Journal of Mountain Area Research

http://journal.kiu.edu.pk/index.php/JMAR

Full length article

SUSTAINABLE DIVERSIFIED AGRICULTURE AND LAND MANAGEMENT IN THE HIMALAYA: IMPLICATIONS FOR CLIMATE CHANGE ADAPTATION AND MITIGATION

R.M. Bajracharya[1,], K. Atreya[1], N. Raut[1], H.L. Shrestha[1], D.K. Gautam.[2] and N.R. Dahal[1]*

1. Department of Environmental Science and Engineering, School of Science, Kathmandu University

2. Nepal Agroforestry Foundation, Koteshwor, Kathmandu

ABSTRACT

The soil and land resources play a vital role in sustaining the local livelihoods of rural communities in the Himalaya. Most of the arable land has already been brought under cultivation, hence the ever-increasing demand for food and fiber has left farmers with no choice but to intensify agriculture. However, producing more crops and greater quantities of food, fiber and other materials on the same parcel of land can to soil fertility and productivity decline with overall degradation of land quality. Therefore, ways and means to intensify agriculture to enhance productivity without degrading the soil and land resource base have become imperative. Agro-forestry, agro-slivi-pastoral systems, and the adoption of a variety of crop, soil and water management and conservation practices offer potential to deliver multiple benefits without sacrificing the very resource upon which the human population depends. Presented herein are findings on approaches to sustainable intensification of agriculture and land management related to soil OM management and C sequestration for multiple benefits, and, agro-forestry as a crop diversification strategy with both livelihood, and climate change adaptation/mitigation benefits. The results indicate that sustainable soil management practices could lead to significant SOC accumulations (4-8 t/ha over 6 yrs). SOC and soil C stocks tend to increase with elevation due to cooler climate and slow decomposition rates. Carbon stocks for the 3 LU types was in the order CF>AF/LH>AG, suggesting that diversified cropping practices including agro-forestry have good potential sequester C while providing livelihood opportunities and climate adaptive capacity for local farming communities. Biochar amendment increased growth of both coffee plants and radish with mixed grass/weed biochar being most effective. Biochar application also significantly decreased emission of GHGs, especially N_2O.

KEYWORDS: Agroforestry, biochar, carbon sequestration, crop diversification, soil quality

*Corresponding author: (Email: rmbaj@ku.edu.np)

1. INTRODUCTION

Soil and land resources have been the backbone of human civilization ever since pre-historic communities established permanent settlements and began settled agriculture some 10,000 years ago [1]. Historical records show that past civilizations (such as the ancient settlements of the Tigris-Euphrates and Nile River valleys), flourished because of access to fertile soils and likewise they declined as a result of land degradation and loss of fertility of agricultural lands [2]. Yet over the millennia, through traditional practices handed down over the generations, previous human communities learned to manage soils and cultivate their lands, even in harsh climates and terrains like the arid region of Egypt and mountainous regions of South Asia [3]. After the industrial revolution of the 1800s the world population has grown tremendously, exceeding 7 billion and growth is still rapid in some parts of the world, such as, Asia, Africa and the Middle East. Arable land has essentially reached the limits of expansion but pressures on land resource base continue to increase, with ever-greater demands for settlements, food and fiber production. The need for producing more food on the same amount of land has evidently fuelled agricultural intensification. Moreover, the impending impacts of climate change pose major challenges to production and human well-being [4]. Hence there is an urgent need for "sustainable" intensification of agriculture as well as land management.

Agricultural intensification is regarded as any change in the cropping or livestock-rearing practices that makes use of a fixed area of land more frequently or intensely than previous traditional or conventional approaches. Thus, increased numbers of crops grown per annual cropping cycle, an increase in the stocking rates of livestock grazed on a parcel of land, or change in types or sequences of crops grown (for example intercropped or relayed) are all forms of agricultural intensification [5-7]. Agricultural intensification can have both beneficial and adverse impacts on the environment and human societies [8, 9]. While intensified production systems provide higher yields, and therefore, returns, it is often achieved through the use of chemical fertilizers and synthetic pesticides, which have far-reaching and long-term consequences for ecological balance and human health [10]. However, with proper balance of inputs and an integrated, holistic approach to farming and land management, it is possible to achieve production goals with while minimizing adverse impacts to the environment and human health [7, 11].

Soil is an essentially non-renewable resource upon which natural ecosystems and agriculture depend that forms the interface and acts as a buffer between terrestrial systems and aquatic systems as well as the atmosphere. Soil organic matter (SOM) can be regarded as a bio-physical property of soil and perhaps the single most important constituent determining soil quality. It has a profound influence on many soil properties and is a dynamic and complex entity having major implications for soils. Sustainable soil or land management and intensified agriculture involves three key components, namely, sustainable soil management practices, crop improvement and diversification, and, water and runoff management. Sustainable soil management revolves around organic matter management and integrated nutrient/fertility management. Crop management includes improved hybrid varieties as well as diversified cropping patterns. Water or runoff management involves water harvesting and recharge, careful disposal of excess water, and, water conservation along with micro-irrigation. This study presents a few approaches to sustainable land management and intensification of agriculture focusing on: SOM management and C sequestration for multiple benefits; and, agro-forestry as a crop diversification strategy with both livelihood and climate mitigation/adaptation benefits.

Sustainable soil management (SSM) practices were introduced by Helvetas of the SDC in 15 mid-hill districts of Nepal. These SSM were centered around SOM management and integrated fertility management. They included farmer practices such as: Improved cattle sheds for separate collection of urine and manure; improved composting with protection from sun light and rain leaching (roof or cover); application of cattle/human urine as N source; legumes, fodder plants, vegetables and cash crops.

Agro-forestry along with diversified cropping has potential as a sustainable land use practice, particularly in hilly regions that do not support intensive food crop production. Such practices offer opportunities for poor rural communities to generate income from high value crops such as medicinal and aromatic plants (MAPs) and fruit tree under unpredictable climate conditions and hence are good climate change adaptive strategies. Moreover, permaculture can, over time, lead to increased carbon capture and storage over conventional agriculture, thus also serving as a climate mitigative approach. Studies have shown that these systems are well suited to hill regions with marginal and steeply sloping land and can lead to improvement of farmers' livelihoods and adaptive capacity [12, 13].

Biochar as a soil amendment has numerous benefits that could enhance soil quality and productivity, especially on marginal lands. Biochar is a pyrolysis product of vegetative biomass combusted under low oxygen conditions. It has the potential to enhance the carbon storage and longevity in soils while simultaneously increases soil productive capacity [14]. It has been known to be used by ancient civilizations in Australia, the Amazon, North West Europe and the Andes [15-17]. The unique structural, porosity, and nutrient retention characteristics of biochar enables it to acts as a catalyst for microbial activity. Highly stabile and resistance to microbial breakdown biochar acts as sites for increased water and nutrient retention [18].

2. MATERIALS AND METHODS

2.1 Sustainable Soil Management Program (SSMP of SDC) on farmer fields

This study was conducted in order to estimation of the total SOC sequestration potential in SSMP farm areas [19]. Four replicate farm fields in 4 districts with SSMP interventions were selected, namely, Baglung, Syangja, Kavrepalanchok and Sindhupalchowk. Comparison of SOC in farm fields over 6 years of SSM practices (mainly improved compost/FYM) were conducted by sampling 4 replicate farms in each district and comparing values with baseline soil organic C data.

The soils on upland farms in each of the districts were sampled in four depth increments: 0-15, 15-30, 30-60 and 60-100 cm to determine total soil C stocks. Calculations of the SOC stocks were done as follows:

$$\text{Total SOC stock (t ha}^{-1}\text{)}, D_{oc} = \text{SOC} \times \text{Bd (i)} \times \text{H} \times (10^4\ \text{m}^{-2}\ \text{ha}^{-1}) \quad (1)$$

Where,

D_{oc} = Soil organic carbon density (t ha^{-1})

SOC = Average soil organic carbon content of soil (%)

Bd = Average bulk density of soil samples (t m^{-3})

H = Thickness of the plow layer = 0.15 m

Further, the determination of the SOC increase rate (t ha^{-1} y^{-1}) was done using the following equation:

$$SOC = \beta Y + C \quad (2)$$

Where,

β = Slope of the regression line

Y = Year (independent variable)

C = Regression constant

Finally, estimation of the total SOC sequestration potential in SSMP farm areas across the Nepal hills (in millions of tons) was done by extrapolation of average SOC increase over the period in the four districts to the entire area in all 15 SSMP districts. Moreover, the hypothetical payments to farmers for enhancing soil C accumulation under a carbon-trading scheme was determined. The calculation of total monetary benefits under carbon trading as per the Kyoto Protocol using nominal payments of $2.50 and $5.00 per ton of C sequestered in soil were presented.

2.2 Land management impacts on soil organic carbon and soil quality

Three districts in central Nepal representing 3 agro-ecological zones: Chitwan (200-300 m); Gorkha (1000-1100 m); and, Rasuwa (1600-1700 m) were selected for the study. In each district, plots were chosen on three land management regimes, namely, community forests (CF), Agro-forestry or leasehold forests (AF/LH), and upland agriculture (AG). Four replicate plots in each LM type for each location (500m2 forest plots; farm fields) were randomly chosen for quantification of total C stocks. The above-ground biomass carbon (AGB-C) was calculated by measuring diameter at breast height (DBH) and tree height and applying the allometric equation by Chave et al. [20]. The below-ground biomass carbon (BGB-C) was estimated as 20% of the AGB-C. The leaf-litter, herbs and grass carbon (LHG-C) was determined by destructive sampling and dry-ashing in a muffle furnace at 550 ºC. The soil organic carbon (SOC) stocks was derived from the soil organic matter content by loss on ignition and the dry bulk density (BD) of the soil. Baseline soil properties such as soil texture, pH, BD, SOC, and total nitrogen (TN) were determined by standard methods according to the USDA-ASA Monograph No. 9 [21].

2.3 Biochar amendment of soil (coffee/vegetable plant growth and GHG emission)

Field trials to examine the effect of biochar application on coffee plant growth and the growth performance of vegetables were established at two locations during 2014. At Panchkhal in Kavre district, a coffee nursery trial with different rates and types of biochar was conducted to determine the effect of different combinations and rates of application of biochar on coffee plant growth. Biochar made from coffee pulp/husk or grass/weeds were applied at 2 tons/ha and 4 tons/ha with and without cattle urine addition. In a separate field trial at Saraswatikhel, Bhaktapur, an agroforestry trial using coffee planted in rows with vegetables (radish) planted between the rows was established. Here a constant rate of 4 tons/ha of biochar made from grass/weed feedstock was applied to both the coffee and radish plants. In both trials, the growth rate (height of plants) was monitored over a period of several months

3. RESULTS

The key findings and notable results of each of the studies described above are summarized in the tables and figures below and discussed in light of sustainable management of soils for enhancing productive capacity of the land.

3.1 Effect of sustainable soil management practices on SOC accumulation

This study revealed that in the fours study districts, the average soil organic matter contents, and hence SOC amounts, 43 ractice

44g significantly compared to baseline values at each of the farm fields where SSM 44 ractice, such as improved composting and application of cattle urine, were adopted by the local farmers (Table 1). The mean SOC contents at the SSM farms in the four districts ranged from two to three times the baseline amounts over a period of six years. The results clearly indicated that total carbon accumulation in soils and the corresponding amounts of carbon sequestered in agricultural lands in the mid-hills region of Nepal could be significantly increased through the use of such SSM practices. This has beneficial implications for the fertility and productivity of these hill soils as well as for climate change mitigation through carbon capture and sequestration.

Table 1. Mean SOC contents (%) of upland soil bef ore and after 6 years of SSMP in four districts of Nepal.

District	Baseline	3-year mean	6-year mean
Baglun g	1.60	3.72	4.96
Kavre	0.68	1.36	2.99
Sindhup alchow k	1.19	1.31	2.45
Syangja	2.29	2.97	6.37
Mean ± Std.Dev .	1.44 ± 0. 86	2.34 ± 1.20	4.19 ± 1.81

Using low and high carbon accumulation scenarios based on Table 1, the SOC increase trends for each case are depicted in Figure 1. The mean SOC accumulation over 6 years for the low carbon accumulation scenario was 2.72 % SOC, while that for the high C accumulation scenario was 4.19% SOC. Based on these C accumulation rates, the total carbon stocks accumulated over the 6-year period for each case over the entire agricultural land area (67,000 ha) of the 15 SSMP districts would be 2.7 million tons of carbon (low scenario) and 4.6 million tons carbon (high scenario), respectively (Table 2).

Then, taking nominal carbon trading values of $ 2.50 per ton C in the low scenario case and $ 5.00 per ton C in the high scenario case, the value of SOC accumulated in 6 years over the 15 SSMP districts of the Nepal mid-hills would range from about USD 2 million to a high of USD 13.5 million. Or on average, a total of USD 6.6 million could be received as compensation for carbon accumulated due to farmers adopting SSM practices in the mid-hills over a period of 6 years (Table 2.). Such returns for climate mitigative actions by local farmers would offer good incentives for them to conserve their soils through adopting sustainable farming practices for improving the fertility and productivity of their lands.

Table 2. Estimated C stocks, annual accumulation, and potential C-trading benefits due to SSMP.

Scenario	Avg. SOC (%)	Bulk density (g cm^{-3})	C density (t ha^{-1})	SOC stock* (mi llion t)	C-trade value (millions $)
Baseline	1.44	1.43	30.9	1.9	
Low scenario	2.72	1.18	41.4	2.7	2.0§
High scenario	4.19	1.18	74.2	4.6	13.5†
Average increase	1.83	1.18	57.8	3.65	6.6‡

*Extrapolated across total area of agricultural land (67,000 ha) in 15 SSMP districts of mid-hills Nepal. §C-trade valued at US$ 2.50 per ton; †C-trade at US$ 5.00 per ton; ‡C-trade at US$ 3.75 per ton of carbon accumulated.

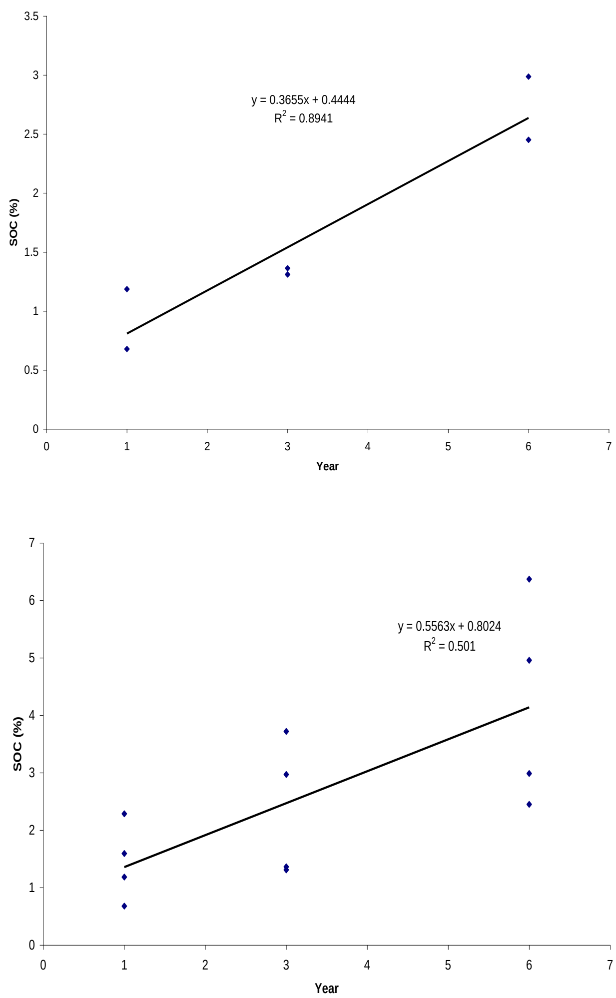


Figure 1. Soil organic carbon increase for low (to p) and high (bottom) carbon accumulation scen arios compared to baseline SOC contents over a 6-year period.

3.2 Land management impacts on SOC and soil quality

As shown in Figures 2 and 3, land use type had an effect on the total SOC contents, soil pH and total nitrogen. The one-way analysis of variance (Table 3) indicated, however, that soil bulk density did not differ according to land use and that SOC differed significantly only in Gorkha district, total N differed significantly only in Chitwan, while soil pH was significantly different among land uses in Chitwan and Gorkha. For Rasuwa district all soil quality parameters did not differ significantly among the land use types. The SOC contents and total N were highest for all land uses in Rasuwa district owing to the cool climate located at elevations of 1700 to 1800 m asl. Under these conditions, the soil organic matter decomposition rates are slow and a net accumulation of SOM tends to occur. Moreover, it was noted that farmers relied

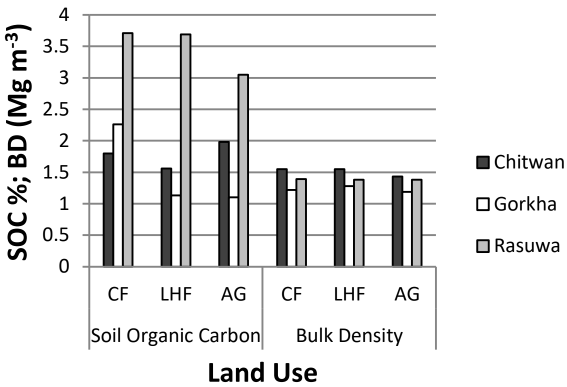


Figure 2. Soil organic carbon contents and bulk densities under different land uses (CF = community forest, LHF = Leasehold forest, and AG = agriculture) at the three study districts.

more on organic manures and compost in Rasuwa compared to Chitwan and Gorkha where chemical fertilizers are more readily available. The soils were more acidic in Rasuwa compared to Chitwan or Gorkha, which likely reflects the nature of the geology and rocks/parent material from which the soil was derived. Contrary to expectations, however, in both Chitwan and Gorkha, soil pH was higher in agricultural soils compared to community or leasehold forests. This may be due to the use of agricultural lime by farmers to ameliorate soil acidity.

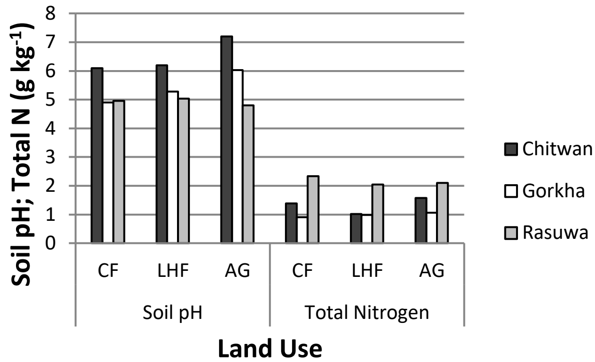


Figure 3. Soil pH and total nitrogen under different land uses (CF = community forest, LHF = Leasehold forest, and AG = agriculture) at the three study districts.

Table 3. One-way ANOVA of soil properties by land use for each location (Agroecological Zone).

	Chitwan		Gorkha		Rasuwa	
Soil Property	F-test value	Signif.	F-test value	Signif.	F-test value	Signif.
SOC %	0.89	ns	12.92	***	1.66	ns
Bulk density	1.32	ns	0.81	ns	0.01	ns
Soil pH	11.86	***	6.85	**	2.41	ns
Total N	4.12	*	0.24	ns	0.72	ns
C-Stock	0.59	ns	15.28	***	1.63	ns

Note: *, **, *** indicate significance at 0.05, 0.01 and 0.001 level of P, respectively.

As expected, the total carbon stock in soils of the three study districts were highly correlated with the SOC content of the soils as shown in Table 4. Soil organic carbon content was also highly correlated with total nitrogen and negatively correlated with soil pH. Similarly, soil carbon stock was positively correlated with total nitrogen and negatively correlated with soil pH (Table 4).

Table 4. Pearson's correlation matrix for soil properties across land uses and locations.

Soil property	BD	C-stock	pH	TN
SOC	-0.77	0.96***	-0.39**	0.75***
BD		0.16	0.24*	0.05
C-stock			-0.34**	0.77***
pH				-0.14
TN				1

*, **, *** indicate significance at the 5%, 1%, 0.1% levels of probability, respectively.

Calculation of the total carbon stocks under each land use in each of the three study districts (Figure 4) revealed that, expectantly, community forests had the highest total C stock due to the presence of trees, resulting in a high above-ground biomass carbon (AGB-C). However, it should be noted that the below-ground (root) biomass and soil organic carbon components were also high and contributed significantly to the total C stocks in forests. Moreover, with the exception of Gorkha, leasehold agroforests (LHAF) also had comparatively high total carbon stocks. In agricultural land use, it is only the soil OC that contributed to the total C stocks as above ground biomass (crops) are harvested annually and cannot be counted in the total carbon stock. Hence, leasehold or agroforestry systems offer potentially sustainable options for meeting the production and income needs of farm households while simultaneously contributing to sequester carbon.

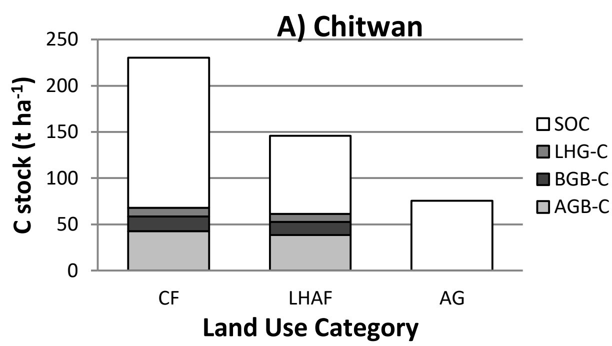
3.3 Effect of biochar amendment on growth of coffee and vegetables.

Biochar applied to the soil in nursery trials at Panchkhal produced a mixed response in the growth of coffee seedlings as seen in Table 5. Compared to the control treatment, which received only vermi-compost according to the usual farmer practice, the mixed (weed/grass) biochar gave the best response as seen in overall plant height and growth rate (Table 5 and Figure 5). The higher application rate of 4 t/ha (20% of FYM) gave the better responses for both mixed and coffee pulp biochar. Other combinations and lower rate (2 t/ha) of biochar application including cattle urine application did not have improved growth over the control treatment.

Table 5. Mean height of coffee plants in the coffee nursery trial at Panchkhal, Kavre.

Treatment*	Days after planting						
	73	91	122	139	172	201	245
Control	2.1	2.7	6	7.7	9.9	13.3	14.1
MB-20	2.4	2.9	6.3	8.4	10.6	13.3	15
CB-20	2.6	3.1	6.1	7.8	10.6	11.9	14.6
MB-20+U	3	3	5.6	7.4	9.1	12	14.2
CB-10	2.3	3.3	5.6	7	9.6	11.5	13.9
CB-10+U	2.8	3.6	6.3	8.6	10	12	13.6
CB-20+U	2.5	3.2	6	8	9.9	11.6	11.9

*MB = mixed biochar, CB = coffee biochar; 10 indicates biochar applied at 2 t/ha; 20 indicates biochar applied at 4 t/ha; U – indicates cattle urine applied as fertilizer.



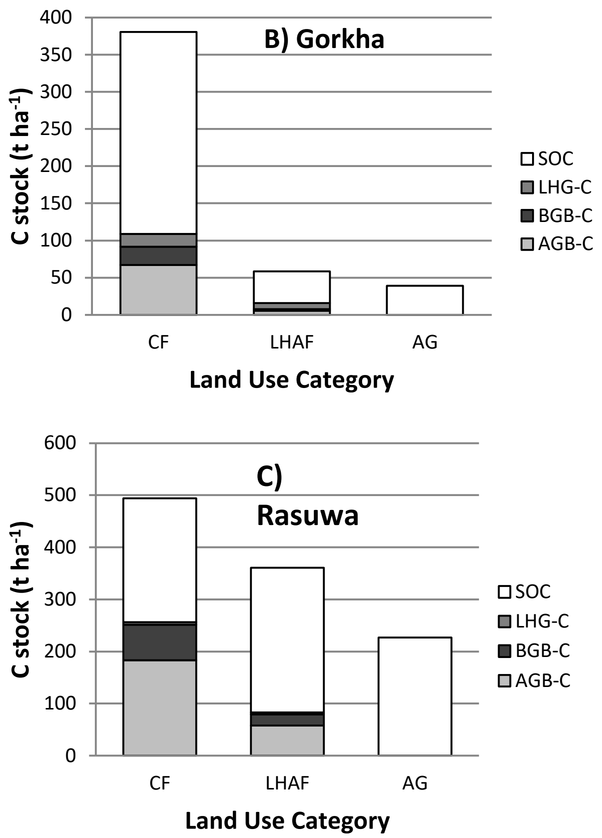


Figure 4. Total carbon stocks in biomass and soil for different land uses in the three study districts. Note: CF = community forest, LHF = Leasehold forest, and AG = agriculture; SOC = soil organic carbon, LHG-C = leaf-litter, herbs and grasses carbon, BGB-C = below ground (root) biomass carbon, and AGB-C = above ground biomass (tree) carbon.

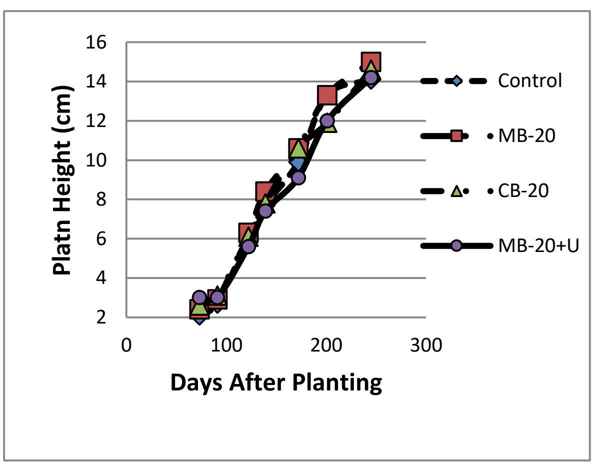


Figure 5. Coffee plant growth following emergence from 73 days after planting at the Panchkhal nursery trial.

In a separate field plot trial at Saraswatikhel, Bhaktapur, the growth rate of coffee plants with mixed grass/weed biochar applied at a rate of 4 t/ha also exhibited a higher growth rate (Table 6). Although the overall mean height of coffee plants was higher for non-biochar plants, the increase in height was more for the biochar applied plants at 5.4 cm over a 30 day period compared to 4.8 cm increase for non-biochar plants. The higher overall plant height in the latter was due to the transplanting of older and taller coffee plants in the non-biochar treatment as compared to the biochar treatment.

Table 6. Coffee plant growth during a thirty day period for biochar applied and non-biochar treatments at Saraswatikhel, Bhaktapur.

Treatment*	Plant Growth (centimeters)		
	Height (11/10/14)	Height (10/12/14)	Ht. Increase (30-day)
w/ biochar	36.8	42.2	5.4
Std. Dev.	2.2	1.9	1.2
No biochar	49.5	54.3	4.8
Std. Dev.	8.6	9.7	4.7

*Biochar applied in two doses of 2 t/ha for a tot al of 4 t/ha.

Table 7. Growth of radish plants in rows between the coffee plants at Saraswatikhel, Bhaktapur during October to December 2014.

Plant Number	Plant length in centimeters	
	With biochar	Without biochar
1	24	15
2	27	25
3	32	17
4	18	24
5	23	20

6	30	18
7	18	15
8	28	20
9	23	20
10	17	15
Mean* ±s td. dev.	**23.9 ± 5.4**	**19.1 ± 3.7**

*Means statistically significantly different at $P < 0.05$.

As with the coffee plants, radish planted in rows between the coffee trees showed a positive response to biochar application, as shown in Table 7. Radish plants that received biochar application (at a rate of 4 t/ha) grew to an average height of nearly 24 cm compared to non-biochar plants, which only reached an average of about 19 cm. This difference in height was statistically significant at the 5% level of probability.

Apart from plant growth rates, biochar influenced the emissions of greenhouse gases from the agroforestry trial plots at Saraswatikhel, Bhaktapur. The flux of GHGs measured at weekly intervals during April and May 2014 showed a general trend of lower emissions for the biochar applied treatment (Table 8). Although the values were not statistically significantly different for carbon dioxide and methane, nitrous oxide flux exhibited significantly ($P < 0.05$) lower values in the biochar amended soil as compared to soil without biochar. This finding is especially relevant for agricultural soils, which are the main source of N2O emission to the atmosphere, particularly with the application of chemical nitrogen fertilizers.

Table 8. Fluxes of greenhouse gases (µg CO_2 m^{-2} h^{-1}) from biochar applied and non-biochar plots at Saraswatikhel, Bhaktapur.

GHG	Treatment	Min.	Max.	Mean	Signif.
CO_2	biochar	10.5	432	225.4	NS
	non-biochar	40.8	589	298.5	
N_2O	biochar	5.12	370	89.0	P<0.05
	non-biochar	6.30	523	157.2	
CH_4	biochar	1.58	22.9	12.1	NS
	non-biochar	0.86	39.8	16.0	

4. DISCUSSION

The results of the above case studies indicate that various sustainable soil and land management practices could provide multiple benefits and adaptive capacity to local communities to tackle the impending climate change impacts on agriculture. This is in agreement with the findings of numerous other studies around the world [12, 22, 23].

Adoption of soil management practices that return organic matter to the soil and minimize the use of chemical fertilizers tend to improve the soil quality and sustainability of crop production. These include practices such as improved composting, residue incorporation, bio-fertilizers, etc.) [24-26]. Moreover, such practices can lead to significant carbon accumulation in the terrestrial pool and help to counter global warming caused by increased greenhouse gas emissions to the atmosphere

[15, 19, 24].

In the context of mountain farming on steep slopes and shallow soils, agroforestry and other permaculture practices offer good potential for both enhancing production and livelihood security, as well as, other benefits like slope stabilization, organic matter enrichment, carbon capture and climate change adaptation. This has been also pointed out in other studies, such as, [12, 27, 28]. Such integrated and diversified farming systems can reduce the production risks, which become significant under unpredictable climatic conditions.

Furthermore, in the case of inherently low quality soils, degraded lands, or acidic soil conditions, amendment with biochar (produced from waste biomass) could offer a locally viable means for improving soil quality and increasing productivity. The third study indicated good initial responses by crops, namely, coffee plants and radish, to the application of biochar at low rates. Similar results have also been demonstrated in other studies [14, 18].

5. CONCLUSIONS

Sustainable soil management practices can lead to significant C accumulations (4-8 t/ha over 6 yrs) in mid-hill districts of Nepal. The SOC contents and soil C stocks tend to increase with elevation due to the cooler climate and slow rates of organic matter decomposition. The total carbon stocks for three land use types, namely, community forest, leasehold/agroforestry, and agriculture followed the trend: CF>LH/AF>AG. However, agroforestry practices also had high total carbon stocks comparable to community forestry, making them a potentially suitable option for enhanced livelihoods of rural communities while helping to sequester carbon in the hill regions of Nepal.

Application of biochar to soil at low rates (2-4 t/ha) increased growth of both coffee plants and radish. Mixed grass/weed biochar gave the best results for coffee seedlings grown on nursery beds. Application of diluted cattle urine did not have a notable effect on coffee seedlings. Biochar amended soil generally had reduced emission of GHGs. This reduction was significantly lower for N2O flux. Hence biochar offers a potentially viable option for sustainably enhancing agricultural production, while also helping to mitigate greenhouse gas emissions and climate change. This conclusion, however, needs further research and verification.

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