [13] found that buried cover crop cuttings can be a source of nitrous oxide, the benefits of using cover crops on agricultural land are greater because they can provide the most profitable on-farm and off-farm ecosystem services. To maximize these ecosystem services and ensure economic benefits, because generally in oil palm plantations, weeds are controlled mechanically and chemically using herbicides, selecting and managing appropriate cover crops is very important and can be location specific, so this research aims to evaluate how pruning and planting *A. gangetica* as a cover crop can improve the chemical properties of the soil in mature oil palm plantations.

2. Materials and Methods

2.1. Description of Research Location

The field experiment was carried out in the people's oil palm plantation of Naga Rejo Village, Galang, Deli Serdang, North Sumatra, Indonesia (3º29'22” N-98º52'02” E). The oil palm plantation used is 15 years old. Naga Rejo Village is one of the centers of smallholder oil palm plantations in Deli Serdang. The soil type is red-yellow podzolic, annual rainfall is 1883 mm and the average annual temperature is 30.35 ℃.

2.2. Research Methods

This research was designed using a non-factorial Randomized Block Design with 4 replications. The treatment given was the planting of the weed *A. gangetica* as a cover crop which was treated with pruning and immersion, namely without pruning and without immersing (P0), pruned at 30 days after planting (DAP) and without immersed (P1), pruned at 30 DAP and immersed (P2), pruned at 60 DAP and not immersed (P3), and pruned at 60 DAP and immersed (P4).

A. gangetica planted as a cover crop comes from saplings around oil palm plantations with the same size and number of leaves and is planted with a spacing of 20 cm x 20 cm. The fertilizer given is urea 150 kg/ha, SP-36 150 kg/ha, and KCl 50 kg/ha. Fertilizer is given at planting time by spreading. Specifically, urea fertilizer is given twice, namely ½ dose at planting time and ½ dose again when the plants are 2 weeks after planting (WAP).

2.3. Soil Sampling, Measurement and Analysis

Soil analysis before treatment was carried out by taking soil samples at a depth of 0-10 cm, then the soil samples were analyzed for pH H_2O, organic C (Walkley & Black Method), total N (Kjeldhal Method), available P (Bray Method with a spectrophotometer), total P (25% HCl extract with a spectrophotometer), available K (Bray method with a flamephotometer), and total K (25% HCl extract with a flamephotometer).

Soil analysis after treatment by taking soil samples with cover crops which are divided into non-rhizosphere soil sampling and rhizosphere soil sampling. Non-rhizosphere soil is the portion of soil without roots and soil attached to roots, while rhizosphere soil is the portion of soil that is directly influenced by plant roots. Non-rhizosphere soil sampling is the same as soil sampling without cover crops, while rhizosphere soil sampling is carried out by first determining the plants to be dug and the soil surface under the plant canopy being cleared of leaves or litter. The soil under the crown around the roots is gently dug up with a soil spoon or spatula, then the roots are separated from large chunks of soil and allowed as much soil as possible to adhere to the roots. Next, the crown of the plant near the base of the roots is cut, then the roots and the soil attached to them are put in plastic, tied with rubber and labeled and then taken to the soil laboratory of the Medan Agricultural Technology Assessment Center to analyze the chemical properties of the soil.

The soil chemical properties analyzed were pH H2O, organic C (Walkley & Black method), total N (Kjeldhal method), available P (Bray method with a spectrophotometer), total P (25% HCl extract with a spectrophotometer), available K (Bray method with a flamephotometer), and K-total (25% HCl Extract with a flamephotometer).

The effect of pruning and immersing the A. gangetica cover crop on the chemical properties of the soil in oil palm plantations was tested using ANOVA and further testing using the LSD test at the 5% level if the treatment given had a significant effect on the chemical properties of the soil.

3. Results and Discussion

Data on pH, organic C, total N, available P, total P, available K and total K before treatment are presented in Table 1.

The chemical properties of the soil before planting, pruning and immersing the *A. gangetica* cover crop (Table 1) appear to be homogeneous and classified as acidic (pH 4.5-5.5), with low organic C content (1.00%-2.00%), moderate total N (0.10%-0.20%), very high available P (>35 ppm), low total P (10-20 mg/100 g), medium available K (0.30-0.50 me/100 g), and high total K (41- 60 mg/100 g).

The chemical properties of the soil after planting, pruning and immersing the *A. gangetica* cover crop (Table 2) showed a significant effect on the chemical properties of the soil. This means that pruning and immersing the *A. gangetica* cover crop can improve soil chemical properties compared to without pruning and immersing the *A. gangetica* cover crop. Just like the research of De Notaris et al. [14] showed that the use of cover crops can improve soil chemical properties. Souza et al. [11] also reported that pruning and burying cover crops can improve soil chemical properties.

Pruning *A. gangetica* at 60 DAP and immersed (P4) was able to increase soil pH from 5.41 ± 0.04 to 5.45 ± 0.05, while other treatments caused a decrease in soil pH, namely from 5.40 ± 0.02 to 5.29 ± 0.02 in treatment P3 (*A. gangetica* was pruned 60 DAP not immersed), from 5.41 ± 0.03 to 5.27 ± 0.03 in treatment P2 (*A. gangetica* pruned 30 DAP and immersed), from 5.42 ± 0.02 to 5.13 ± 0.01 in treatment P1 (*A. gangetica* pruned 30 DAP not immersed), and from 5.42 ± 0.04 to 4.82 ± 0.01 in treatment P0 (A. *gangetica* not pruned not immersed). The same results were also reported by Souza et al. [11] found that the presence of cover crops was able to maintain soil pH stability at a depth of 0-10 cm. Likewise, the research results of Darma and Fahrunsyah [15] found that improving soil pH can be done by providing soil amendments derived from composted organic material.

Table 1. Chemical Properties of Soil (depth 0-10 cm) Before Treatment Without Pruned and Without Immersed/Control (P0), Pruned at 30 DAP and Without Immersed (P1), Pruned at 30 DAP and Immersed (P2), Pruned at The Age of 60 DAP and Without Immersed (P3), and Pruned at The Age of 60 DAP and Immersed (P4)

Treatments	P0	P1	P2	P3	P4
pH H_2O	5.42±0.04	5.42±0.02	5.41±0.03	5.40±0.02	5.41±0.04
C Organik (%)	1.93±0.04	1.93±0.01	1.93±0.03	1.94±0.03	1.93±0.03
N Total (%)	0.24±0.01	0.26±0.01	0.25±0.01	0.26±0.04	0.25±0.03
P Available (ppm)	51.08±0.02	51.05±0.01	51.07±0.05	51.07±0.04	51.06±0.03
P Total (mg/100 g)	17.60±0.10	17.60±0.17	17.60±0.20	17.70±0.10	17.70±0.17
K Available (me/100 g)	0.39±0.02	0.38±0.03	0.38±0.02	0.37±0.01	0.37±0.03
K Total (mg/100 g)	51.54±0.14	51.50±0.08	51.53±0.07	51.52±0.19	51.52±0.11

Table 2. Chemical Properties of Soil (depth 0-10 cm) After Treatment Without Pruned and Without Immersed/Control (P0), Pruned at 30 DAP and Without Immersed (P1), Pruned at 30 DAP and Immersed (P2), Pruned at The Age of 60 DAP and Without Immersed (P3), and Pruned at The Age of 60 DAP and Immersed (P4)

Treatments	P0	P1	P2	P3	P4
pH H_2O	4.82±0.01b	5.13±0.01a	5.27±0.03a	5.29±0.02a	5.45±0.05a
C Organik (%)	1.68±0.12c	2.06±0.05b	2.11±0.04a	1.60±0.05c	2.57±0.03a
N Total (%)	0.11±0.02c	0.23±0.01a	0.11±0.04c	0.19±0.01b	0.19±0.02b
P Available (ppm)	32.92±0.18b	27.50±0.15c	38.88±1.14ab	39.16±0.86ab	42.80±0.70a
P Total (mg/100 g)	96.90±0.20c	150.70±0.60a	96.00±2.00c	86.40±0.10d	103.78±0.02b
K Available (me/100 g)	0.24±0.02c	0.45±0.10a	0.28±0.02c	0.33±0.07b	0.49±0.03a
K Total (mg/100 g)	35.60±0.10c	46,00±0.70a	39.53±0.45b	43.90±0.62ab	48.10±0.72a

Note: Numbers on the same line followed by different notations are significantly different at the 5% level based on the LSD Test

Soil organic matter is an important indicator of soil quality and its increase leads to improvements in soil nutrient balance, cation exchange capacity, buffer capacity and crop productivity [16]. The results of this study showed that there was an increase in soil organic C content after planting, pruning and immersing the *A. gangetica* cover crop except that in the control (P0) and P3 treatments (*A. gangetica* pruned 60 DAP not immersed) there was a decrease in soil organic C content (Table 1, Table 2). Blanco-Canqui and Ruis [17] stated that cover crops are an effective way to improve sustainable agriculture and support ecosystem services such as soil carbon (C) absorption and nutrient retention, so that with *A. gangetica* cover crops, whether pruned and immersed or not can increase soil organic C content. Adetunji et al. [18] also found the same thing that planting cover crops can increase soil organic C content.

The decrease in soil organic C content after treatment in the P3 treatment (*A. gangetica* pruned at 60 DAP not immersed) was due to the analysis of soil chemical properties carried out at 90 DAP, so that *A. gangetica* litter from pruning at 60 DAP was still experiencing decomposition and needed carbon for the decomposition process which was taken from the soil, so that the carbon content in the soil decreases. Yahya et al. [2] found that the release of organic C from *A. gangetica* litter was greater after a 60-90 days decomposition period. According to Thapa et al. [19], in the early stages of decomposition, the use of decomposed carbon increases and decreases with the litter decomposition rate. Meanwhile, the decrease in soil organic C content after P0 treatment (*A. gangetica* was not pruned, not immersed) was thought to be because organic C was absorbed by plants for growth and development without any addition of soil organic matter through decomposition of pruning litter.

The total N content of the soil before treatment was classified as moderate (0.24%-0.26%) and decreased after treatment, namely to 0.11 ± 0.02% in treatment P0 (*A. gangetica* not pruned not immersed), 0.11 ± 0.04% in P2 (*A. gangetica* pruned 30 DAP and immersed), 0.23 ±0.01% in treatment P1 (*A. gangetica* pruned 30 DAP not immersed), 0.19 ± 0.01% in treatment P3 (*A. gangetica* pruned 60 DAP not immersed) and 0.19 ±0.02% in P4 (*A. gangetica* pruned at 60 DAP and immersed) (Table 2). The same results were also found in the research by Chinta et al. [20], Indriyati et al. [21]. According to Reed et al. [22], the decrease in soil N content was caused by an increase in the number and activity of soil microorganisms to decompose cover crop residues caused by higher N demand from decomposers consistent with an increase in decomposer respiration. Kaniszewski et al. [23] found that the N content in the top layer of soil (0–30 cm) decreased by an average of 46% at the end of intensive nutrient uptake research for plant development. Furthermore, the Natural Resources Conservation Service (USDA) [24] states that total N is the fraction of organic nitrogen that has the potential to be converted into forms available to plants (minerals) under conducive conditions of temperature, humidity, aeration, and time. During the 120 days incubation period, decomposition of organic matter occurs; Organic N compounds undergo an ammonification process and produce NH_4^+ ions, and this is followed by a nitrification process, namely changing NH_4^+ ions into nitrate ions (NO_3^-) by releasing protons (H^+). This resulted in a decrease in the total N content, and soil pH too (Table 1, Table 2).

There was a decrease in soil available P content after treatment, namely to 32.92 ±0.18 ppm, 27.50 ±0.15 ppm, 38.88 ±1.14 ppm, 39.16 ±0.86 ppm, and 42.80 ±0.70 ppm respectively in treatment P0 (*A. gangetica* was not pruned and not immersed), P1 (*A. gangetica* pruned 30 DAP not immersed), P2 (*A. gangetica* pruned 30 DAP and immersed), P3 (*A. gangetica* pruned 60 DAP not immersed), and P4 (*A. gangetica* pruned 60 DAP and immersed). This is due to the immobilization of P into a less available form of P, P is absorbed onto the surface of clay-sized minerals dominated by aluminum and iron oxide and is deposited [25]. Apart from that, it is also influenced by low soil pH, which affects the balance of adsorption/desorption of inorganic and organic forms with mineral surfaces [26,27,28].

Table 2 shows that although there was a decrease in soil available P content after treatment, with pruning and immersion of *A. gangetica* cover crops (P1, P2, P3, and P4) the decrease in soil available P was lower compared to without pruning and immersion of cover crop *A. gangetica* (P0). This is because the presence of organic material (*A. gangetica* pruning) can increase the available P content of the soil. The same results were reported by Indriyati et al. [21] that there was a decrease in soil available P with the addition of soil organic matter except for the addition of legumes. Kannan et al. [29] stated that the addition of organic matter can increase soil available P by 28%.

The total soil P content increased after planting, pruning and immersion treatments. According to Kannan et al. [29], although P is abundant in soil, its availability for plant growth is limited because most soil P exists in an unavailable form (total P). According to Rengel and Marschner [30], inorganic P generally occurs in insoluble mineral complexes in soil and this insoluble precipitate form cannot be absorbed by plants.

The highest total soil P content was in treatment P1 (*A. gangetica* pruned 30 DAP and not immersed), namely 150.70 ± 0.60 mg/100 g followed by treatment P4 (*A. gangetica* pruned 60 DAP and immersed), namely 103.78 ± 0.02 mg/ 100 g, P0 (*A. gangetica* not pruned and not immersed), namely 96.90 ± 0.20 mg/100 g, P2 (*A. gangetica* pruned 30 DAT and immersed), namely 96.00 ± 2.00 mg/100 g, and the lowest at P3 treatment (*A. gangetica* pruned at 60 DAP not immersed), namely 86.40 ± 0.10 mg/100 g. It is suspected that in the P3 treatment (*A. gangetica* was pruned at 60 DAT without being immersed) the organic matter was not decomposed so the activity of microorganisms in using the phosphatase enzyme increased resulting in decrease in the total P content of the soil [31,32].

The soil available K content after treatment was the highest and increased in treatments P4 (*A. gangetica* pruned at 60 DAP and immersed), and P1 (*A. gangetica* pruned at 30 DAP not immersed), namely 0.49 ± 0.03 me/100 g and 0.45 respectively. ±0.10 me/100 g, while the lowest and decreasing soil available K after treatment was found in treatment P0 (*A. gangetica* not pruned and not immersed), namely 0.24±0.02 me/100 g followed by treatment P2 (*A. gangetica* pruned 30 HST and embedded), and P3 (*A. gangetica* pruned 60 DAP not immersed), namely 0.28 ± 0.02 me/100 g and 0.33 ± 0.0 me/100 g, respectively.

A. gangetica pruning that is buried will decompose more quickly than those that are not buried, so that pruning can increase the K available in the soil. Predick et al. [33] reported that buried litter decomposes more quickly compared to litter on the ground because the influence of sunlight on reducing litter weight can be negated by the rate and level of mixing of litter with soil which can ultimately be determined by the extent of litter cover by soil [34].

Pruning and immersing the *A. gangetica* cover crop also had a significant effect on the total K content of the soil after treatment, but total K in the soil decreased after treatment (Table 2). The greatest decrease in total K was in treatment P0 (*A. gangetica* was not pruned and not immersed), namely from 51.54 ±0.14 mg/100 g to 35.60 ± 0.10 mg/100 g, while the lowest decrease in total K was in treatment P4 (*A. gangetica* was pruned 60 DAP and immersed), namely from 51.52 ±0.11 mg/100 g to 48.10 ± 0.72 mg/100 g. This is because without *A. gangetica* cover crop pruning, more K nutrients are lost or absorbed by the plant for growth [35]. Apart from that, the low pH (4.82 ± 0.01) in the P0 treatment (*A. gangetica* was not pruned and not immersed) caused the soil to become acidic. de Campos et al., [36] stated that the soil acidification process can result in Al poisoning and deficiencies in essential nutrients for plant growth, including K, Ca, and Mg.

4. Conclusions

This research was conducted to determine the effect of planting, pruning and immersing *A. gangetica* cover crops on soil chemical properties in mature oil palm plantations. The chemical properties of the soil before treatment showed acid soil pH (pH 4.5-5.5), low organic C content (1.00%-2.00%), medium total N (0.10%-0.20%), very high available P (>35 ppm), P low total (10-20 mg/100 g), moderate available K (0.30-0.50 me/100 g), and high total K (41-60 mg/100 g). After the *A. gangetica* pruning treatment at 60 DAP and immersing (P4), it was able to increase soil pH, organic C, total P and available K. Pruning *A. gangetica* 30 DAP without immersed (P1) was only able to increase organic C, total P and soil available K, but reduced soil pH. Pruning *A. gangetica* 30 DAP and immersing (P2) increased organic C and total soil P, while pruning *A. gangetica* 60 DAP without immersing (P3) and without pruning *A. gangetica* (P0) only increased total P content of the soil.

In this study, the analysis of soil chemical properties was carried out at 90 DAP, so the influence of cover crops on soil chemical properties still requires time for organic matter to decompose. However, the results of this research can help oil palm plantations to utilize the *A. gangetica* weed as a cover crop for high yield oil palm plantations which will help reduce the costs of weed control and fertilization, especially on smallholder oil palm plantations in Nogo Rejo Village and similar lands.

Acknowledgements

This research was funded by the Ministry of Education, Culture, Research and Technology of the Republic of Indonesia through a Basic Research Grant. Thank you also to the People's Palm Oil Plantation in Naga Rejo Village, Galang District, Deli Serdang Regency, North Sumatra for providing land for research.

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