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The Effects of Fern (*Gleichenia linearis*) Mulching on Soil Properties, Humus Substance and Microbial Fauna in Soils Growing Tea in Phu Tho Province, Vietnam

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Abstract: ***In Vietnam, Fern (Gleichenia linearis) is one of mulch materials for tea cultivation brings positive benefits such as moisturizing, protecting the soil from erosion and improving crop yield. Because of the high composition of total polysaccharide and C/N ratio, Fern residues have high persistent and should slowly decay is especially important to contribute to maintain organic matter in soil. A study was conducted on a typical Acrisol growing tea in Phu Tho province (Vietnam) to evaluate the effects of Fern mulch on soil properties, especially soil organic matter accumulation. The findings of this study suggest that Fern mulch application had positive effects on soil properties, particularly on soil humus and soil moisture. In general, soil moisture, soil bulk density, humus content and quality of soil is improved, and the activities of soil microorganisms are also enhanced. The effects of Fern mulch on soil properties depends on the rate of Fern application and timing. In this research, the rate of 25 tons of Fern/ha is considered more appropriate.***

Keywords: *Fern (Gleichenia linearis) mulching, soil properties, humus substances, soil microbial fauna*

1. Introduction

Soil organic matter (SOM) is composed of plant, animal, and microbial residues at varying stages of decomposition and amorphous humic substances. The content of organic carbon has long been recognized as a key component of soil quality [1], and thus maintenance of soil organic carbon in cropland soils is a major determinant of the productivity and long-term stability of agricultural systems [2]. Natural organic mulch eventually breaks down and becomes a part of the soil and a source of plant nutrients [3] [4]. Increasing the amount of SOM is regarded as the main advantage of organic mulch [5]. The influence of mulch on soil agrochemical properties depends on the chemical composition of mulch. An increase in the total content of SOM in organic farming was also established by Marinari et al. (2010) [6]. Careful soil organic matter management is important for the soil quality and productivity improvement of the slopping land in northern mountainous region of Vietnam. Plant residues mulch applications, which affect soil characteristics significantly, are regard as an effective pattern of soil organic improvement. Fern (*Gleichenia linearis*) is wild grasses very common in the northern mountainous region of Vietnam. They are often used for firewood or mulch in agricultural production on slopping land. The advantage of using Fern to soil mulch are that they decompose slowly in the natural environment conditions and should have the effect of preventing weeds, reduce soil erosion, and have important implications in maintaining soil moisture [7].

Fern also is used as mulch for tea cultivation in some regions such as Tan Cuong (Thai Nguyen province) and Phu Ho (Phu Tho province) with the main purpose is to keep the soil moisture. As a conventional management in the study region, Fern mulch are used for slopping land regularly, but little is known about their effects on soil properties functioning. Therefore, this study focused on evaluating the effects of Fern mulching at different amounts to soil properties, especially in soil humus and microbial fauna in soils grown tea in Phu Ho, to find effective solutions to improve tea production efficiency and soil protection towards sustainable tea production in the Northern mountainous region of Vietnam.

2. Materials and Methods

In order to evaluate the effects of Fern mulch on soil properties, field experiments were carried out during period of 2010-2013 at a tea plantation area during harvesting period (tea plants at 6 year old) in Phu Tho province, the Northern mountainous region of Vietnam. Phu Tho is located in the tropical monsoon climate, with cold winter. The average annual temperature is about 23oC; the average annual rainfall is about 1,600 to 1,800 mm however approximately 70 % of annual rainfall happened in rainy season, which is from April to October.

The five treatments including control of fern mulch were studied in a randomized block design with three replications. These treatments of surface mulch applications are designed based on the conventional farming management in the study area. The Fern is mulched one time at the beginning of the experiment at the rates of 0, 15, 25, 35 and 45 tons/ha (fresh weight). The area of each plot is 45 m2 (10x4.5m) with tree rows of tea plant. The basal chemical fertilizer was applied every year according to local recommendations at the rates of 300 kg N, 100 kg P2O5 and 100 kg K2O per ha.

The studied soil will be classified as Acrisols with the texture of medium loam and the following properties: pH (KCl) 4.28; total SOM 2.68%; soil microbial fauna of total

bacteria 9.8x105 CFU/g, total actinomycetes 2x103 CFU/g and total fungi 4x103 CFU/g soil. The Fern trees application are high proportion of 58.21% C; 0.84% N; 0.51% P2O5; 0.71% K2O; 0.17% MgO; 1.56% CaO; 0.44% Mn; 0.46% Fe and C/N ratio of 69/1. Fern materials also have high total polysaccharide content, accounting for hemicellulose 26.4%; cellulose 23.11% and lignin 30.57%. These result shows that Fern is a good mulch, potentially providing an organic matter and minerals contribute significantly improve and maintain soil fertility. The soil samples were taken in December every year (in dry season) at each plot to a depth of 0-30 cm to analyze the soil fertility indicators by methods commonly used in the laboratory of soil analysis. Using Excel statistical software to process and evaluate the research data.

3. Results and Discussion

3.1. Effect of mulching Fern on physical and chemical properties of soils

3.1.1. Effect of Fern mulch on physical properties of soil

Increased soil moisture is mainly due to Fern remnants on the ground have the ability to reduce water evaporation; helps maintain and increase soil moisture. The cumulative effect of mulching on moisture after two years (in 2012) is not only by residues on the soil surface not yet fully decomposed, but also by the high humus content in the soil also contribute to improve soil moisture. After three years (in 2013), although the amount of Fern residue cover are almost completely decomposed, leaving only a very few but by the soil organic matter content is high so maintaining high moisture holding capacity [8].

The results in Table 1 also shows Fern mulching has significantly improved bulk density of the soil after three years of the experiment. Accordingly, the bulk density has decreased from 1.37 and 1.35 g/cm3 (after two and three years of the experiment) in the control to 1.25 and 1.17 g/cm3 in the Fern mulch rate of 45 tons/ha. The improvement of soil bulk density is significant for the development of tea roots as well as ensuring soil biota. Although soils are compacted by mechanical action through active tea to fertilize and harvest, with the results of this study clearly shows the effect of Fern mulching on improving the soil bulk density [9].

Fern mulch on soil surface prevented the soil from erosion, promoted crop root elongation; both of them resulted in a relative porous structure and better infiltration. These results were in agreement with the reports in other areas. Mulumba and Lal (2008) [10] reported that straw mulch was an effective soil physical environment modifier, which decrease the bulk density, increase the total porosity, stable aggregates percent, available water capacity and soil moisture retention significantly. Also, Pervaiz et al. (2009) [11] reported that straw mulch decreased bulk density and soil strength. It was reported that soil porosity and aggregate stability could be improved significantly with the increasing mulching rates [12].

Fern mulch may affect a number of physical properties of soil. However, this paper only focuses on soil moisture and bulk density. The data presented in Table 1 shows the soil moisture has changed over time and the Fern mulch rates. The soil moisture reached the highest values at all treatments after two year of application. In 2012, the soil moisture has increased 2.22%; 3.37%; 5.61% and 7.54%, respectively, compared to the control when the rates of Fern much increased to 15 tons, 25 tons, 35 tons and 45 tons/ha.

Table 1: Some physical properties of soil in the experiment

Mulching Fern (ton/ha)	*Soil moisture (%)*			*Soil bulk density (g/cm3)*	
	2011	2012	2013	2012	2013
0	20.87	26.53	25.63	1.37	1.35
15	21.68	28.75	27.99	1.28	1.23
25	23.73	30.26	28.85	1.25	1.19
35	24.00	32.14	30.73	1.24	1.19
45	24.99	34.07	32.02	1.25	1.17

The effect of mulching method on soil properties and growth and crop yield of cowpea in Akwa Ibom State, Southeastern Nigeria was reported by Ogban et al. (2008) [13]. The benefits of these soil management practices include improved water transmission characteristics, formation of stable soil aggregates, reducing soil bulk density, and increases in organic matter content and crop yields [13].

3.1.2. Effect of Fern mulch to soil chemical properties

The soil acidity express as the pH values is not significant difference between treatments during the first year (in 2011). But these differences began to appear from the 2nd year and that really showed in the 3rd year after Fern application (Table 2). In the control treatment, the pH values decreased slightly from 4.28 to 4.12 after three years of the experiment. However, the pH values have significantly improved at all treatments with Fern mulch. The causes of this problem may be due to the increase of the leaching process of alkaline and earth alkaline metals, leading to an accumulation of H+ and Al3+ in the soil without mulching. Whereas, soil mulch with Fern residues may contribute to limit leaching of earth alkaline metals in the soil and eventually contribute as the acidity of the soil decreases.

Table 2: Soil pH and exchangeable cations of soil in the experiments

Mulch Fern (tons/ha)	*pH(KCl)*			*Ca2+*	*Mg2+*	*Al3+*
	2011	2012	2013	2013 (Cmol/kg)		
0	4.19	4.18	4.12	1.50	0.08	5.72
15	4.37	4.27	4.48	2.08	0.25	3.82
25	4.22	4.32	4.50	3.13	0.33	3.14
35	4.18	4.25	4.57	3.27	0.67	2.91
45	4.13	4.24	4.61	3.67	0.91	2.55

3.2. Effect of Fern mulch on soil humus

Fern mulch has a strong influence on humus in soil. They not only increase the total amount, but also contribute to improving the quality of soil humus. In general, the total content of soil organic matters (SOM) in all treatments with Fern mulch were significantly increased compared to the control (Table 3). SOM is always increasing proportional to the increasing rates of Fern application. In particular, SOM increased from 2.16% in the control to 3.83% at the Fern application rate of 45 tons/ha after one years of the experiment; from 2.27% to 4.15% after two years of the experiment, and from 2.97% to 4.45% after three years of the experiment.

Natural organic mulch eventually breaks down and adds organic material to the soil. The increase of amount of soil organic carbon is regarded as the main advantage of organic mulches. A higher content of SOM established in all mulched experimental plots compared with the unmulched plots was reported by Kristina Bajoriene et al. (2013) [14].

Table 3: Content of soil organic matter in the experiments

Mulch Fern (tons/ha)	*SOM (%)*			*HF/SOM*		
	2011	2012	2013	2011	2012	2013
0	2.16	2.27	2.97	27.78	31.10	38.38
15	2.57	3.14	3.90	35.14	39.67	38.46
25	3.02	3.95	4.01	31.06	34.22	35.96
35	3.51	4.01	4.37	30.44	40.38	32.49
45	3.83	4.15	4.45	32.43	46.29	35.51

The slight increase of SOM in the control after three years of experiment (2010-2013), from 2.16% to 2.97% is due to tea leave and stems fall down annually, and the death roots in soil. While there was an increase much faster in treatments with Fern mulched. For example in 2013, the SOM increase to 3.90%, 4.01%, 4.37% and 4.45%, corresponding to the rates of Fern mulch of 15; 25; 35 and 45 tons/ha. Obviously Fern mulch has contributed significantly to improve the organic matter content in soil. Because of high contents of lignin, cellulose, hemicelluloses, and C/N ratio (69/1), the decomposition rate of Fern residues should takes place slowly. This is also reflected in research results of the proportion of humic and fulvic acid in soil organic matter (HF/SOM) presented in Table 3. This ratio is quite high in the 2nd year and gradually decreased until the 3rd year in all the treatments with Fern mulch. While the HF/SOM ratio in the control has increased.

Increasing proportions of humic acids in SOM is also indicated the quality of soil humus improved. Notably, although the contents of humic and fulvic acid decreases in total soil organic matter after two year of Fern mulch but their contents remain in the soil increased over time along with the increase of the Fern mulch rates. For example, the contents of humic acid increased from 0.09% to 0.39%; fulvic acid also increased from 0.21% to 0.42% after two years of the experiments (Table 4). These results indicate the role of Fern mulch for improving soil humus in soil. The results also note that, over time, content of humic acid is continuously increasing while fulvic acids tend to decrease after two years of the experiments.

Table 4: The contents of humic and fulvic acids in soil

Mulch Fern (tons/ha)	*Humic acid (%)*			*Fulvic acid (%)*			*Humic/Fulvic (H/F)*		
	2011	2012	2013	2011	2012	2013	2011	2012	2013
0	0.09	0.08	0.13	0.21	0.27	0.44	0.43	0.29	0.30
15	0.14	0.18	0.35	0.44	0.62	0.40	0.32	0.29	0.88
25	0.19	0.25	0.34	0.43	0.46	0.39	0.44	0.54	0.87
35	0.34	0.29	0.31	0.37	0.56	0.40	0.94	0.52	0.78
45	0.39	0.35	0.38	0.42	0.68	0.41	0.93	0.51	0.93

The causes of these may be due to the humic acid is capable of bonding with the mineral components in soils, especially iron and aluminum compounds which are quite high in the studied soils, while fulvic acids easy washed deeper down the soil or lost from the soil due to the high mobility [15] [16]. The ratio of humic acid/fulvic acid (H/F) tends to decrease during two first years of the experiments may be explained by the decomposition of Fern residues in the high acidic soil it favors the formation of fulvic acids. However, after three years of the experiment, the H/F ratio is not much different between treatments with different rates of Fern mulch. At this time, the amount of Fern mulch may be destroyed all and the processes of SOM accumulation in soil took place depend on the natural environment factors.

3.3. Effect of Fern mulch on soil microbial fauna

The results of Fern mulch on soil microbial fauna are presented in Table 5 shows that there has been a significant increase in the composition of soil microorganisms. This reflects the positive role of using Fern mulch to improve the biological properties of soils.

Table 5: Total number of main groups of microorganisms in soils (CFU/g)

Mulch Fern (tons/ha)	*Bacteria*		*Actinomycetes*		*Fungi*		*Carbon metabolism bacteria*	
	2012	2013	2012	2013	2012	2013	2012	2013
0	3.4 x10 5	8.6 x10 5	1.5 x10 2	2.0 x10 2	1.8 x10 3	3.0 x10 3	2.2x1 04	1.3x1 04
15	1.4 x10 7	2.1 x10 5	4.3 x10 2	2.0 x10 3	2.5 x10 4	6.2 x10 3	6.7x1 05	5.7x1 04
25	5.2 x10 8	2.5 x10 6	3.4 x10 3	4.5 x10 3	3.1 x10 5	1.1 x10 4	4.9x1 06	1.8x1 05
35	3.3 x10 9	9.2 x10 6	6.2 x10 3	5.5 x10 3	1.6 x10 5	2.7 x10 4	4.8x1 07	4.3x1 05
45	9.7 x10 9	8.6 x10 6	1.6 x10 4	7.4 x10 3	1.8 x10 5	3.0 x10 4	7.2x1 07	4.7x1 05

The data in Table 3 show the number of main groups of soil microorganisms (bacteria, actinomycetes, fungi) increased after two years of Fern mulching, and then gradually decreased at three years of experiments. In the two years' time (2012), the number of total bacteria in the treatments with Fern mulch are higher than the control from 100 to 10,000 times and has reached the highest number in the treatment mulching 45 tons Fern per ha. Similarly, the number of actinomycetes and fungi in the treatments with Fern mulching were also higher than the control 10 to 100 times. The number of carbon metabolism bacteria also increased after two years of the experiment. In all rate of Fern application, the numbers of carbon metabolism bacteria are 10 to 1,000 times higher than the control. This result shows that this is happening stage decomposition powerful Fern remnants by soil biota populations.

After three years of Fern application, the number of soil microorganisms tends to reduce. The reducing number of major groups of microorganisms in soil can involve a large amount of organic residues were completely decomposed and converted into stable humus compounds and leading to lack of carbon substrate and nutrients necessary for soil biota. However, the results indicated that the role of the addition of Fern residues to change the soil environment that improve soil biological activities in soils.

4. Conclusions

Fern mulch has significantly affected the physical, chemical and biological properties of soils. In general, it improves moisture, bulk density and humus substances in soil, and also enhances the activities of soil microorganisms. The degree of influence increases with the amount of Fern residues application. The Fern mulch rate of 25 tons/ha is considered more appropriate for tea plantation in the area. At lower rate of Fern application, the soil fertility was little changed and at very high rate of Fern application, the effectiveness of soil improvements have not increased much corresponding to the rate of Fern mulch.

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