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BIOCHAR AMENDMENT OF SOIL AND ITS EFFECT ON CROP PRODUCTION OF SMALL HOLDER FARMS IN RASUWA DISTRICT OF NEPAL

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ABSTRACT

The application of biochar to soils have shown benefits for agricultural production, particularly through improving soil properties and crop productivity. However, very few studies examining the effects of biochar have been done on small holder mountain farms in the Himalaya. This paper presents the results of research focused on the use of biochar and Farm Yard Manure (FYM) at the rate of 5t/ha and 20t/ha, in farmer fields as a soil amendment on high mountain silt loam soils of small holder farmsin Rasuwa district of Nepal. The study indicated that there were significant ($P<0.05$) positive effects in certain soil properties like soil pH, SOM and nutrient status, and crop production of small holder farms. Results of this study suggest that the practice of biochar application to soil at low rates along with FYM normally has immediate positive effects on the vegetative growth of crops/plants, however, soil properties and overall crop yields may take a longer time to show improvement.

Keywords: biochar, soil quality, soil fertility, crop production

1. Introduction

Use of biochar is a promising new technology in farming practices offering considerable capacity to maintain and improve soil quality and nutrient cycling (Barrow 2012; Bayu et al. 2016; Mao et al. 2012). Soil fertility is an important factor to maintain the productive capacity of soil and to supply nutrients required by crops (Tiwari et al. 2006; Glaser et al. 2002). Biochar is a by-product of the pyrolysis of biomass feedstocks as a carbon-rich amendment to improve soil biophysical and chemical quality(Njoku et al. 2016; Ścisłowska et al. 2015; Woolf 2008; Revell et al. 2012; de Melo Carvalho et al. 2014; Chan et al. 2007; Zheng et al. 2010).It is derived from

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organic materials such as wood, leaves, grasses, crop residues and manure after heating in a closed container (temperature ranging 300 to 500 degrees Celsius) in an oxygen limited condition(Yu et al. 2013; Maia et al. 2011). Biochar is an emerging and potential additive for enabling increased production on degraded and low fertility acidic soils(Lehmann et al. 2006; Laird et al. 2010; Novak et al. 2009; Bayu et al. 2016; Glaser et al. 2002; Alburquerque et al. 2013; Mao et al. 2012).An increasing number of research studies have indicated that biochar is a potentially viable alternative to augment soil physical and chemical properties and productivity (Ścisłowska et al. 2015; Bayu et al. 2016; Yamato et al. 2006; Alburquerque et al. 2013; Soderberg 2013; Major et al. 2010; Atkinson et al. 2010).Incorporating biochar into soil leads to increased soil pH, nutrient availability, moisture absorption and carbon sequestration (Novak et al. 2012; Crane-Droesch et al. 2013; Spokas 2013; Lal 2004) It is worthy to note that biochar is not a compost material, rather, it is a catalyst for soil microbial activity which enhances soil fertility and water holding capacity to increase crop growth and yields(Steiner et al. 2007; Mekuria & Noble 2013; Ahmad et al. 2014; Liu et al. 2012; Zhang et al. 2012; Jeffery et al. 2011; Carter et al. 2013).

The quality of biochar depends on the type of feedstock, methods of preparation, and temperature and oxygen levels maintained during pyrolysis(Steinbeiss et al. 2009; Manyà 2012; Shackley et al. 2010). Application of biochar to the soil can also contribute to climate change mitigation and adaptation by improving the management of waste materials, as well as, serving as a long-term sink for carbon (Alburquerque et al. 2013).Yu et al. (2013) reported that,application of yellow pinewoody biochar in to loamy sand soils in North Carolina, USA, with a high percentage mixture of biochar resulted in notable increase in water holding capacity. Furthermore, (the use of biocharmay also help to mitigate global warming by reducing GHGs emissions from soil, mainly N_2O,while contributing to sustainable agriculture (Bajracharya et al. 2015; Kammann et al. 2012; Cayuela et al. 2013; Lal 2004; Case et al. 2012). Thus, the findings of numerous studies suggest that biochar could significantly mitigate climate change, enhance soil quality and increase crop production. However, the use of biochar in small holder agriculture in hill regions of South Asia not been extensively documented.

The overall aim of this study was, therefore, to use biochar produced from locally available invasive forest shrub *(Eupatorium odenophorum)* biomass and apply it to the soil on farmer fields to evaluate its effects on soil properties and crop production in mountain farming system of central Nepal. Specifically, the objectives were:

1) To study the effects of biochar application on soil quality indicators, and
2) To study crop growth and yield enhancing effects of biochar on small holder farms.

2. MATERIALS AND METHODS

2.1 Site description and soil sampling:

The field trials were carried out at Ramche in Rasuwa district (28°2. 221″N, 85°13.179″E, altitude 2050 m.a.s.l) of Nepal. It is situated102 Km north of Kathmandu city where the climate is temperate (Figure 1). Local farmers were contacted to determine their willingness to adopt the option of biochar application in their fields. Among them 12 local farmers agreed to conduct the trials in their hill terraces. The research trial plots were established on terraces of12 farmer fields where medicinal plants chiraito (*Swertia chirayita*) and other cash crops/vegetables like, mustard (*Brassica nigra*), radish (*Raphanus sativus*), potato (*Solanum tuberosum*) and garlic (*Allium sativum*) were cultivated in different seasons. The soils on the trial plots were mostly silt loam texture with high organic matter refelecting the cold climate at high altitudes.

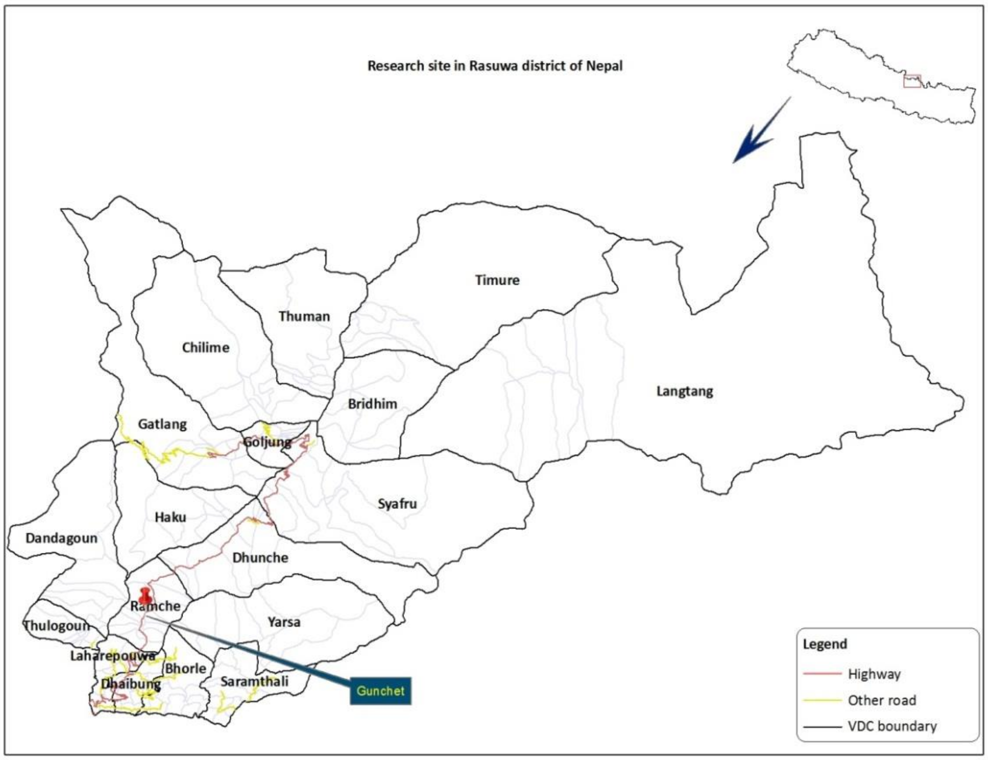

Figure 1. Location map showing the study site.

2.2 Experimental design:

The experimental plot design used was a completely randomized design with each 10 m^2 plot divided into two parts. One half was taken as a control in which the usual farmer practice was maintained without addition of biochar. The other half was the treatment plot with 5 t/ha biochar and 20 t/ha FYM applied. There were a total of 12famer fields (replicates), hence a total of 24 plots. The plot layout is shown in figure 2.

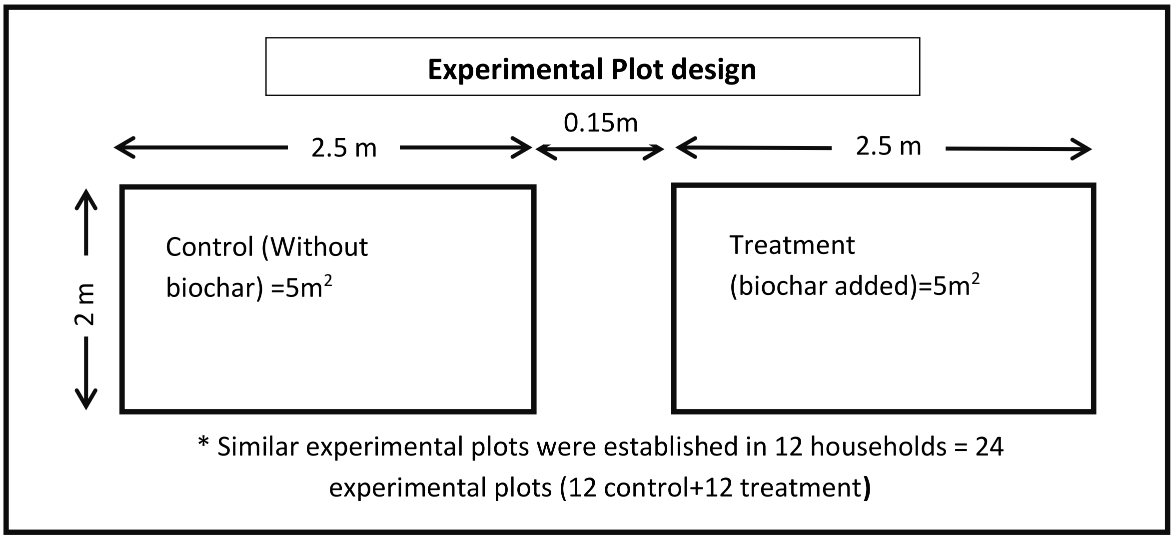

Figure 2: Experimental plot Layout (total area: 10 square meters)

Figure 2. Establishment of plots on small holder farms in Rasuwa district.

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The soil samples were taken before use of biochar in November, 2014 and after in August 2016 respectively. Soil samples were collected from 24 randomly selected farm plots. Each of the soil samples were collected from the topsoil (0-15 cm) and the sub-soil (15-30 cm) horizon to examine the soil nutrient levels and soil quality for lab analysis; soil samples were kept in closed plastic bags and transported to the Aquatic Ecology Center (AEC) laboratory at Kathmandu University. For laboratory analysis all samples were air dried ground and passed through a 2 mm sieve for soil physical and chemical analysis. The soil physical and chemical properties were determined using USDA standard methods: soil texture by the Bouyoucossoil hydrometer method (Gee and Bauder 1986), soil pH (1:1 soil: water mixture) using adigital pH meter and probe (McLean 1982), bulk density (BD) by core method (Blake and Hartge 1986), soil organic carbon (SOC) dry combustion (loss on igniton) method (Nelson and Sommers 1982), total nitrogen (TN) by Kjeldahl method (Bremner and Mulvaney 1982), available phosphorus (AP) by modified Olsen's method (Olsen and Sommers 1982), exchangeable potassium (EK) by ammonium acetate extraction followed by atomic absorption spectro-photometryand cation exchange capacity (CEC) by ammonia acetate extraction method (Rhoades 1982).

2.3 Application of Biochar : Biochar mixed with Farm Yard Manure (FYM) was applied in the field trials at the rate of 5 ton biochar and 20 ton FYM per hectare, respectively. Biochar was produced locally from available feed stocks (Eupatorium sp.)at 300°C to 500°C under low pyrolysis process for 3-5 hours, whereas FYM was made from cattle and buffalo dung mixed with leaf-litter and weed biomass and animal bed materials which were composted in a pit near the farmstead. Biochar characterization was performed at the Aquatic and Ecology Center (AEC) Soil and Water Analysis Laboratory of Kathmandu University, Dhulikhel. The characterization of biochar is given in table 1.

Table 1: Chemical properties of biochar

Parameters	Mean Value	Test method/ Instrument employed
pH	11.13	Probe method (McLean, 1982)
Organic Matter (OM)%	53.58	Loss on Ignition (Nelson and Sommers 1982)
Total Nitrogen (ppm)	1988	Kjeldhal method (Bremner & Mulvaney, 1982)
Available Phosphorus (ppm)	7835	Dry ash followed by Modified Oslen's (Olsen & Sommers, 1982)
Available Potassium (ppm)	1528	Ammonia Acetate followed by Atomic

		absorption Spectrometer(AAS) (Knudsen et al., 1982)
Micro Nutrients		
Iron (Fe) (mg/kg)	8533	DPTA followed by AAS (Olson & Ellis, 1982)
Manganese (Mn) (mg/kg)	125.64	DPTA followed by AAS (Gambrell & Ellis, 1982)
Zinc (Zn) (mg/kg)	13.182	DPTA followe AAS (Baker and Amacher 1982)
Copper (Cu) (mg/kg)	8.696	DPTA followed AAS (Baker and Amacher 1982)

2.4 Statistical analysis:

Results obtained from measurement of soil physical and chemical properties and crop production were analyzed by use of Minitab 17 software. The inferential differences were determined significant at the rate 5% level of significance (p/0.05). Paired "t" test was employed for the determination of statistical significance for the measured parameters, namely, crop yield, soil pH, SOM, TN, AP, EK and CEC.

3. RESULTS

3.1 Soil properties

The mean values of soil physical and chemical properties of topsoil (0-15cm) and sub soil (15-30 cm) before biochar application (baseline data), after biochar and FYM amendment and, after only FYM addition are given below in tables 2 and 4.

Table 2: Mean values (± std.dev.) of topsoil (0-15 cm) physical and chemical properties prior to plot establishment (baseline), for biochar and FYM treatment and for FYM only control.

Parameters	**Baseline**	**Biochar + FYM**	**FYM only**
pH	5.3 ± 0.6a	5.3 ± 0.3a	5.4± 0.9a

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Soil Organic Matter (%)	10.9 ± 1.5a	11.6 ± 1.7a	11.6 ± 2.2a
Total Nitrogen (ppm)	4526 ± 1089a	3647 ± 1422a	4272 ± 818a
Available Phosphorus (ppm)	516.0 ± 161.1a	312.0 ± 185.5b	207.7 ± 96.b
Exchangeable Potassium (ppm)	205.0 ± 67.0a	201.0 ± 72.6a	1699 ± 75.0a
Cation Exchange Capacity ($cmol_c$/kg)	51.0 ± 9.0a	41.5 ± 10.0b	47.7 ± 15.4a

Means in the same rows followed by same letters are not significantly different at p<0.05.

Regarding the topsoil, AP increased significantly (P<0.05) in both biochar and non-biochar plots after application of biochar + FYM and FYM only in to the soil. In contrast CEC decreased significantly (P<0.05, Table 3) in biochar amended plot compared to FYM only plot. These trends were readily explained and may be due to sampling and analytical variability.

The topsoil of the biochar + FYM amended treatment and only FYM added plots showed EK was slightly higher in biochar-cum-FYM amended soils compare to only FYM added soils with no statistical significance. Whereas, pH,SOM ,TN were observed to be somewhat higher in the FYM only control treatment (Table 3).

Table 3. Paired 't' test p-values and statistical significance for physical and chemical properties of top soil (0-15 cm).

Parameters	**Biochar + FYM (p value)**	**Significance**	**FYM only (P value)**	**Significance**
pH	0.642	Ns	0.713	Ns
Soil Organic Matter (%)	0.998	Ns	0.207	Ns
Total Nitrogen (ppm)	0.119	Ns	0.192	Ns
Available Phosphorus (ppm)	0.002	**	0.000	**
Exchangeable Potassium	0.291	Ns	0.291	Ns

(ppm)				
Cation Exchange Capacity (m.e/100gm)	0.008	**	0.538	Ns

*significant at P<0.05; ** highly significant at P<0.01; NS = non significance

Table 4: Mean values (± std. dev.) of subsoil (15- 30 cm) physical and chemical properties prior to plot establishment (baseline), for biochar and FYM treatment and FYM only plots.

Parameters	Baseline	Biochar + FYM	FYM only
pH	5.2 ± 0.37a	5.2 ± 0.27a	5.4 ± 1.0a
Soil Organic Matter (%)	9.4 ± 2.4a	11.2 ± 1.2b	11.0 ± 1.5b
Total Nitrogen (ppm)	4165 ± 788a	3310 ± 1352b	4032 ± 493a
Available Phosphorus (ppm)	363.0 ± 154.7a	282.0 ± 177.6a	160.0 ± 12.0.b
Exchangeable Potassium (ppm)	111.4 ± 48.0a	177.5 ± 47.b	157.0 ± 57.0b
Cation Exchange Capacity (m.e/100gm)	49.0 ± 8.0a	43.7 ± 8.0b	400. ± 9.0b

Means in the same rows followed by same letters are not significantly different at p<0.05

Regarding the subsoil, SOM, TN, EK increased significantly (P<0.05),whereas, in contrast CEC decreased significantly (p<0.05) after biochar and FYM addition to the soil. Similarly AP increased slightly in biochar and FYM amended soils but the difference was not statistically significantly (Table 5).

In a similar manner, while comparing the sub-soil of the biochar + FYM treatment and only FYM added plots; pH and AP (not significantly), SOM, TN and EK (significant at P<0.05) were higher in the biochar and FYM amended soil. Whereas, parameters such as AP,EK (significantly different at P<0.05), and pH and TN (not significantly different) were higher in soil of the FYM only treatment (Table 5).

Table 5. Paired‘t’ test p-values and statistical significance for physical and chemical properties of sub-soil (15-30 cm).

Parameters	Biochar + FYM (p value)	Significanc e	FYM only (P value)	Significance
pH	0.681	Ns	0.286	Ns

Soil Organic Matter (%)	0.011	*	0.013	*
Total Nitrogen (ppm)	0.074	*	0.554	Ns
Available Phosphorus (ppm)	0.203	Ns	0.001	**
Exchangeable Potassium (ppm)	0.004	**	0.043	*
Cation Exchange Capacity (m.e/100gm)	0.043	*	0.002	**

**significant at P<0.05; ** highly significant at P<0.01; ns = non significance*

3.2 Influenceof biochar and FYM on crop yields

Crop yield (ton/ per hectare) of all crops planted within the hill farming system, namely, mustard, potato, radish and garlic were observed to be significantly (p<0.05) higher in the biochar & FYM amended soils compared to only FYM added soils (Table 6). Clearly, mustard showed the greatest differences in yields due to biochar addition (77% higher) over FYM only treatment. However, the vegetative growth and yields of the high value medical plant *Swertia chirayita*were also markedly higher in the biochar amended plots (by 66%) compared to FYM only plots. For other crops the biochar amended treatment gave 17.5 to 40% higher yields compared to FYM only treatments.

Table6: Mean values (± std. dev.) of crop yield (t/ha)for biochar and FYM treatment and FYM only along with paired 't' test p-values and statistical significance.

Crop	Biochar +FYM	FYM only	P value	Significance
Mustard	1.3 ± 0.4	0.3 ± 0.1	0.001	**
Potato	8.0 ± 3.0	6.6 ± 2.4	0.012	*
Radish	11.6 ± 5.2	9.0 ± 3.0	0.058	*
Garlic	5.0 ± 4.0	3.0 ± 2.1	0.066	*
Chiraito§	3.04 ± 2.4	2.0 ± 1.4	0.039	*

**Means are significantly different at P=0.05; **Means are significant at P=0.01*

§High value medicinal plant *Swertia chirayita*sp.

Species | With biochar | Without biochar

Swertia chirayita

Raphanus sativus

4. DISCUSSION

4.1 Soil properties in relation to soil depth

As seen from the baseline soil data (Tables 2 and 4) it is an apparent that the top soil (0-15cm) and sub-soil (15-30 cm) in this field experiment were of a fertile silt loamy soil with chemical properties generally in the medium range for commercial crop production. In as seen from the results, most of the measured parameters were not significantly different between biochar + FYM amended soils and those with only FYM added. This was likely due to the fact that the soil was already of good quality with high SOM status. Higher AP levels of the biochar amended soils could be due to improved availability of phosphorous as a result of biochar addition(Alburquerque et al. 2013; Asai et al. 2009). Lower values of CEC in these plots despite high SOM compared to the FYM only control, were however, not easily explained. Generally, the CEC of soil is a function of the clay type and content and would not expect to change significantly with addition of biochar.

In both top soil and sub soil, increase in pH was observed in the biochar amended soil compared to the baseline values and the FYM only control treatment. This was evidently due to the alkaline nature of biochar (Barrow 2012), which, upon addition to the soil could have contributed towards reducing the acidic level of soil. Nonetheless, the increase was, expectantly, not significant in the

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sub soil, which was due to the application of low rates of biochar and is incorporation with tillage only within the top 15-20cm of soil. Moreover, addition of the organic manure could have resulted in nitrification which releases protons to the soil (Deal, Brewer et al. 2012).

In contrast, there was a significant decrease in CEC availability in biochar amended top soil and sub soil. Here, the biochar might have become intimately associated with SOM and clay particles reducing the number of exchange cites available to adsorb cations. In the case of the subsoil, the above influence of biochar was likely insignificant as the biochar was applied only to the surface layer(Naisse et al. 2015). Also, mineralization of organic matter in the soil could have occurred which is heavily dependent upon the temperature and moisture levels of the soil (Qadeer, Batool et al. 2014).

4.2 Use of bichar and FYM on crop yields

The results of this study indicated that the application of biochar along with FYM in fertile soils in hill farming systems of small holder farmers generally increased the crop yields in biochar and compost amended soils (Claudia et al.2014; Getachew et al. 2016).However, it was observed that the yield difference due to addition of biochar to soil of mustard was considerably higher than that of other crops. This might be due to biochar amendment being more effective in enhancing the vegetative growth of plants rather than the growth of tuber crops such as potato and radish(Upadhyay 2015; Vaccari et al. 2015).

5. CONCLUSIONS

This study has confirmed that, in general, biochar application does improve certain soil properties like soil pH, SOM and nutrient status. Moreover, it also enhances the growth and yields of most crops as seen in the case of small holder mountain farming in Nepal. The effects of biochar are, however, likely to be more pronounced when applied to soil of poor quality or degraded status. Furthermore, it could be said that while the effect of biochar amendment on crop growth and yield improvement is readily observed in the short-term, improvement in soil properties is likely to be seen only in the long-term (several years) as the overall soil quality takes a longer time to improve.

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