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The Effect of Providing Ultrafine Nanobubbles (UFB) Liquid Organic NPK Fertilizer on the Growth of *Pueraria javanica* Plants in Ex-Coal Mining Land Areas

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Abstract: One of the main challenges in the reclamation process of former coal mining land is low soil fertility. Common soil characteristics found in former mining land include unbalanced pH, low organic matter content, poor soil structure, and minimal availability of nutrients. This makes it difficult for plants to grow and develop optimally in former mining land areas. This type of research is an experimental research with a Research Design using a Completely Randomized Design (CRD) 4 x 6. The population of this study was all Ruji Bean Plants (*Pueraria javanica*) growing in the Wire House area of PT. Pacific Coal Mining with a sample of this study of 24 Ruji Bean Plants (*Pueraria javanica*). The results of this study are that the provision of UFB Organic NPK fertilizer has been proven to help improve soil conditions. The dosage of UFB liquid organic NPK fertilizer solution for optimal Ruji Bean plant growth is in treatment 4 with a dose (90 ml). In terms of economy, the production of UFB liquid organic NPK fertilizer is IDR 40,300/liter, while the price of liquid NPK fertilizer on the market is IDR 100,000/liter. So, the use of UFB liquid organic NPK fertilizer solution can be a good choice for reclamation activities, this can save fertilization costs for post-mining land reclamation activities and is environmentally friendly because UFB liquid organic NPK fertilizer is made from organic materials.

Keywords: Coal; Organic NPK; *Pueraria javanica*; Ultrafine Nanobubbles (UFB)

Introduction

Coal mining activities carried out openly (open pit mining) have caused various environmental problems, especially damage to ex-mining land (Mahfud et al., 2022; Yusnikusumah et al., 2024). The impacts include changes in the landscape, decreased soil quality, loss of natural vegetation, and disruption of the ecosystem balance (Worlanyo & Jiangfeng, 2021; Punia & Bharti, 2023). This condition requires rehabilitation and land reclamation efforts to restore the ecological function of the area (Zhang, 2020).

One of the main challenges in the reclamation process of former coal mining land is low soil fertility (Rouhani et al., 2023). Soil characteristics commonly found in former mining land include unbalanced pH, low organic matter content, poor soil structure, and minimal nutrient availability. This makes it difficult for

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plants to grow and develop optimally in the former mining land area (Anda et al., 2022).

In efforts to rehabilitate ex-coal mining land, selecting the right type of cover crop is very important (Soendjoto et al., 2023). One of the species that has been proven effective is the plant *Pueraria javanica*, a legume that has high adaptability to less fertile soil conditions (Antara et al., 2023). This plant not only functions as a ground cover to control erosion, but is also able to increase soil fertility through its ability to fix atmospheric nitrogen through symbiosis with rhizobium bacteria in its root nodules (Situmorang, 2022).

Even though the plants *Pueraria javanica* has good adaptability, its growth on ex-mining land is often not optimal because the soil conditions are very unsupportive (Sajimin et al., 2021). Therefore, additional input in the form of fertilization is needed to support the growth of this plant. The use of organic NPK fertilizer is a strategic choice because in addition to providing essential nutrients, it can also improve the physical, chemical, and biological properties of the soil sustainably (Wan et al., 2021).

In an effort to optimize growth *Pueraria javanica* in ex-mining land, proper fertilizer application is a crucial factor (Pratiwi et al., 2021). The use of liquid organic NPK fertilizer with Ultrafine Nanobubbles (UFB) technology offers a promising solution. UFB technology is the latest innovation in agriculture that is capable of producing nano-sized bubbles with high stability in solution (Chaurasia, 2023; Neliyarti et al., 2024). The very small particle size (nanometers) allows for more effective nutrient absorption by plants (Singh et al., 2024). In addition, the resulting nanobubbles can increase the dissolved oxygen content in the fertilizer solution, which plays an important role in plant metabolism and soil microorganism activity (Pal & Anantharaman, 2022).

The combination of organic NPK fertilizer with UFB technology is expected to have a positive influence on plant growth *Pueraria javanica*. Nitrogen (N) plays an important role in the formation of proteins and vegetative growth of plants (Liu et al., 2022). Phosphorus (P) is needed for the formation of root systems and energy transfer, while potassium (K) plays a role in various metabolic processes and plant resistance to environmental stress (Wang et al., 2021).

The use of organic fertilizers in liquid form has several advantages compared to solid fertilizers. Nutrients in liquid form are more easily absorbed by plants and can be distributed evenly throughout the plant. In addition, liquid organic fertilizers can also improve the physical, chemical, and biological properties of the soil sustainably (Tariq et al., 2023).

Research on the effectiveness of liquid organic NPK fertilizer with UFB technology is still limited, especially its application to plants used in reclamation areas on former mining land. This study is important to evaluate the potential of this technology in supporting sustainable mining land reclamation programs. The results of the study are expected to provide scientific information that is useful for the development of fertilizer technology in the future (Zhukovskiy et al., 2021).

The successful growth of Pueraria javanica as a cover crop can provide various ecological benefits. In addition to preventing erosion and improving soil structure, the biomass produced can be a source of organic matter that is important for improving soil fertility. Optimal growth will also accelerate the process of natural succession and ecosystem recovery in ex-mining land (Aida et al., 2018).

Based on these various considerations, research into the effect of administering liquid organic NPK fertilizer Ultrafine Nanobubbles (UFB) on the growth of *Pueraria javanica* in areas of former coal mining land is very relevant to do. It is hoped that the results of this research can make a significant contribution to the development of technology that can be used for more effective and environmentally friendly reclamation of ex-mining land.

Method

The type of research used in this study is experimental research using a Completely Randomized Design (CRD) 4 x 6 Research Design. Completely Randomized Design is a field design where all experimental units are homogeneous. RAL is the simplest design when compared to other designs (Anshori et al., 2021).

In this design, the sources of diversity observed are only treatments and errors. Therefore, RAL is generally suitable for use in homogeneous environmental conditions, tools, and media. The population of this study was all Ruji Bean Plants (*Pueraria javanica*) growing in the Wire House area of PT. Pacific Coal Mining. The sample of this study was 24 stems of Ruji Bean Plants (*Pueraria javanica*).

The factor used is the concentration of the administration of Ultrafine Nanobubbles (UFB) Liquid Organic NPK Fertilizer solution. Each factor has 4 treatment levels with 6 replications (4 X 6). The concentration of the solution used is 0 ml (Control), 30, 60, and 90 ml. The Completely Randomized Design (CRD) Test Method as an analysis method and the steps are arranged in accordance with the method in carrying out the research.

Results and Discussion

Time and Location of Research

The research schedule is carried out in the period June - November 2024 located at PT. Pacific Coal Mining. Administratively located in Barunang Village, Kapuas Tengah District, Kapuas Regency, Central Kalimantan Province. An overview of the research location can be seen in Figure 1.

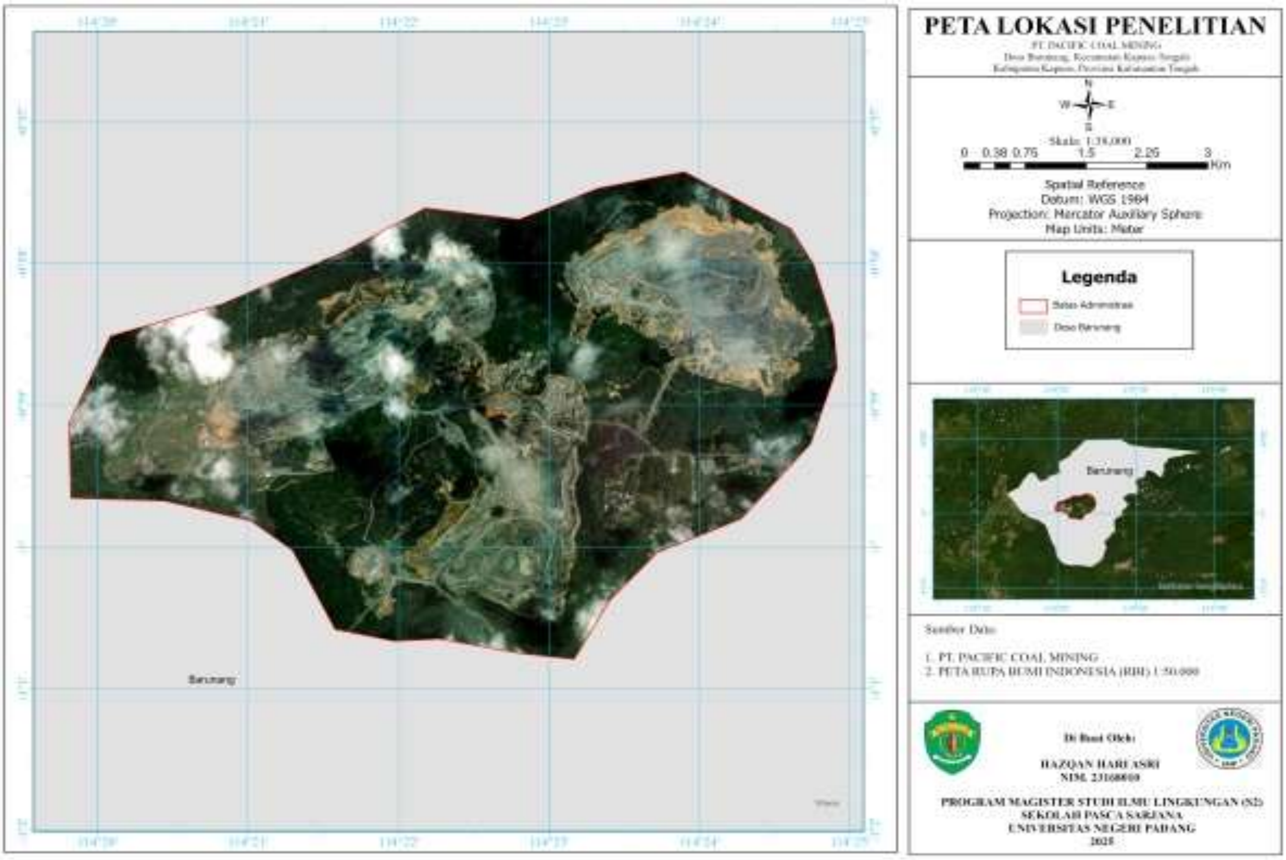

Figure 1. Map of research locations at PT. Pacific Coal Mining (Source: PT. Pacific Coal Mining Document, 2025)

Analysis of the Growth of Bean Plants (Pueraria javanica)
Stem Length Growth

Growth in plant stem length *Pueraria javanica* on the provision of liquid organic NPK fertilizer solution Ultrafine Nanobubbles (UFB) with 4 treatments that were observed for 8 weeks. The first week is a very important acclimation period for plant survival. During this period, plants will develop various defense mechanisms and adjustments in order to survive and carry out their physiological functions normally in the new environment. This adaptation process is very crucial because it can reduce plant stress levels due to environmental changes and provide time for plants to build their defense systems.

After the acclimation period is complete, namely from the second week onwards, the *Pueraria javanica* plants begin to enter the treatment phase by administering a liquid NPK Organic fertilizer solution Ultrafine Nanobubbles (UFB). At this stage, the plants have adapted well to their new environment so that they are ready to receive and respond to the nutrients provided. The growth rate of the stem length of the *Pueraria javanica* plant with the administration of a liquid NPK Organic fertilizer solution Ultrafine Nanobubbles (UFB) can be seen in Figure 2.

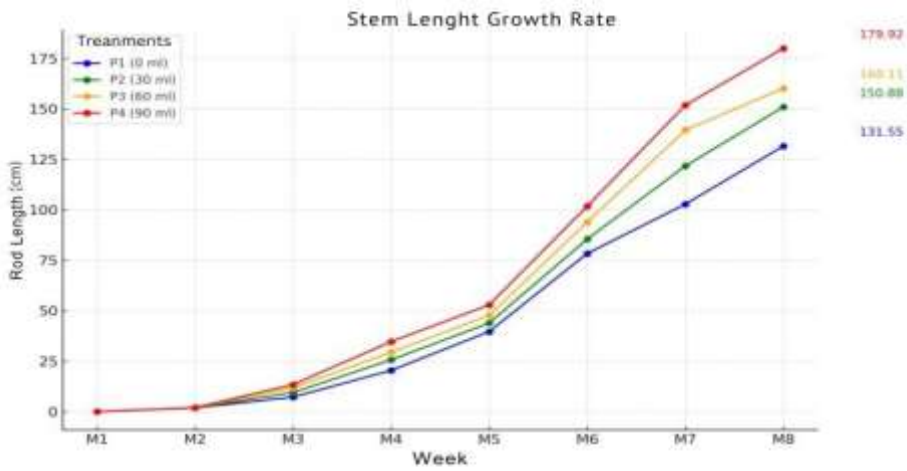

Figure 2. Plant stem length growth rate *Pueraria javanica* regarding the administration of UFB liquid organic NPK fertilizer solution in each treatment (Source: Author analysis, 2025)

From Figure 2, it can be seen that at the beginning of the observation in the first week (M1) to the second week (M2), all treatments showed relatively slow and almost uniform growth. Entering the third week (M3), differences in growth began to be seen where P4 with a dose of 90 ml showed faster growth than other treatments. The growth rate increased significantly from the fifth week (M5) to the eighth week (M8) in each treatment. The P4 treatment with the highest dose (90 ml) consistently showed the most rapid growth, reaching a final stem length of 179.92 cm. Followed by P3 (60 ml) with a final length of 160.11 cm, P2 (30 ml) with 150.88 cm, and P1 (0 ml) with the lowest growth of 131.55 cm.

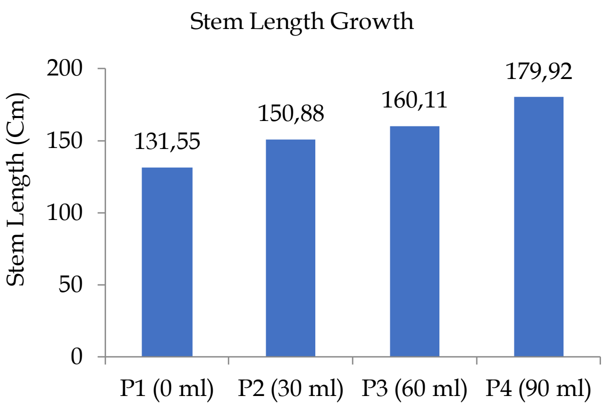

Figure 3. Comparison of average plant stem length growth rates *Pueraria javanica* regarding the administration of UFB liquid organic NPK fertilizer solution in each treatment (Source: Author analysis, 2025)

From these results, it can be seen that there is a positive correlation between the number of treatment doses and the rate of stem length growth, where the higher the dose given (from 0 to 90 ml), the higher the growth rate produced. Treatment P4 with a dose of 90 ml proved to be the most effective in increasing the growth of plant stem length. These results are reinforced by the calculation of the comparison of the average value of stem length growth. The results of the comparison of stem length growth can be seen in Figure 3.

Number of Leaves

The calculation of the number of leaves of *Pueraria javanica* plants is an important parameter in measuring plant growth and development. The calculation process is carried out by manually counting the number of leaves on each sample plant. In this study, the growth of *Pueraria javanica* leaves with the provision of liquid NPK Organic fertilizer solution (UFB) was carried out to see the effect of fertilizer concentration on the growth of the number of leaves. To see leaf growth, an experiment was carried out using 4 different treatments with variations in the concentration of liquid NPK Organic fertilizer solution UFB which were different in each treatment. The growth rate of *Pueraria javanica* leaves with the provision of liquid NPK Organic fertilizer solution UFB can be seen in Figure 4.

From Figure 4, it can be seen that in the first week to the fourth week (M1-M4), all treatments showed identical leaf growth, starting from 4 leaves in M1, increasing to 7 leaves in M2, 10 leaves in M3, and 13 leaves in M4. The difference began to appear in the fifth week (M5), where P3 and P4 showed better growth with 17 leaves, while P1 and P2 had 16 leaves. In the sixth week (M6), the difference became more visible with P3 and P4 reaching 24 leaves, P2 reaching 23 leaves, and P1 only 22 leaves. This increase continued until the seventh (M7) and eighth (M8) weeks.

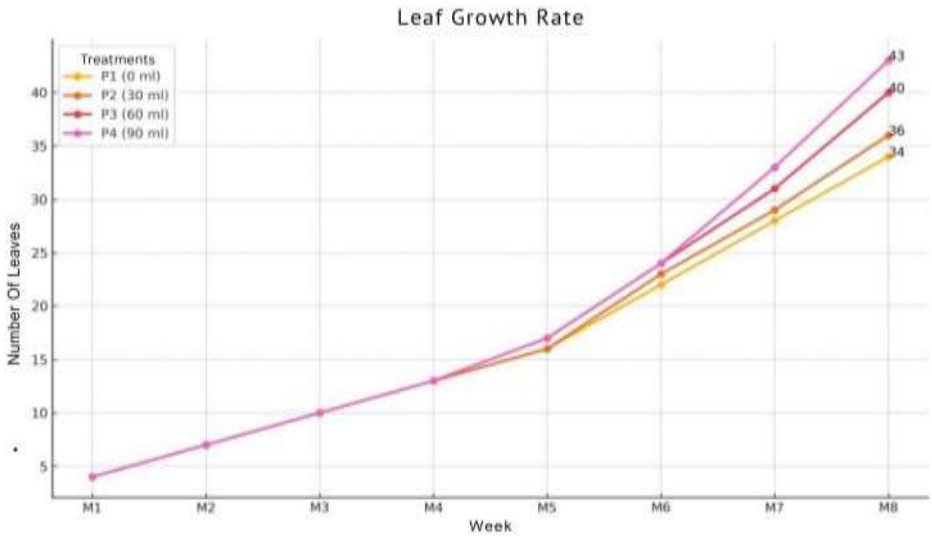

Figure 4. Growth rate of number of leaves of *Pueraria javanica* plants on UFB liquid organic NPK fertilizer solution for each treatment (Source: Author analysis, 2025)

At the end of the observation in the eighth week (M8), the P4 treatment with a concentration of 90 ml showed the best results with 43 leaves, followed by P3 (60 ml) with 40 leaves, P2 (30 ml) with 36 leaves, and P1 (0 ml) with 34 leaves. These data indicate that the higher the concentration of the solution given, the better the leaf growth produced, with P4 showing the most optimal results compared to other treatments. These results are reinforced by the calculation of the comparison of the number of leaves in each treatment. The results of the comparison of the average number of leaves can be seen in Figure 5.

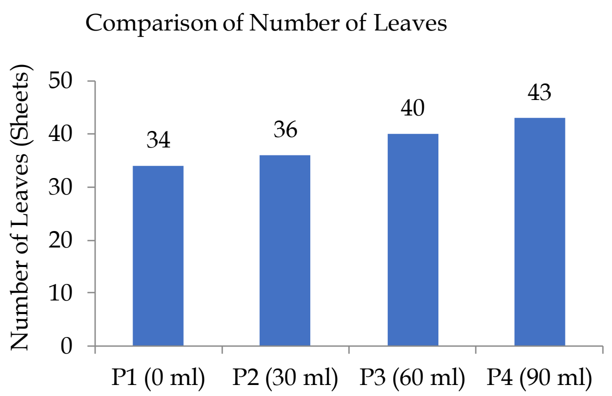

Figure 5. Comparison of the average growth in the number of leaves of *Pueraria javanica* plants when given UFB liquid organic NPK fertilizer solution for each treatment (Source: Author analysis, 2025)

Number of Leaf Branches

Differences in solution concentration UFB Liquid Organic NPK Fertilizerhas a significant influence on the formation and growth of leaf branches in plants. NPK as a compound fertilizer containing essential elements Nitrogen (N), Phosphorus (P), and Potassium (K) plays an important role in the process of leaf branch growth. When plants are given different concentrations of NPK, the response of leaf branch growth will also vary. Concentrations that are too low can cause suboptimal branch growth due to lack of essential nutrients. Conversely, giving too high a concentration can cause toxicity or even inhibit leaf branch growth due to too high osmotic pressure on plant tissue. Therefore, determining the optimal concentration of NPK solution is a critical factor in plant growth management. The growth rate of the number of leaf branches of *Pueraria javanica* plants with the administration of UFB Organic NPK liquid fertilizer solution can be seen in Figure 6.

From Figure 6, it can be seen from the first week to the fourth week (M1-M4), all treatments showed the same branch growth pattern, starting from 1 branch in M1, gradually increasing to 2 branches in M2, 3 branches in M3, and 4 branches in M4. The difference began to appear in the fifth week (M5), where P4 with a concentration of 90 ml showed better growth with 6 branches, while P1, P2, and P3 had 5 branches. In the sixth week (M6), the difference was even more apparent with P4 reaching 9 branches, P3 reaching 8 branches, while P1 and P2 only had 7 branches.

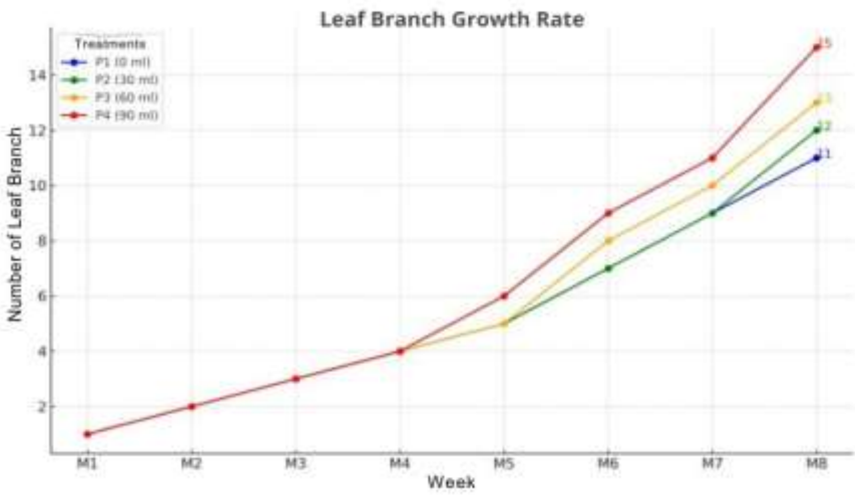

Figure 6. Growth in the number of plant leaf branches *Pueraria javanica* regarding the administration of UFB liquid organic NPK fertilizer solution in each treatment (Source: Author analysis, 2025)

At the end of the observation in the eighth week (M8), the P4 treatment showed the best results with 15 branches, followed by P3 with 13 branches, P2 with 12 branches, and P1 with 11 branches. These data indicate that the provision of UFB liquid organic NPK fertilizer solution with a higher concentration has a positive effect on the growth of the number of leaf branches of *Pueraria javanica* plants, with P4 (90 ml) showing the most optimal results compared to other treatments. These results are reinforced by the calculation of the comparison of the number of leaf branches in each treatment. The results of the comparison of the average number of leaf branches can be seen in Figure 7.

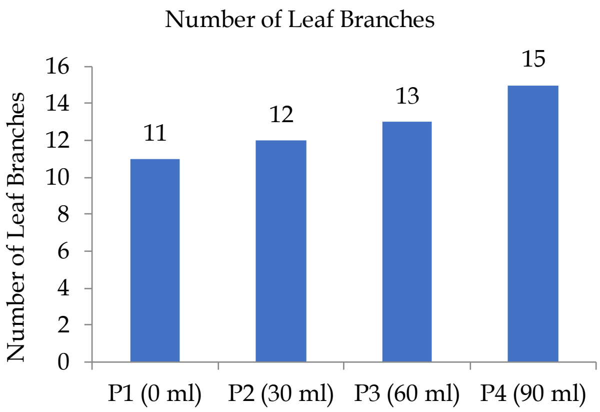

Figure 7. Comparison of average number of branches and leaves of plants *Pueraria javanica* regarding the administration of UFB liquid organic NPK fertilizer solution in each treatment (Source: Author analysis, 2025)

Root Length

Root length is an important growth parameter in measuring plant responses to environmental conditions. The roots themselves are vegetative organs of plants which generally grow into the soil, function to absorb water and nutrients, become a storage place for food reserves, and play a role in supporting the plant's uprightness. In *Pueraria javanica* plants, application of UFB liquid organic NPK fertilizer solution can influence the growth and development of the root system. The comparison of the average root length of *Pueraria javanica* plants with the application of Ultrafine Nanobubbles (UFB) liquid organic NPK fertilizer solution can be seen in Figure 8.

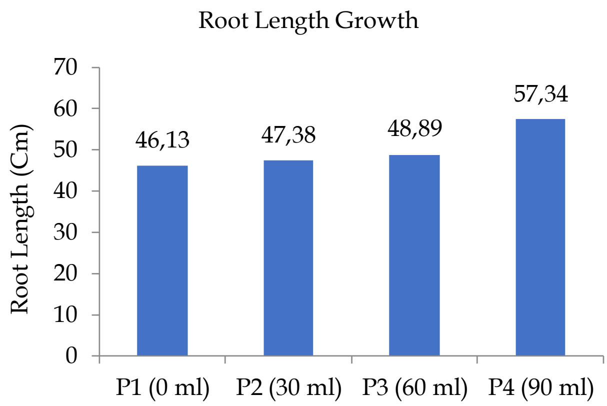

Figure 8. Comparison of the average root length of *Pueraria javanica* plants against the UFB liquid organic NPK fertilizer solution for each treatment (Source: Author analysis, 2025)

Based on Figure 8 above, it can be seen that there is an increase in the length of the roots of the *Pueraria javanica* plant along with the addition of the fertilizer treatment dose. In the P1 treatment (control/0 ml) showed an average root length of 46.13 cm. Then there was an increase in P2 with a dose of 30 ml which produced a root length of 47.38 cm, followed by P3 with a dose of 60 ml which produced a root length of 48.89 cm. The most significant increase was seen in the P4 treatment with a dose of 90 ml which produced a root length of 57.34 cm.

The above data also shows that the administration of a 90 ml fertilizer dose gives the best effect on the growth of the root length of Pueraria javanica plants compared to other treatments. The difference in growth between the control treatment (P1) and the best treatment (P4) reached 11.21 cm, which indicates that the administration of fertilizer can have a positive effect on the development of the plant root system.

Number of Root Nodules

Root nodules are special structures formed in the root system of *Pueraria javanica* plants as a result of mutualistic symbiosis with rhizobium bacteria. This symbiosis occurs when rhizobium bacteria infect the root hairs of the pea plant, which then triggers the formation of root nodules (Lumbanraja et al., 2024). These root nodules play an important role in the process of atmospheric nitrogen fixation, where the rhizobium bacteria living in them are able to convert free nitrogen from the air into a form that can be utilized by plants. In *Pueraria javanica* plants, root nodules generally begin to form around 2-3 weeks after planting, depending on environmental conditions and the presence of suitable rhizobium bacteria in the soil. The comparison of the average number of root nodules of *Pueraria javanica* plants with the administration of Ultrafine Nanobubbles (UFB) Organic NPK liquid fertilizer solution can be seen in Figure 9.

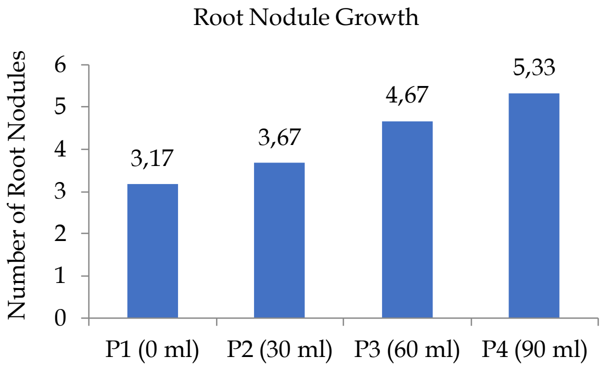

Figure 9. Comparison of average number of root nodules of plants *Pueraria javanica* regarding the administration of UFB liquid organic NPK fertilizer solution in each treatment (Source: Author analysis, 2025)

Based on Figure 9 above, there is an increase in the average number of root nodules of *Pueraria javanica* plants along with the increase in the dose of fertilizer treatment given. In treatment P1 (control/0 ml) showed an average number of root nodules of 3.17. Then there was an increase in P2 with a dose of 30 ml which produced an average number of root nodules of 3.67, followed by P3 with a dose of 60 ml which produced an average number of root nodules of 4.67. The most significant increase was seen in treatment P4 with a dose of 90 ml which produced an average number of root nodules reaching 5.33. This shows that the administration of a fertilizer dose of 90 ml has the best effect on the formation of root nodules of *Pueraria javanica* plants compared to other treatments.

Plant Growth Analysis

In this study, there was an influence on plant growth *Pueraria javanica* on the addition of liquid Organic NPK fertilizer solution Ultrafine Nanobubbles (UFB), based on analysis of variance (ANOVA) carried out on stem length, number of leaves, number of leaf branches, root length and number of plant root nodules *Pueraria javanica*. Plant variant analysis *Pueraria javanica* can be seen in Table 1.

Table 1. Analysis of variance (ANOVA) of *Pueraria javanica* plants against all treatments

Parameter	F Test		Information
	F Count	F Table	
Stem Length	2964.37	3.10	Influential
Number of Leaves	21.87	3.10	Influential
Number of Leaf Branches	21.87	3.10	Influential
Root Length	600.26	3.10	Influential
Number of Root Nodules	23.62	3.10	Influential

Source: Author analysis, 2025

Based on the table of results of the analysis of variance (ANOVA) displayed, it can be seen that all growth parameters of *Pueraria javanica* plants show a significant effect on the treatment given. This can be proven from the calculated F value which is greater than the F table on all parameters measured. The stem length parameter shows a very significant difference with the highest calculated F value of 2964.377. This indicates that the treatment given has a very strong effect on the growth of the stem length of *Pueraria javanica* plants. Likewise, the root length parameter which has a calculated F value of 600.262, shows a very significant response to the treatment.

For the number of leaves and number of leaf branches, both have the same F count value of 21.875, which is also higher than the F table. This shows that the treatment given has a significant effect on leaf formation and branching in *Pueraria javanica* plants. The parameter of the number of root nodules also shows a significant effect with an F count value of 23.621. Overall, the results of this ANOVA analysis show that all growth parameters of *Pueraria javanica* plants provide a significant response to the treatment given, with varying levels of influence on each parameter. To find out the differences between treatments specifically, further analysis is needed using the Duncan or DMRT test.

Duncan's test or DMRT can help in identifying treatments that differ significantly in terms of plant growth *Pueraria javanica*. After conducting an analysis of variance to compare the treatments as a whole, the Duncan test was used to compare all treatment pairs individually. This allowed the researcher to determine which treatment groups were significantly different from each other in terms of plant growth. The use of the Duncan test in the study of the provision of UFB organic liquid NPK fertilizer solution on plant growth *Pueraria javanica* it is very important to gain a deeper understanding of the differences in treatment in terms of plant growth. The analysis of the Duncan test can be seen in Table 2.

Table 2. Duncan plant test *Pueraria javanica* on all parameters

Treatment	Duncan's test				
	Long Stem	Amount Leaf	Amount Branch Leaf	Long Root	Number of Root Nodules
P 1 0 ml	a	a	a	a	a
P2 30 ml	b	a b	a b	b	a
P3 60 ml	c	b	b	c	b
P4 90 ml	d	c	c	d	c

Information: Based on DMRT at the a = 5% level, numbers followed by the same letter in the same column are not significantly different.

Based on the results of the Duncan or DMRT test shown in Table 2, it can be analyzed that treatments with different doses have varying effects on various growth parameters of *Pueraria javanica* plants. The results of the Duncan test showed that treatment 4 with a dose of 90 ml consistently gave the best results for all growth parameters of the spoke bean plant, while the control treatment (0 ml) showed the lowest results. This indicates that increasing the dose of treatment is directly proportional to the increase in growth of the *Pueraria javanica* plant.

Soil Quality Analysis

Soil pH Value Analysis

Soil pH analysis is a key parameter in evaluating soil fertility and quality because it has a direct influence on the availability of nutrients and the activity of soil microorganisms. Optimal soil pH generally ranges from 6.0 to 7.5, where most nutrients are maximally available to plants. The results of soil pH measurements before and during treatment in this study can be seen in Figure 10.

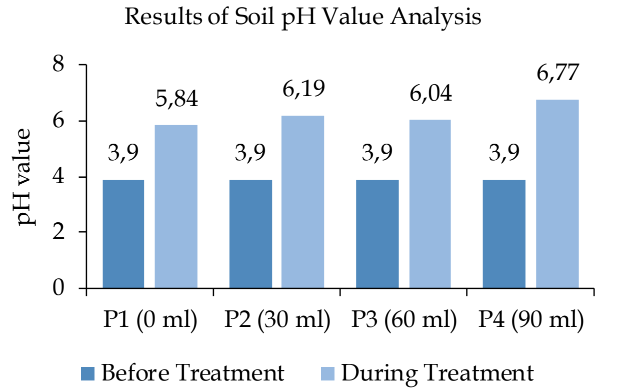

Figure 10. Results of soil pH value analysis (Source: Author analysis, 2025)

In Figure 10, it can be seen that before the treatment, the soil pH value showed a uniform condition of 3.9 at all points (P1-P4), which indicates a very acidic soil condition. After the treatment, there was an increase in pH that varied in all treatments. In sample P1 (0 ml), the pH increased from 3.9 to 5.84, indicating a change in soil conditions from very acidic to moderately acidic. In sample P2 (30 ml), the pH increased to 6.19, which is a condition close to neutral and optimal for soil nutrient availability.

For point P3 (60 ml), the soil pH increased to 6.04, still within a good range for plant growth. The most significant increase in pH occurred in sample P4 (90 ml) where the pH value reached 6.77, indicating neutral and optimal conditions for soil nutrient availability. This indicates that higher treatment volumes tend to result in higher pH increases.

Carbon (C) Analysis

Analysis of carbon content in soil is one of the important parameters in assessing soil quality and fertility. Soil organic carbon is the main component of soil organic matter that plays a vital role in maintaining soil health and productivity. The results of measuring Carbon (C) levels before and after treatment in this study can be seen in Figure 11.

In Figure 11, it can be seen that the initial conditions (before treatment), all samples have the same carbon content, which is 0.02%. After being treated, there was an increase in carbon content in all samples, but at different levels. In treatment P1 (0 ml) showed the most significant increase in carbon content, from 0.02 to 0.07%, which is an increase of 0.05%. For treatments P2 (30 ml) and P3 (60 ml), both experienced the same increase from 0.02 to 0.05%. Meanwhile, treatment P4 (90 ml) showed the smallest increase, from 0.02 to 0.04%.

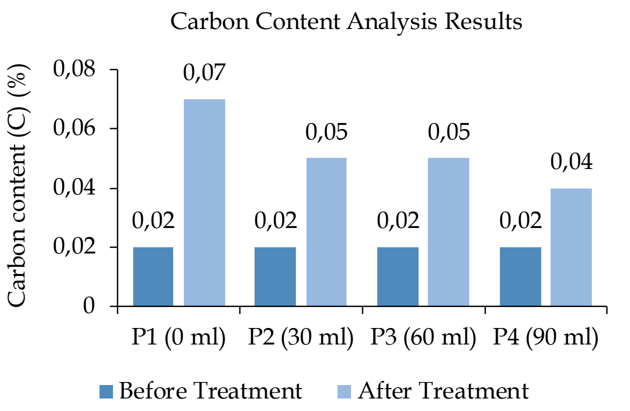

Figure 11. Carbon content analysis results (Source: Author analysis, 2025)

From the data above, it can be seen that there is a decrease in the effectiveness of the treatment along with the increase in volume, where the sample with a volume of 0 ml (P1) gives the highest increase in carbon content, while the sample with the largest volume of 90 ml (P4) gives the lowest increase. This indicates that the increase in volume is inversely proportional to the increase in carbon content in the tested sample.

Nitrogen (N) Analysis

Nitrogen (N) is one of the essential macronutrients that is very important for plant growth and soil fertility. In soil analysis, measuring nitrogen levels is a key parameter for assessing soil quality and productivity. The results of measuring Nitrogen (N) levels before and after treatment in this study can be seen in Figure 12.

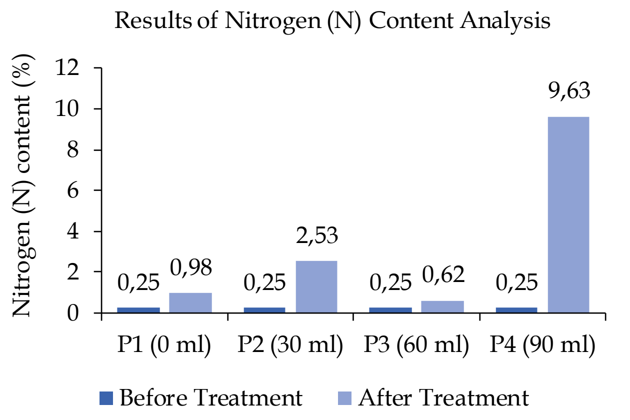

Figure 12. Nitrogen (N) analysis results (Source: Author analysis, 2025)

In Figure 12, the initial condition (before treatment), all samples have the same nitrogen content, which is 0.25%. After being treated, there was an increase in nitrogen content in all samples with significantly varying levels. Sample P4 (90 ml) showed the greatest increase, from 0.25 to 9.63%, the highest increase among all samples. Sample P2 (30 ml) experienced a moderate increase from 0.25 to 2.53%. Meanwhile, sample P1 (0 ml) experienced a smaller increase from 0.25 to 0.98%, and P3 (60 ml) showed the most minimal increase from 0.25 to 0.62%.

On the other hand, it can be seen that there is no linear pattern in the increase in nitrogen levels along with the increase in volume. The sample with the largest volume (P4 - 90 ml) did show the highest increase, but sample P3 (60 ml) actually showed a lower increase compared to P2 (30 ml) and P1 (0 ml). This indicates that the volume factor is not the only determinant in increasing nitrogen levels.

Phosphorus (P) Analysis

Phosphorus (P) is the second essential macronutrient after nitrogen which is vital for plant growth and development. In soil analysis, measuring phosphorus levels is an important parameter for evaluating soil fertility and productivity potential. Phosphorus in the soil can be found in various forms, both organic and inorganic, but not all of these forms can be directly absorbed by plants. The results of measuring phosphorus (P) levels before and after treatment in this study can be seen in Figure 13.

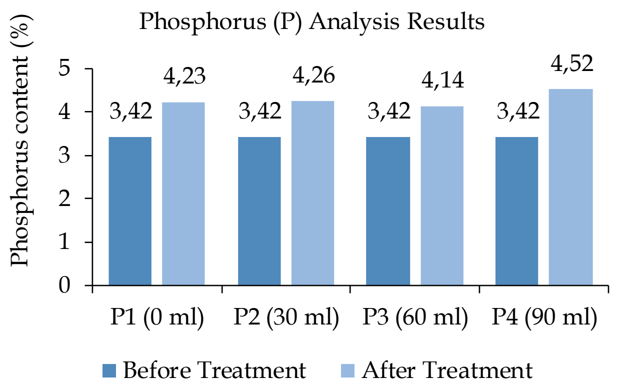

Figure 13. Phosphorus (P) analysis results (Source: Author analysis, 2025)

In Figure 13, it can be seen that the initial conditions (before treatment), all samples have a uniform phosphorus content of 3.42%. After being treated, there was an increase in phosphorus levels in all samples with relatively small variations. Sample P4 (90 ml) showed the highest increase, from 3.42 to 4.52%, followed by P2 (30 ml) which increased to 4.26%. Sample P1 (0 ml) increased to 4.23%, while P3 (60 ml) showed the smallest increase to 4.14%. Overall, the range of increase in phosphorus levels after treatment was between 0.72 and 1.1%.

Analysis Potassium (K)

Potassium (K) is the third essential macronutrient after nitrogen and phosphorus which is very important in plant growth and development. In soil analysis, measuring potassium levels is an important indicator to assess soil fertility and its productivity potential. The availability of potassium in the soil is influenced by various factors such as soil texture, soil pH, cation exchange capacity (CEC), organic matter content, and interactions with other cations such as Ca and Mg (Fahmi et al., 2022). The results of measuring Potassium (K) levels before and after treatment in this study can be seen in Figure 14.

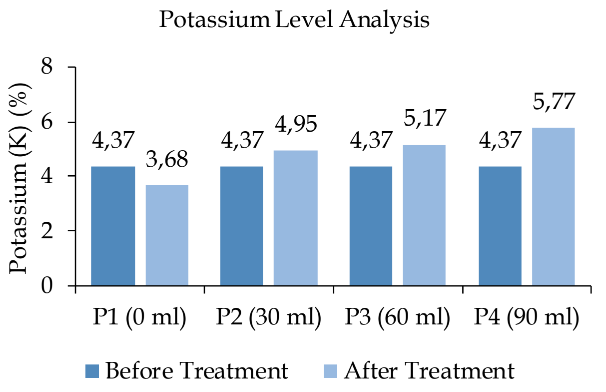

Figure 14. Potassium (K) analysis results (Source: Author analysis, 2025)

Figure 14 above shows a comparison of potassium levels before and after treatment on four different samples (P1-P4) with varying volumes. In the initial condition (before treatment), all samples had a uniform potassium level of 4.37%. After being treated, there was an increase in potassium levels in all samples with significant variations.

In sample P1 (0 m), the Potassium content was 3.68%, the only sample that experienced a decrease. Furthermore, in sample P2 (30 m), the Potassium content increased to 4.95%, indicating an increase of 0.58% from the initial condition. Further increases were seen in sample P3 (60 m) with a content of 5.17%, and reached the highest value in sample P4 (90 m) of 5.77%.

On the other hand, there is an increase in Potassium levels that is directly proportional to the addition of treatment volume, where the higher the volume level, the higher the Potassium level. This indicates that the treatment given has different effects depending on the volume, with the most optimal effect seen in the 90 ml treatment (P4).

C/N Analysis

The C/N (Carbon/Nitrogen) ratio is one of the important parameters in soil fertility analysis that shows the comparison between carbon and nitrogen content in the soil. This parameter is a key indicator to assess the level of organic matter decomposition and the availability of nutrients for plants. The ideal C/N ratio value for agricultural soil is generally between 10-12. When the C/N ratio is too high (> 30), this indicates that the organic matter decomposition process is slow and nitrogen in the soil tends to be mobilized by soil microorganisms, so that its availability for plants is limited. Conversely, a C/N ratio that is too low (< 10) indicates rapid nitrogen mineralization, which can cause nitrogen loss through leaching or volatilization (Santoso & Cholid, 2021). The results of the C/N ratio measurements before and after treatment in this study can be seen in Figure 15.

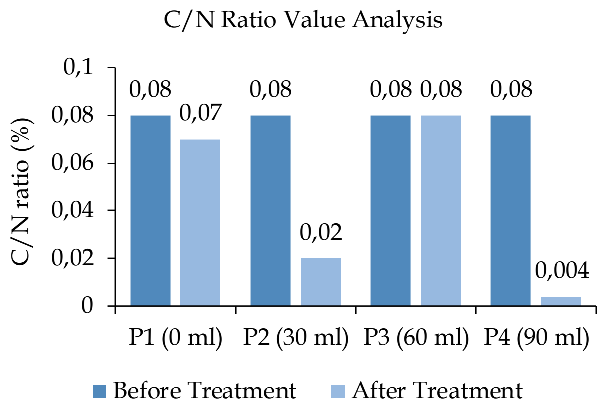

Figure 15. C/N ratio analysis (Source: Author analysis, 2025)

From Figure 15 above, it shows that before treatment, the C/N ratio value was consistent at 0.08% at all sampling points (P1, P2, P3, and P4). However, after treatment, there were varying changes and tended to decrease at almost all sampling points. At point P1 (0 m), there was a relatively small decrease in the C/N ratio from 0.08 to 0.07%. A very significant decrease was seen at point P2 (30 m), where the C/N ratio dropped drastically from 0.08 to 0.02%. At point P3 (60 m), the C/N ratio value remained stable at 0.08% even after treatment. Meanwhile, the most drastic decrease occurred at point P4 (90 m), where the C/N ratio dropped very significantly from 0.08 to 0.004%.

Overall, the data show that the treatments tended to decrease the soil C/N ratio, with the most dramatic effect seen at the furthest sampling point (P4). These very low C/N ratio values (< 10) indicate a very rapid rate of nitrogen mineralization, which could pose a risk of nitrogen loss through volatilization.

Valuation UNBs Liquid Organic NPK Fertilizer Solution Economy

Economic valuation of liquid organic NPK fertilizer solution Ultrafine Nanobubbles (UFB) is an analysis that assesses the economic aspects and benefits of making liquid organic NPK fertilizer UFB. The total investment for making liquid organic NPK fertilizer UFB is IDR 2,015,000. This cost includes the purchase of Ultrafine equipment for IDR 1,000,000 which is a long-term investment because it can be used repeatedly. While the remaining IDR 1,015,000 is the operational cost and raw materials consisting of supporting equipment and materials.

With a cost of Rp. 2,015,000, 50 liters of liquid organic NPK fertilizer have been obtained. So if the price of liquid organic NPK fertilizer UFB Rp. 2,015,000 is divided by 50 liters, then the price is Rp. 40,300 / liter. While the price of liquid NPK fertilizer from factories circulating in the market is Rp. 100,000. In this case, the price of liquid organic NPK fertilizer UFB is more affordable.

Another economic advantage is that the Ultrafine technology used can increase the efficiency of nutrient absorption by plants, so that fertilizer use can be better. By considering the sustainability aspect and long-term benefits, investing in the manufacture of UFB liquid organic NPK fertilizer can be a more economical choice than continuously buying conventional liquid NPK fertilizer, especially for farmers or farmer groups who use large amounts of fertilizer routinely.

Discussion

Based on the research results, the provision of liquid organic NPK fertilizer UFB has a significant effect on the growth of *Pueraria javanica* plants in ex-coal mining land. This can be seen from the increase in all growth parameters measured, including stem length, number of leaves, number of leaf branches, root length, and number of root nodules. These results are in line with the research of Antara et al. (2023) which found that liquid NPK fertilizer can increase the vegetative growth of ground cover legume plants in mine reclamation areas.

P4 treatment with a dose of 90 ml consistently showed the best results for all growth parameters. In the stem length parameter, P4 reached 179.92 cm compared to the control which was only 131.55 cm. This significant increase can be attributed to the nitrogen content in the fertilizer which plays an important role in the vegetative growth of plants. Research by Li et al. (2024) reported that the administration of NPK fertilizer with nanobubble technology can increase the efficiency of nutrient absorption by up to 40% compared to conventional fertilizers.

The number of leaves and leaf branches also showed a positive response to the administration of UFB liquid organic NPK fertilizer. The P4 treatment produced 43 leaves and 15 branches, much higher than the control which only produced 34 leaves and 11 branches. This increase is in line with the research of Arablousabet & Povilaitis (2024) which states that nanobubble technology can increase surface area, making it more easily absorbed by plants.

The root system of *Pueraria javanica* plants also showed good development with the treatment of UFB liquid organic NPK fertilizer. The root length in P4 reached 57.34 cm, an increase of 24% compared to the control (46.13 cm). The number of root nodules also increased from 3.17 in the control to 5.33 in P4. Similar results were reported by Al-qasy & Al-Shammari (2022) which showed that NPK fertilizer with nanobubble technology can increase rhizobium colonization and root nodule formation in legume plants.

Soil analysis showed an increase in pH from very acidic conditions (3.9) to near neutral (6.77) at P4. This change in pH is very beneficial because it creates more optimal conditions for plant growth and soil microorganism activity. Research by Munawwarah & Sulaeman (2023) also found that the application of liquid organic fertilizer can improve the chemical properties of ex-mining soil, including increasing soil pH.

Nitrogen levels in the soil increased dramatically in P4, from 0.25 to 9.63%. This increase was much higher than other treatments, indicating the effectiveness of UFB technology in increasing nitrogen availability. This is supported by research by Pradila & Razak (2024) which shows that the use of nanobubbles can increase nitrogen efficiency by up to 65%.

Phosphorus and potassium also showed an increase after treatment, although at a more moderate level than nitrogen. Phosphorus levels increased from 3.42 to 4.52% in P4, while potassium increased from 4.37 to 5.77%. According to Suryanti (2024), this moderate increase is still within the optimal range to support the growth of ground cover legumes.

The C/N ratio decreased significantly after treatment, especially in P4 which reached 0.004%. Although this decrease indicates rapid nitrogen mineralization, research by Arohman et al. (2023) shows that this can be beneficial in the short term because it increases the availability of nitrogen to plants, especially in the early stages of growth.

In terms of economy, UFB liquid organic NPK fertilizer shows better cost efficiency compared to conventional fertilizers. With a price of IDR 40,300/liter compared to conventional liquid NPK fertilizer at IDR 100,000/liter, this technology offers significant savings. Economic research by Antara et al. (2023) confirmed that the use of nanobubble technology in fertilization can provide a return on investment within one planting season.

The advantages of Ultrafine Nanobubble (UFB) technology in increasing nutrient absorption efficiency also contribute to sustainability aspects (Razak et al., 2022). Reducing the amount of fertilizer needed is not only economically beneficial but also reduces the potential environmental impact of excessive fertilizer use. This is in accordance with the findings of Ariana & Romadona (2021) which show that nanobubble technology can reduce environmental pollution due to fertilizer residues.

Overall, the results of this study demonstrate the great potential of UFB liquid organic NPK fertilizer in supporting revegetation of ex-coal mining land using *Pueraria javanica*. The combination of increased plant growth, improved soil quality, and economic efficiency makes this technology a promising solution for the rehabilitation of degraded land.

Conclusion

The provision of UFB organic liquid NPK fertilizer solution has been proven to help improve soil conditions. The dosage of UFB organic liquid NPK fertilizer solution for optimal growth of Ruji Bean plants is in treatment 4 with a dose (90 ml). In terms of economy, the production of UFB organic liquid NPK fertilizer is IDR 40,300/liter, while the price of liquid NPK fertilizer on the market is IDR 100,000/liter. So the use of UFB organic liquid NPK fertilizer solution can be a good choice for reclamation activities, this can also save fertilization costs for post-mining land reclamation activities and is environmentally friendly because UFB organic liquid NPK fertilizer is made from organic materials.

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Author Contribution

H.H.A.: preparation of original draft, results, discussion, methodology, conclusion; A.R., N.S., S.D., and M.S.: analysis, review, proofreading and editing.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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