agronomy

MDPI

Article

Proposed Techniques to Supplement the Loss in Nutrient Cycling for Replanted Coffee Plantations in Vietnam

The Trinh Pham [1], Ngoc Hoi Nguyen [2], Pham Nguyen Dong Yen [2], Tri Duc Lam [3] and Ngoc Thuy Trang Le [4,*]

[1] Department of Science and Technology in DakLak Province, 15A Truong Chinh, Buon Ma Thuot City 630000, Vietnam; trinhkhcn@yahoo.com
[2] Institute of Applied Materials Science, Vietnam Academy of Science and Technology, Ho Chi Minh City 700000, Vietnam; hoi83bmt@gmail.com (N.H.N.); phamngdongyen@gmail.com (P.N.D.Y)
[3] NTT Hi-Tech Institute, Nguyen Tat Thanh University, Ho Chi Minh City 700000, Vietnam; ltduc@ntt.edu.vn
[4] Institute of Research and Development, Duy Tan University, Danang 550000, Vietnam
* Correspondence: lenthuytrang4@duytan.edu.vn

Received: 23 May 2020; Accepted: 23 June 2020; Published: 25 June 2020

Abstract: Nutrient cycling of the coffee ecosystem is often characterized by nutrient losses during the harvest, tree's growth, leaching and erosion. The "Coffee Rejuvenation Strategies in Vietnam" has risked not being complete on schedule, with the low survival rate of seedlings on replanted soil, due to the nutrient loss and imbalance supplements after a long-term of monoculture and intensive cultivation. In this study, measures, including biochemical and organic treatments were applied to replanted coffee farm, in order to supplement the loss of nutrient cycling. Survival rate, growth indicators, and soil properties from the controls and treatments, were monitored and compared during the experimental periods. The results suggested the optimal tillage model as follow: Remove old coffee trees with their stumps and roots; liming 1.5 tons/ha; dry tillage soil for the first 6 months; Intercrop Mexican marigold *(Tagetes erecta)* with new coffee plants for the next 6 months; From the second year, apply 5 kg of microbial organic fertilizer /hole/year; bury 30 kg of green manure/hole/2–3 years; apply NPK fertilizers according to the governmental recommended procedure. This would be a proposed integrating tillage method to supplement the lost nutrients and restore the fertility of replanted coffee soil in Vietnam.

Keywords: biochemical treatment; nutrient cycling; organic treatment; proposed technique; replanted coffee soil

1. Introduction

Nutrient cycling, one of the most important processes of cropland ecosystems, in general, and coffee ecosystem in particular, is expected to be delivered from agricultural soils [1]. For coffee, nitrogen (N), phosphorous (P) and potassium (K) are the major nutrients that affect the tree's growth as well as the bean's yield [2]. Nitrogen is the most important element, which is essential for high-yield production, phosphorus plays an important role for the root system to grow from young to fruit-bearing tree. Meanwhile potassium takes the main contribution to beans' quality and quantity [3,4]. However, nutrient cycling is often characterized by nutrient losses, which is due to the removal of crops, as well as the inefficiencies in internal nutrient cycling and poor synchronization of nutrient availability with plant demand and nutrient supply [5]. Similarly, the lost nutrients of the coffee ecosystem occurs during the harvest, tree's growth, leaching and erosion

[6]. Therefore, these lost nutrient amounts are made up by the inputs, dominated mainly by fertilizers, and partly from organic matter mineralization.

In Vietnam, coffee is one of the 10 most important export commodities and in the world, Vietnam has ranked second in coffee production after Brazil from the 1990s. Recently, Vietnam's coffee area is about 720 thousand ha with the production of more than 1700 thousand tons, in which the Daklak province is the biggest coffee region with 204 thousand ha area and 490 thousand tons production [7–9]. Due to the sustainable development of the coffee industry, the decision of "Coffee Rejuvenation Strategies in Vietnam" were issued by the government. Accordingly, nearly 28 thousand ha of old, low production and low quality coffee areas would be renewed [2–4]. However, the strategy has been at risk of not being complete on schedule due to the low survival rate of seedlings on replanted land [5].

The loss and imbalance supplements of nutrients in the nutrient cycle can be one of the main causes for the low survival rate of coffee seedlings in replanted coffee fields in the Central Highlands of Vietnam. It has been estimated that the major nutrients removed in one ton of coffee green beans per ha may be 33 kg N, 1 kg P_2O_5 and 30 kg K_2O [10]. After a period of nearly 30 to 40 years of monoculture and intensive cultivation of coffee, the soil was seriously degraded due to the loss in nutrient cycling [11]. Moreover, farmers in Vietnam applied unbalanced quantities of chemical fertilizers (i.e., higher rates than recommended) with a constant rate between years. The overuse of chemical fertilizers in Vietnam threatens the sustainability of coffee farming [6]. In particular, local farming customs, with less organic fertilizers, made the soil chemical components become unbalanced and unable to regenerate [12,13]. Re-establishing the balance of chemical components, improving the organic properties of the replanted soil will help solve the mentioned problems [14].

There have been several methods applied to supplement the nutrient loss for replanted coffee plantations. Applying organic matter, including green manure and organic fertilizer has been proved to positively impact on soil organic matter. Organic fertilizer meets part of the crop's nutritional needs and creates favorable environment for soil microorganisms to develop. It provides growth stimulants for plants to grow and resist unfavorable conditions [15]. It also helps maintain the soil biological balance, as well as preventing the growth of harmful microorganisms in the soil through destruction, antagonistic and inhibiting mechanisms [16]. Intercropping is also an agricultural practice, which improves the organic matter in the soil. In this technique, two or several crops are planted in the same field simultaneously with the main crop to generate a wide variety of yields per land surface [17]. Many kinds of plant and tree have been studied and applied to intercrop with coffee such as palm trees, macadamia, banana [18–20]. Individual measures have the effect of improving one or several aspects of soil properties. It is necessary to develop an optimal combination of methods to improve the overall properties of the soil.

In the current work, separate measures including biochemical and organic treatments were applied to replanted coffee plantations. Survival rate, growth indicators and soil nutrient contents from the controls and treatments were monitored and compared during the experimental periods. From these results, a proposed model of fertility restoration of replanted land was built and applied on field site in Daklak province, Vietnam.

2. Materials and Methods

2.1. Site Characteristics

The experiment was carried out in Hoa Dong commune, Krong Pak district, Daklak province. Daklak province (12°40′ N, 108°03′ E, 400–800 m a.s.l), located at Central-Highlands in Vietnam, is the region with tropical highland monsoon climate having two distinct seasons a year with the average temperature 24.3 °C and average rainfall 1688 mm. The rainy season starts from May to October with 80–85% of annual rainfall and the dry season from November to April next year. The long dry season is a favorable condition for coffee plants to differentiate flower sprouts and concentrate bloom. Weather conditions of the Daklak province are suitable for coffee trees to grow, develop and get high yields [21]. There were no major climatic changes during the time the research was carried out.

Dak Lak province has a total natural land area of 1,308,474 ha divided into 8 main land groups, of which the red-yellow soil group accounts for 73.08% of the total natural land area of the province (956,218 ha). This is a suitable soil group for industrial crops in Dak Lak province, of which coffee is one of the main industrial crops of the province. Among the red-yellow soil group, there is the red-brown soil type developed on basalt with the largest area (290,049 ha), then yellow-red soil type on acid magma rock (249,649 ha), on clay and metamorphic rocks (230,543 ha) and light yellow soil on sandy sand (156,540 ha) [21]. The soil of the experimental area-Hoa Dong commune, Krong Pak district, Daklak province, is finely textured soil with the slope from 2 to 5% and has been classified as Fk (Reddish brown soils on basalt), which correlates with Acric Ferralsols according to World Reference Base for Soil Resources [22,23].

2.2. Materials

The original plants of *Coffea canephora* at 6-month age and plants of Mexican marigold (*Tagetes erecta*), at 2-weeks of age, were supplied by the Daklak province plant nursery. Coffee husk compost was made by mixing compost maker and other components, following the method described by NA Dzung and co-workers, and then incubating for 3 months before using [24]. Microbial organic fertilizer was purchased from Song Gianh Corporation, a popular fertilizer brand in Daklak province (Humidity: 30%; Organic matter: 15%; P_2O_5: 1, 5%; Humic Acid: 2, 5%; Secondary Nutrients: Ca, Mg, S; Useful Microorganisms: *Bacillus* 1×10^6 CFU/g, *Aspergillus* 1×10^6 CFU/g and *Azotobacter* 1×10^6 CFU/g). The green manure was the remains of leguminous (mung bean plants (*Vigna radiate*) and black bean plants (*Vigna cylindrical Skeels*)) after being harvested and Mexican sunflower plants (*Tithonia diversifolia*), which were collected from crop fields surrounding the experimental area.

2.3. Experimental Setup

The soil in replanted farms was separately applied 2 treatments including biochemical treatment (BCT) to improve soil chemistry, and organic treatment (OGT) to improve soil organic matter and physical properties. After that, proposed models of fertility restoration of replanted soil would be suggested based on the results of the 2 previous treatments (Figure 1).

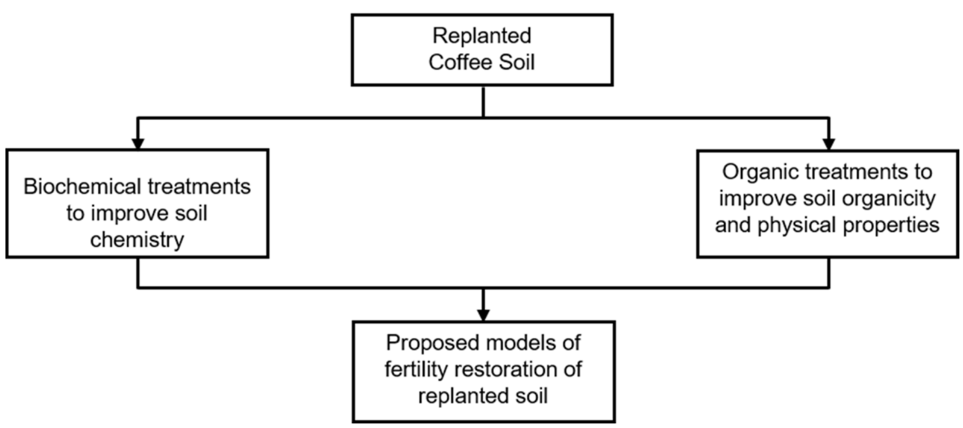

Figure 1. Flow chart of research on supplementing the loss of nutrient cycling for replanted coffee soil.

2.3.1. Biochemical Treatments to Improve Soil Chemistry

Biochemical treatments were conducted for 4 years from 2nd (2015) to 5th (2018) year using biochemical treatments to improve soil chemistry. The experiment was carried out in a randomized complete block design in coffee replanted plantations as follow: Treatments = 5; replication = 4; block area = 250 m^2; planting hole size = 3 m × 3 m. River tamarind (*Leucaena leucocephala*) trees were shade trees (existed before in the replanted coffee field) with spacing 6 m × 24 m and regulate the light in the replanted coffee field. Plants of Mexican marigold (*Tagetes erecta*) at 2-week age were planted with spacing 3 m × 0.25 m [25]. After being harvested flowers, the residual of marigold plants were cut down and left covering the soil. The soil of the five treatments was removed old coffee trees with their stumps and roots, ploughed and applied lime with the amount of 1.5 tons/ha, then solarized for 6 months in the first treating year and applied NPK fertilizers according to the procedure as follow: 60 kg N; 90 kg P_2O_5; 40 kg K_2O/ha (New planting; 1st year); 90 kg N; 90 kg P_2O_5; 90 kg K_2O/ha (2nd year); 115 kg N; 90 kg P_2O_5; 120 kg K_2O/ha (3rd year). This is the recommended amount given by Vietnamese Ministry of Agriculture and Rural Development based on the nutrient demand and nutrient uptake efficiency of *C. Canephora* [26]. The detail of each treatment was presented in Table 1.

Table 1. Biochemical treatments to improve soil chemistry.

Treatment	Description
BCT1	Crop new coffee plants in the 1st year; No biochemical treatment
BCT2	Crop Mexican marigold (*Tagetes erecta*) in the 1st year; Crop new coffee plants in the 2nd year; Apply 20 kg of manure/hole/year
BCT3	Intercrop Mexican marigold (*Tagetes erecta*) with new coffee plants in the 1st year; Apply 20 kg of manure/hole/year
BCT4	Intercrop Mexican marigold (*Tagetes erecta*) with new coffee plants in the 1st year; Apply 5 kg of microbial organic fertilizer/hole/year
BCT5	Intercrop Mexican marigold (*Tagetes erecta*) with new coffee plants in the 1st year; Apply 20 kg of coffee husk compost/hole/year

BCT, biochemical treatment.

2.3.2. Organic Treatments to Improve Soil Organic Matter and Physical Properties

In the organic treatments experiment, the remains of leguminous and Mexican sunflower (*Tithonia diversifolia*) were used as the green manure to improve soil organic matter and physical properties. The experiments were conducted for 4 years from 2nd (2015) to 5th (2018) year in a randomized complete block design in coffee replanted plantations as follow: treatments = 5; replication = 4; block area = 250 m^2; planting hole size = 3 m × 3 m. Coffee trees were grown under the weak-direct-sunlight regulated by shade trees River tamarind (*Leucaena leucocephala*) with spacing 6 m × 24 m (existed before in the replanted coffee field). The soil of the five formulations was removed old coffee trees with their stumps and roots, applied lime with the amount of 1.5 tons/ha, then solarized for 6 months in the first treating year and applied NPK according to the procedure as follow: 60 kg N; 90 kg P_2O_5; 40 kg K_2O/ha (New planting; 1st year); 90 kg N; 90 kg P_2O_5; 90 kg K_2O/ha (2nd year); 115 kg N; 90 kg P_2O_5; 120 kg K_2O/ha (3rd year). The detail of each treatment was presented in Table 2. Green manure was manually left covering on the soil (around the coffee trees) in OGT2 and OGT3 cases, or buried directly into the soil (in ditches near the coffee trees) in OGT4 and OGT5 cases. Lime was applied only before the last rake to avoid loss or unevenness. Bio-preparations were applied before planting.

Table 2. Organic treatments to improve soil organic matter and physical properties.

Treatment	Description
OGT1	No organic treatment
OGT2	Cover 10 kg of green manure/hole/year for the first 3 years
OGT3	Cover 15 kg of green manure/hole/year for the first 2 years
OGT4	Bury 10 kg of green manure/hole/year for the first 3 years
OGT5	Bury 15 kg of green manure/hole/year for the first 2 years

OGT, organic treatment.

2.4. Soil Characteristics

The organic matter was measured by the Walkey-Black method (potassium dichromate oxidation) [25]. The total nitrogen (N) was measured using the Kjeldahl method [27]. Available phosphorus (P) was extracted using the Mehlich III Extractant followed by quantification in a UV-Vis spectrophotometer [28]. Available potassium (K) was extracted by leaching NH_4OAc and analyzed by flame emission spectrometry [29].

2.5. Data Collection and Analysis

The survival rate of the coffee plants was determined by the following formulation,

$$\text{Survival rate (\%)} = \frac{\text{B-A}}{\text{A}} \times 100\% \quad (1)$$

where: A was the total of dead plants and plants with yellowing leaves and B was the total experimental plants.

Survival rate, tree height, stump diameter, canopy diameter and number of branch pairs were monitored, as well as soil properties were determined in every experimental year. Bean productivity was recorded in the last 2 experimental years. Differences in means between treatments were tested, by one-way ANOVA, with subsequent post comparisons of mean (LSD test, at $p = 0.05$). The data was aggregated and analyzed using the Statistic Analyze Software of Excel.

3. Results and Discussion

3.1. Proposed Techniques to Improve of Soil Chemistry

To improve the chemical properties of replanted soil, four biochemical treatments (BCT2 to BCT5) combining soil preparation, liming, intercropping with green manure, etc. were applied to compare to the control (BCT1). The survival rate and growth indicators of coffee plants in 3 years from second to fourth year as well as productivity of the third and fourth years were also monitored. Because of the correlations of survival rate and growth indicators between years, and the yield in the early years tended to be stable over time, the results of survival rate and growth indicators and fresh berry yield in the fourth year of cultivation were chosen to be presented in Table 3.

Table 3. Survival rate, growth rate and fresh berry yield by biochemical treatments.

Treatment	Survival rate (%)	Tree height (cm)	Stump diameter (cm)	Canopy diameter (cm)	No. of primary branch	No. of secondary branch	Fresh berry yield (kg/ha)
BCT1	72.0 ^{a}	116.5 ^{a}	2.83	185.6 ^{a}	13.0	6.9 ^{a}	6969.0
BCT2	81.3 ^{b}	121.4 ^{b}	3.59 ^{a}	192.3 ^{ab}	14.8 ^{a}	8.3 ^{ab}	8163.0 ^{a}
BCT3	80.0 ^{ab}	122.6 ^{b}	3.52 ^{a}	200.0 ^{bc}	15.1 ^{a}	7.8 ^{b}	8596.5 ^{b}
BCT4	82.5 ^{b}	127.9	3.78 ^{b}	205.6 ^{c}	15.4 ^{a}	8.2 ^{b}	8668.0 ^{b}
BCT5	80.0 ^{ab}	122.5 ^{b}	3.57 ^{ab}	199.7 ^{bc}	14.8 ^{a}	7.9 ^{b}	8453.5 ^{a}
$LSD_{0.05}$	5.61	4.92	0.24	9.04	0.68	0.63	378.21

BCT, biochemical treatment. LSD, Least significant difference. Means with the same letters are not statistically different based on the least significant difference at $p < 0.05$.

In general, treatments (from BCT2 to BCT5) had higher survival rate, growth indicators and fresh berry yield than the control (BCT1). In particular, although BCT2, BCT3, BCT4 and BCT5 were not statistically different to each other, BCT4 appeared to have the highest values of survival rate, growth indicators and fresh berry yield ($p < 0.05$).

To be able to identify how the four treatments (from BCT2 to BCT5) changed the soil chemistry compare to the control (BCT1), the main soil chemical components of soil after 4 years of coffee cultivation was analyzed including total organic matter, total nitrogen, available phosphorus and available potassium. The results were presented in Figure 2. For total organic matter, treatments (from BCT2 to BCT5) had higher values in range of 2.18–2.35% compared to BCT1 with 2.03%. All the treatments in the experiment were statistically different in the total nitrogen, in which BCT4 reached the highest values of 2.31‰ (p < 0.05). Similar to organic matter, available phosphorus values of treatments were higher than the control and ranged from 15.9 to 16.6 mg/100 g of soil. Among 4 chemical soil values, the treatments made the clearest changes in available potassium. The available potassium values of these treatments ranged from 11.7 to 13.4 mg/100 g of soil, while the control reached 10.3 mg/100 g of soil.

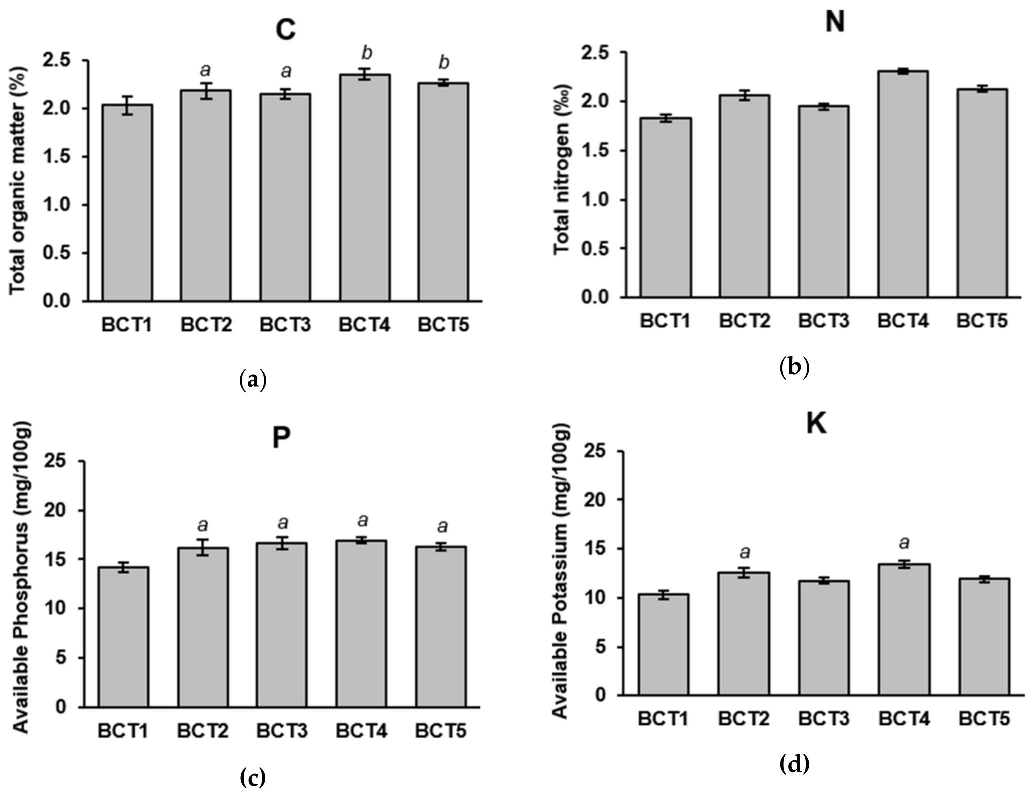

Figure 2. The contents of total organic matter (**a**), total nitrogen (**b**), available phosphorus (**c**) and available potassium (**d**) in the soil at the 4th cultivating year by biochemical treatments. BCT, biochemical treatment. Bars show means ± SD. Bars with the same letters are not statistically different based on the least significant difference at p < 0.05.

Between biochemical treatments, BCT4 and BCT5 appeared to have the highest index of survival rate, growth indicators and fresh berry yield (p < 0.05). In BCT4 treatment, old coffee trees with their stumps and roots were removed and soil was limed 1.5 tons/ha then solarized for the first 6 months, after that Mexican marigold (*Tagetes erecta*) was intercropped with new coffee plants for the next 6 months; during cultivating, microbial organic fertilizer was applied with 5 kg/hole/year and NPK were applied according to the governmental recommended procedure. Compared to the control (BCT1), the liming and intercropping contributed to the soil fertility. Indeed, liming has been a traditional practice, often applied to soils to restore Calcium and Magnesium availability for plants and adjust soil acidity [30,31]. Intercropping has been proven to enhance soil quality by integrating organic materials from the trees or crops into the soil, resulting in an improvement of both physical (porosity) and chemical soil properties (soil pH, enzymes) [32]. Moreover, Mexican marigold intercropping was reported to help reduce nematodes and other pathogenic microorganisms, leading to the improvement in survival rate and growth indicators of the coffee trees [9,33,34]. When BCT4 treatment was designed, microbial organic fertilizer was expected to have effective impacts on soil properties due to the previous results [35,36]. However, the result in the current research showed a quite faint role of microbial organic fertilizer on soil property improving. This might due to the low treated amount of microbial organic fertilizer used (5 kg of microbial organic fertilizer/hole/year compared to 20 kg of manure or coffee husk compost/hole/year). Despite this, microbial organic fertilizer still has been expected to improve soil properties in long term treating. In BCT5, 20 kg of coffee husk compost was applied instead of 5 kg of microbial organic fertilizer in BCT4. A low or medium dose of compost, applied with green manure, was reported to be a viable alternative for the nutrition of coffee plantations. The result of BCT5 in this study is consistent with the previous study [11]. Between BCT4 and BCT5, BCT4 appears to be more dominant in terms of survival rate, growth indicators and soil nutrient components. This may be due to the contents of available nutrients in microbial organic fertilizer being higher and better in meeting the nutrient demands of the coffee plants, comapred to the coffee husk compost. From the results of biochemical treatments, BCT4 which intercroped Mexican marigold (*Tagetes erecta*) with new coffee plants in the first year and applied 20 kg of coffee husk compost/hole/year was the chosen technique to improve the soil chemistry of replanted coffee fields.

3.2. Proposed Techniques to Improve of Soil Organic Matter

Due to the long-term monoculture and intensive cultivation of coffee, using amount of high primary-, less secondary- and almost no trace-element chemical fertilizers, as well as no organic fertilizers, the soil chemical components have become unbalanced and not regenerated, leading to changes in the chemical, physical and biological properties in a way that is unfavorable for Robusta coffee in the next cycle. Organic treatments such as covering and burring green manure techniques were applied to improve the organic matter of replanted soil. The brief results, including survival rate, growth indicators and fresh berry yield in the fourth year of cultivation were presented in Table 4.

Table 4. Survival rate, growth rate and fresh berry yield by organic treatments.

Treatment	Survival Rate (%)	Tree Height (cm)	Stump Diameter (cm)	Canopy Diameter (cm)	No. of Primary Branch	No. of Secondary Branch	Fresh Berry Yield (kg/ha)
OGT1	71.3 ^{a}	115.9	2.73	187.6	13.0	6.5	6869.5
OGT2	77.5 ^{ab}	123.2 ^{a}	3.20 ^{a}	194.2 ^{a}	14.4 ^{a}	7.7 ^{a}	7580.5 ^{a}
OGT3	78.8 ^{b}	123.6 ^{a}	3.23 ^{a}	198.5 ^{a}	14.7 ^{ab}	7.9 ^{ab}	7949.8 ^{a}
OGT4	78.7 ^{b}	129.6 ^{b}	3.20 ^{a}	204.7 ^{b}	15.7 ^{b}	8.5 ^{b}	8019.0 ^{ab}
OGT5	86.2	130.0 ^{b}	3.42	205.4 ^{b}	15.9 ^{b}	8.6 ^{b}	8283.5 ^{b}
$LSD_{0.05}$	*3.67*	*2.92*	*0.09*	*2.97*	*0.61*	*0.36*	*350.16*

OGT, organic treatment. LSD, Least significant difference. Means with the same letters are not statistically different based on the least significant difference at $p < 0.05$.

There was a clear contrast between groups with and without green manure treatment. All groups covering or burying green manure had higher survival rates, growth indicators, and fresh berry yields than the control. However, there was no statistical difference between green manure treatments in this index ($p < 0.05$).

The main soil chemical components of soil after 4 years of coffee cultivation including total organic matter, total nitrogen, available phosphorus and available potassium were identified so that it could be analyzed how the four treatments (from OGT2 to OGT5) affected the soil chemistry compare to the control (OGT1) (Figure 3).

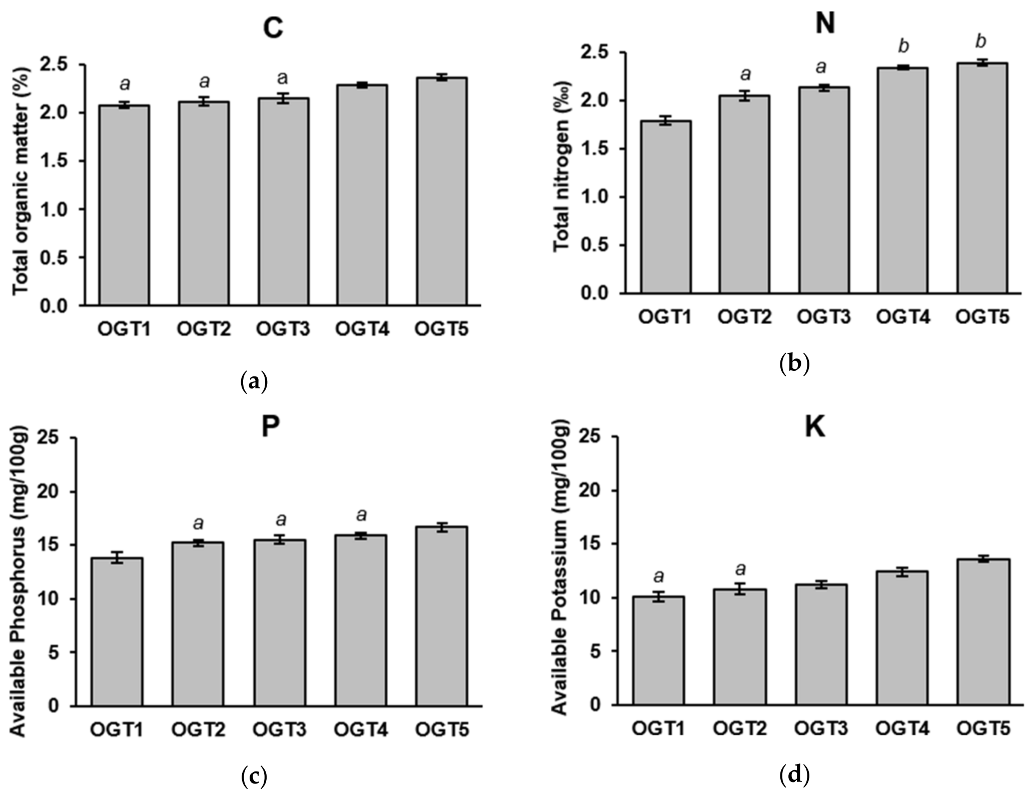

Figure 3. The contents of total organic matter (**a**), total nitrogen (**b**), available phosphorus (**c**) and available potassium (**d**) in the soil at the 4th cultivating year by organic treatments. OGT, organic treatment. Bars show means ± SD. Bars with the same letters are not statistically different based on the least significant difference at $p < 0.05$.

The evaluation of coffee soil, showed that after 4 years of implementing organic complementary solutions for coffee growing soil by green manure treating, quite clearly showed an increase in the total organic matter (from 2.08 up to 2.37%), total nitrogen (from 1.792 up to 2.39‰), available phosphorus (from 13.8 up to 16.7 mg/100 g of soil) and available potassium (from 10.1 up to 13.6 mg/100 g of soil). Among the treatments, OGT5 which was buried 15 kg of green manure/hole/year for the first 2 years seemed to be the best organic treatment with the highest values of the 4 observed chemical index.

Besides intercropping of short-term crops with coffee, covering or haft burying crop cutting and pruning residues on/into the soil have also been useful techniques in improving the organic properties of soil [37,38]. The results of plant survival rates, growth indicators and soil main components from organic treatment experiments (OGT2 to OGT5) compared to the control (OGT1) reaffirmed this fact. A closer look at the results between organic treatment samples showed that burying green manure into the soil improved plant survival rate, growth indicators and soil properties better than covering. Composting might occur faster and the decomposition products could concentrate better for the coffee plants when the green manure was buried in the soil. However, the differences between the treatments that buried green manure (OGT4 and OGT5) were insignificant. Therefore, both OGT4 and OGT5 could be the chosen techniques to improve the soil organic matter of replanted coffee fields.

In summary, the current study examined and compared the effects of the two treatments including biochemical treatments and organic treatments on supplementing the loss in nutrient cycling for replanted coffee soil. Total organic matter within the soil contains all of the essential plant nutrients hence serves as a storehouse of plant nutrients and as an agent to improve soil structure, maintain tilt and minimize erosion also [39]. However, total organic matter contents of all biochemical treated soils and organic treated soils were lower than the expected range of 3–10% [40].

This is mainly due to the long-term monoculture of coffee trees with less or almost no organic matter supplying. A positive sign was that although the total organic matter of the soil after 4 years been treated had not reached 3%, it has been on the rise. Organic matter accumulation is a long process. Therefore, in order to recover the chemical and organic properties of replanted soil, the rate of organic matter addition from crop residues, manure and any other sources must be higher than the rate of decomposition, and take into account the rate of uptake by plants and losses by leaching and erosion.

4. Conclusions

Biochemical and organic treatments, of which liming, short-term crop intercropping, microbial organic fertilizer and green manure covering/burying were applied, helped improving coffee plant growth indicator and survival rates. The soil main components including total organic matter, nitrogen and available phosphorous, potassium of treated samples were increased compared to the controls. Among the treatments, the organic treatments OGT4, OGT5 and the biochemical treatment BCT4 performed the best effects on the fertilities of replanted coffee soil. Based on these, the proposed procedure to improve replanted soil fertility for coffee cultivation in Daklak province, Vietnam was suggested as follow: In the first year, remove old coffee trees with their stumps and roots; liming 1.5 tons/ha; solarize soil for the first six months; Intercrop Mexican marigold *(Tagetes erecta)* with new coffee plants for the next six months; from the second year, apply 5 kg of microbial organic fertilizer /hole/year; bury 30 kg of green manure/hole/2–3 years; apply NPK according to the governmental recommended procedure. Although the proposed procedure combined the best results of the biochemical and organic treatments, the interaction between the two techniques affect soil properties when applied together should be carefully examined. In the first cultivating year in particular, the remainder of marigold (in biochemical treatment) is cut down and becomes green manure covering the soil surface. Hence, the application of green manure (in organic treatment) should be adjusted so that the total applied green manure does not exceed the needs of the coffee plants, which can increase the potential for environmental pollution from the high level of P. Moreover, the effects of the proposed procedure on the quality coffee beans should also be further investigated.

Author Contributions: Conceptualization, N.T.T.L. and T.T.P.; methodology, T.T.P.; software, T.D.L.; validation, N.H.N.; formal analysis, P.N.D.Y.; investigation, N.T.T.L.; resources, T.T.P.; data curation, P.N.D.Y.; writing—original draft preparation, N.H.N.; writing—review and editing, N.T.T.L.; visualization, T.D.L.; supervision, N.T.T.L.; project administration, T.D.L.; funding acquisition, P.N.D.Y. All the authors have read and agreed to the published version of the manuscript.

Funding: This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

Acknowledgments: In this section you can acknowledge any support given which is not covered by the author contribution or funding sections. This may include administrative and technical support, or donations in kind (e.g., materials used for experiments).

Conflicts of Interest: The authors declare there are no conflicts of interest.

References

1. Schröder, J.; Schulte, R.; Creamer, R.; Delgado, A.; Van Leeuwen, J.; Lehtinen, T.; Rutgers, M.; Spiegel, H.; Staes, J.; Tóth, G. The elusive role of soil quality in nutrient cycling: a review. *Soil Use Manag.* **2016**, *32*, 476–486.
2. Wintgens, J.N. *Coffee: Growing, Processing, Sustainable Production. A Guidebook for Growers, Processors, Traders, and Researchers*; WILEY-VCH Verlag GmbH & Co. KGaA: Weinheim, Germany, 2004.
3. Molin, J.P.; Motomiya, A.V.d.A.; Frasson, F.R.; Faulin, G.D.C.; Tosta, W. Test procedure for variable rate fertilizer on coffee. *Acta Sci. Agron.* **2010**, *32*, 569–575.
4. Melke, A.; Ittana, F. Nutritional requirement and management of Arabica Coffee (Coffea arabica L.) in Ethiopia: national and global perspectives. *J. Exp. Agric. Int.* **2015**, *5*, 400–418.

5. Sanchez, P.A. *Properties and Management of Soils in the Tropics*; Cambridge University Press: Cambridge, UK, 2019.
6. Byrareddy, V.; Kouadio, L.; Mushtaq, S.; Stone, R. Sustainable Production of Robusta Coffee under a Changing Climate: A 10-Year Monitoring of Fertilizer Management in Coffee Farms in Vietnam and Indonesia. *Agronomy* **2019**, *9*, 499, doi:10.3390/agronomy9090499.
7. Shahbandeh, M. World's largest coffee producing countries in 2018 (in 1,000 60 kilogram bags). In *Largest Coffee Producing Countries 2018*; Statista: Hamburg, Germany, 2019.
8. Thuy, P.T.; Niem, L.D.; Ho, T.M.H.; Burny, P.; Lebailly, P. Economic Analysis of Perennial Crop Systems in DakLak Province, Vietnam. *Sustainability* **2019**, *11*, 81, doi:10.3390/su11010081.
9. Giang, B.L.; Nguyen, N.H.; Yen, P.N.D.; Hoang, V.D.M.; Ha, B.T.L.; Le, N.T.T. Combination of Mycorrhizal Symbiosis and Root Grafting Effectively Controls Nematode in Replanted Coffee Soil. *Plants* **2020**, *9*, 555.
10. Tiemann, T.; Aye, T.M.; Dung, N.D.; Tien, T.M.; Fisher, M.; de Paulo, E.N.; Oberthür, T. Crop nutrition for Vietnamese Robusta coffee. *Better Crop. Plant Food* **2018**, *102*, 20–23.
11. Martins Neto, F.L.; Peralta-Antonio, N.; De Paula Pimenta, M.; Pinto Coelho Evangelista, J.S.; Silva Santos, R.H. Soil chemical characteristics on coffee plantations fertilized with continuous application of compost and green manure. *Commun. Soil Sci. Plant Anal.* **2020**, *51*, 829–838.
12. Zhao, Q.; Xiong, W.; Xing, Y.; Sun, Y.; Lin, X.; Dong, Y. Long-Term Coffee Monoculture Alters Soil Chemical Properties and Microbial Communities. *Sci. Rep.* **2018**, *8*, 11, doi:10.1038/s41598-018-24537-2.
13. Velmourougane, K. Impact of Organic and Conventional Systems of Coffee Farming on Soil Properties and Culturable Microbial Diversity. *Scientifica (Cairo)* **2016**, *2016*, 9, doi:10.1155/2016/3604026.
14. Chemura, A. The growth response of coffee (Coffea arabica L) plants to organic manure, inorganic fertilizers and integrated soil fertility management under different irrigation water supply levels. *Int. J. Recycl. Org. Waste Agric.* **2014**, *3*, doi:10.1007/s40093-014-0059-x.
15. Pampuro, N.; Caffaro, F.; Cavallo, E. Reuse of animal manure: A case study on stakeholders' perceptions about pelletized compost in northwestern Italy. *Sustainability* **2018**, *10*, 2028.
16. Oka, Y. Mechanisms of nematode suppression by organicsoil amendments. *Appl. Soil Ecol.* **2010**, *44*, 15, doi:10.1016/j.apsoil.2009.11.003.
17. Harelimana, A.; Goff, G.L.; Rukazambuga, D.T.N.; Hance, T. Coffee Production Systems: Evaluation of Intercropping System in Coffee Plantations in Rwanda. *J. Agric. Sci.* **2018**, *10*, 12, doi:10.5539/jas.v10n9p17
18. Van Asten, P.J.; Wairegi LW, I.; Mukasa, D.; Uringi, N.O. Agronomic and economic benefits of coffee–banana intercropping in Uganda's smallholder farming systems. *Agric. Syst.* **2011**, *104*, 326–334, doi:10.1016/j.agsy.2010.12.004.
19. Perdoná, M.J.; Soratto, R.P. Higher yield and economic benefits are achieved in the macadamia crop by irrigation and intercropping with coffee. *Sci. Hortic.* **2015**, *185*, 8, doi:10.1016/j.scienta.2015.01.007.
20. L.S.Moreira, S.; V.Pires, C.; E.Marcatti, G.; H.S.Santos, R.; M.A.Imbuzeiro, H.; B.A.Fernandes, R. Intercropping of coffee with the palm tree, macauba, can mitigate climate change effects. *Agric. For. Meteorol.* **2018**, *256–257*, 12, doi:10.1016/j.agrformet.2018.03.026.
21. Daklak-Provincial-People's-Committee. Daklak Overview. Availabe online: https://daklak.gov.vn/web/english/about-daklak (accessed on 29 November 2019).
22. Wrb, I.W.G. World reference base for soil resources 2014, update 2015: International soil classification system for naming soils and creating legends for soil maps. In *World Soil Resources Reports*; Fao: Rome, Italy, 2015; p. 192.
23. Berding, F.; Tan, T.; Tuyen, T.; Hue, T.; Deckers, J.; Langohr, R. Soil Resources of Dak Lak Province. In *Correlation with the World Reference Base for Soil Resources. KU Leuven University, Belgium, Internal Project Report—NIAPP-KULeuven, Land Evaluation for Land Use Planning and Development of Sustainable Agriculture in South Vietnam*; International Soil Reference and Information Centre ISRIC: Wageningen, Netherlands, 1999.
24. Dzung, N.A.; Dzung, T.T.; Khanh, V.P. Evaluation of coffee husk compost for improving soil fertility and sustainable coffee production in rural central highland of Vietnam. *Resour. Environ.* **2013**, *3*, 77–82.
25. Sato, J.H.; Figueiredo, C.C.d.; Marchão, R.L.; Madari, B.E.; Benedito, L.E.C.; Busato, J.G.; Souza, D.M.d. Methods of soil organic carbon determination in Brazilian savannah soils. *Sci. Agric.* **2014**, *71*, 302–308.
26. Center, N.A.E. *Good Agricultural Practices for Robusta Coffee Production*; Vietnamese Ministry of Agriculture and Rural Development: Hanoi, Vietnam, 1999.

27. Zhixiang, W.; Guishui, X.; Zhongliang, T. Characteristics of soil organic carbon and total nitrogen in rubber plantations soil at different age stages in the western region of Hainan Island. *Agric. Sci. Technol.* **2010**.
28. Eriksson, A.K.; Ulén, B.; Berzina, L.; Iital, A.; Janssons, V.; Sileika, A.; Toomsoo, A. Phosphorus in agricultural soils around the Baltic Sea–comparison of laboratory methods as indices for phosphorus leaching to waters. *Soil Use Manag.* **2013**, *29*, 5–14.
29. Rees, G.L.; Pettygrove, G.S.; Southard, R.J. Estimating plant-available potassium in potassium-fixing soils. *Commun. Soil Sci. Plant Anal.* **2013**, *44*, 741–748.
30. Carvalho, M.C.S.; Van Raij, B. Calcium sulphate, phosphogypsum and calcium carbonate in the amelioration of acid subsoils for root growth. *Plant Soil* **1997**, *192*, 12, doi:10.1023/A:1004285113189.
31. A., C.R.; J.S., T.; P., E.; M., T.M.; A., M.; A., N. Phosphate Sorption Characteristics of Andosols of the Volcanic Highlands of Central African Great Lakes Region. *J. Environ. Sci. Eng. A* **2013**, *2*, 8.
32. Wang, Z.-g.; Bao, X.-g.; Li, X.-f.; Jin, X.; Zhao, J.-h.; Sun, J.-h.; Christie, P.; Li, L. Intercropping Maintains Soil Fertility in Terms of Chemical Properties and Enzyme Activities on a Timescale of One Decade. *Plant Soil* **2015**, *391*, 18, doi:10.1007/s11104-015-2428-2
33. Hethelyi, E.; Danos, B.; Tetenyi, P.; Koczka, I. GC-MS analysis of the essential oils of four tagetes species and the anti-microbial activity of Tagetes minuta. *Flavour Fragr. J.* **1986**, *1*, 169–173.
34. Soule, J. Tagetes minuta: A potential new herb from South America. In *New Crops*; Wiley: New York, NY, USA, 1993; pp. 649–654.
35. Dung, P.T.; Dok, Y.N.H. Microbial organic fertilizer application for safe coffee production at Daklak, Vietnam. *Int. Soc. Southeast Asian Agric. Sci.* **2009**, *15*, 10.
36. Dawid, J. Organic Fertilizers Requirement of Coffee (Coffea Arabica L) Review. *Int. J. Res. Stud. Agric. Sci.* **2018**, *4*, 8, doi:10.20431/2454-6224.0407003.
37. Martins, B.H.; Araujo-Junior, C.F.; Miyazawa, M.; Vieira, K.M. Humic substances and its distribution in coffee crop under cover crops and weed control methods. *Soils Plant Nutr.* **2016**, *73*, 8, doi:10.1590/0103-9016-2015-0214.
38. Matos, E.d.S.; Mendonça, E.d.S.; Cardoso, I.M.; Lima, P.C.d.; Freese, D. Decomposition and nutrient release of leguminous plants in coffee agroforestry systems. *Rev. Bras. Ciência Solo* **2011**, *35*, 141–149.
39. Bot, A.; Benites, J. *The Importance of Soil Organic Matter_Key to Drought-Resistant Soil and Sustained Food Production*; Food and Agriculture Organization of The United Nations: Rome, Italy, 2005; p. 78.
40. Araújo, L.G.; Figueiredo, C.C.d.; Borges, I.B.; Ramos, M.L.G.; Rocha, O.C.; Guerra, A.F. Organic matter fractions in soil under coffee with split applications of phosphorus and water regimes. *Rev. Bras. Eng. Agríc. Ambient.* **2014**, *18*, 6, doi:10.1590/1807-1929/agriambi.v18n10p1017-1022.