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Forschungsinstitut für biologischen Landbau
Institut de recherche de l'agriculture biologique
Research Institute of Organic Agriculture
Istituto di ricerche dell'agricoltura biologica
Instituto de investigaciones para la agricultura orgánica

Recommendations for application of coffee pulp biochar in Vietnamese coffee plantations



Michael Scheifele
Andreas Gattinger

Subproject of

"Pyrolysis Based Coffee Drying in Vietnam"

All activities are based on:

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FiBL Schweiz / Suisse
Ackerstrasse, CH-5070 Frick
Tel. +41 (0)62 865 72 72
info.suisse@fibl.org, www.fibl.org

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1. Introduction

The Vietnamese coffee sector is facing several environmental and economic challenges calling for concrete changes also on the technology side of coffee processing, in particular the drying of coffee cherries. Vietnam went through a dramatic increase in coffee production over the last decade, making the country the world's second largest coffee producer and exporter, after Brazil. However, drought, frost, unpredictable rainfall patterns, declining soil fertility and ground water overuse combined with fluctuating prices on international markets and cost pressure have already led to a substantial decrease of exports {Nguyen, 2016 #1908}. In this context the drying of the coffee cherries plays a crucial and multiple role. Presently there is a major change ongoing away from traditional sun drying to artificial bed or tower driers using coffee husks as heat source. However, these current burners are very inefficient and cause heavy smoke exposure with a negative effect on the quality of the coffee beans. At this point pyrolysis can be introduced as a technology with high potential and high adaptability to tackle these problems, since it valorizes agricultural waste (like coffee husks) providing two main products: clean heat, which can be used for drying purposes, and biochar, which can be applied as soil enhancer for reducing the high fertilizer application rates {Lehmann, 2007 #303;Verheijen, 2010 #166}.

The purpose of the ongoing project "Pyrolysis Based Coffee Drying in Vietnam" is to support the market introduction of pyrolysis technology into the Vietnamese agricultural sector with a focus particularly on coffee cherry drying, including technology transfer, local manufacturing and pilot implementations. These steps are accompanied and implemented with a process which integrates all relevant actors and stakeholders on farm and processing level.

The current subproject concentrates on the possible best use of the produced biochar in coffee plantations. Therefore an overview on soil characteristics and agricultural management in coffee plantations is given. In combination with an experimental evaluation of biochar soil mixtures, the most promising way to use biochar in the coffee plantation is assessed, and proposals for the implementation of coffee pulp biochar into the current coffee plantation management are made.

1.1 Project aims

This is a complementary project to "Pyrolysis Based Coffee Drying in Vietnam" evaluating the best use of coffee pulp biochar for coffee farming systems

The objective of this project is to 1) improve knowledge about the agricultural management of coffee plantations and 2) to assess soil and biochar characteristics, and to propose a safe use of the produced biochar in coffee plantations as well as 3) to make further suggestions for field- or farm-scale experiments.

2. Materials and methods

Assembling site characteristics

Geography, geology and soil characteristics

Geography, geology and soil characteristics in the Buon Ma Thuot region were adapted from {Berding, 1999 #1907} and summarized.

Coffee plantation and management

Knowledge of plantation characteristics, agricultural management on site as well as production and preferred use of biochar was achieved by interrogation via email, the results are summarized.

Soil and Biochar analysis

Soil and Biochar total organic carbon (C_{org}) and N content was assessed by a CN analyzer, Jena, Germany. Soil and Biochar pH and WHC were determined during the experiment as described below. Biochar total content of all elements heavier than Natrium were obtained by XRF. Further analyses for whole biochar characteristics were conducted by third party laboratories in Germany and Vietnam (Annexes 4 and 5).

Experimental

The top 10 cm of soil from a Coffee plantation in Buon Ma Thuot was sampled and sieved (2mm). Biochar was sampled right from the production site, air dried and milled. Biochar was mixed into the soil at 0.375,1.5, 3.75, 7.5 and 15 % (m/m) dry mass, that corresponds to a biochar amendment rate of 0, 5, 20, 50, 100, 200 t/ha, respectively. The mixtures were incubated at 20°C for 10 days and then measured for pH and WHC after FiBL internal protocols.

3. Results

Site characteristics

Geography

The region Buon Ma Thuot sits upon a basaltic plateau with deep red soils. Coffee, pepper and rubber plantations constitute the economic heart of Dak Lak Province. The topography varies from gently undulating to steeply dissected. The altitude ranges roughly from 900 m in the Northeast to about 350 m in the Southwest. The average annual rainfall varies from 1400 to 1800 mm, the South and Southwest receiving more rain (1600-1800 mm) than the North and Northeast (1400-1600 mm). Average monthly temperatures in January range from 18-19 °C in the North to 20-21 °C in the lower lying areas in the South, those of July from 22-23 in the North to 23-24 in the South. The average length of the dry season is about 4.5 to 5 months from November to April.

Soil

Soils of the high plateau area are classified as Fk (Reddish brown soils on basalt) with soil depth generally in class 1 (>100cm). These soils are correlated with the World Reference Base for soils (WRB) reference group of Ferralsols because of the presence of a ferralic horizon, the main characteristic of which is a dominance of low activity clay (CEC clay of <16 cmol+/kg). Because these soils generally meet the clay increase requirements of an argic horizon and a base saturation of <50%, the principal lower level unit would be an Acric Ferralsol. Other qualifiers such as “vetic” (<6 cmol+/kg clay of exchangeable bases plus exchangeable acidity), “humic” (weighted organic carbon content >1.4% in upper 100 cm, presence of an umbric surface horizon) and “rhodic” (dominant dark red colours) may also frequently be found. In the narrow transition zone from higher to lower plateau, the parent material (porous basaltic rock) may be present at shallow depth or even outcrop, giving rise to Eutric Leptosols, Luvisols, Lixisols and possibly Phaeozems. These latter soils occupy very small areas only. On the high plateau a number of isolated hills have been identified which seem to correspond to volcanic hills. They also occupy a very modest area and the soils on them are usually rather shallow.

Agricultural management in coffee plantations

In the coffee plantations coffee trees are planted every 25-30 years in the early rainy season in May/June in rows about 3 m from each other, the planting density is about 1000-1100 trees per ha. In between two coffee plants other crops like pepper are grown. Each coffee tree stands in a cavity of around 1.5 to 2 m diameter and 30 cm depth, the cavity prevents water runoff during watering. Watering rounds are conducted with a sprinkler system every 25- 30 days, depending on weather conditions. Approximately 450-500 l water are applied for each tree per round. Various mineral and organic fertilizers are applied in 3 rounds per year, mostly in form of fertigation simultaneously with the water applications in May, July and September, i.e. in the cavities (Table 1). The first fertilizer application is in the early wet season during May, early June. The 2^{nd} and 3^{rd} applications take place in the following watering rounds.

Table 1 Fertilizer management

Inputs of different fertilizers used in the Vietnamese coffee plantations. Three rounds of fertilization take place during the growing period from May to November. The principal fertilization consists of mineral fertilizers supplemented by organic fertilizers depending on availability.

Round (month)	**1 (May)**	**2 (July)**	**3 (September)**
Fertilizer*			
NPK (w/w/w)	300 kg/ha (16/16/8)	300 kg/ha (16/16/8)	300 kg/ha (16/8/16)
Urea	If avail.	If avail.	If avail.
Potassium 60%	250 kg/ha	250 kg/ha	250 kg/ha
Fused phosphate	1000 kg/ha		
Liquid (bio-king)	-	10 l/tree	-
Microbial fertilizer (unknown)	-	-	1000 kg/ha
Compost**	8 m^3/ha	-	-

*The amounts correspond to the product applied

**Compost is made from cow manure and on-farm residues

Biochar availability

In one year, around 2.4t/ha green beans are produced, this corresponds to 0.75 t/ha coffee pulp biochar. The biochar further is regarded by the people as a high value fertilizer, thus they intend to use the biochar rather for pepper and durian plants as those are seen to be more valuable than coffee.

Biochar characteristics

Nutrient content

The produced coffee pulp biochar is a very nutrient rich biochar (Table 2 and 3). It further has a high ash content of 35% (Annex 4) which explains its high pH. Most of this ash (8% of the biochar) is pure potassium. Further, it is quite rich in Sulphur (S) and nitrogen (N) and carries significant amounts of micronutrients which could be of nutritional value if plant-available. The specific amounts of the most important plant nutrients that would be incorporated into soil are displayed in table 4.

Table 2: Biochar macronutrients

List of macronutrients elemental content in coffee pulp biochar in permille.

N (‰)	P (‰)	K (‰)	Ca (‰)	S (‰)	Mg (‰)
18.9	2.9	81.3	11.3	5.1	5.9

Table 3: Biochar micronutrients

List of micronutrients elemental content in coffee pulp biochar in permille.

Fe (‰)	Mn (‰)	Zn (‰)	Cu (‰)	Co (‰)	Mo (‰)	B (‰)
2.8	0.018	0.035	0.028	0.028	- *	- **

*Molybdenum (Mo)) was below detection limit < 0.05 $\mu g g^{-1}$

**Boron (B) was not measured

Table 4: Nutrient* input by biochar application

Input of macronutrients by biochar application per hectare. The nutrient input correspond to input for each chemical in its elemental form

Sample	Biochar t/ha	Biochar (w/w) ‰	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	S (kg/ha)
BC5	5	3.75	95	15	407	43	22	19
BC20	20	15	379	58	1626	170	89	77
BC50	50	37.5	948	146	4065	426	222	193
BC100	100	75	1895	292	8130	851	444	386
BC200	200	150	3790	584	16260	1703	889	771

Soil pH and water holding capacity

The soil had an organic carbon concentration of 2.32 % C and a total nitrogen concentration of 0.17 % N. The pH of the soil and biochar mixtures (Figure 1) shows a steady increase in pH towards the pH of the biochar itself. The pH for best plant physiological performance ranges between 6.5 and 7.0 as indicated in figure 1.

The water holding capacity of the biochar itself is about twice that of the soil (Figure 2). The WHC increases slowly with increasing biochar content. Figure 2 shows a jump in WHC increase from 100 t/ha to 200 t/ha. This result might be biased.

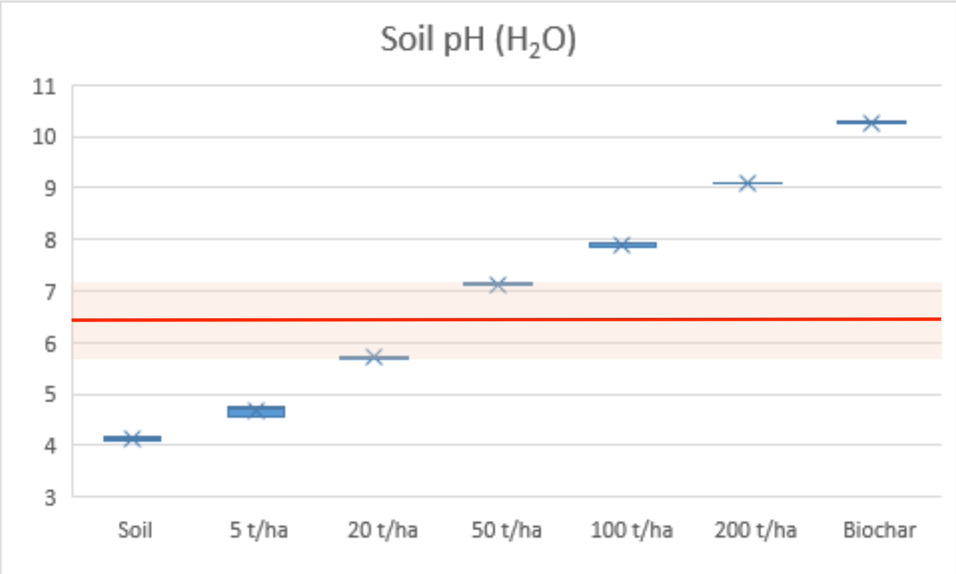

Figure 1: Soil pH (measured in demineralized water) of a soil from a plantation in the Buon Ma Thuot region in Vietnam amended at different rates of coffee pulp biochar and biochar itself. Nutrient availability is generally at an optimum in the red shaded part of the figure, the red line depicts the ideal soil pH.

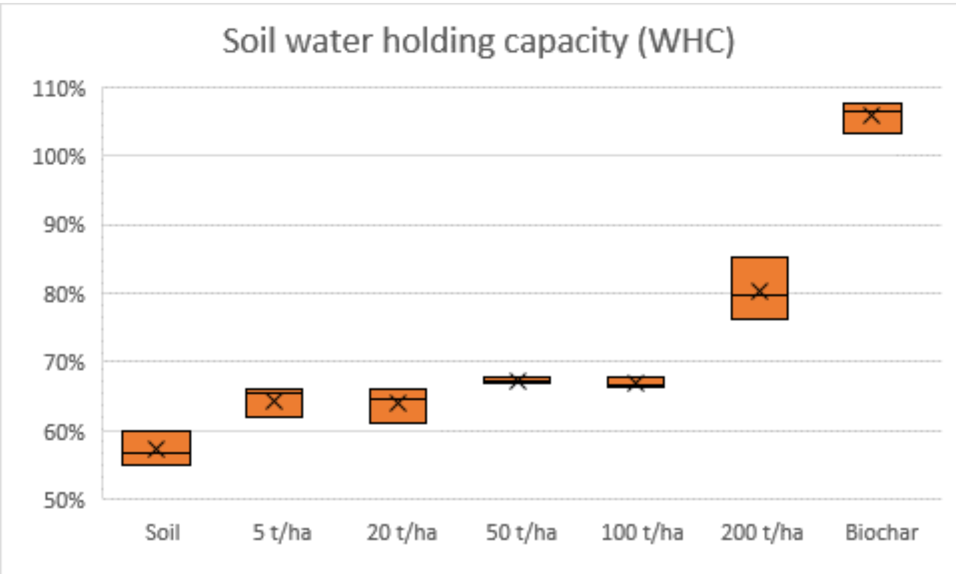

Figure 2: Soil water holding capacity (WHC) of a soil from a plantation in the Buon Ma Thuot region in Vietnam, the same soil amended at different rates of coffee pulp biochar and the biochar itself.

4. Discussion

Coffee pulp biochar as fertilizer

The coffee pulp biochar is rich in nutrients. Nutrients needed in large amounts by plants are referred to as macronutrients and include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) {Havlin, 2005 #1909}. Elements that plants need in trace amounts are called micronutrients. Micronutrients are not major components of plant tissue but are essential for growth {Havlin, 2005 #1909}. They include iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), cobalt (Co), molybdenum (Mo), and boron (B). Except for Mo, all these nutrients are present in the coffee pulp biochar.

How far biochar nutrients are plant available depends on the configuration in which the nutrient is present in the biochar. This is still under research. Elements that may form covalent bindings with carbon like N and S may be partly present as heteroatoms in the carbon backbone of the biochar and thus become available only by biochar decay. Because of high recalcitrance of biochar in soil, the nutrients present as heteroatoms can be regarded as unavailable. If present in other forms like oxides and hydrates, nutrient availability depends more on physical accessibility and transfer within the biochar backbone. Recent research suggest that biochar N, P and S can be partly available {Scheifele, 2017 #1906}, but actual forms and mechanisms how these nutrients are transferred to plants are unknown. Elements that mostly form salts in nature, like K, Ca, Mg and all micronutrients are regarded to be present in their cation forms in biochar {Chan, 2009 #498}. In this form they can migrate from biochar into soil solution and are regarded as the main cause of biochar liming effect {Verheijen, 2010 #166}. These nutrients can be regarded as nearly fully plant available.

In conclusion one must be cautious by interpreting the fertilization value of biochar based on its N, P and S content. In order to evaluate the fertilization value of coffee pulp biochar with respect to N, P and S, systematic experimentations on site would be necessary. But it is safe to say that about 10% of biochar N, P and S are plant available {Scheifele, 2017 #1906}. In contrast, one can rely that the biochar K, Ca, Mg and micronutrient content is plant available {Chan, 2009 #498}.

Regarding the coffee pulp biochar, one has to point out the exceptional high amounts of K. As K is present in biochar in its soluble form K^+, it can be regarded as directly available to plants. Thus the coffee pulp biochar can be regarded as a potent K fertilizer along with significant amounts of other plant macro- and micronutrients.

Coffee pulp biochar as a soil pH conditioner

The red-brownish Ferralsol soils of the Buon Ma Thuot region are rich in nutrients but are extremely acidic, with a pH (H_2O) of 4.1. Plants growing in acidic soils can experience a variety of symptoms including (Al), (H), and/or manganese (Mn) toxicity, as well as nutrient deficiencies of calcium (Ca) and magnesium (Mg). Al toxicity is the most widespread problem in acidic soils, and dissolved Al^{3+} is toxic to plants; Al^{3+} is most soluble at low pH, above pH 5.2 little Al is in soluble form in most soils. Aluminum inhibits root growth; lateral roots and root tips become thickened and roots lack fine branching; root tips may turn brown {Havlin, 2005 #1909}.

Both macronutrient and micronutrient availability are affected by soil pH. In slightly to moderately alkaline soils, molybdenum and macronutrient (except for phosphorus) availability is increased, but P, Fe, Mn, Zn, Cu, and Co levels are reduced and may adversely affect plant growth. In acidic soils, micronutrient availability (except for Mo and Bo) is increased. Mineral N will have the highest concentrations in soil with pH 6–8. Concentrations of available N are less sensitive to pH than concentrations of available P. Availability of P is optimum in a pH range between 6.0 and 7.5. If pH is lower than 6, P starts forming insoluble compounds with iron (Fe) and aluminium (Al), and if pH is higher than 7.5, P starts forming insoluble compounds with calcium (Ca). Most nutrient deficiencies can be avoided between a pH range of 5.5 to 7, provided that soil minerals and organic matter contain the essential nutrients {Havlin, 2005 #1909}.

The results show that with an amendment rate of 20-50 t/ha biochar the soil pH could be raised to an ideal pH range. For the study, the biochar was finely milled and evenly mixed with soil. For field applications, it needs to be considered, that this effect can only reached, when biochar can be evenly distributed and with particles sizes not exceeding 10 mm. As biochar is easiest applied punctually to plant roots, already a lower biochar dose could show effects as soil pH might be raised locally.

Improving soil water holding capacity with coffee pulp biochar

The average annual rainfall of 1400 to 1800 mm and temperatures from 18 to 24 °C, with an annual dry season of 4.5 to 5 months characterize a humid subtropical to tropical savanna climate. From the rainfall sum, sufficient water supply can be suggested, but the distribution of rainfall with a dry season of about 4.5 to 5 months makes the climate less than ideal for Robusta coffee and explains why supplementary irrigation during the dry season is considered necessary to obtain satisfactory yields {Berding, 1999 #1907}. The application of biochar could bridge the water shortage by providing a soil water reservoir for a longer period of time and thus saving irrigation water.

However, biochar applications of more than 100 tons/ha are required to show a significant effect. Not considered in our study are mid- and long-term soil physical improvements following biochar application through soil organic matter build-up and its benefits on aggregate stability and water storage {Verheijen, 2010 #166}.

Biochar management and application

Field applications of biochar can vary a lot and are mostly depending on the arrangement of the plantation and available machinery {Verheijen, 2010 #166}. The application can take place once or repeatedly. The coffee plantations consist of massive trees and are mainly managed by manual labour. Thus, biochar application at high rates for soil improvement in the planting holes and adjacent areas is only possible during new plantations every 25 to 30 years.

For annual application, a direct placement of biochar to the plants, if possible to the plant root system would be most effective. For single applications the same can be claimed. This could also be achieved by planting new seedlings next to big biochar cushions buried in soil. The biochar cushions could locally contribute to soil improvements.

Possible negative effects of biochar application

Nutrient adsorption from soil solution

Biochar has been shown to adsorb plant available nutrients in soil, resulting in transient plant nutrient deficiency {Chan, 2009 #498}. It is not proven that this occurs also in the case of the freshly produced coffee pulp biochar, but to avoid negative effects of biochar application caution has to be taken regarding this issue. Adsorption of available nutrients from the soil solution can easily be avoided by mixing the biochar beforehand with a fertilizer. Best results are obtained with liquid N fertilizers of mineral or organic nature like ammonium nitrate (NH_4NO_3) or human/livestock urine or slurry. Also, the mixing of biochar with compost is regarded as a straightforward solution. The mixtures should be allowed to stand for some time, 12 h -10 d for mixtures with liquid fertilizers and one to two months for mixtures with compost, until an equilibrium between solved and adsorbed nutrients is reached. The mixture can then be regarded as a high value long term fertilizer as the nutrient on the biochar surface will not be washed out, but will become available as soon as the concentration of nutrients in the soil solution decreases.

Raising pH to alkalinity

The coffee pulp biochar has a pH of about 10.5. As already mentioned, above a pH of 7.5 P starts forming insoluble compounds with calcium (Ca), and levels of available Fe, Mn, Zn, Cu, and Co are reduced {Havlin, 2005 #1909}. This could lead to plant nutrient deficiencies. Our results show that a pH of about 7.5 is reached by the application of more than 50 t/ha biochar. Considering the low production rate and the high nutrient content of the biochar, such a high application rate is unlikely. But if the biochar is applied locally the pH will also rise locally, leading to patches of different pH in the field. Thus, caution must be taken that the pH locally does not exceed 7.5, otherwise plant health could be in danger.

Biochar dislocation by wind and water erosion

Biochar shows a low bulk density and can thus be easily transported by wind and water. Wind or water transportation of biochar might lead to unwanted accumulations of biochar in the field, or even transfer the biochar out of the field {Verheijen, 2010 #166}. Caution must be taken that this will not happen, as such an unintended biochar accumulation could lead to unevenly distributed nutrients in the field and alkaline patches or even nutrient runoff from the field. If the biochar is covered by soil, plant roots will quickly grow around it and thus maintain it in place. If accumulation of biochar in the field is observed, the biochar should be redistributed evenly.

Overfertilization of the field

The agricultural management of the coffee plantation exhibits a relatively high nutrient (NPK) input, similar to coffee plantations in Brazil {Pinto, 2017 #1910}. That high amount needed can be explained by decreased nutrient availability in the soil caused by the low pH and potentially high nutrient leaching during the growing period of the coffee trees. The application of biochar will iprove pH and nutrient retention {Verheijen, 2010 #166}. Continued uncontrolled biochar application with a concurrent high fertilizer application could lead to an overfertilization of the plantation and thus overfertilization effects {Albornoz, 2016 #1911}. To avoid such scenarios, the biochar application and concurrent NPK fertilizer application need to be monitored. In order to find the safest way to implement biochar in the agricultural management of the coffee plantations, field experiments examining different application methods and fertilization regimes would be necessary.

5. Conclusions

Biochar application could effectively improve coffee plantations in the Buon Ma Thuot region. Otherwise lost macro- and micronutrients would be brought back to the field, adsorption of nutrients to the high surface area of the biochar would prevent them from leaching, and the extremely low pH of the plantations could be increased through biochar application, making soil nutrients more plant available and reducing the risk of Al root toxicity. Additionally, the soil water holding capacity could be improved slightly, reducing drought stress in plantations.

Risks of biochar applications are relatively low, and negative effects are anticipated only at biochar applications above 50 t/ha. Due to the annual production of 1 t /ha, such high application rates to the whole plantation are regarded as unlikely. But by local biochar accumulation, the pH might rise locally affecting single trees, such circumstances have to be prevented by sound agricultural management.

As the biochar sorption capacity could reduce plant nutrient availability shortly after biochar application we strongly recommend to mix the biochar with liquid N fertilizer such as human/livestock urine or slurry, also co-composting of biochar could be a suitable preparation of biochar for field usage.

Continued biochar application has the potential to lead to an ideal soil pH and better soil nutrient retention. This would lead to an overall better nutrient availability and reduced nutrient leaching during the raining season and thus less nutrient demand. Nevertheless, a good monitoring of nutrient balances is needed to avoid overfertilization of the coffee plantations.

6. Recommendations

General recommendation

The coffee pulp biochar is very rich in plant available potassium (Annex 5). Thus it is most convenient to use the coffee pulp biochar as potassium fertilizer. The following conversion table helps the user to calculate the amount of coffee pulp biochar needed to replace traditional K fertilizers. If applied directly as a substitution of K fertilizer, caution must be taken to reduce the risks of biochar accumulation and following alkalinity.

Table 5: Potassium conversion table
Conversion table for different potassium fertilizers used in coffee plantations

	Biochar (10% K_2O)	KCl (60% K_2O)	K_2O	Elemental K
Elemental K	0.08	0.52	0.83	1

Specific recommendations

1. Annual application of biochar as a substitute of K fertilizer

Regarding the availability, the benefits and the risks of biochar we propose the following management:

The coffee pulp biochar K content corresponds to a 10% K fertilizer. In the current plantation management, 750 kg/ ha potassium fertilizer is used, this would be fully replaced by 4.5 t ha coffee pulp biochar. With a tree density of 1100 coffee trees per hectare this corresponds to 4.09 kg coffee pulp biochar per tree.

The best time point to implement the new potassium fertilizer is during plant flowering when the coffee plants need additional K, that means at the second round of fertilization when also 10 l / tree bio-king liquid fertilizer are applied.

4 kg coffee pulp biochar could therefore be mixed with 10 l liquid bio king fertilizer and left for at least 2 days to reach adsorption equilibrium, and applied to each tree into its cavity.

The biochar is applied locally surrounding the tree, thus the biochar density will reach about the same level as 20 t /ha evenly distributed. This means that locally the pH of the soil could be brought in the ideal range for plant nutrient uptake. But already after 3 years of such an application procedure the biochar content would locally exceed 50 t/ha which could affect plant physiology because of the alkaline pH.

We therefore recommend a rotation procedure of 5 years. The biochar production from coffee pulp yield per year of 5 hectares together gives exactly the biochar need of one hectare. Thus, the amount of biochar produced in 5 fields is applied as described above to the first field in the first year and the second field in the second year and so on, returning to the first field in the sixth year. With this procedure, the risk of biochar accumulation can be reduced to a minimum.

This recommendation is summarized for printing (Annex 1).

2. Production and usage of a high value biochar NK fertilizer

The procedure described in the point above, “The annual application of biochar as a substitute of potassium fertilizer”, is may easily transformed into an industrial production and usage of a biochar NK fertilizer.

In order to produce biochar NK fertilizer in an industrial way, the following steps are proposed:

Milled Biochar (<5mm) is mixed with soluble N fertilizer (e.g. Ammonium-Nitrate) at a ratio of 40:1. The mixture is filled in a reaction container. Water is added to the container until it is full. In order to equilibrate, the mixture needs to stand for at least 24h. Afterwards the mixture is drained, the water runoff is used for the next batch. The mixture is air dried to a water content of 20-40%. Again, 4 kg of biochar NK fertilizer covers the annual need of potassium per tree. We propose to add the biochar in a circle around the tree during flowering during the second fertilization round in July every fifth year. The proposed amount of Nitrogen loaded on the biochar corresponds to the amount added in one fertilization round. The increase in pH will make Phosphorus already in soil plant available. The proposed biochar NK fertilizer replaces actual Potassium fertilization and no NPK fertilization is needed in the 2nd fertilization round when the biochar NK fertilizer is applied.

Analogous to the production of biochar NK fertilizer also biochar NPK Fertilizer, and Biochar urine fertilizer could be produced. In order to estimate the nutritional value of those fertilizers an analysis of nutrient content after production and experimental evaluations as proposed below are necessary.

This recommendation is summarized for printing (Annex 2).

3. Biochar application to new plantations as soil conditioner

New plantations provide the opportunity to apply biochar more evenly to the field or to apply biochar directly to the plant root system. It is not clear if plantations are replaced as a whole field or tree by tree.

Whole field replacement:

If the suitable machinery is present we propose to evenly distribute 20 to 40 t/ ha of coffee pulp biochar to the whole field and mixing it with the first 20 cm of soil by tillage. As the coffee trees are planted in rows it makes sense to apply biochar in these rows only. The biochar should be evenly distributed in the whole rooting zone of the trees, we suggest that the single rows should be at least 2 m wide. Caution has to be taken that the local biochar concentration does not exceed 40 t/ha. For this application, no nutrient enrichment of biochar is needed if routine fertilization to new plant seedlings is realized anyway.

Tree by tree replacement:

When an old tree is replaced, biochar could be applied in form of a biochar cushion direct under the new tree. For this application an amount of about 0.5 m^3 of biochar/ soil or biochar/compost mixture (1/1) (v/v) is filled in a whole covered with some soil, the new tree is planted above it. The biochar cushion will adsorb water and nutrients from the runoff area of the plants roots und thus reduce nutritional and water stress. The exact amount of biochar needed for such a cushion is not known, thus local trials would be necessary to evaluate the best procedure. Initially the cushion itself will have an elevated pH, but the surrounding soil does not, with time the pH of the cushion falls due to the dissolution of cations into the surrounding soil volume where pH rises. It remains a carbon rich cushion that serves as a water and nutrient reservoir for the trees lifetime.

4. Local trials

All newly introduced biochar management practices should be monitored. To compare different measures taken and to assess the best way of biochar application, scientific agricultural field experiments are beneficial.

To achieve evaluable results single experiments must include control treatments, at least 3 replicates, randomized structure and must be documented such that every measure can be followed.

Another way would be trials using single trees or field strips with different biochar management on farm. Here the replicative factor would be the single farm. As the farmers practice is a major source of differences, more replicates, i.e. up to 20 farms doing the same experimentations would be necessary.

Proposed Experiment 1: Compare and assed the nutrient value of biochar fertilizer

The proposed annual usage of biochar as a substitution of potassium fertilizer may lead to different nutrient availabilities in the field. To gain knowledge which combination of biochar and fertilizer (subsequently called biochar-fertilizer) has the best response in the field and how to adapt the actual fertilizer management we propose to test following treatments:

1. 4 biochar treatments: No biochar and 3 biochar fertilizers: NK, NPK, Urine.
2. 3 conventional fertilization regimens: no additional fertilization (biochar fertilizer only), half fertilization, full fertilization.

The following measurements would serve a proper evaluation of the treatments taken:

Soil: soil pH, soil nutrient content, soil nutrient availability.

Plant: plant growth, number of flowers, leaf chlorophyll content, foliar and fruit nutrient content and coffee yield.

Proposed Experiment 2: Compare and assess biochar value as soil conditioner.

The proposed usage of biochar as soil conditioner may lead to different nutrient availabilities and water retention in the field. To gain knowledge for which of the proposed biochar application has the best response in the field and how to adapt the actual fertilizer management we propose to test the following treatments in a new plantation:

1. Row application 20 t/ha, row application 40 t/ha, 1 row biochar cushion

The following measurements would serve a proper evaluation of the treatments taken:

Soil: soil pH, soil nutrient content, soil nutrient availability. soil humidity in intervals.

Plant: plant growth, number of flowers, leaf chlorophyll content, foliar and fruit nutrient content and coffee yield.

7. Acknowledgements

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8. Annexes

1. Summarized recommendation 1: Annual application of biochar as a substitute of K fertilizer.
2. Summarized recommendation 2: Production and usage of a high value biochar NK fertilizer.
3. Elemental contents of coffee pulp biochar, XRF results, FiBL.
4. Biochar analysis according the European Biochar Certificate (EBC), EUROFINS, Germany.
5. Biochar Analysis in relation of fertilization value, IASVN, Vietnam