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Studies on Growth of Chir Pine (*Pinus roxburghii* Sargent) Forests Along Elevational Gradient Using GIS

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ABSTRACT

The investigation was carried out in the Solan Forest Division (900m to 2100m a.m.s.l) of Himachal Pradesh to determine the site factors influencing the forest growing stock (FGS) and to develop growth prediction model functions. All site factors i.e. temperature, slope, aspect, soil depth, soil organic carbon, and bulk density were significantly responsible to influence the forest growing stock. Temperature had a positive effect on the volume of forest growing stock and FGS decreased with decrease in temperate along altitudinal gradient from 900 m to 1900 m. South west and south facing slopes resulted in lower FGS as compared to the north eastern and north facing slopes. The FGS was much higher on gentle slopes as compared to higher and steep slopes. Similarly, forests having deep soils rich in organic carbon and low bulk density supported the growth of the FGS. The Principal Component Analysis reveals that first three components contributed to 81.47 % of total variations in FGS and therefore, temperature, aspect and soil depth were the major site factors that influenced the FGS. The step wise multiple linear regression performed to develop growth prediction model functions demonstrated that contribution of the different site factors to the FGS in descending order were as temperature > aspect > soil depth > organic carbon > Bulk density > Slope. Among various model functions, the model incorporating temperature, aspect, soil depth and organic carbon were the best fit for the estimation of FGS.

Key words: Forest growing stock, edaphic factors, topographic factors, climatic factors

INTRODUCTION

The climate of the Himalayan region has become warmer (especially in winter) over the past century, and these trends are likely to continue in the future. How will forests respond to a changing climate? To develop management strategies for climate change mitigation and adaptation, it is important to know more specifically how forest growth responds to climatic variability and which factors limit growth. Growth may respond differently to climate in different biogeographic locations, however, relationships between climate and tree growth vary at smaller spatial scales as a function of aspect (Liu *et al.*, 1991), elevation (Luo *et al.*, 2004); and species (Fundora *et al.*, 2004). Growth–climate relationships also vary at multiple temporal scales, and growth has been shown to respond to climate differently for different time periods within the 20th century (Pezzotti *et al.*,1994).

Given the rapid rise of temperature and possible average increase in precipitation of about 3.4 per cent globally per 1°C temperature rise that we face (Allen and Ingram, 2002) it is critical that we take climatic factors into consideration in the assessment of forest growth and prediction (Bonan *et al.*, 1990) especially in areas where climatic change is likely to effect forest growth and cover. Interest to estimate the possible effects of site factors and climate change on forest growth has a particular importance when dealing with chir pine forests, a major component of sub-tropical pine forest which occupy an area of 3853 km^2 (10.40%) of total forest area at an altitudinal range of 600 to 2300 m in Himachal Pradesh (IFS, 2002). The species has been exploited for multifarious uses in the past (such as railway slippers, electric transmission poles, packing cases, pulpwood, general carpentry works and building construction) and now has gained much ecological importance with imposition of ban on green felling since 1985. The present investigation was therefore carried out to have an understanding of the site factor interaction with forest growth and possibility of assessment of forest growth on the basis of site factors.

MATERIAL AND METHODS

Study area

The study was carried out in Solan Forest Division of Himachal Pradesh during 2007-08, which is located between 30° 45' to 31° 10' N latitude and 76° 55' to 77° 15' E longitude, covering an area of about 57,158ha. The climate of the study area varies from extreme hot in the lower elevation and extreme cold in higher elevations, precipitation is in the form of rains mainly during rainy season and snowfall in winter at higher elevations. The Chir Working Circle has 161 forest compartments, distributed in five forest ranges. The forests in Solan Forest

Division have pure crop of chir pine and mostly conform to forest type 9C1a-Lower or Shiwalik chir pine forests (Champion and Seth, 1968).They lie between 900-2100 m a.m.s.l. The overstorey vegetation comprises of *Pinus roxburghii, Quercus leucotricophora, Cedrus deodara, Terminalia tomentosa, Dalbergia sissoo, Pyrus pashia, Albizia chinensis, Juglans regia, celtis australis, Acacia catechu* etc, and the understory vegetation comprises of *Berberis species, Prinsepia utilis, Indigofera* sp., *Rosa* sp., *Sarcococca saligna, Rubus* sp., *Hydera helix, Euphorbia* sp., etc.

Determination of slope and aspect

The elevation data in topo-sheets (1:50,000) acquired by the Forest Survey of India were used to generate Digital Elevation Model (DEM). The DEM was generated by digitizing contours of each forests by on-screen digitization at an interval of 20m in various steps in CartaLinx1.2 (GIS data builder software) and IDRISI 32 (Image processing and GIS software) developed by Clark Lab, Clark University, Worcester MA, USA. The study area was then stratified into five elevation classes, i.e. 900-1100 m, 1100-1300 m, 1300-1500 m, 1500-1700m and 1700-1900 m with the help of DEM using re-class module in IDRISI 32. The topographic variables (slope and aspect) of each sample plot were extracted from the DEM which were in conformity to the topographic information given in the Compartment History Files (CHF) available with the respective Forest Ranges.

Determination of forest growing stock

Two sample plots were taken at each altitudinal class i.e. 900-1100m, 1100-1300m, 1300-1500m, 1500-1700m and 1700-1900m. The sample plot comprises of sampling units selected randomly following sampling intensity of 5 per cent (proportionate to the area of the sample plots) following Griffith (1984). The sampling unit size comprised of 20mx20m dimensions and in total there were 138 sampling units. All trees above 10cm diameter were measured at breast height. Data on Forest Growing Stock i.e., volume was determined by multiplying trees of each diameter class with standard volume factor for the corresponding diameter class in the volume table published by Ministry of Environment and Forests, Govt. of India. The volume of all sampling units within sample plots was then averaged and volume of the sample plot was calculated on per hectare basis.

Estimation of temperature and precipitation

The relationships between historic temperature data and altitude and latitude information acquired from six meteorological stations in and around the study area were not strong enough to be used to estimate the temperature of sample plots distributed along altitudinal gradient in the Chir Working Circle of the Solan Forest Division (R^2 =0.3808 for latitude and R^2=0.317 for elevation). Therefore, temperature of the sample plots was determined by using equation given by Yang *et al.* (2006) as

$$T=15.4-0.628 \times (L-4.7)-0.52 \times (E/100)$$

Where: T is annual average air temperature
L is latitude in degrees (taken lowest latitude of study area)
E is elevation in metres above sea level

A value of -0.52 °C per 100m elevation rise from the lowest elevation was used to calculate the temperature of each sample plot. The temperature so determined for each elevation group is given in Table 1.

Table 1. Temperature of sample plots at various elevations

Elevation(m)	Temperature(C^0)
900-1100	15.12-14.60
1100-1300	13.59-13.07
1300-1500	12.55-12.03
1500-1700	11.51-10.99
1700-1900	10.47-9.95

The precipitation figures for the sample plots could not be determined as equation based on historical precipitation data and altitude & latitude showed completely a flat relationship and hence this factor was ignored. This was obvious as latitudinal variation in the study area was very small.

Estimation of soil characteristics

In order to determine soil attributes viz organic carbon, bulk density and soil pH, composite soil samples comprising of sub samples from three soil depths i.e. 0-15cm, 15-30cm, 30-45cm representing each elevation class i.e. 900-1100 m, 1100-1300 m, 1300-1500 m, 1500-1700 m and 1700-1900 m were taken. The soil samples were first air dried in shade and then crushed in a wooden pestle and mortar and passed through a 2 mm sieve. Bulk density was determined by the clod saturation method developed by Prihar and Hundal (1971) and Organic carbon was determined by wet digestion method of Walkley and Black (1934). Soil pH was determined using digital pH meter (Jackson, 1973). Natural terraces and landslides were used for determination of soil depth at top, middle and bottom of the sample plot which were then averaged to give mean depth

Statistical analysis

All statistical analyses including Analysis of Variance (ANOVA), Principal Component Analysis (PCA), Correlation and Step wise multiple linear regressions were made on Statistical Package for Social Sciences (SPSS 10). ANOVA was performed to find out the significant differences in FGS between different groups of independent site variables. The PCA is probably the most widely used technique in factor analysis and factor reduction (Harman, 1970). The aim of PCA in the present study was to determine major factors (from various factors like temperature, slope, aspect, soil depth, bulk density and organic carbon) which contributed maximum towards volume of FGS. Karl Pearson's correlation coefficient between FGS and site factors (temperature, slope, aspect, soil depth, bulk density and organic carbon) was worked out to separately analyze the importance of these factors in influencing the forest growth.

Step-wise multiple linear regression analysis by taking the site factors as independent variables and the FGS as dependent variable was performed to develop growth prediction model functions.

RESULTS AND DISCUSSION

Effect of site factors on forest growing stock

Influence of temperature on FGS

The data presented in Table 2 reveals that the effect of temperature on forest growing stock was statistically significant and the forest growing stock decreased with decrease in temperature along altitudinal gradient from 900 to 1900m (Table 1). Pair-wise multiple comparison of the five temperature groups showed that FGS was significantly higher and maximum (158.5 $m^3 ha^{-1}$) in temperature group (T_1: 15.12°C-14.6°C) than FGS under rest of the temperature groups. However effect of temperature groups T_2 (13.59°C-13.07°C) and T_3 (1.2 55 °C -12.03 °C) on FGS was at par but their effect on FGS was significant over temperature group T_4 (11.51 °C - 10.99 °C) and T_5 (10.47 °C - 9.95 °C). Increase in volume of FGS with descending elevation was obvious as a result of increase in temperature with corresponding decrease in altitude. Such differences in volume of the forest growing stock with temperature and elevation have also been reported by Woodward (1988), Chong *et al.* (1993), Liu *et al.* (1991) and Sanneh (2007). Similar results have also been reported by Luo *et al.* (2004) in *Pinus tabulaeformis* and *Robinia pseudoacacia* and Poso and Kujala (2006) in *Pinus sylvestris* and *Betula pubescens*.

Table 2. Forest growing stock under different temperature ranges

Treatment	Temperature (°C)	FGS (m^3/ha)
T_1	15.12- 14.60	158.5
T_2	13.59-13.07	128.8
T_3	12.55- 12.03	121.7
T_4	11.51- 10.99	113.2
T_5	10.47- 9.95	76.20

$CD_{0.05} = 9.45$

Influence of slope on FGS

Data on forest growing stock under different slope classes showed significant variation (Table 3). The FGS decreased with increase in slope from 5-10 to 25-30%, showing an inverse relationship. The maximum FGS (40.74 m^3ha^{-1}) was found under slope class 5-10% which was significant over rest of the slope classes. However, FGS in slope classes 10-15% and 15-20% and slope classes 15-20%, 20-25% and 25-30% were at par. The minimum FGS (26.47 m^3ha^{-1}) was reported under slope class of 25-30%. This may be explained in the light of comparatively higher soil depth and soil moisture availability at gentle than steeper slopes. The results are in agreement with the findings of Abdollah *et al.* (2003) in *Pinus eldarica*, Parn (2003) in *Pinus sylvestris*, Oberhuber and Kofler (2003) in *Pinus cembra*, Poso and Kujala (2006) in *Pinus sylvestris* and *Betula pubescens* and Shujuan *et al.* (2005) in *Fraxinus mandshurica* and *Juglans manshurica*.

Table 3. FGS under different slope classes

Treatment	**Slope (%)**	**FGS (m^3/ha)**
S_1	5-10	40.74
S_2	10-15	34.58
S_3	15-20	31.54
S_4	20-25	29.44
S_5	25-30	26.47

$CD_{0.05} = 3.49$

Influence of aspect on FGS

A perusal of data (Table 4) indicates that forest growing stock was significantly influenced by the aspect. The values of FGS decreased from north eastern to south western aspect. Pair wise multiple comparisons showed that north facing slopes had a significantly higher FGS than south facing slopes. Forest growing stock was maximum (149.0 m^3ha^{-1}) under north eastern aspect and minimum (82.23 m^3ha^{-1}) under south western aspect. The southern aspects are in general warmer and normally do not support the growth of forest vegetation. The results are in agreement with the findings of Lu *et al.* (1991), Yang *et al.* (1993), Liu *et al.* (1996), and Li *et al.* (2002). Similar response has been observed by Worrell and Malcolm (1990) in *Pinus pinaster*, Bahar (2005) in *Pinus roxburghii*, Fekedulegn *et al.* (2003), Baduni and Sharma (1999) in *Quercus floribunda*, Sharma and Baduni (2000) in *Abies pindrow*, Dhanai *et al.* (2000) in *Quercus leucotrichophora* and Poso and Kujala (2006) in *Pinus sylvestris* and *Betula pubescens*.

Table 4. Forest Growing Stock (FGS) under different aspects

Treatment	Aspect	FGS (m^3/ha)
A_1	North Eastern	149.0
A_2	North Western	129.5
A_3	South Eastern	104.7
A_4	South Western	82.2

$CD_{0.05}$ = 15.90

Physico-chemical attributes of soil and their influence on the FGS

The organic carbon content of soils varied from 0.50 per cent to 1.50 per cent for the three soil depths at all the five altitudinal classes (Table 5). The surface soils were noticed to have higher organic carbon content and it decreased with depth at all the altitudes. The highest values of per cent organic carbon were observed at altitudinal class 900-1100 m which was found to decrease with ascending altitude. This may be due to run off from higher hill slopes and accumulation of litter at the lower altitudes. Similar observations have been recorded by Banerjee and Badola (1980), Gupta *et al.* (1991), Kaushal (1992) and Malik (1992) in forest soils of coniferous forests in Himachal Pradesh. The soil depth recorded the same pattern for the same reason as explained earlier for soil organic carbon. The results are in concordance with the observation of Hart *et al.* (1992), Singh (2004) and Broquen *et al.* (1999).

Observations on bulk density of the soils (Table 5) showed that BD varied from 1.10 g cm^{-3} at elevation class 900-1100m to 1.70 g cm^{-3} at elevation class1700-1900m indicating increasing trend with increase in elevation. The bulk density was also found to increase with increase of soil depth from 0-15 cm to 30-45 cm.

Table 5. Physico-chemical characteristics of soils along elevational gradient

Elevation (m)	Bulk density (gcm^{-3})				pH				Organic carbon (%)				Soil depth (cm)			
	D1	D2	D3	Mean	D1	D2	D3	Mean	D1	D2	D3	Mean	Bot	Mid	Top	Mean
900-1100	1.00	1.14	1.17	1.10	6.1	6.4	6.7	6.4	1.59	1.39	1.19	1.50	118	110	90	105
1100-1300	1.23	1.26	1.27	1.25	6.3	6.5	6.7	6.5	1.29	1.01	1.01	1.30	110	100	85	98.3
1300-1500	1.37	1.38	1.39	1.40	6.3	6.5	6.9	6.5	1.39	1.03	1.02	1.10	103	97	80	93.3
1500-1700	1.38	1.42	1.43	1.55	6.5	6.7	6.9	6.7	0.93	0.90	0.87	0.90	98	92	79	89.6
1700-1900	1.51	1.54	1.57	1.70	6.7	6.8	6.9	6.9	0.53	0.50	0.49	0.50	92	90	69	83.6

D1: 0-15cm (Top) D2:15-30cm (Middle) D3: 30-45cm (Bottom)

The results are supported by Sharma and Qahar (1989) and Kaushal (1992) and Malik (1992) who reported that lower value of bulk density is indicative of increased clay content.

The data pertaining to soil depth at various elevations (Table 5) reveal that soil depth decreased with ascending elevation. The higher run off and erodability down hill slopes and its accumulation in lower elevations was responsible for this trend. The similar trend is well documented in literature by several authors like, Zhang *et al.* (1996), Singh (2004), Broquen *et al.* (1999) and Kadunc and Kotar (2005). The soil pH ranged from 6.4 to 6.9 along altitudinal gradient (Table 5).

Influence of bulk density on FGS

It is evident from table 6 that FGS was significantly influenced by bulk density. The FGS was recorded to decrease with increase in bulk density and it was significant to each other in different BD classes.

Table 6. FGS under different bulk density classes

Treatment	Bulk density (g/cm^3)	FGS (m^3/ha)
BD$_1$	0.95-1.10	65.48
BD$_2$	1.10-1.25	59.15
BD$_3$	1.25-1.40	51.15
BD$_4$	1.40-1.55	44.35
BD$_5$	1.55-1.70	38.25

CD$_{0.05}$ = 6.02

Influence of organic carbon on FGS

A perusual of the data indicate that FGS differed in different soil organic carbon classes (Table 7) and it increased with increase in soil organic carbon. Among the various levels of soils organic carbon, OC$_5$ (1.30-1.50%) registered highest (76.83 m^{3}ha^{-1}) value for FGS followed by OC$_4$, whereas, smallest FGS (36.04 m^{3}ha^{-1}) was obtained under OC$_1$. The differences in values of forest growing stock under all OC soil classes were significant to each other.

Table 7. FGS at different organic carbon classes

Treatment	Organic carbon (%)	FGS (m^3/ha)
OC_1	0.50-0.70	36.04
OC_2	0.70-0.90	44.03
OC_3	0.90-1.10	54.63
OC_4	1.10-1.30	66.89
OC_5	1.30 - 1.50	76.83

$D_{0.85} = 7.22$

Influence of soil depth on FGS

The FGS was found to be influenced significantly by soil depth (Table 8). The higher FGS (95.94 $m^3 ha^{-1}$) was recorded at soil depth class of 100-105 cm which was significantly higher over FGS in the rest of the soil depth classes. However, FGS in soil depth classes D1 and D2, D2 and D3 and D3 and D4 were statistically at par among each other.

Table 8. FGS under different soil depths

Treatment	Soil depth (cm)	FGS (m^3/ha)
SD_1	80-85	52.20
SD_2	85-90	58.80
SD_3	90-95	65.46
SD_4	95-100	73.73
SD_5	100-105	95.94

$CD_{0.05} = 10.59$

Major Factors influencing FGS

Out of six site factors subjected to PCA, three factors i.e. temperature, aspect and soil depth (Table 9) were able to record Eigen value greater than unity and explained 81.47 percent variation (temperature 36%, aspect 24% and soil depth 21.47%) in FGS and rest of the variation of 18.53 per cent was explained by other factors (organic carbon, bulk carbon and slope). Therefore, only first three factors were considered as major factors influencing the FGS of Chir pine. Similar type of work was reported by Pezzotti *et al.* (1994) on *Dactylis glomerata* L. and Fundora *et al.* (2004) on *Arachis hypogeae* L. cultivars.

Component loading of first three Principal Components are presented in Table 10. The variable loadings for first Principal Component are positive and highest for four variables namely temperature (0.99), aspect (0.86), soil depth (0.76) and organic carbon (0.68) and negative for bulk density (-0.57) and slope (-0.49). The variable loading for second Principal component is highest for aspect (0.92) and for other variables loading is at par whereas the variable loading for third Principal Component is highest for soil depth (0.66). Thus, the PCA suggests that temperature, aspect, soil depth, organic carbon and bulk density should be selected.

The contribution of each factor to three principal components was as under:

$F_1 = 0.99_{\text{temperature}} + 0.86_{\text{aspect}} + 0.76_{\text{soil depth}} + 0.68_{\text{organic carbon}} - 0.67_{\text{bulk density}} - 0.49_{\text{slope}}$

$F_2 = 0.92_{\text{aspect}}$

$F_3 = 0.66_{\text{soil depth}}$

Temperature reported maximum Eigenvector value of 0.99 in the component I, indicating its more contribution among all the site factors to FGS (Table 10). This could be due to the influence of temperature on photosynthesis which is an important factor in FGS enhancement. The results are in conformity with the findings of Yang *et al.* (2006), Harman (1970), Amoriello *et al.* (2003) and Doi and Sakurai (2004). The observations are also supported by the findings of Budantsev *et al.* (2001) in *Pinus strobes*, Davel and Ortega (2003) and Romanya and Vallejo (2004) in *Pinus radiata*. On the other hand, in component II, the aspect (0.92) and in component III, the soil depth (0.66) was important to influence the FGS among all the site factors.

Table 9. Total variance explained by different components

Components	Initial	Eigen values			Extraction sum of squared loadings %	
	Total	% of variance	Cumulative %	Total	% variance	Cumulative
Temperature	2.16	36.00	36.00	2.16	36.00	36.00
Aspect	1.44	24.00	60.00	1.44	24.00	60.00
Soil depth	1.30	21.47	81.47	1.30	21.47	81.47
Organic carbon	0.46	7.53	89.00			
Bulk density	0.36	6.00	95.00			
Slope	0.30	5.00	100.00			

Table 10. Eigenvectors of different Principal components corresponding to site factors

	Components		
Factors	Temperature	Aspect	Soil Depth
Aspect	0.86	0.92	0.35
Soil depth	0.76	-0.21	0.66
Temperature	0.99	0.12	0.10
Organic carbon	0.68	-0.18	0.05
Slope	-0.49	-0.15	-0.10
Bulk density	-0.57	0.20	-0.06

Correlation between site factors and forest growing stock

Simple correlation between FGS (volume) and site factors influencing forest growth viz., temperature, slope, aspect, soil depth, bulk density and organic carbon is given in Table 11. Among different correlating factors, FGS was having highest correlation with temperature (0.91) followed by aspect (0.83), soil depth (0.77) and organic carbon (0.75). Thus, the major probable factors influencing forest growth are temperature, aspect, soil depth and organic carbon which are in agreement with results of PCA. The strong correlation between volume of FGS and site factors could be due to interaction between effective climatic, edaphic, topographic and biotic conditions of a site which influence vegetation of a locality. Zhang *et al.* (1996); Yang *et al.* (2006), Marques (1991) and Tagelmark (1998) also reported the same positive correlation between volume of FGS and site factors in *Pinus sylvestris.*

Table 11. Correlation between site factors and FGS

Sr. No.	Correlating factors	Correlation coefficient
1	FGS and temperature	0.91*
2	FGS and aspect	0.83*
3	FGS and soil depth	0.77*
4	FGS and organic carbon	0.75*
5	FGS and bulk density	-0.54**
6	FGS and slope	-0.53**

* (Significant at 1% level)

** (Significant at 5% level)

Estimation of FGS (Growth prediction model functions)

The various models obtained by stepwise multiple linear regression analysis to estimate and assess volume of forest growing stock are presented in Table 12. The contribution of the site factors to FGS can be listed as: temperature > aspect > soil depth > organic carbon > bulk density > slope. It can be inferred from the results that model 3 and 4 were the best as they incorporate maximum site factors; having highest adjusted r^2 and lowest value of mean square error (MSE) and therefore, can be used for estimation of forest growing stock. Similar results have also been reported by Yang *et al.* (2006) who estimated FGS of *Pinus tabulaeformis* and *Robinia pseudoacacia* by using best regression equation with maximum adjusted regression coefficient, marimum mean square error, eigen root greater than unity and maximum loadings (eigen values). The results are also in agreement with those of Louw and Scholes (2006); Marques (1991); Woolery *et al.* (2002) and Amoriello *et al.* (2003).

Table 12. Models for predicting forest growing stock functions

Sr. No.	Model function	Adj.R^2	Mean square error (MSE)
1	$V = 3628.235 - 6.560T$ (0.45)	0.950*	11.45
2	$V = -1775,860 + 0.741T + 7.91A$ (4.67) (5.04)	0.960*	10.125
3	$V = 1812,838 + 3.293T + 0.274A + 10.116SD$ (1.93) (2.39) (1.66)	0,994*	9.275
4	$V = 1133.921 + 3.563T - 0,846A + 9.984SD + 5.275OC$ (4.33) (2.78) (1.71) (6.25)	0,995*	9.265
5	$V = -965.675 - 0.449T - 0.582A + 9.187SD + 5.211OC + 0.109BD$ (5.16) (3.25) (3.63) (6.94) (0.42)	0.992*	12.241
6	$V = -3000.683 - 2.353T + 1.674A + 10.475SD + 6.60OC + 0,138BD + 8,642S$ (6.25) (4.86) (4.36) (7.75) (0.45) (12.91)	0.991*	13.351

*P value <0.01,

V is forest growing stock (M^3/ha), T is temperature (C°) A is aspect, SD is soil depth (cm), OC is organic carbon (percent), BD is bulk density (gcm^{-3}) and S is slope (%).

CONCLUSIONS

All site factors i.e. temperature, slope, aspect, soil depth, soil organic carbon, and bulk density were significantly responsible to influence the forest growing stock. Temperature had a positive effect on the volume of forest growing stock and FGS decreased with decrease in temperate along altitudinal gradient from 900 m to 1900 m. The FGS was much higher in the south-west and south facing slopes as compared to north-eastern and north facing slopes. Gentle slopes had higher FGS as compared to steep slopes. Similarly, forests having deep soils rich in organic carbon and low bulk density supported the growth of the FGS. Among site factors the temperature, aspect and soil depth were the major factors that influenced the FGS. The step wise multiple linear regression analysis demonstrated the contribution of the different site factors to the FGS in descending order as temperature > aspect > soil depth > organic carbon > bulk density > slope; and among various model functions, the model incorporating temperature, aspect, soil depth and organic carbon were the best fit for the estimation of FGS. Finally, to the scope of future work, the models recommended be further tested and validated for a large number of sites using other validation techniques also.

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