Article

Effect of primary soil nutrients (NPK) on forests' biomass production and SOC density of Nepalese forests

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Abstract
Soil nutrients in the forests ecosystem play crucial roles in performing key ecological functions. This research was carried out to quantify biomass and SOC, and to see the responses of primary soil nutrients (NPK) and other soil properties on biomass and SOC density in the forests. Three community forests (CFs) from Dadeldhura district of Far Western Province of Nepal were taken as a study area. Simple random sampling with concentric circular plots of various sizes was laid for necessary data collection. Altogether 45 plots were measured. All the parameters were estimated and analyzed using standardized procedures. Generalized Linear Model (GLM) was fitted and respective tests were performed base on data characteristics. A relatively medium quantity of biomass density, SOC and NPK were found and these differed significantly between forests. The result showed the SOC, N and bulk density influenced significantly but inversely to biomass density. However, K, P and pH did not respond significantly on biomass density. Similarly, phosphorous responded significantly and positively on SOC but bulk density and pH showed significantly but the inverse effect on SOC. Results indicate that soil pH, P and K hardly influence forests' biomass. The higher the SOC does not necessarily produce higher biomass in the forest as SOC, N, and bulk density responds inversely to biomass density. Likewise, biomass density, N and K rarely affect the SOC in forests. This result will be a reference to policy and practical implications at forestry. Because of the wide variability of soils characteristics, similar research to generalize the results is recommended.

Keywords biomass density; community forests (CFs); Western Nepal; primary soil nutrients (NPK); SOC density.

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1 Introduction

Soil is the foundation for all fauna and flora in the terrestrial ecosystem. This is the medium in which roots grow, anchor the plants and is the reservoir of water and nutrient necessary for the terrestrial plant life. Forest soil influences the composition of forest stand and ground cover, rate of tree growth, a vigour of natural reproduction, and other silvicultural important factors (Poudel and Sah, 2003). The plants actively absorb and assimilate nutrients and are good indicators of the number of accessible nutrients (Fried and Dean 1952). Nutrient uptake by forest crops is similar to that of other plant crops but the amount accumulated in the biomass is about one quarter to one-third of uptake (Miller 1981). Total nutrient content varies from soil to soil depending upon the nature of parent materials and other soil-forming processes. Only the plant-available form of nutrient in the soil is relevant for crops and is chemically determined through appropriate testing methods (Reddy et al., 2012).

The soil properties indicate the health of a particular land area such as forests. The use of soil properties as indicators of soil quality focused on soil nutrient availability for plant growth (Tiwari et al., 2006) especially N, P, and K provide the evidence of limiting factors for forest plants growing on relatively fertile soil in the lowland tropics (Wright et al., 2010). Nitrogen is available in virtually unlimited quantities in the atmosphere and is continually recycled among plants, soil, water and air which require for a vigour plant growth and development, P for root development, seed formation and diseases resistance, and K encourages normal cell division in young meristematic tissues of the plant. Soil pH is an important property that indicates the acidity and alkalinity of soil solution by which it can predict the availability of plant nutrients, toxins and activity of many essential microorganisms (KC et al., 2013).

Forests' production mainly depends on the availability of nutrients in the soil. However, despite the importance of plant-soil nutrient relationship, only hand counts researches are in place on forest soil nutrient. But we could hardly find any research on a cause and effect analysis on biomass density and SOC by NPK and other soil properties in Nepal. Begum et al. (2010) have highlighted the requirement of further studies to clarify the complex interactions between soil properties (physio-chemical and biological), vegetation and slope aspect in Nepal (Begum et al. 2010). Assessment on biomass and soil carbon accumulation show some indication in ecological and economic function associated with forests ecosystem. Also, benefits to the local people as well as to enhance the carbon storage capacity of the typical forest through soil nutrients assessment to examine the key ecological functions which linked to the survival of all terrestrial living beings including human. Moreover, wild animals obtain different types of soil nutrients such as extractable Phosphorus, Potassium, Magnesium, Calcium, Sodium, and Sulphur concentrations from soil (Moe, 1993). Hence this study also helps to identify the forests types that whether the forests could be managed as wildlife habitat without compromising the anthropogenic attachment to forests. Realizing these facts, the study was conducted to quantify the amount and accumulation of carbon content in plant biomass and soil as well as the responses of primary soil nutrients (NPK) and other soil characteristics on biomass production and SOC in the Nepalese forests. The findings will provide key insights of understanding on the interrelation of biomass, SOC and NPK in the natural environment.

2 Study Area and Methodology

2.1 Study site

The study was carried out in Dadeldhura district, Far Western Province of Nepal, covering an area of 1,538 km², located between 28.59° to 29.26° N latitude and 80.12° to 80.47° E longitude (Fig. 1). The district is located about 800 km towards the west from capital city Kathmandu and had a population of 142,094 in 2011 (CBS 2011). The altitudinal range of the district is 462 m above sea level (asl) to 2639 m asl.

Geographically, the district is categorized into four vegetation zones, namely, lower tropical, upper tropical, subtropical and temperate constituting an area of 0.6%, 34.7%, 55.8% and 8.9% respectively (DFO-Dadeldhura, 2010). The average maximum temperature is 32.7^{0}C and an average minimum temperature of 3.6^0 C; and the average annual rainfall of 1343.6 mm (DHM, 2016).

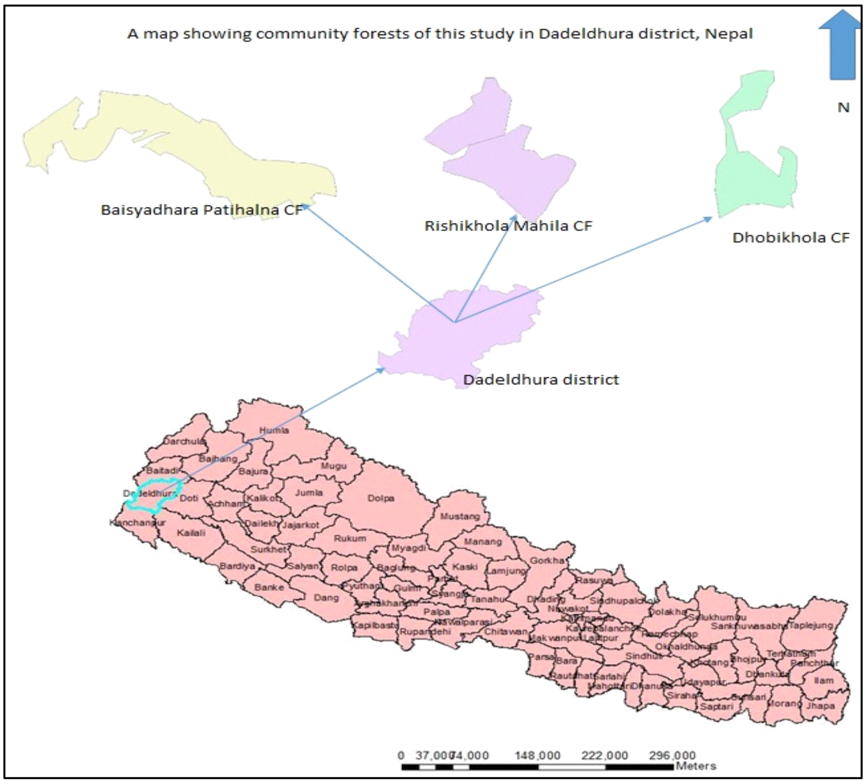

Fig. 1 Map showing the study area indicating Nepal, Dadeldhura district and the community forests took for the study.

Nepal is widely famous in the international arena because of its successful community forestry program. Till this date, the country has about 22519 CFs. This was commenced in the late 1970s and continues to the date. In Dadeldhura district, the formal handover of community forest (CF) was commenced in 1991. So far the district comprises more than 450 CFs. Brief introduction of community forests that had been taken into consideration for this study is presented here (Fig. 1).

Baisydharghatal Patihalna Community Forest (BPCF): This CF was located in Amargadhi municipality-2 of Dadeldhura district. The total forest area was 60.75 ha which was divided into two blocks for management purpose. The forest extends between 1623.56-1866.05 m asl altitudinal range. The forest was formally handed over as CF in July 1993. The household size was 152 and forest user group population was 936 (CFUG 2015). The forest was dominated by *Quercus leucotrichophora* and located in the southern aspect that prevails more disturbance than other two forests under study. Major associate species were *Myrica esculenta*, *Quercus lanata*, *Rhododendron arboretum*, *Pyrus pashia*, *Lyonia ovalifolia*, *Pinus roxburghii* and *Sauraria nepalensis*. The forest area per household was 0.4 ha.

Rishikhola Mahila Community Forest (RMCF): This CF was located in Amargadhi municipality-5 of Dadeldhura district. The forest covers an area of 66.26 ha which was divided into two blocks for management goals. The altitudinal range of community forest was 1654.29 to 1868.16 m asl. It was formally handed over as a CF in July 1994. The household size was 244 and forest user group population was 1633 (CFUG 2015). The forest was located in north-eastern aspect and dominated by *Quercus leucotrichophora*. Major associate species were *Myrica esculenta*, *Quercus lanata*, *Rhododendron arboretum*, *Pyrus pashia*, *Castanopsis tribuloides*, *Pinus roxburghii, Pinus patula*, *Lyonia ovalifolia* and *Sauraria nepalensis*. The forest area per household was 0.3 ha.

Dhobi Khola Community Forest (DKCF): This CF was located in Amargadi Municipality-5, Jhurkali of Dadeldhura district. The total forest area was 55.41 ha with 3 blocks for management objectives. The altitudinal range of this community forest was about 1400-1840 m asl. It was formally handed over as CF in 2014. The household size was 38 and forest user group population was 265 (CFUG 2015). The forest was located in western aspect and was dominated by *Pinus roxburghii*. Major associate species were *Quercus leucotrichophora*, *Quercus lanata*, *Rhododendron arboretum*, *Myrica esculenta*, *Sauraria nepalensis* and *Pinus patula*. There was a provision of resin collection from *Pinus roxburghii* in this CF. The forest area per household was 1.46 ha.

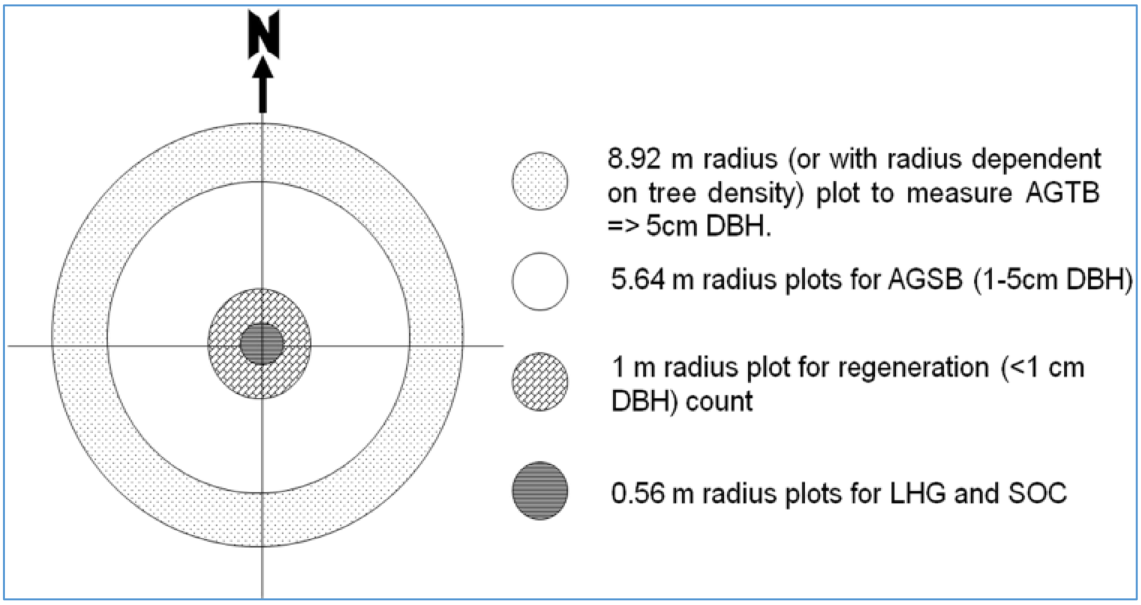

Fig. 2 Design of sample plot layout in the field (Source: Subedi et al., 2010).

2.2 Data collection

Simple random sampling method with a 0.62% sampling intensity was used for collecting data. Altogether 45 samples were assigned to collect the data from CFs constituting 15 samples in each where concentric circular sample plots of radius 8.92 m were laid out. Within each plot, several subplots were established for specific purposes. The 8.92 m radius plot was used for tree measurement, the subplot of 5.64 m radius was established for saplings measurement and sub-plot of 1 m radius for counting regeneration (seedlings) and 0.56 m radius plots for sampling leaf litter, herbs, grass, and soil sample collection (Fig. 2). Diameter at breast height (DBH) at 1.30 m and a total height of all trees, poles and saplings were measured using diameter-tape (D-tape) and clinometers in respective sample plots. All herbaceous plants, leaf litter and woody vegetation inside 0.56 m radius were clipped to take the fresh weight. And the representative samples of 300 gm of both leaf litter and herbaceous vegetation was taken to the lab for further analysis. Soil samples were collected from the centre of sample plots at different depths in three layers i.e. 0-10 cm, 10-20 cm and 20-30 cm using standardized procedures (Subedi et al., 2010) for soil organic carbon assessment, pH and nutrients analysis. For bulk density, a core ring sampler (5 cm diameter and 10 cm long) was used to estimate the bulk density of the soil.

2.3 Data analysis

All the data were analyzed using the guidelines for measuring carbon stocks in community-managed forests (Subedi et al., 2010) referring to the predictive allometric equations (models). In estimating above-ground tree biomass (AGTB), the model developed by Chave et al. (2005) was used to estimate forest biomass density. Sapling (dbh <5 cm) biomass was calculated by using national allometric biomass tables (Tamrakar, 2000). Soil organic carbon (SOC) was calculated using the methods as Pearson et al. (2007). Measurements of root biomass were indeed highly uncertain, and the lack of empirical values for this type of biomass had for decades been a major weakness in the ecosystem (Geider et al., 2001). To simplify the process for estimating below-ground biomass, we used the root-to-shoot ratio value of 1:5 (MacDicken, 1997). Biomass on leaf litter, deadwood, stumps, SOC and NPK constituents were analyzed in the lab taking a sample from the field as aforementioned. All the laboratory works were performed in the Soil Laboratory of Agriculture Technology Center, Lalitpur, Nepal.

The following generalized model (GLM) was fitted and tested against two response variables, i.e. biomass density (t ha^{-1}) and SOC (t ha^{-1}) with the parameters under study using R and R-Studio version 3.5.2 (R Core Team, 2018).

Mathematically,

$$Y_1 = a_{ij} + a_0CFs + a_1X_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_6 + e_{ij} \quad \text{(Model 1)}$$

$$X_1 = b_{ij} + b_0CFs + b_1Y_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + e_{ij} \quad \text{(Model 2)}$$

where, Y_1 = Biomass density, X_1 = SOC density, CFs = community forests type, x_2 = soil pH, x_3 = Nitrogen (N) percentage, x_4 = soil bulk density, x_5 = Phosphorous (P) density, and x_6 = Potassium (K) density. Similarly, a_{ij} and b_{ij} are intercepts; a_0, b_0, a_1, b_1, a_2, b_2, a_3, b_3, a_4, b_4, a_5, b_5, a_6, b_6, are constants for respective predicting variables and e_{ij} is the error term.

Data characteristics of SOC showed Gaussian distribution. Therefore, an identity-linked model with Chi-square tests was performed. Biomass density showed the Quasi-Poisson distribution, by the way, the residual deviance value did not get improvement in further analysis. So that the final distribution for biomass density was also considered as Poisson distribution of log-linked functions and the corresponding tests were Chi-square. The test results have been presented in tabular form.

3 Results and Discussion

3.1 Basic characteristics of the forests

The study sites were in Dadeldhura district of Far Western Province of Nepal. Thus, it is quite relevant to compare the basic parameters between the CFs and with a similar study within the country. The comparative parameters and comparable quantities are presented in Table 1.

Table 1 Basic characteristics of the forests.

Forests	Biomass Density (t ha^{-1})	SOC Density (t ha^{-1})	Mean Bulk Density	Mean pH	N (%)	P Density (kg ha^{-1})	K Density (kg ha^{-1})
BPCF	140.48	69.67	0.97	5.03	0.19	35.00	650.00
RMCF	148.80	99.23	0.88	5.25	0.32	55.80	936.38
DKCF	234.87	74.79	0.93	5.06	0.22	19.35	649.20

The result showed the highest density of biomass density was found in DKCK and the lowest was in BPCF. However, SOC was highest in RMCF and lowest in BPCF. Forests' soil bulk density ranged from 0.88 to 0.97 gm cm^{-3}. All the CFs had acidic soil having pH just above 5. Nitrogen percentage in the soil ranged from 0.19 % to 0.32 % for BPCF to RMCF respectively. Phosphorous density was highest in RMCF (55.80 kg ha^{-1}) and lowest in DKCF (19.35 kg ha^{-1}). Fortunately, Potassium density was about equal (650.00 kg ha^{-1}) in DKCF and BPCF but was highest in RMCF (936.38 kg ha^{-1}) (Table 1). Turkey's Honestly Significant Difference (HSD) test result showed that there was a significant difference in the mean quantity of biomass, SOC, Phosphorous, available Potassium of the community forests. However, the mean quantity of Potassium of RMCF found highest among study CFs (Table 1).

These results can be compared with the similar finding within the country and from different places (Table 1). The biomass in DKCF is higher than national above-ground average (194.51 t ha^{-1}) but lower in BPCF and RMCF whereas SOC was higher in all CFs than the national average (66.88 t ha^{-1}) (DFRS, 2015a) but far less than the study in Kasmir India that total tree biomass ranged from 319.2±208.5 Mg ha^{-1} to 496.7±278.9 Mg ha^{-1} in the forest (Dar and Sahu, 2018). Similarly, in Middle Mountains region, the national forest resource assessment result showed that total air-dried biomass (195.51 t ha^{-1}) was higher than BPCF and RMCF but lower than DKCF whereas SOC showed (54.33 t ha^{-1}) lower than all CFs in the study (DFRS 2015b). Soils under natural forests were characterized by higher SOC associated with all primary particle (Shrestha et al., 2007). The SOC in Kadapa hills of India is far less (27.5 - 32.3 t ha^{-1}) than our findings (Ramana et al., 2017). This is attributed to the steepness of Indian study sites than the study. Also, Shrestha et al. (2007) found the SOC stock (mean ± SE, kg cm^{-2}) in the topsoil (0–10 cm) was higher in grazing land (3.4 ± 0.1) compared to forest soil (1.4 ± 0.2). Forest and grazing lands had similar SOC contents, but the higher content of gravel and stone was found in forest soil resulted in the lower amount of the SOC density (Shrestha et al., 2004). The higher values of humus, organic matter, nitrogen and potassium (7.34%, 2.42%, 0.117%, 267.73 kg ha^{-1}, respectively) were found in pure *Shorea robusta* forest (Paudel and Sah, 2003). Similarly, the estimated mean of SOC density in the top 1 m was 41.4 kg m^{-2} in fir forest soils (Dorje et al., 2014). The SOC and N stocks (0–15 cm) was in the undisturbed forest found 74 and 5.9 Mg ha^{-1} at 2600 m asl, demonstrating the effects of cover and elevation, above 2800 m asl. the cover type changed from grass to coniferous forest, and the SOC and N stocks steadily increased at the summit level (3200 m asl.) to 65 and 6.9 Mg ha^{-1}, respectively in Mardi Watershed of Nepal (Awasti et al., 2005).

Forests and the minor areas of shrubs and grasslands have higher SOC densities and stocks than other land covers (Dorje et al., 2014). The nitrogen for oak and pine forests was 0.15 % and 0.19% respectively whereas Phosphorus in the oak forest was higher (17.99 kg ha^{-1}) than in pine forest (16.88 kg ha^{-1}) and exchangeable Potassium was 188.92 kg ha^{-1} in oak forest and 166.43 kg ha^{-1} in a pine forest (Sheikh and Kumar, 2010). On the contrary, results from modelling indicated the declining trend of soil fertility in the forests with elevation (Brown et al., 2006). Similarly, a detailed watershed study showed that the overall soil fertility in the forest soils found the poorest conditions compared to other land use types (Brown et al., 2006; Dahal and Bajracharya, 2013) as a result of biomass removal (Brown et al., 2006) and containing higher constituents of gravel and stone in the soil (Shrestha et al., 2004).

Forest species also indicate the soil organic carbon and other soil properties. This is also aligned with dense canopy cover and the presence of mixed species and nitrogen-fixing trees are indicators of higher SOC in Nepalese forests' soils (Maraseni and Pandey, 2014). Nutrient availability in forest soil is hardly deficit but moisture deficit in the sloppy land of Mid-hills hinder the uptake of nutrients to produce biomass. However, partial recovery of lost SOC is possible through forest management, especially if erosion is abated (Shrestha et al., 2009). The soil pH of three community forests is acidic (Table 1). A similar finding was obtained in the study from two ecological regions (Pandey and Bhusal, 2016) and in Dadeldhura district (Pandey et al., 2019) of Nepal. SOC and NPK decrease with increases in soil depths. The soil bulk density varies with soil depths. The soil available potassium and phosphorous decrease with increasing soil depths. The higher amount of available Phosphorous in the RMCF is due to a higher level of soil pH and high value of the organic matter in that forest. The percentage of total nitrogen of the RMCF was found to be higher due to the higher proportion of broadleaved species that enrich the N through leaf litter decomposition in the forest.

3.2 Biomass density

The Poisson distribution of log-linked model in GLM with Chi-square test was performed to see the responses from primary soil nutrients on biomass density in community forests. The analysis estimated that the dispersion parameter for Poisson family was taken to be 1, null deviance of 2418.4 on 44 degrees of freedom whereas residual deviance was 1592.4 on 36 DF. The detail of the test result is presented (Table 2).

Table 2 Test outputs on biomass density by the predicting variables under consideration.

Parameters	Estimate	Standard Error	Z-value	P-value	Significance
Intercept	10.3249696	2.7095363	3.811	0.000139	Yes
DKCF	0.5796641	0.1828085	3.171	0.001520	Yes
RMCF	0.4238903	0.1832496	2.313	0.020712	Yes
SOC	-0.0152275	0.0056578	-2.691	0.007115	Yes
pH	-0.4304322	0.4302573	-1.000	0.317114	No
Nitrogen percent	-0.4552516	0.1494721	-3.046	0.002321	Yes
Bulk density	-2.0886489	0.5877691	-3.554	0.000380	Yes
Phosphorous	0.0003341	0.0073226	0.046	0.963607	No
Potassium	-0.0001940	0.0001021	-1.900	0.057398	No

The test results showed that the model with Quasi-Poisson family test did not improve the significance and residual deviance on biomass density (Table 2). So, the final model was chosen to be the Chi-square test with log-link Poisson distribution. A similar scenario has been found in the SOC case too. However, the dispersion parameter for biomass density was found to be 36.69 and for SOC was found to be 0.08.

Biomass production varies with a different type of forests. Also, the response of primary nutrients and other soil properties showed a mixed effect on biomass density (Table 2). A similar study was carried out by Wright et al. (2011) and found that K and N together were associated with significant increases in growth rates of saplings and poles (1–10 cm in diameter at breast height) and a further marginally significant decrease in stand - level fine - root biomass whereas P was associated with a marginally significant ($P = 0.058$) increase in fine - litter production (Wright et al. 2011). Nitrogen is the main responsible for biomass production that supports in vigour growth of the plant but P and K responsible for increase resistivity, root formation etc. (KC et al., 2013) that resulted in the insignificant response on biomass density in the study area. The higher the SOC reduced the biomass density in the study area. In other words, SOC and biomass carbon are in inverse relation. This result suggests replicating the research to verify the output of this study. This may be due to the accumulation of atmospheric carbon to the soil through the process of photosynthesis in matured forest stands. The bulky soil also hinders the biomass production in the forests. Significant variation in biomass production in different CFs indicates that the individual level of assessments is needed for managing a particular type of forests.

3.3 Soil organic carbon density

The Poisson distribution of log-linked model was fitted in GLM to see the response of SOC by various parameters. The analysis obtained that the dispersion parameter for the Poisson family was found to be 1 and the residual deviance and degree of freedom (DF) found to be 2.8243 and 36 respectively. Null deviance and DF found to be 282.3652 and 44 respectively. Soil Organic Carbon has responded by the biomass density and other factors are presented (Table 3). Chi-square test results showed that different community forests responded significantly different ways upon forest organic soil density. Similarly, soil pH, soil bulk density, Phosphorous density had a significant effect on SOC. At the meantime, biomass density, Nitrogen percentage, and Potassium density in the soil had found no significant effect on SOC (Table 3).

Table 3 Test result of factors' response on SOC density

Parameters	Estimate	Standard Error	Z value	P-value	Significance
Intercept	1.035e+01	1.036e+00	9.987	<2e-16	Yes
DKCF	3.371e-01	9.310e-02	3.621	0.000294	Yes
RMCF	4.194e-01	9.806e-02	4.277	1.89e-05	Yes
Biomass density	-2.147e-05	2.482e-04	-0.087	0.931046	No
pH	-1.084e+00	1.937e-01	-5.595	2.21e-08	Yes
Nitrogen percent	-6.639e-02	2.404e-01	-0.276	0.782443	No
Bulk density	-1.293e+00	5.666e-01	-2.282	0.022478	Yes
Phosphorous	1.428e-02	4.196e-03	3.404	0.000664	Yes
Potassium	-1.612e-05	1.265e-04	-0.127	0.898635	No

Mixed responses on SOC by different parameters under the study have been found (Table 3). Because of the wide variability of soil characteristics (Reddy et al., 2012), the different CFs have significantly different findings of SOC density. Regular leaf-litter collection, firewood removal, dead and dying trees removal, execution of regular operations as prescribed by the operational plan of forest users' group, regular grazing, frequent fires followed by heavy monsoonal rain in sloppy terrains that washout all the ashes and litters from the CFs. As a result, the insignificant response of biomass density on SOC density was found in the study area (Table 3). As the finding of Maraseni and Pandey (2014), the forests having leguminous trees, a higher diversity of plant facilitates in SOC density in forest soil. These attributes were lacking in the study area. Also, the planted dry forests (*Pinus roxburghii*) that hardly foster the SOC accumulation and possibility of significant contribution to NPK and other soil characteristics are prominent factors seemed in many sites of the study area.

4 Conclusions

The relatively higher amount of biomass and SOC signifies the high potentiality of carbon sequestration of Mid-hills community-managed forests. Moisture deficit in the sloppy land of Dadeldhura's forests hardly showed a clear trend of responses on SOC and biomass density by the primary soil nutrient (NPK) but mixed results find. The significant influence of biomass density on SOC but the non-effect of SOC on biomass density signifies the one-way effect on biomass production by SOC in the forests. Biomass, soil pH and bulk density differ significantly for each CF indicate the wide variation of these characteristics in a natural environment. Only N plays a significant but inverse influence on biomass production reveals that N is not a limiting factor for biomass increase in the forests. P and K have no significant response to biomass production indicating that they are mostly responsible for disease resistance and root formation but lesser into biomass production in the forests. Higher bulk density and acidic soil showed a reverse effect on SOC density in forest soils. Among NPK, the only P had a significant progressive effect on SOC in the forests of Dadeldhura district, Far Western Province, Nepal. The findings may provide insights on the interrelationship among biomass production, SOC and NPK in the forest ecosystems, and would have a reference for policy and practical implication in forestry.

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