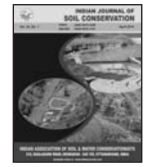
Vol. 42, No. 2, pp 135-142, 2014

Indian Journal of Soil Conservation

Online URL:http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home



Comparative estimation of litter carbon inputs by two different modeling approaches in central Himalayan forests

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ARTICLE INFO

Article history :
Received : February, 2013
Revised : January, 2014
Accepted : March, 2014

Key words :
Forest soils,
MODIS NPP,
RothC,
Soil organic carbon dynamics

ABSTRACT

The Soil Organic Carbon (SOC) status found in forest soils is the result of the balance between litter input to the soil and decomposition. Plant litter input to the soil is closely linked to net primary production (NPP). At equilibrium, the NPP is equal to the litter input to soil. In this study, plant litter input to a depth of 30 cm was estimated for ten forest sites located at different altitudes in Central Himalaya using the Rothamsted Carbon model (RothC) and was compared with estimated litter inputs from the NPP data from Moderate Resolution Imaging Spectroradiometer (MODIS). The litter carbon input calculated using RothC and that derived from MODIS NPP were positively correlated (r= 0.62), but the mean estimated litter input from RothC was 32.8% lesser than that estimated from MODIS. However, student's t-test revealed non-significant mean difference at 5% significance level between the estimates. RothC estimated litter carbon inputs were closer to MODIS NPP in case of dense and comparatively less degraded forests whereas large deviations were found in case of degraded forests. The discrepancy was probably because of the different temperature controls for the MODIS algorithm and the RothC model, and simple assumptions made in the RothC calculation. The mismatch in scale between the 1 km grid of satellite products (MODIS NPP) and the relatively small scale of ground-scale observations (SOC) might have also contributed to the disagreement observed. However, this approach merits further study to accept satellite-derived NPP data to be used as plant carbon input to soil system to drive soil models to estimate changes in forest soil carbon stocks under future climate/land management scenario.

1. INTRODUCTION

The dynamics of soil organic matter is critical for understanding the global carbon cycle. Climate, vegetation, parent material and time - all affect the processes controlling accumulation and decomposition of organic matter in soils (Trumbore, 1997). Countries are required to assess changes in the carbon stocks of forest soils under the United Nations Framework Convention on Climate Change (UNFCC) and for industrialized countries under the Kyoto Protocol. Ecosystem models are often used to predict the sensitivity of soil C turnover to climate, land use and parent material. However, in contrast with forest plant biomass inventories, soil inventory datasets are, in general, limited because of the higher cost of sampling and measuring C in soils. As a result, modeling approaches are often needed for assessment (Peltoniemi *et al*., 2007). The SOC is a net balance between the rate of input of organic matter (e.g. litter) to the soil and the rate of decomposition of soil organic matter (Raich *et al*., 1997). Soil C inputs are closely related to net primary production (NPP), with higher productivity leading to higher carbon inputs to the soil (Smith, 2008). Accurate assessment of NPP is, hence, essential for understanding the soil carbon cycle. NPP indicates the net carbon gain by the plant, and is an important index for evaluating changes in SOC, and also for estimating net ecosystem production. The International Biological Program (IBP) reported NPP values, mostly calculated from dry matter measurements (Cannell, 1982), the data from which have been used in many models (Alexandrov *et al*., 2002). Ecosystem models are a useful tool for estimating NPP and for studying the carbon cycle (Cramer *et al*., 1999; Kurz *et al*., 2008) especially on regional scales (Ito, 2003; Ito and Sasai, 2006). Ecosystem models are often applied on a regional scale and used as a tool for estimating regional carbon stocks. The combination of ecological models with satellite data and field observation is a common approach for understanding and quantifying carbon turnover (Ciais *et al*. 2005; Chiesi *et al*., 2007; Maselli *et al*., 2008). One of the most widely used NPP datasets, which was derived by combining a simple ecological model (algorithm) and satellite data, is the NPP data product from Moderate Resolution Imaging Spectroradiometer (MODIS; dataset MOD17A2/A3). Gross primary production (GPP) and maintenance and growth respiration are estimated from satellite radiometric indices, and NPP is then calculated by subtracting respiration from GPP. The GPP and maintenance respiration are estimated daily, and NPP is estimated annually. The method for deriving NPP was described in detail by Running *et al*. (2000). The dataset covers the global terrestrial surface at 1 km spatial resolution. MODIS NPP has been evaluated against ground observation data, and the MODIS NPP and GPP products showed no overall bias in the evaluation (Turner *et al.,* 2005, 2006). Jenkinson *et al*. (1999) estimated NPP using measurements of soil organic matter and a soil organic matter model (RothC, Rothamsted Carbon turnover model). When a forest is at equilibrium in respect of carbon, carbon inputs to the tree/soil system are balanced exactly by carbon losses from the tree/soil system, mainly through soil and tree respiration. In these conditions, the NPP is equal to the litter carbon input to the soil. Usually, soil carbon turnover models receive organic matter input and estimate changes in the soil organic matter content of the soil. The NPP required to balance the measured SOM content is inversely calculated, if the soils are assumed to be at equilibrium (Jenkinson *et al*., 1992, 1999; Jenkinson and Coleman, 1994). In other words, in the inverse application, the amount of soil carbon is used by the soil carbon model to back-calculate the litter carbon input needed to maintain this carbon stock. This is a very common initialization process in applying the RothC model (Smith *et al*., 2005, 2006). However, few studies (Hashimoto *et al*., 2010) have examined the relationships between estimated litter input from the RothC model and estimated litter inputs from other NPP data (e.g. biometry-based estimates, flux based estimates and satellite-based estimates). If satellite-derived NPP data can be used to drive soil C models, modeling systems could be developed that use soil carbon or ecosystem models and remotely sensed NPP data to estimate changes in forest soil carbon stocks under future climate/land management (potentially in real time) situations, for the purpose of scientific studies or for accounting under post-Kyoto climate agreements.

In this study, comparison was made between litter input from satellite-derived NPP (MODIS NPP values) with estimated litter inputs by inversely calculating the input of carbon to the soil with the RothC model for forest sites in central Himalaya.

2. MATERIALS AND METHODS

Study Sites and Soil Analysis

The present study was carried out in a part of Kumaon Himalaya, covering 600 to 1420 m altitude. The characteristics of study sites are given in Table 1 and 2. Soil samples were taken with an auger from 0-30 cm soil depth for different study sites in a spatial extent of approximately 100 m x 100 m at regular intervals (6 months) for a period of two years (2008-10). The samples were air dried at 25 to 35°C and 20 to 60% relative humidity (Jackson, 1958). Soil texture was determined by international pipette method and soil bulk density by using core sampler. Soil organic carbon (SOC) was determined by Walkley and Black's rapid titration method (1934). The SOC percent was converted to total organic carbon (t ha^{-1}) using the following equation:

TOC (t ha^{-1}) = SOC (%) x soil depth (cm) x soil bulk density (g cc^{-1}) x 1.195 ……. (1)

Where, 1.195 is the correction factor as suggested by Ghosh *et al.* (2001) for converting SOC to TOC. The TOC value thus obtained was averaged out both spatially and temporally for a particular site to represent the TOC status of the same site.

Deriving Long Term Climate Data for Use in RothC Inverse Modeling

Long term climate data for temperature and precipitation was derived by using New_LocClim_1.10 software developed by FAO. The RothC model requires monthly pan evaporation data in addition to temperature and precipitation data, the mean monthly temperature data thus obtained by utilising New_LocClim_1.10 was converted to potential evapotranspiration by using Thornthwaite method (Thornthwaite, 1948) which was again divided by 0.75 to get the pan evaporation. Though New_LocClim_1.10 gives evapotranspiration values, Thornthwaite method was selected for the purpose to make the approach simpler where observed data are to be used as it only needs temperature data for calculating evapotranspiration whereas the former uses Penman-Monteith equation which requires other data such as relative humidity, sun shine hours, wind speed etc. The long term mean monthly temperature varied from 30.1^{0}C in May to 13.3^{0}C in January at Amritpur site which is

Table: 1
Geographical coordinates and altitude of study site

Site names	Latitude	Longitude	Altitude, amsl, m	Slope aspect
Amritpur	29°17.815N	79°33.524E	600	South
Salari	29°19.004N	79°33.628E	850	North
Dogaon	29°19.368N	79°30.298E	905	North
Majhera	29°30.270N	79°28.647E	940	North
Jeolikote	29°20.517N	79°29.381E	1093	North
Itaula	29°39.675N	79°38.223E	1170	South
Mahatgaon	29°38.956N	79°37.743E	1236	South-east
Matela	29°37.448N	79°37.836E	1246	North-east
Jyoli	29°37.710N	79°35.630E	1365	South-east
Kwerali	29°38.669N	79°35.513E	1420	North-west

Table: 2
Physical and vegetation characteristics at different study sites

Site names	Soil bulk density ($g\ cc^{-1}$)	Soil texture	Clay content (%)	Forest characteristics
Amritpur	1.28	Loam	12.80	Dense, mixed oak forest
Salari	1.25	Silty loam	11.20	Moderately dense mixed oak forest
Dogaon	1.21	Loam	12.80	Dense mixed oak forest
Majhera	1.21	Silty loam	9.60	Degraded mix pine forest
Jeolikote	1.02	Silty loam	16	Highly degraded mixed pine forest
Itaula	1.31	Sandy loam	17.60	Highly degraded pure pine forest
Mahatgaon	1.28	Loam	7.60	Slightly degraded pure pine forest
Matela	1.13	Loamy sand	9.60	Highly degraded pure pine forest
Jyoli	1.35	Sandy loam	14.40	Slightly degraded pure pine forest
Kwerali	1.25	Sandy loam	16	Degraded pure pine forest

located at the lowest altitude (600 amsl) among all sites. The same parameter varied from 23.6^{0}C in May to 10.6^{0}C in January at Kwerali site having the highest altitude (1420 above msl) among the sites. Monthly pan evaporation varied from 300.2 mm in May to 25.3 mm in January at Amritpur site. Monthly pan evaporation had a different trend at Kwerali which varied from 168.1 mm in June to 28.4 mm in February. Long term data of monthly rainfall revealed that the study sites fall into two rain fall zones, *i.e.* high and medium. Amritpur, Salari, Dogaon, Majhera and Jeolikote fall under high rainfall zone. The annual rainfall varied from 2306.7 mm at Salari to 2201.0 mm at Dogaon. More than 90% of annual rainfall is received in the monsoon season, *i.e.* from June to October at these sites. Itaula, Mahatgaon, Matela, Jyoli and Kwerali fall under medium rainfall zone. Annual rainfall varied from 1289.7mm at Kwerali to 1281.8 mm at Matela and more than 85% rainfall is received in the monsoon season (Table 3).

RothC Model and Estimation of Plant Litter Input

The Rothamsted carbon model (RothC) is one of the most widely used and tested model under wide variety of ecosystems including croplands, grasslands, and forests and in various climate regions (Jenkinson, 1990; Coleman *et al*., 1997; Smith *et al*., 1997, 2005, 2006; Falloon *et al*., 2006; (Chaturvedi and Melkania, 2012). RothC is a model of the turnover of organic carbon in non-waterlogged soils that allows for the effects of soil type, temperature, moisture content and plant cover on the turnover process. It uses a monthly time step to calculate total organic carbon, microbial biomass carbon and D14C (from which the radiocarbon age of the soil can be calculated) on 'years to centuries' timescale (Jenkinson 1990; Jenkinson and Coleman 1994). The input is monthly rainfall (mm), monthly open-pan evaporation (mm), monthly mean temperature (^{o}C), clay content of the soil, an estimate of the decomposability of the incoming plant material, soil cover, monthly input of plant residues ($t\ C\ ha^{-1}$), monthly input of farmyard manure (FYM) ($t\ C\ ha^{-1}$), and depth of soil layer sampled (cm). Incoming plant input is split into decomposable plant material (DPM) and resistant plant material (RPM), and then, during the decomposition process, these are split into CO_2, microbial biomass (BIO), and humified organic matter (HUM). The inert organic matter (IOM) compartment is resistant to decomposition. Each compartment decomposes by a first-order process with its own decomposability. For most agricultural and improved grassland, a DPM/RPM ratio of 1.44 is used; for deciduous or tropical woodland a DPM/RPM ratio of 0.25 is used. Both DPM and RPM decompose into CO_2, BIO, and HUM, and the proportion that goes into CO_2 and BIO and HUM is controlled by the clay content of the soil. The decomposition constant is controlled by the factors for temperature, moisture, and plant cover. The effect of temperature is given by $a = 47.9/ (1/e^{(106/(tm+18.3))})$, where, tm is the average monthly air temperature (^{o}C); the effect of moisture is controlled by the moisture deficit of the topsoil. There is no limitation until topsoil moisture deficit exceeds 20 mm. The effect of moisture decreases linearly with increasing deficit when the deficit is between 20 and 44.4 mm. RothC has been used to make regional and global scale predictions in a variety of studies (Falloon and Smith, 2002; Smith *et al*., 2005). In this study "*Calculate plant inputs knowing total carbon*" option available in current version of RothC model (RothC 26.3) was used to estimate the plant litter inputs at different study sites.

MODIS NPP Data for the Study Sites

The annual NPP data product from MODIS was used (MOD17A3); which is available from the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC, 2011). In the products, daily GPP, leaf and fine root maintenance respiration, and net photosynthesis are calculated using satellite radiometric indices. Solar radiation, temperature, and moisture affect GPP. The temperature factor which ranges from 0 to 1, increases linearly with increasing daily minimum temperature (TMIN) between minimum TMIN (-8^0C) and maximum TMIN (810^0C; for forest biomes), which are defined for each biome classification. The factors for below minimum TMIN and above maximum TMIN are 0 and 1, respectively. The vapor pressure deficit (VPD) factor, which ranges from 0 to 1, decreases linearly with increasing VPD between minimum VPD (650-1100 Pa) and maximum VPD (2500-3900 Pa; for forest biomes). The factors for below minimum VPD and above maximumVPD are 1 and 0, respectively. Leaf and fine root maintenance respiration increase exponentially with daily average temperature. Daily net photosynthesis is calculated by subtracting maintenance respiration from GPP. NPP is calculated annually by subtracting growth respiration from GPP (Hashimoto *et al*., 2010). The method for deriving NPP for MOD17 is described in detail elsewhere (Running *et al.,* 2000). In this study, the average NPP value from 2008 to 2010 at 1 km resolution was calculated for different forest sites.

3. RESULTS AND DISCUSSION

The comparison of RothC estimated litter carbon input with MODIS NPP for the ten forest sites showed RothC estimated values to be higher in case of sites; Amritpur, Salari and Dogaon where as the reverse trend was

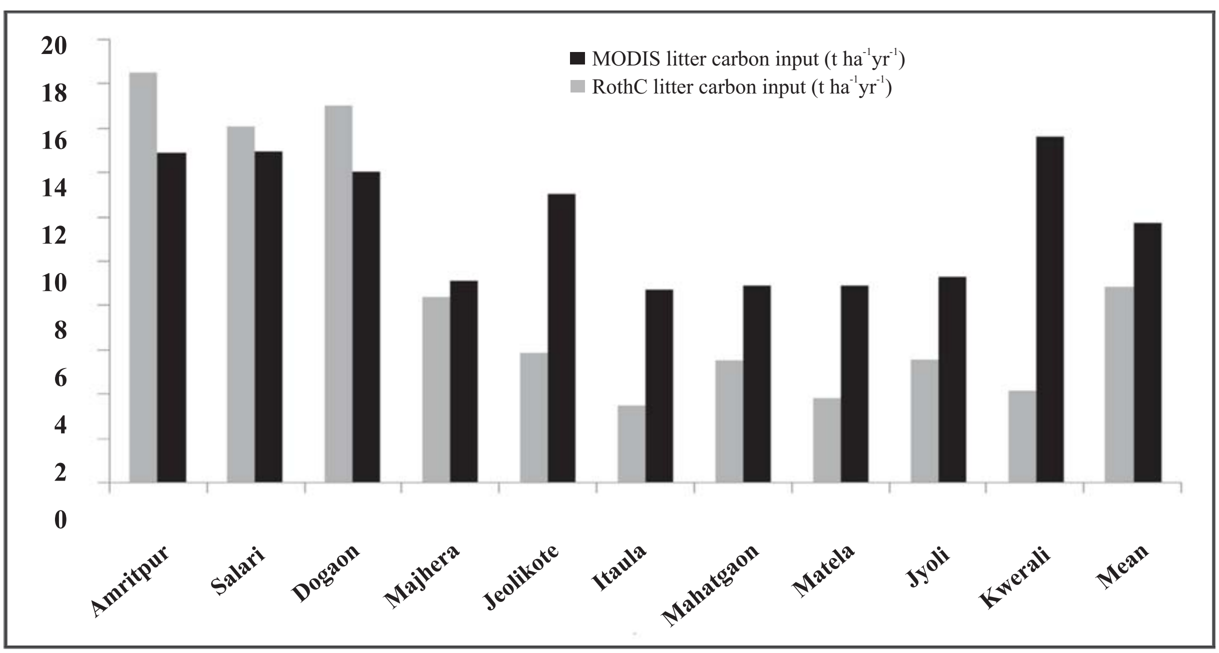


Fig. 2. Comparison of RothC estimated litter input with MODIS NPP for different sites

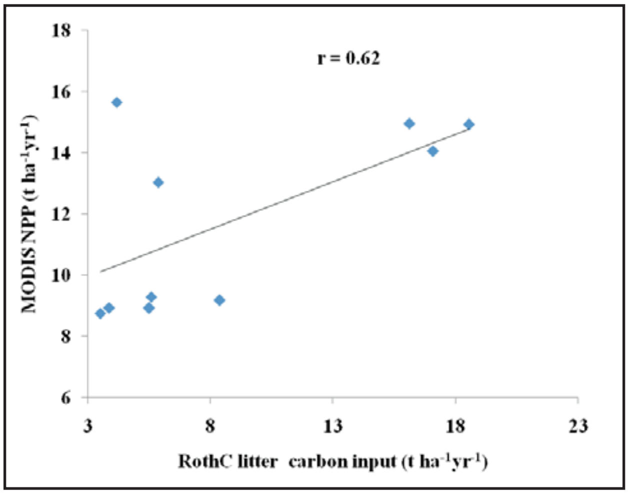


Fig. 2. Correlation between RothC estimated litter carbon input and MODIS NPP

observed in rest of the sites (Fig.1). The forests sites at Amritpur, Salari and Dogaon consisted of dense mix oak forests with higher SOC and other sites were comparatively degraded (low SOC) (Tables 2 and 4). The litter carbon input calculated using RothC and that derived from MODIS NPP were positively correlated (r= 0.62) (Fig. 2), but the mean estimated litter input from RothC was 32.8% less than that estimated from MODIS. However, student's t-test revealed non-significant mean difference at 5% significance level between the estimates (t Stat=-1.91, t Critical two-tail = 2.13). The two estimates were closer in dense and comparatively less degraded forests where as large deviations were found in case of degraded forests (Table 4). The reasons for such a trend might be attributed to spatial biases and inherent difference in mechanism including temperature controls between the two methods.

Recently, the difficulty of comparing satellite-based data and ground-based measurement, called a scaling issue, has been pointed out (Turner *et al.*, 2004, 2005). The mismatch in scale between the 1 km grid of satellite products and the relatively small scale of ground-scale observation makes the comparison, including model parameterization and validation, challenging. The SOC data were used based on ground observation, and the MODIS NPP is satellite based 1-km resolution; the results might

Table: 3
Long term mean monthly temperature, monthly rainfall and pan evaporation at different study sites

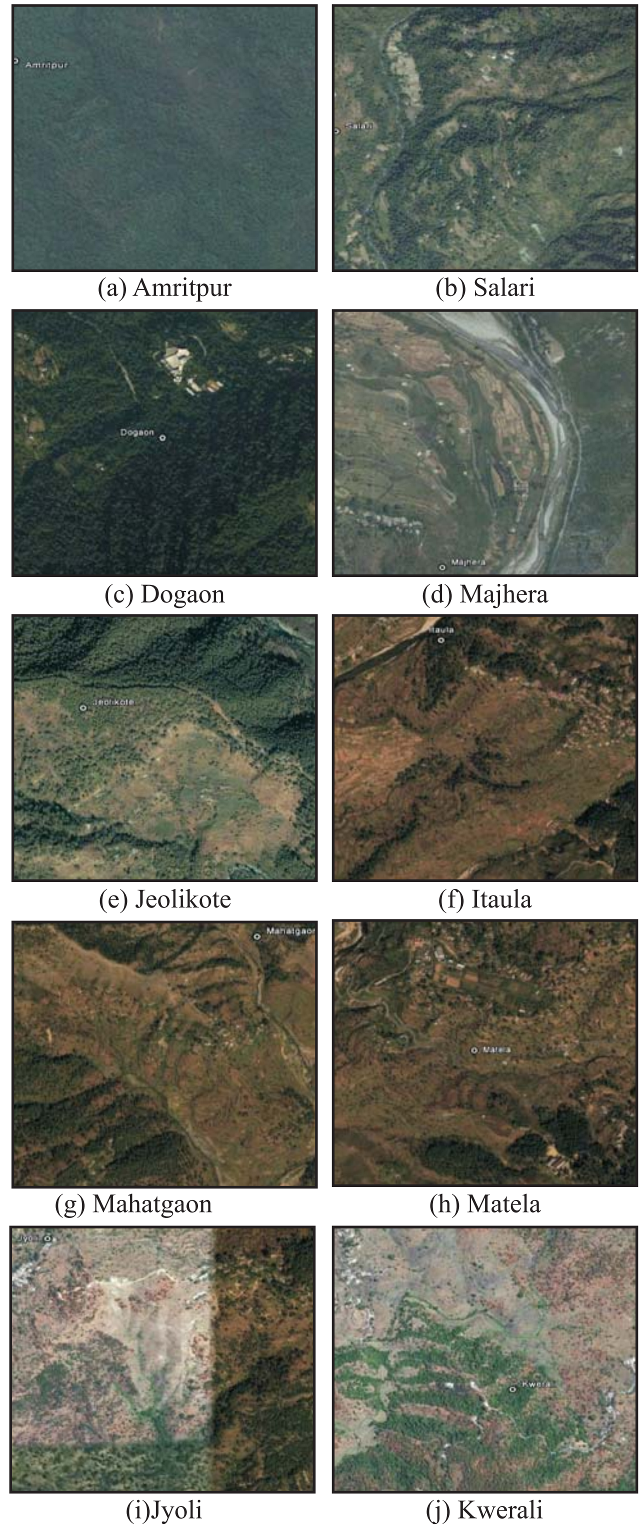
Sl. No.	Site Name	Mean Temp (°C) Min. (month)	Mean Temp (°C) Max. (month)	Total Average Annual Rainfall (mm)	Pan Evaporation (mm) Min. (month)	Pan Evaporation (mm) Max. (month)
1.	Amritpur	13.3 (Jan)	30.1 (May)	2260.7	25.3 (Jan)	300.0 (May)
2.	Salari	12.3 (Jan)	28.3 (May)	2306.7	25.3 (Jan)	247.9 (May)
3.	Dogaon	12.0 (Jan)	28.0 (May)	2201.2	25.2 (Jan)	241.4 (May)
4.	Majhera	12.3 (Jan)	27.8 (May)	2236.2	26.5 (Jan)	238.1 (May)
5.	Jeolikote	11.2 (Jan)	26.7 (May)	2258.1	25.0 (Jan)	214.5 (May)
6.	Itaula	11.8 (Jan)	25.2 (May)	1280.1	29.5(Jan)	189.7 (May)
7.	Mahatgaon	11.5 (Jan)	24.8 (May)	1282.2	29.2 (Jan)	183.3 (May)
8.	Matela	11.4 (Jan)	24.7(May)	1281.8	29.0 (Jan)	182.2 (May)
9.	Jyoli	11.8 (Jan)	24.3 (May)	1287.8	31.7 (Jan)	177.3 (May)
10.	Kwerali	10.66 (Jan)	23.6 (May)	1289.71	28.48 (Jan)	168.17 (May)

Table: 4
Average TOC status and relative error between RothC estimated litter carbon input and MODIS NPP

Sites	Average TOC status (t ha^{-1})	RothC litter carbon input (t $ha^{-1}yr^{-1}$)	MODIS NPP (t $ha^{-1}yr^{-1}$)	Difference (%)
Amritpur	146.84	18.53	14.93	19.43
Salari	129.5	16.12	14.96	7.20
Dogaon	140.54	17.08	14.06	17.68
Majhera	65.5	8.39	9.18	-9.42
Jeolikote	49.73	5.88	13.04	-121.77
Itaula	42.26	3.51	8.76	-149.57
Mahatgaon	67.54	5.51	8.92	-61.89
Matela	42.13	3.87	8.94	-131.01
Jyoli	65.82	5.58	9.30	-66.67
Kwerali	47.94	4.18	15.65	-274.40
Mean	79.78	8.87	11.77	-32.81

therefore be affected by the scaling issue. On the other hand, the SOC value was used and calculated from the average of measurements made in much less resolution (100 m x 100 m); hence, this estimate may seriously suffer from scaling issues particularly in case of degraded forests (Fig. 3 and Table 4). In a 1 km^2 grid area, there can be two or more kinds of environment. In some part there may be a thick vegetation cover whereas in another half of the 1km^2 area, a rocky or barren land or a water body may co-exist. This will affect the overall NPP value of that grid. The difference arises with respect to the sites from where soil sample was taken. In such a case, if sample is taken from the dense vegetation site, then RothC NPP value will be greater than that of MODIS and if the sampling site is from the rocky barren land, the reverse occurs. Besides land use, climate and management are also other stochastic abiotic factors that affect SOM turnover in the soil. The occurrence of micro-climate in some regions will affect NPP values even though these are not taken into consideration while running the model due to insufficient data. Topography also plays its role in carbon turnover. Soils of relatively higher degree of slope will have less SOM though the site's NPP might be high, as a considerable amount of soil erosion takes place each year the monsoon sets in. Erosion affects mostly top soil whereas the growth of trees may not be affected by altered soil properties alone, in such a case, the top soil is worst affected. Representative SOC values for degraded forest may, hence, require more number of data points to avoid scaling issues. As conducted in the NPP and GPP studies (Turner *et al.,* 2004, 2005), the mismatch in scale in soil data need to be investigated.

Another probable reason is the different temperature functions. In MODIS NPP estimation (equivalent to litter input), daily minimum temperature linearly affects GPP, but the temperature does not affect GPP when minimum temperature is below a specific temperature, which could reduce the variation in NPP estimation in colder regions. On the other hand, in the RothC model temperature exponentially affects the decomposition, or inversely estimated litter input. Being different from the MODIS estimation, there is no assumption of a threshold in the RothC model; therefore, the estimate from the RothC model is probably more predictably affected by temperature. In order to apply the method used in this study, steady state is assumed, which is a common assumption for initializing the RothC model. Real equilibrium will rarely exist in nature because of annual and long-term fluctuations in climate, disturbance, land management, *etc.* A recent study has pointed out that soils that were disturbed centuries ago were not at equilibrium (Wutzler and Reichstein, 2007), and relaxing the steady-state assumption resulted in better performance of carbon cycle modeling (Carvalhais *et al*., 2008). Despite the fact that the soils are not at equilibrium, the estimates of the RothC plant litter input were close to the MODIS litter input estimates in this study, and the two were positively correlated. This shows that even though, the soils are not in equilibrium, the assumption made in this study,



(a) Amritpur (b) Salari
(c) Dogaon (d) Majhera
(e) Jeolikote (f) Itaula
(g) Mahatgaon (h) Matela
(i)Jyoli (j) Kwerali

Fig. 3. Google earth images (1km x 1 km) of selected study sites

does not critically affect the results except in severely degraded forests. The comparison between litter input (NPP data) and inversely estimated plant litter input is helpful for understanding the stability of soil carbon. If these two estimates were quite different, it perhaps implies that soil carbon could be rapidly changing, or that there is another mechanism/process that keeps soil carbon level low/high. Regionally distributed SOC contents might produce a closer match between RothC litter input and MODIS litter input and would improve the approach when such data become available.

4. CONCLUSIONS

In this study, plant litter input to a depth of 30 cm was estimated for ten forest sites located at different altitudes in Central Himalaya using the Rothamsted Carbon model (RothC) and was compared with estimated litter inputs from the NPP data from MODIS. Despite many simplifications and assumptions used in this study, RothC estimates of litter inputs and MODIS estimates had a reasonably good correlation. However, this approach needs further investigations to accept satellite-derived NPP data to be used as plant carbon input to soil system to drive soil models to estimate changes in forest soil carbon stocks under future climate/land management scenario.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation and thanks to G.B. Pant University of Agriculture & Technology (Uttarakhand) and Uttarakhand State Council of Science and Technology (UCOST) for supporting this work.

REFERENCES

Alexandrov, G.A., Oikawa, T. and Yamagata, Y. 2002. The scheme for globalization of a process-based model explaining gradations in terrestrial NPP and its application. *Ecol Model.,* 148: 293-306.

Cannell, M.G.R. 1982. World forest biomass and primary production data. Academic Press, Tokyo.

Carvalhais, N., Reichstein, M., Seixas, J., Collatz, G.J., Pereira, J.S., Berbigier, P., Carrara, A., Granier, A., Montagnani, L., Papale, D., Rambal, S., Sanz, M.J. and Valentini, R. 2008. Implications of the carbon cycle steady state assumption for biogeochemical modeling performance and inverse parameter retrieval. *Glob Biogeochem Cycles.,* 22:GB2007. DOI:101029/2007GB003033.

Chaturvedi, S. and Melkania, U. 2012. Modelling Soil organic Carbon from forest ecosystems and mid Himalayas, India. *Ind. J. Soil Cons.,* 40(3): 225-230.

Chiesi, M., Maselli, F., Moriondo, M., Fibbi, L., Bindi, M. and Running, S.W. 2007. Application of BIOME-BGC to simulate Mediterranean forest processes. *Ecol Model.,* 206: 179-190.

Ciais, P., Reichstein, M., Viovy, N., Granier, A., Ogee, J., Allard, V., Aubinet, M., Buchmann, N., Bernhofer, C., Carrara, A., Chevallier, F., De Noblet, N., Friend, A.D., Friedlingstein, P., Gru¨nwald, T., Heinsch, B., Keronen, P., Knohl, A., Krinner, G., Loustau, D., Manca, G., Matteucci, G., Miglietta, F., Ourcival, J.M., Papale, D., Pilegaard, K., Rambal, S., Seufert, G., Soussana, J.F., Sanz, M.J., Schulze, E.D., Vesala, T. and Valentini, R. 2005. Europe-wide reduction in primary productivity caused by the heat and drought in 2003. *Nature.,* 437: 529-533.

Coleman, K., Jenkinson, D.S., Crocker, G.J., Grace, P.R., Klı´r, J., Ko¨rschens, M., Poultion, P.R. and Richter, D.D. 1997. Simulating trends in soil organic carbon in long-term experiments using RothC-26.3. *Geoderma,* 81: 29-44.

Cramer, W., Kicklighter, D.W., Bondeau, A., Moore, B III., Churkina G., Nemry, B., Ruimy, A. and Schloss, A.L. 1999. Comparing global models of terrestrial net primary productivity (NPP): overview and key results. *Glob. Change Biol.,* 5: 1-15.

Falloon, P. and Smith, P. 2002. Simulating SOC changes in long-term experiments with RothC and CENTURY: model evaluation for a regional scale application. *Soil Use Manag.,* 18: 101-111.

Falloon, P., Smith, P., Bradley, R.I., Milne, R., Tomlinson, R., Viner, D., Livermore, M. and Brown, T. 2006. RothCUKa dynamic modeling system for estimating changes in soil C from mineral soils at 1-km resolution in the UK. *Soil Use Manag.,* 22: 274 -288.

Ghosh, B.N., Vedprakash, Kundu, S., Singh, R.D. and Gupta, H.S. 2001. Relationship between oxidizable and total organic carbon content in an inceptisol after twenty-seven years of soyabean-wheat cropping. *J. Indian Soc. Soil Sci.,* 49(4): 744-745.

Hashimoto, S., Wattenbach, M. and Smith, P. 2010. Litter carbon inputs to the mineral soil of Japanese Brown forest soils: comparing estimates from the RothC model with estimates from MODIS. *J .For. Res.,* (2011), 16:16-25, DOI 10.1007/s10310-010-0209-6.

Ito, A. 2003. A global-scale simulation of the CO2 exchange between the atmosphere and the terrestrial biosphere with a mechanistic model including stable carbon isotopes, 19531999. *Tellus B.,* 55: 596-612.

Ito, A. and Sasai, T. 2006. A comparison of simulation results from two terrestrial carbon cycle models using three climate data sets. *Tellus B.,* 58: 513-522.

Jenkinson, D.S. 1990. The turnover of organic carbon and nitrogen in soil. *Philos. Trans. R. Soc. B.,* 329: 361-368.

Jenkinson, D.S., Harkness, D.D., Vance, E.D., Adams, D.E. and Harrison A.F. 1992. Calculating net primary production and annual input of organic-matter to soil from the amount and radiocarbon content of soil organic-matter. *Soil Biol Biochem.,* 24: 295-308.

Jenkinson, D.S. and Coleman, K. 1994. Calculating the annual input of organic-matter to soil from measurements of total organic carbon and radiocarbon. *Eur. J. Soil Sci.,* 45: 167-174.

Jenkinson, D.S., Meredith, J., Kinyamario, J.I., Warren, G.P., Wong, M.T.F., Harkness, D.D., Bol, R. and Coleman, K. 1999. Estimating net primary production from measurements made on soil organic-matter. *Ecology,* 80: 2762-2773.

Kurz, W.A., Stinson, G. and Rampley, G. 2008. Could increased boreal forest ecosystem productivity offset carbon losses from increased disturbances? *Philos. Trans. R. Soc. B.,* 363: 2261-2269.

Maselli, F., Chiesi, M., Fibbi, L. and Moriondo, M. 2008. Integration of remote sensing and ecosystem modelling techniques to estimate forest net carbon uptake. *Int. J. Remote Sens.,* 29:2437-2443.

Oak Ridge National Laboratory Distributed Active Ar-chive Center (ORNL DAAC), "MODIS Subsetted Land products," 2011. http://daac.ornl.gov/MODIS/modis.html

Peltoniemi, M., Thurig, E., Ogle, S., Palosuo, T., Schrumpf, M., Wutzler, T., Butterbach-Bahl, K., Chertov, O., Komarov, A., Mikhailov, A., Gardenas, A., Perry, C., Liski, J., Smith, P. and Makipaa, R. 2007. Models in country scale carbon accounting of forest soils. *Silva Fenn.,* 41: 575-602.

Raich, J., Russell, A.E. and Vitousek, P.M. 1997. Primary productivity and ecosystem development along an elevational gradient on Mauna Loa, Hawai'i. *Ecology,* 78: 707-721.

Running, S.W., Thornton, P.E., Nemani, R. and Glassy, J.M. 2000. Global terrestrial gross and net primary productivity from the earth observing system. In: Sala, O.E., Jackson, R.B., Mooney, H.A. and Howarth, R.W. (eds) Methods in ecosystem science. *Springer,* New York, pp. 44-57.

Smith, P. 2008. Land use change and soil organic carbon dynamics. *Nutr. Cycl. Agroecosyst.,* 81:169-178.

Smith, P., Powlson, D.S., Glendining, M.J. and Smith, J.U. 1997. Potential for carbon sequestration in European soils: preliminary estimates for five scenarios using results from long-term experiments. *Glob. Change Biol*., 3: 67-79.

Smith, J., Smith, P., Wattenbach, M., Zaehle, S., Hiederer, R., Jones, R.J.A., Montanarella, L., Rounsevell, M.D.A., Reginster, I. and Ewert, F. 2005. Projected changes in mineral soil carbon of European croplands and grasslands, 19902080. *Glob. Change Biol.,* 11: 2141-2152.

Smith, P., Smith, J., Wattenbach, M., Meyer, J., Lindner, M., Zaehle, S., Hiederer, R., Jones, R.J.A., Montanarella, L., Rounsevell, M., Reginster, I. and Kankaanpaa, S. 2006. Projected changes in mineral soil carbon of European forests, 1990-2100. *Can. J. Soil Sci.,* 86: 159-169.

Turner, D.P., Ritts, W.D., Cohen, W.B., Maeirsperger, T.K., Gower, S., Kirschbaum, A.A., Running, S.W., Zhao, M.S., Wofsy, S.C., Dunn, A.L., Law, B.E., Campbell, J.L., Oechel, W.C., Kwon, H.J., Meyers, T.P., Small, E.E., Kurc, S.A. and Gamon, J.A. 2005. Site-level evaluation of satellite-based global terrestrial gross primary production and net primary production monitoring. *Glob. Change Biol.,* 11: 666-684.

Turner, D.P., Ritts, W.D., Zhao, M.S., Kurc, S.A., Dunn, A.L., Wofsy, S.C., Small, E.E. and Running, S.W. 2006. Assessing interannual variation in MODIS-based estimates of gross primary production. *IEEE Trans. Geosci. Remote,* 44: 1899-1907.

Wutzler, T. and Reichstein, M. 2007. Soils apart from equilibrium consequences for soil carbon balance modelling. *Biogeosciences,* 4:125-136.