Comparative study on litter production and nutrient return to soil in Tarai and Hill Sal (*Shorea robusta* Gaertn.) forests of eastern Nepal

K. P. Bhattarai[1]* and T. N. Mandal[2]

Litter production and nutrient return to soil through litterfall is important pathway for the regulation of nutrient cycling and primary production of the forest. Litterfall dynamics is generally influenced by phenology of tree species, seasons and altitude of the forest stand. As most of the information on litter production are from temperate and dry tropical region. A comparative study on litter production and nutrient return were conducted in Terai Sal forest (TSF) and Hill Sal forest (HSF) located in moist tropical region of eastern Nepal. Litter samples were collected from the litter traps (1m × 1m size) placed randomly in the forest. Collection was done at two months interval for one year. Annual litterfall in TSF (8.82 Mg $ha^{-1}y^{-1}$) was significantly ($p < 0.001$) higher than in HSF (7.18 Mg $ha^{-1}y^{-1}$).There was distinct seasonality in litter production. In TSF and HSF, litterfall was maximum in the summer (6.57 Mg ha^{-1} and 5.05 Mg ha^{-1}, respectively) and minimum in winter season (0.86 Mg ha^{-1} and 0.72Mg ha^{-1}, respectively). Amount of nutrient return to forest soil through litterfall (kg ha^{-1} y^{-1}) was higher in TSF (72.44 N, 6.80 P and 33.23 K) than HSF (54.31 N, 4.84 P and 22.23 K). The difference in litter production between these two forests was influenced by the phenology of dominant tree species, variation in altitude and seasons. Nutrient return through litterfall is a great input of nutrients in soil which is required for production process. Thus, litter constitutes a significant role in forest management.

Key words: Hill Sal forest, litterfall, nutrient return, seasonal variation, Tarai Sal forest

Plant litter production and its decay are the two important processes which provide the main input of organic matter in soil and regulate the patterns of nutrient cycling in forest ecosystems. Litterfall reflects primary productivity which represents approximately 30% of annual production and characterizes a major proportion of forest carbon fluxes (Macinnis-Ng and Schwendenmann, 2014). It is a central nutrient resource in tropical forest ecosystems where soils are generally nutrient poor and highly weathered (Maritus *et al*., 2004). So, litterfall is an important pathway of nutrient succession which preserves soil fertility in forest ecosystems (Bellingham *et al*., 2013).

Litterfall compilation is a standard non-destructive method for assessing the productivity and turnover of organic matter in a forest. Therefore, determining the dynamics of litterfall and nutrient return to the soil through it with time is a fundamental aspect of functioning of terrestrial ecosystem (Maritus *et al*., 2004). Litterfall dynamics in the natural forest ecosystems is strongly influenced by species composition (Singh and Kushwaha, 2006), age structure (Stonhlgren, 1988), seasons (Sundharapandian and Swamy, 1999), altitude (Garkoti and Singh, 1995) and latitude (Bray and Gorham, 1964). Precipitation, temperature, radiation and soil features are also major controlling factors of litterfall in tropical forests where it occurs during the dry season (Zhang *et al*., 2014).

Litterfall exhibits distinct seasonality in different forest ecosystems and depends mainly upon the location and nature of plant species. Many deciduous species shed their leaves during

1. Department of Botany, Mechi Multiple Campus, TU, Bhadrapur, Nepal * E-mail: krishnaprbhattarau@gmail.com
2. Department of Botany, Post Graduate Campus, TU, Biratnagar, Nepal

the dry season (Elliott *et al*., 2006). Distinct seasonality occurs in sub-tropical mixed oak forest of northeastern India, where maximum litterfall takes place during November to March (Devi and Yadava, 2010). Zhang *et al*. (2014) documented the seasonal pattern of litterfall in forest ecosystems by collecting data from existing literature and concluded that the peak of litterfall in tropical forest was in drought season corresponding to spring or winter season. However, peak of litterfall could occur at various seasons in temperate broadleaved and needle-leaved evergreen forests, and peak of litterfall was observed in autumn in temperate deciduous broadleaved and boreal evergreen needle-leaved forests. From a large number of published and unpublished datasets across South American tropical forests, it is concluded that seasonality in litterfall was significantly correlated with the rainfall (Chave *et al*., 2010).

As the litter is the above ground source of nutrients, it helps to manage the nutrient cycling process for better forest production. Regarding the litterfall and its seasonality mostly the information are from dry tropics. Here, an attempt has been made to document the information from moist tropical region. The present study was carried out to answer the following questions. (I) What is the status of litter production in Tarai and Hill Sal forests ? (ii) Does seasonality affect the litter production in these forests ? (iii) What is the contribution of litter in providing the nutrients (N, P, K) to the soil in Sal forests?

Materials and methods

Study area

The study was carried out in Sal forest located in Tarai and Hilly regions of eastern Nepal. Sal forest of Tarai region is addressed as Tarai Sal forest (TSF) and Hilly region as Hill Sal forest (HSF). TSF is located at Jalthal near Kechana (extreme low land of Nepal) of Jhapa district. It occupies an area of 6300 ha. of land and lies in between 87° 55' and 88° 03' E longitude and 26° 27' and 26° 32' N latitude. The forest floor has uneven surface and topographical variation ranges from 62 to 129 m msl. HSF is located at Kiteni of Kolbung, Ilam district. The forest lies in sub-himalayan tract (Shiwaliks) at an altitudinal range of 500 to 850 m msl. The HSF is situated in between 88° 02' and 88° 04' E longitude and 26° 44' and 26° 47' N latitude (Fig. 1).

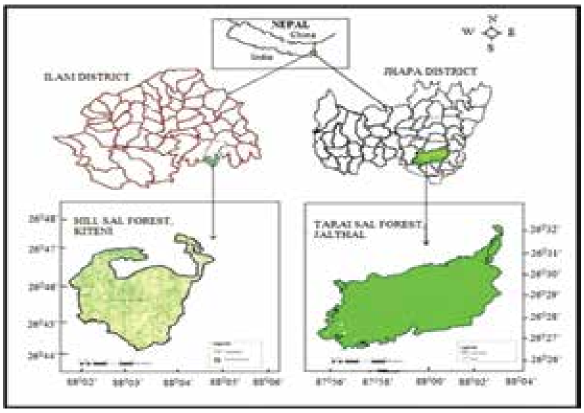


Fig. 1: Location of study area of Hill Sal forest at Kiteni, Ilam district and Tarai Sal forest at Jalthal, Jhapa district in eastern Nepal

The climate of the study area is tropical monsoon type. Based on the data pertain to the period, 2001— 2014, the mean monthly minimum temperature of TSF ranged from 10°C to 24°C and maximum temperature ranged from 23.9°C to 33.4°C (Fig. 2a). Likewise, the mean monthly minimum temperature of HSF ranged between 9.4°C to 19.9°C and maximum temperature between 16.4°C to 25.9°C (Fig. 2b). The average annual rainfall of TSF was 2130.4 mm and HSF was 1776.07 mm in which maximum rainfall (80 — 85%) occurred during rainy season.

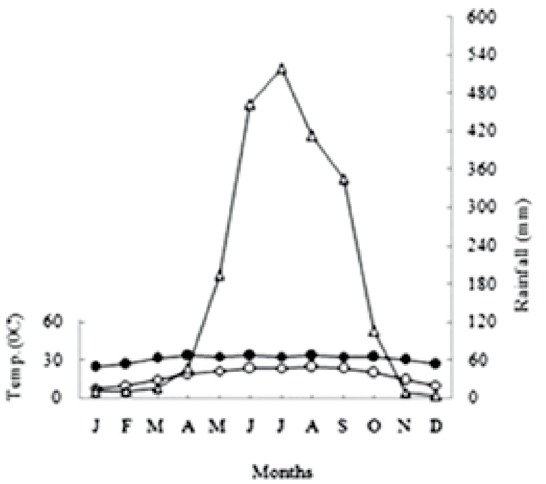


Fig. 2a: Ombrothermic representation of the climate the climate in Tarai Sal forest

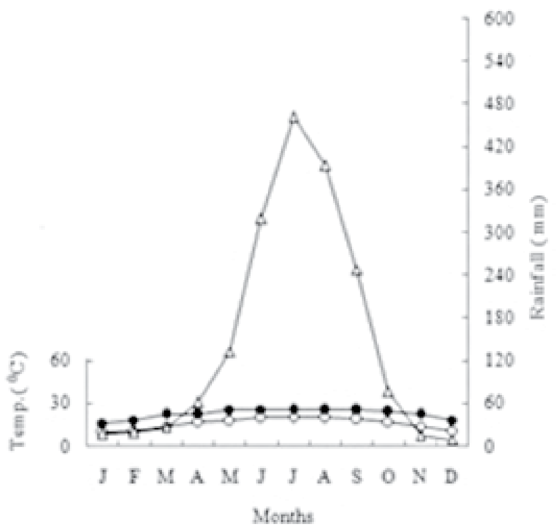


Fig. 2b: Ombrothermic representation of in Hill Sal forest

The temperature (-o-; mean monthly mimimum and-●-; mean monthly maximum) and-Δ-; rainfall data pertain to the period, 2001—2014.

Both TSF and HSF (tropical moist forest according to the life zone classification of Holdridge *et al*., 1971) are dominated by *Shorea robusta* Gaertn. The main associated species like *Lagerstroemia parviflora* Roxb., *Dillenia pentagyna* Roxb., and *Schima wallichii* D. C Korth are common in both forests. All these species are summer deciduous (Gautam, 2015). However, TSF is peculiar in containing *Artocarpus chaplasa* Roxb. and sub-tropical species like *Castanopsis indica* (Roxb.) Miq, *Michelia champaca* Land *Madhuca longifolia* (Koenig) Mac. Soil of TSF is Sandy loam Mollisols which has dark top soil. In the HSF, soil is Sandy loam Entisols with much gravel, stones and rock fragment (Jackson, 1994).

Estimation of litter fall

The inner core area in each forest stand (TSF and HSF) was divided into 100 grids each having 100m ×100m size. Among them 30 grids were selected randomly for the study purpose. Selection of grids was done alternately in clockwise direction for periphery to centre. Within each selected grid a permanent plot of 20m × 20m was fixed. Sampling plot was fixed in three ways e.g. at upper, middle and lower portion of the grids in each forest.

Litter fall samples were collected from the litter traps. One litter trap (1m × 1m size) was fixed in each plot. Within the thirty plots in each forest the litter traps were located near the trees, far from the trees and between the trees. Collection was done at an interval of two months for one year from March 2013 to February 2014. The collected samples were brought to the laboratory and separated into leaf and non-leaf (small branches, reproductive parts and miscellaneous) components. Litter samples were oven dried at 80ºC for 24 hours and the mean bi-monthly dry weight value for each forest was estimated. For the purpose of the chemical analysis, litter samples were mixed and pooled separately component wise in proportion to their volume to represent annual sample for each forest site. Pooled samples were stored in dried form in air-tight polythene bags for chemical analysis.

Chemical analysis of litter

The oven dried form of pooled samples of each litter component were ground separately and passed through 1mm mesh screen. Chemical analysis was done in triplicates for each litter component. The total nitrogen concentration was determined by micro-Kjeldahl method (Peach and Tracey, 1956). Using the method of Allen *et al*. (1974), 200 mg oven dried plant material was digested in 7 ml triacid mixture (5:1:1, nitric acid: sulphuric acid: perchloric acid), cooled and transferred on hot plate till the material changed to pink color and diluted to 100 ml by using triple distilled water. Using 5ml aliquot, ammonium molybdate and $SnCl_2$, the total P was determined by developing blue colour and with the help of spectrophotometer. Potassium was determined by atomic absorption spectrophotometer.

Statistical analysis

Statistical tests were carried out in SPSS (IBM Statistics, ver. 20) packages. The data were checked for normality (Kolmogorov-Smirnov test) before statistical analysis. Two ways ANOVA was used to test the significant difference in the amount of litterfall due to forest types (TSF and HSF) and seasons.

Table 1: Annual litter fall (Mg ha^{-1} y^{-1}± 1 SE) in Tarai Sal forest and Hill Sal forest

Forests	Leaf litter	% of total	Non-leaf litter	% of total	Total
Tarai Sal forest	6.16±0.06	70	2.66±0.05	30	8.82±0.06
Hill Sal forest	5.01±0.12	70	2.17±0.08	30	7.18±0.19

Results and discussion

Litter production in TSF and HSF

Annual litterfall in TSF (8.82 Mg ha^{-1}y^{-1}) was higher than in HSF (7.18 Mg ha^{-1}y^{-1}) (Table 1).

ANOVA suggested that the variation in litterfall was significantly ($p < 0.001$) different for forest types (Table 2).

Table 2: Effect of forest sites, seasons and forest sites × seasons interaction in the litterfall in TSF and HSF as indicated by ANOVA.

Source of Variation	df	F	Significance
Forest	1	113.76	P<0.001
Seasons	2	4038.84	P<0.001
Forest × Seasons	2	96.45	P<0.001

Contribution of leaf litter was always higher (70%) than non-leaf litter (30%) in both forests. Leaves comprised the most important part of litterfall, as has been found for most of the forest ecosystems (Paudel *et al*., 2015; Wang *et al*., 2007; Yang, 2005; Martius *et al*., 2004; Arunachalam *et al*., 1998).

In the present study the higher litter production in TSF than HSF could mainly be due to differences in microclimate and soil properties which affect the productivity (Vitousek, 1984). As temperature declines with increasing altitude (Girardin *et al*., 2010), the decomposition process and nutrient supply became retarded due to which above-ground net production including litter production declined (Belligham *et al*., 2013; Kitayama and Aiba, 2002; Garkoti and Singh,1995).

Comparative account of litter production in some tropical and sub-tropical forests is presented in table 3. The value estimated for TSF was

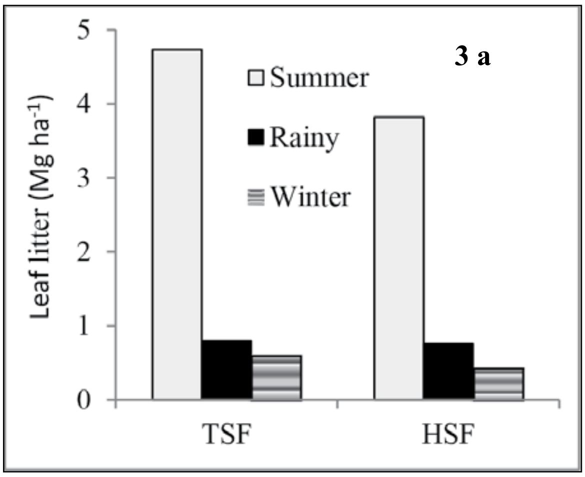
Table 3: Comparative account of litter production (Mg ha^{-1} y^{-1}) in some tropical and sub-tropical forests

Location	Forest types	Litter production	References
Nepal			
Jalthal, Jhapa	Tarai Sal forest	8.82	Present study
Kiteni, Ilam	Hill Sal forest	7.18	Present study
Charkoshe, Sunsari	Tropical moist Sal forest	11.8	Gautam, 2015
Panchakanya, Sunsari	Plateau Sal forest	10.3	Mandal, 1999
India			
Manipur	Sub- tropical Oak forest	10.94	Devi andYadaba, 2010
Kodiyar, Tamilnadu	Deciduous forest	5.76 - 8.65	Sundarapandian and Swamy, 1999
Kodiyar, Tamilnadu	Evergreen forest	5.63 - 7.84	Sundarapandianand Swamy, 1999
Vidhyan plateau	Dry tropical savannahs	2.8 - 5.9	Tripathi and Singh, 1995
Nanda Devi Reserve	Forests of Central Himalaya	4.22	Garkotiand Singh, 1995
Thrissur, Kerala	Moist deciduous	12.2 - 14.4	Kumar and Deepu, 1992
Mornihills, Haryana	Moist deciduous	10.4	Gupta and Raut, 1992
	Sal and mixed Sal forest	2.8 - 7	Sharma *et al*., 1990a, b
	Deciduous forest	1 - 6.2	Singh, 1968
Other counties			
China	Evergreen broad-leaved forest	3.28 - 11.26	Paudel *et al*., 2015
China	Global pattern	3.0 - 11	Zhang *et al*., 2014
New Zealand	Evergreen montane rain forest	2.81	Bellingham *et al*., 2013
South America	Tropical forests (n= 81)	8.61	Chave *et al*., 2010
China	Sub tropical forest	4.89 - 10.61	Zhou *et al*., 2007
China	Evergreen broad-leaved forest	4.63 - 8.85	Yang *et al*., 2005

comparable to Plateau Sal forest of Nepal (10.3 Mg $ha^{-1}y^{-1}$; Mandal, 1999) and moist deciduous forest of Moni Hills, Haryana, India (10.4 Mg $ha^{-1}y^{-1}$; Gupta and Raut, 1992). On the other hand the value obtained for HSF was comparable to tropical forests of South America (8.61 Mg $ha^{-1}y^{-1}$; Chave *et al*., 2010).

Seasonal variation in litter production

There was distinct seasonality in the pattern of litter production in both forests (Table 2). In TSF and HSF, it was higher in the summer season (6.57 Mg $ha^{-1}$and 5.05 Mg ha^{-1}) followed by rainy (1.39 Mg ha^{-1} and 1.41Mg ha^{-1}) and winter season (0.86 Mg ha^{-1} and 0.72 Mg ha^{-1}), respectively (Fig. 3). Environmental variables like temperature and rainfall greatly influence the seasonal pattern of litter fall in tropical forests (Zhang *et al*., 2014; Chave *et al*., 2010). High temperature during summer season reduces the humidity and increases the rate of transpiration which enhances the rate of litter fall (Twilley *et al*., 1986).



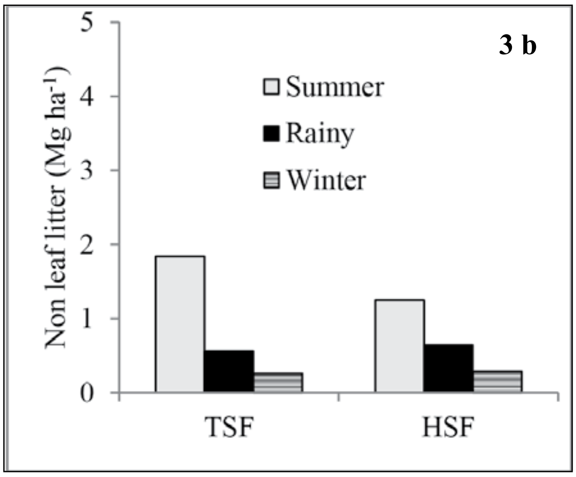


Fig. 3 a & 3 b: Seasonal variation in litterfall (Mg ha^{-1}) in Tarai Sal forest and Hill Sal forest of eastern Nepal. Seasonal representations are as: Summer (March-June), Rainy (July-October) and Winter (November-February).

Nutrient return through litter fall

Nutrient concentration of different components of litter was slightly higher in TSF than HSF as summarized in table 4. Concentration of nutrients in different litter components in diminishing order was: N>K>P in both forests. Nutrient concentration in leaf litter was nearly 1.5 times higher than the non-leaf litter in each forest. Generally, the woody litter has lower N and P concentration than the foliage (Arunachalam *et al*., 1998) because woody litter has high amount of sclerophyllous tissue which contains less amount of nutrient (Vitousek and Sanford, 1986).

The total amount of nutrient return to forest soil through litterfall is mentioned in table 5. N, P, K return through litterfall (kg $ha^{-1}y^{-1}$) was higher in TSF than HSF due to higher amount of litterfall. Along with, it also depends upon the nutrient

Table 4: Concentration (% ± SE) of nutrients in litterfall in Tarai Sal forest and Hill Sal forest

Forests/Components	Nutrients		
	N	**P**	**K**
Tarai Sal forest			
Leaf litter	0.93±0.023	0.086±0.001	0.41±0.01
Non leaf litter	0.57±0.024	0.057±0.002	0.30±0.02
Hill Sal forest			
Leaf litter	0.85±0.023	0.077±0.001	0.34±0.01
Non leaf litter	0.53±0.025	0.046±0.002	0.24±0.02

Table 5: Amount of nutrient return (kg ha^{-1} y^{-1} ± SE) through litterfall in Tarai Sal forest and Hill Sal forest

Forests/Components	Nutrients		
	N	**P**	**K**
Tarai Sal forest			
Leaf litter	57.28±2.15	5.29±0.09	25.25±0.7
Non leaf litter	15.16±0.63	1.51±0.03	7.98±0.38
Total	72.44±1.22	6.80±0.11	33.23±1.09
Hill Sal forest			
Leaf litter	42.81±0.28	3.85±0.04	17.03±0.72
Non leaf litter	11.50±0.52	0.99±0.07	5.20±0.37
Total	54.31±0.92	4.84±0.04	22.23±1.1

concentration of litter of tree species involved (Yang *et al*., 2005). Generally, montane forest leaves have lower nutrient concentration than those of fertile lowland forest (Vitousek and Sanford, 1986).

The nutrient contribution to the forest floor through the litterfall was comparable to Wanmulin Nature Reserve, China (Yang *et al*., 2005), forest of central Himalaya, India (Garkoti and Singh, 1995) and Plateau Sal forest, Nepal (Mandal, 1999). However, in Sal forest and mixed Sal forest of Bidhyan plateau, India (Sharma *et al*., 1990a) and in deciduous forest, India (Singh, 1968) the nutrient return from litterfall was relatively lower than the present study.

Litterfall is only the above ground source of soil organic matter which enriches the soil with nutrients essential for forest production. Removal or reduction of litter from forest floor can directly reduce the soil nutrients which ultimately affect the forest productivity. Hence, litter stands as an essential factor for better forest management.

Conclusion

It is concluded that litter production is influenced by the phenology of dominant tree species, variation in altitude and seasons, due to which low land Tarai Sal forest showed greater litter production and nutrient return to the soil. As TSF is rich in litter production and nutrient input in soil, it may have high production potential. Further, to manage the soil fertility, litter should remain undisturbed on the forest floor to regulate the nutrient cycling process. As the litter and litter mediated soil nutrients are essential for biomass production, it serves as a pronounced factor for the forest management.

Acknowledgements

We are grateful to the Head, Department of Botany and to the Campus Chief of Post Graduate Campus, T. U., Biratnagar, Nepal for providing laboratory and library facilities. The first author is grateful to the Institute of Science and Technology, Tribhuvan University, Kathmandu for study leave and to the University Grants Commission, Nepal for the research fellowship.

References

Allen, S.E., Grimshaw, H.M., Parkinson, J.A. and Quarmby, C. 1974. **Chemical Analysis of Ecological Materials**. Blackwell Scientific Publication, Oxford, UK.

Arunachalam, A., Arunachalam, K., Pandey, H. N. and Tripathi, R.S. 1998. Fine litterfall and nutrient dynamics during forest regrowth in the humid sub-tropics of north-eastern India. *Forest Ecology and Management* **110:** 209 — 219.

Bellingham, P. J., Morse, C. W., Buxton, R. P., Bonner, K. I., Mason, N. W. H. and Wardle, D. A. 2013. Litterfall, nutrient concentrations and decomposability of litter in a New Zealand temperate montane rain forest. *New Zealand Journal of Ecology* **37 (2):** 162—171.

Chave, J., Navarrete, D., Almeida, S., Alvarez, E., Arag, L.E.O.C., Bonal, D., Chatelet, P., Silva- Espejo, J.E., Goret, J.Y., vo Hildebrand, P., Jimenez, E., Patino, S., Penuela, M.C., Philips, O.L., Stevenson, P. and Malhi, Y. 2010. Regional and seasonal patterns of litterfall in tropical South America. *Biogeosciences* **7:** 43—55.

Devi, N. B. and Yadava, P.S. 2010. Influence of climate and litter quality on litter decomposition and nutrient release in sub-tropical forest of Northeast India. *Journal of Forestry Research,* **21 (2):** 143—150.

Elliott, S., Baker, P.J. and Borchert, R. 2006. Leaf flushing during the dry season: the paradox of Asian monsoon forests. *Global Ecology and Biogeography* **15:** 248— 257.

Garkoti, S. C. and Singh, S.E. 1995. Forest floor mass, litterfall and nutrient return in Central Himalayan high altitude forests. *Vegetatio* **120:** 33—48.

Gautam, T. 2015. Species Composition, Production and Nutrient Dynamics in Tropical Forest of Sunsari District, Eastern Nepal. Ph.D. Thesis, Tribhuvan University, Kathmandu, Nepal.

Girardin, C. A. J., Malhi, Y., Aragão, L. E. O. C., Mamani, M., Huaraca Huasco, W., Durand, L., Feeley, K. J., Rapp, J., Silva-Espejo, J. E., Silman, M., Salinas, N. and Whittaker, R. J. 2010. Net primary productivity allocation and cycling of carbon along a tropical forest elevational transect in the Peruvian Andes. *Global Change Biology* **16:** 3176—3192.

Gupta, R. and Raut, S. K. 1992. Litter dynamics and nutrient turn over in a mixed deciduous forest. In *Tropical Ecosystems: Ecology and Management* (eds.) Singh, K. P. and Singh, J. S. Wiley Eastern, New Delhi, India.

Holdridge, L.R., Grenke, W.C., Hatheway, W.H., Liang, T. and Tosi, J.A. Jr. 1971. **Forest Environments in Tropical Life Zones: A Pilot Study**. Pergamon Press, Oxford, UK.

Jackson, J. K. 1994. **Mannual of Afforestation of Nepal**. Vol. 1. Forest Research and Survey Center, Ministry of Forests and Soil Conservation, Kathmandu, Nepal.

Kikuzawa, K., Asai, T. and Fukuchi, M. 1984. Leaf litter production in a plantation of *Alnus inokumae*. *Journal of Ecology* **72:** 993— 999.

Kitayama K. and Aiba S-I. 2002. Ecosystem structure and productivity of tropical rain forests along altitudinal gradients with contrasting soil phosphorus pools on Mount Kinabalu, Borneo. *Journal of Ecology* **90:** 37—51.

Kumar, B.M. and Deepu, J. K. 1992. Litter production and decomposition dynamics in moist deciduous forests of the Western Ghats in Penninsular India. *Forest Ecology and Management* **50 (34):** 181—201.

Macinnis-Ng, C. and Schwendenmann, L. 2014. Litterfall, carbon and nitrogen cycling in a southern hemisphere conifer forest dominated by kauri (*Agathis australis*) during drought. *Plant* Ecology **216 (2):** 247—262. doi: 10.1007/s11258-014-0432-x

Mandal, T. N. 1999. Ecological Analysis of Recovery of Landslide Damaged Sal Forest Ecosystem in Nepal Himalaya. Ph. D. Thesis, Banarus Hindu University, Varanasi, India.

Martius, C., Höfer, H., Garcia, M. V. B., Römbke, J.and Hanagarth, W. 2004. Litterfall, litter stocks and decomposition rates in rainforest and agroforestry sites in central Amazonia. *Nutrient Cycling in Agroecosystems* **68:** 137—154.

Pandey, R. R., Sharma, G., Tripathi, S. K.

and Singh, A. K. 2007. Litterfall, litter decomposition and nutrient dynamics in a subtropical natural oak forest and managed plantation in northeastern India. *Forest Ecology and Management,* **240 (1—3):** 96—104. doi: 10.1016/j.foreco.2006.12.013

Paudel, E., Dossa, G. G. O., Xu, J. and Harrison, R. D. 2015. Litterfall and nutrient return along a disturbance gradient in a tropical montane forest. *Forest Ecology and Management* **353:** 97—106. doi: 10.1016/j.foreco.2015.05.028

Peach, K. and Tracey, M. V. 1956. **Modern Methods of Plant Analysis**. Vol. 1. Springer- Verlag, Berlin, Germany.

Sharma, R. B., Moolchandra and Singh, K. P. 1990a. Variations in forest biomass and productivity. In *Enviromental Degradation of Obra-Renukoot-Singrauli Area and Its Impact of Natural and Derived Ecosystem* (eds.) Singh, J.S., Singh and M. Agrawal, M.), Final Technical Report Submitted to Ministry of Environment and Forests, New Delhi, 109—124.

Sharma, R. B., Moolchandra and Singh, K. P. 1990b. Changes related to forest nutrient cycling. In *Enviromental Degradation of Obra-Renukoot-Singrauli Area and Its Impact of Natural and Derived Ecosystem* (eds.) Singh, J.S., Singh and M. Agrawal, M.), Final Technical Report Submitted to Ministry of Environment and Forests, New Delhi, 125—143.

Singh, K. P. 1968. Litter production and nutrient turnover in deciduous forests of Varanasi. In: *Proceedings of Symposium on Recent Advances in Tropical Eco-logy* (eds.) Misra, R. and Gopal, B., International Society of Tropical Ecology, Varanisi, 655—665.

Singh, K. P. and Kushwaha, C. P. 2006. Diversity of flowering and fruiting phenology of trees in a tropical deciduous forest in India. *Ann. Bot.* **97:** 265—276. http:// dx.doi.org/10.1093/aob/mcj028.

Stonhlgren, T. J. 1988. Litter dynamics in two Sierran mixed conifer forest. I. Litterfall and decomposition rates. *Canadian Journal of Forest Resources* **18:** 1127—1135.

Sundarapandian, S. M. and Swamy, P. S. 1999. Litter production and leaf-litter decomposition of selected tree species in tropical forests at Kodayar in the Western Ghats, India. *Forest Ecology and Management* **123:** 231—244.

Tripathi, S. K. and Singh, K. P. 1995. Litter dynamics in a recently harvested and mature bamboo savanna in a dry tropical region in India. *Journal of Tropical Ecology* **11:** 403—417.

Twilley, R. W., Lugo, A. E. and Patterson-Zucca, C. 1986. Litter production and turnover in basin mangrove forests in southwest Florida. *Ecology* **67:** 670—683.

Vendrami, J. L., Jurinitz, C. F., Castanho, L. L. and Oliveira, A. A. 2012. Litterfall and leaf decomposition in forest fragments under different successional phases on the Atlantic Plateau of the state of Sao Paulo, Brazil. *Biota Neotropica* **12** :http://www.biotaneotropica.org.br/v12n3/en/abstract?article+bn03312032012.

Vitousek P. M. 1984. Litterfall, nutrient cycling, and nutrient limitation in tropical forests. *Ecology* **65:** 285—298.

Vitousek, P. M. and Sanford, R. L. 1986. Nutrient cycling in moist tropical forest. *Annual Review of Ecological Systematics* **17:** 137—167.

Wang, Q., Wang, S., Fan, B. and Yu, X. 2007. Litter production, leaf litter decomposition and nutrient return in *Cunninghamia lanceolata* plantations in south China: effect of planting conifers with broadleaved species. *Plant and Soil* **297:** 201—211.

Yang, Y. S., Guo, J. F., Chen, G. S., Xie, J. S., Gao, R., Li, Z. and Jin, Z. 2005. Litter production, seasonal pattern and nutrient return in seven natural forests compared with a plantation in southern China. *Forestry* **78 (4):** 403—415.

Zhang, H., Yuan, W., Dong, W. and Liu, S. 2014. Seasonal patterns of litterfall in forest ecosystem worldwide. *Ecol. Complex* **20:** 240—247.

Zhou, G., Guan, L., Wei, X., Zhang, D., Zhang, Q., Yan, J., Wen, D., Liu, J., Liu, S., Huang, Z., Kong, G., Mo, J. and Yu, Q. 2007. Litterfall production along successional and altitudinal gradients of subtropical monsoon evergreen broadleaved forests in Guangdong, China. *Plant Ecology* **188:** 77—89.