Annals of Plant and Soil Research 24(2):231-237 (2022)
https://doi.org/10.47815/apsr.2022.10154

Litter decomposition dynamics of *Taxus contorta* Griff. in western Himalayan region

VIJENDER PAL PANWAR AND S. SIVARANJANI*

Forest Ecology and Climate Change Division, Forest Research Institute, Dehradun 248006, Uttarakhand, India

Received: September, 2021; Revised accepted: January, 2022

ABSTRACT

Litterfall is the essential source of organic matter and soil nutrients. The quality and quantity of litter production affect the carbon and nutrient fluxes in forest ecosystems. This study aims to determine the litter decomposition rate and macronutrients (N. P, K, Ca and Mg) in Taxus contorta Griff forests. The results showed that the maximum weight loss due to decomposition was recorded from June to October, and decay constant (K) was 0.534 during two years of study. Decomposition was significantly affected by climatic variables and positively correlated with temperature, rainfall, number of rainy days and relative humidity. The decomposing needles showed a continuous increase in nitrogen (0.97-1.27%) and phosphorus (0.11-0.13%) concentration and a gradual decrease in potassium (0.35-0.31%), calcium (0.93-0.45%) and magnesium (0.21-0.16%). Total nutrient return (37.33 kg ha^{-1}) from the decomposing litter were observed in the order of Ca (15.09) > N (12.13) > K (5.73) > Mg (2.87) > P (1.50) through the input from different litter components, which were found in the order of needles > twigs > bark > miscellaneous litter > reproductive litter. Maximum nutrient return (15.82 kg ha^{-1}) was observed through needle litter and was recorded as N (6.49), P (0.85), K (2.84), Ca (4.39) and Mg (1.24). Out of the total nutrients returned through needle litter, an annual release of 67% and accumulation of 33% nutrients over the forest floor of Taxus contorta was recorded.

Keywords: Litterfall, release, return, accumulation, Taxus

INTRODUCTION

Litter decomposition is the essential process through which nutrients present in the plant biomass are released and finally get incorporated into the forest soils for recycling. It is a complex and often prolonged process in which both physical and biological agencies participate, either together or separately, to reduce the litter to soil organic matter and the mineral elements. As a controlling component of nutrient cycling, its rate and mechanism have attracted considerable attention. Nevertheless, decomposition rates are essential factors determining the level of nutrients available to the crop and the soil invertebrate community (Paudel *et al.*, 2015). Decomposition of litter is an excellent indicator of the intensity of nutrient cycling in the forest stands. This process leads to the chemical simplification of various complex compounds resulting in the liberation of CO_2, NH_4, H_2O and other mineral elements. Accordingly, these nutrients are released back into the soil for their re-circulation. The release of nutrients from forest litter through the decomposition process is essential for nutrient cycling, whereby essential mineral elements tied up in plant biomass are made available for further plant growth (Bot and Benites, 2005). The rate of litter decomposition and nutrient release strongly influence the physical and chemical properties of the soil and the ecosystem's primary production. Accumulation of available nutrients in the soil is a crucial process related to forest succession that significantly improves plant nutrient availability and leads to only minor changes in carbon/nutrient ratios and humus quality (Walker and Wardle, 2014). Plant litter decomposition is one of the crucial processes of biogeochemical cycling in the forest ecosystem and is mainly governed by an interplay of abiotic and substrate quality variables (Giweta, 2020). The principal mineral flow pathways mainly affect the nutrition of terrestrial communities. In order of internal degree of mineralization, they are geochemical, biogeochemical and biological cycling. The geochemical pathway links the external environment to an ecosystem, whereas the biogeochemical cycling is the circulation of nutrient capital between soil, standing crop and litter subsystem (Smith *et al.*, 2015). Biological processes include nutrient redistribution in living biomass that conserves nutrients within the

*Corresponding author email: ranjani.agri@gmail.com

standing crop. These major pathways are coupled in overall community nutrition, but the relative significance of each of them differs from element to element. The present study aimed to find the litter decomposition and how much nutrients were transferred/released through the decomposed litter of *Taxus contorta* in the forests of Western Himalayas.

MATERIALS AND METHODS

Study area

The study was conducted in the *Taxus* forest of the Narkanda region at 31º13'25.86''N, 77º25'32.91''E in Himachal Pradesh. *Taxus contorta* mainly occurs at 1800-3300 m above msl and prefers moist shady places. The major part of precipitation is received through the rain in summers (April-June) and during the monsoon season (July- September), with areas experiencing snowfall in winters. Mean relative humidity varied from 24 per cent (April) to 85 per cent (July). It is a medium-sized tree and often forms an understorey to the broad-leaved species or other tall confers *viz*., silver fir and spruce. The site experienced an annual rainfall ranging from 900 mm to 1600 mm, usually well spread and distributed throughout the year.

Litter decomposition

The litter decomposition was estimated using the litter bag method (Ewel, 1976). The nylon mesh litter bags of 30x15 cm dimensions were stapled all along their sides, leaving a gap of 5 cm between the two staples to allow easy entry of macro-fauna like arthropods, annelids etc. About 25 gm air-dried needles (leaves) were filled in each of 72 litterbags and were equally placed at three randomly selected sites in the study area. Such three samples were brought to the laboratory to assess their initial oven-dry weights and chemical constituents. Subsequently, three bags from each site starting from March to November were retrieved at monthly intervals (except during winter months *i.e.*, December to February every year when these areas remain under snow) and brought to the laboratory. The samples were made free from any foreign material and kept for oven drying at 80±2^{o}C till constant weight was achieved. These samples were powdered and analyzed for their chemical constituents.

Decomposition Constant (k) and Nutrient Contents

The decomposition rate and decomposition constant (k) were calculated using the equations of Olson (1963) and Jenny *et al.* (1949), respectively. Above oven-dried and processed litter samples for chemical analysis were digested using tri-acid [nitric acid (9 parts), perchloric acid (4 parts) and sulphuric acid (1 part)] following Misra (1968). Phosphorous, Potassium, Calcium and magnesium in tri-acid digest were determined by Atomic Absorption Spectrophotometer. Nitrogen was estimated by the Micro-Kjeldahl method using Kjeltec Auto analyzer.

Nutrient Return, Release and Accumulation

For calculating the total amount of nutrients returned through litterfall, the concentrations of different nutrients present in the monthly litter samples were multiplied by the amount of litterfall of that particular month. Concentrations of nutrients in the control samples (initial nutrient contents of the samples at the time of laying out of the experiment for decomposition) and nutrient concentrations remaining in the litter bag samples retrieved at monthly intervals from the experimental site were multiplied with the fraction of the original weight and litter mass remaining in the decomposition bags, respectively. The nutrient loss (%) was calculated by subtracting the per cent remaining contents of decomposing samples in the litter bag (retrieved every month) from the original litter contents *i.e.*, control. The nutrient release was computed by multiplying the per cent nutrient loss with the monthly nutrient return through litterfall (kg ha^{-1}). The fraction then was divided by the original nutrient contents of the control sample. Finally, the values of nutrient accumulation on the forest floor for the corresponding month were calculated by subtracting the values of nutrient release from those of nutrient return.

RESULTS AND DISCUSSION

Litter decomposition

The annual dry weight loss of *T. contorta* needle litter was 41.5 and 24.0 % during the first and second years, respectively. Maximum weight loss due to decomposition was recorded from May to October (Table 1). The decomposition constant (k) values varied from 0.002 to 0.095 and 0.005 to 0.081 during the first and second year, respectively. The mean annual decomposition constant (k) was 0.534. In two years, needle litter weight loss due to decomposition was 65.6 % (Berger and Berger, 2012). The maximum dry weight loss was recorded during summer and rainy months than winter (Devi and Yadav, 2010; Berg, 2014).

Table 1: Decomposition constant (k) and dry weight loss (%) in decomposed needle litter

Month	I Year		II Year	
	k Value	Weight Loss (%)	k Value	Weight Loss (%)
March	0.029	2.73	0.005	1.84
April	0.022	2.21	0.017	1.69
May	0.048	4.69	0.079	7.63
June	0.057	5.57	0.081	7.78
July	0.089	8.55	0.077	7.39
August	0.058	5.65	0.074	7.09
September	0.049	4.82	0.062	5.98
October	0.095	9.08	0.078	7.47
November	0.002	0.18	0.045	4.39

The time required to reach a 50% level of decomposition was 1.30 years. The estimations based upon the above further revealed that 95% weight loss might occur after a lapse of 5.63 years (Horodecki and Jagodzinski, 2019). The rate of needle litter decomposition was at 0.1139 % per day in the first year and 0.0659 % per day during the second year. The per cent weight loss increased continuously with time. Therefore, correlation and regression analysis were performed between the per cent biomass remaining (Y) and days elapsed (X) and were found significant ($p<0.1$) and negatively correlated (-0.979). The regression equation obtained was Y= 95.90-0.087X. The correlation between the natural log of per cent weight loss and the number of days elapsed was found significant ($p<0.1$) and positively correlated (0.918), the regression equation obtained was Y= 2.543+0.002X.

Climate and decomposition

The decomposition constant (k) values, were found positively correlated with temperature (x_1), rainfall (x_2), number of rainy days (x_3) and relative humidity (x_4) (Table 2). The multiple correlation (R^2= 0.588) between monthly decomposition constant (k) and different climatic variables were also significant at p< 1 ($Y = -6.631324E{-}02 + 5.2850E{-}03x_1 + 7.9804E{-}05\ x_2 - 2.9420E{-}03\ x_3 + 6.9313E{-}04x_4$).

Table 2: Correlation coefficients and their regression equations between needle litter decomposition constant k (y) and different climatic variables (x)

Characters	Regression equations	Correlation coefficients
Temperature Vs k	Y = -0.04 + 0.005 x	0.638**
Rainfall Vs k	Y = 0.04 + 0.000 x	0.534*
No. of Rainy Days Vs k	Y = 0.04 + 0.002 x	0.497*
Relative Humidity Vs k	Y = 0.00 + 0.001 x	0.614**

**Significant at 5% probability level, ** Significant at 1% probability level*

High values of litter decomposition during rainy months in *T. contorta* may be attributed to a combined effect of humidity, rainy days and temperature. Lowering decomposition rates with the decrease in temperature during winter months is mainly because of low temperature on microbial activity. These results have also been confirmed by significant correlation coefficients (R^2) amongst decomposition constants (k) and climatic variables. Kreyling (2010) had also observed maximum weight loss during summers and minimum during the winter season in different habitats. It has also been reported that the decrease in decomposition rate with plantation age is associated with increased shading and a decrease in the amplitude of the diurnal temperature cycle (Singh *et al.*, 2017).

Nutrients in decomposed litter

During two years, decomposing needle litter showed a continuous increase (0.97 % to 1.27 %) in nitrogen concentrations (Table 3). On the other hand, an average of about 27% nitrogen loss occurred from the needle litter

Table 3: Nutrient concentrations (%) in decomposed needle litter

Year/ Month	I Year					II Year				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Control	0.97	0.11	0.35	0.93	0.21					
March*	0.98	0.11	0.34	0.89	0.20	1.16	0.12	0.33	0.69	0.18
April	0.99	0.11	0.34	0.87	0.20	1.17	0.12	0.33	0.67	0.18
May	0.99	0.11	0.34	0.85	0.20	1.18	0.12	0.32	0.65	0.18
June	1.01	0.11	0.34	0.83	0.20	1.19	0.12	0.32	0.63	0.18
July	1.09	0.12	0.34	0.81	0.19	1.21	0.12	0.32	0.60	0.17
August	1.12	0.12	0.33	0.78	0.19	1.22	0.12	0.31	0.54	0.17
September	1.13	0.12	0.33	0.76	0.18	1.24	0.13	0.31	0.49	0.17
October	1.15	0.12	0.33	0.74	0.18	1.25	0.13	0.31	0.45	0.16
November	1.15	0.12	0.33	0.73	0.18	1.27	0.13	0.31	0.45	0.16

(= Represents cumulative values from December to March)*

decomposition (Table 4). Most of this loss occurred during the rainy months (June-September). However, the losses had started appearing from April onwards, approximately five months after the initiation/laying out of the experiment. The trend in the data reveals that immobilization of nitrogen had taken place during winters.

Table 4: Nutrient loss during needle litter decomposition

Nutrients	Initial nutrients (g) per litter bag	Final nutrients (g) per litter bag	Nutrient Loss (g) (2 years)	Nutrient Loss per year (%)
N	0.27	0.12	0.14	27.46
P	0.03	0.01	0.01	30.10
K	0.09	0.03	0.06	34.58
Ca	0.25	0.04	0.21	41.68
Mg	0.05	0.01	0.04	36.62

Like nitrogen, phosphorus concentration also showed a continuous increase (0.11% to 0.13%) in the decomposing needle litter during both years. On average, 30% phosphorus loss per annum was observed in decomposed needle litter. Most of the phosphorus loss occurred during rainy months (June-September), and its immobilization started during winters and continued till May in the second year. A gradual decrease in potassium concentration was recorded during decomposition from 0.35 to 0.31% in two years. Annually, about 35% potassium loss was recorded from decomposing litter. In both years, decreasing calcium and magnesium concentrations trends were observed during decomposition, leading to approximately 42% and 37% losses of these nutrients, respectively (Table 4). Magnesium loss started occurring after five months, *i.e.*, from May onwards. The mobility of different nutrients in the decomposing needle litter was in the order of Ca > Mg > K > P > N. The correlation analysis between per cent weight remaining and net nutrient content in the residual matter during decomposition indicated highly significant relationships with all the nutrients studied, where K, Ca and Mg were positively correlated and N and P were negatively correlated (Table 5).

Table 5: Correlation coefficient and regression equations between per cent biomass remaining (x) and nutrient concentration (y) in residual material of *T. contorta* during two years

Nutrient	Regression equation	Correlation coefficient (r)
N	y = 1.46 + - 0.005 x	- 0.987***
P	y = 0.14 + - 0.000 x	- 0.992***
K	y = 0.29 + 0.001 x	0.972***
Ca	y = 0.23 + 0.008 x	0.970***
Mg	y = 0.14 + 0.001 x	0.988***

**** Significant at 0.1% probability level*

The existence of the significant inverse relationship between per cent weight remaining and N and P concentration in residual material indicated that N and P were not lost from the litter as fast as other nutrients (Giweta, 2020). It also confirmed that evergreens had the highest N and P use efficiency. A significant inverse relationship of nitrogen indicated that the release phase dominated the annual nutrient cycling.

Nutrient Return, Release and Accumulation

In general, total return of nutrients was in the order of Ca > N > K > Mg > P. The order of nutrient input from different litter components was: needles > twigs > bark > miscellaneous litter > reproductive litter. The annual nutrient return was recorded 37.33 kg ha$^{-1,}$ and the maximum nutrient return was observed from May to July every year. The needle component alone returned 42% of the total nutrients to the forest floor (Canellas and San, 1998).

Table 6: Nutrient return (kg ha^{-1}) from different litter components

Component of Litter	Year	N	P	K	Ca	Mg	Total
Needle	I	7.41	0.96	3.43	5.30	1.46	18.56
	II	5.58	0.74	2.25	3.48	1.03	13.08
	Mean	6.49	0.85	2.84	4.39	1.24	15.82
Twigs	I	2.35	0.26	1.12	7.67	0.98	12.37
	II	1.99	0.22	1.02	5.69	0.78	9.71
	Mean	2.17	0.24	1.07	6.68	0.88	11.04
Reproductive Litter	I	0.84	0.16	0.70	0.26	0.14	2.09
	II	0.88	0.17	0.71	0.28	0.15	2.19
	Mean	0.86	0.16	0.70	0.27	0.14	2.14
Bark	I	1.17	0.09	0.29	2.85	0.40	4.80
	II	0.97	0.07	0.26	2.63	0.33	4.26
	Mean	1.07	0.08	0.27	2.74	0.36	4.53
Miscellaneous litter	I	1.71	0.18	0.92	1.09	0.27	4.17
	II	1.37	0.15	0.76	0.94	0.22	3.43
	Mean	1.54	0.17	0.84	1.01	0.24	3.80
Total of Means		12.13	1.50	5.73	15.09	2.87	37.33

The mean nitrogen return (12.13 kg ha^{-1}) contributed 32.4% towards the total nutrient return annually. The total annual nitrogen return of 6.49 kg ha^{-1} from needle litter alone contributed 53.5% to the total nitrogen return (Table 6). Out of this nitrogen returned from needle fall, 3.5 kg ha^{-1} (55%) was released through decomposition and 2.9 kg ha^{-1} (45%) accumulated on the forest floor annually (Table 7). The mean phosphorus return (1.50 kg ha^{-1}) contributed least (4.02%) towards the total annual nutrient return. The mean potassium return (5.73 kg ha^{-1}) contributed 15.2 % of the total annual nutrient return. The needle litter contributed 2.84 kg K ha^{-1} yr^{-1}, out of which 69% was released and 31% accumulated on the forest floor (Table 7).

Table 7: Annual average return, release and accumulation of different nutrients through needle fall (kg ha^{-1})

Nutrients	Return	Release	Accumulation
N	6.49	3.57	2.93
P	0.85	0.51	0.34
K	2.84	1.97	0.88
Ca	4.39	3.66	0.73
Mg	1.24	0.91	0.33
Total	15.82	10.61	5.20

The total annual calcium return was 15.09 kg ha^{-1} which contributed 40.42% towards the total nutrient return. The twig litter contributed maximum in total annual calcium return 6.68 kg ha^{-1} (44.27%). Out of total calcium return (4.39 kg ha^{-1} yr^{-1}) from needle litter, 83% was released, and 17% was accumulated on the forest floor. The magnesium contributed 7.69% towards the total nutrient return annually. Out of the total Mg returned through the needle, 73% was released, and 27% was simultaneously accumulated for further decomposition (Table 7). The pattern of nutrient return also depends upon the physiological status of forest stand or internal status of the plant, etc., those invariably are responsible for such type of variations.

In the present study, the nutrient return showed the annual pattern as: Ca > N > K > Mg > P, showing relatively high calcium return in the species. This phenomenon can be attributed to the higher amount of twig component (28.46%) found in the total litter during the study along with the high calcium contents of the twigs (Rani *et al.*, 2016). In the present study, nitrogen, calcium and potassium contents returned about 88% of the total nutrients (Sanderman and Amundson, 2003). N and Ca, however, were the major constituents amongst various nutrients returned through litterfall, accounting for 73% of the nutrient pool.

The needle fall contributed significantly (42%) towards total litterfall in *Taxus contorta* forests of the western Himalaya. The litter decomposition was higher during the summer and rainy seasons than in winter. The time required to reach a 50% level of decomposition was 1.30 years, and 95% decomposition might occur after a lapse of 5.63 years. Significant relationships were observed between climatic variables and leaf litter decomposition. Nutrient concentrations in decomposing needle litter varied significantly. Most of the nitrogen, phosphorus and potassium loss occurred during the rainy season. N, Ca and K contents returned about 88% of the total nutrients, in which the former two contributes 73% of the nutrient pool. Nutrient concentration, their accumulation and transfers in different plant compartments varied significantly. The existence of the significant inverse relationship between per cent weight remaining and N and P concentration in residual material indicated that N and P were not lost from the litter as fast as other nutrients confirming that evergreens had the highest N and P use efficiency.

REFERENCES

Berg, B. (2014) Foliar litter decomposition: a conceptual model with focus on pine (*Pinus*) litter-a genus with global distribution. *International Scholarly Research Notices* 2014.

Berger, T.W. and Berger, P. (2012) Greater accumulation of litter in spruce (*Piceaabies*) compared to beech (*Fagus sylvatica*) stands is not a consequence of the inherent recalcitrance of needles. *Plant and soil* **358**(1): 349-369.

Bot, A. and Benites, J. (2005) The importance of soil organic matter: Key to drought-resistant soil and sustained food production (No. 80). Food & Agriculture Organization of the United Nations,Vialedelle Terme di Caracalla, 00100 Rome, Italy

Canellas, I. and San, A.M. (1998) Litter fall and nutrient turnover in Kermes oak (*Quercus coccifera* L.) shrublands in Valencia (eastern Spain). *Annales des Sciences Forestieres* **55** (5): 589-597.

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.

Ewel, J.J. (1976) Litterfall and leaf decomposition in a tropical forest succession in Eastern Guatemala. *Journal of Ecology* **64**: 293-308.

Giweta, M. (2020) Role of litter production and its decomposition, and factors affecting the processes in a tropical forest ecosystem: a review. *Journal of Ecology and Environment* **44**: 1-9.

Horodecki, P. and Jagodziński, A.M. (2019) Site type effect on litter decomposition rates: A three-year comparison of decomposition process between spoil heap and forest sites. *Forests* **10**(4): 353.

Jenny, H., Gessel, S.P. and Bingham, F.T. (1949) Comparative study of decomposition rates of organic matter in Temperate and Tropical regions. *Soil Science* **68**: 419-432.

Kreyling, J. (2010) Winter climate change: a critical factor for temperate vegetation performance. *Ecology* **91**(7): 1939-1948.

Misra, R. (1968) Ecology workbook. Oxford and IBH Publ. Co. Calcutta, pp. 244.

Olson, J.B. (1963) Energy storage and the balance of producers and decomposers in ecological system. *Ecology* **94**: 322-333.

Paudel, E., Dossa, G.G., de Blécourt, M., Beckschäfer, P., Xu, J. and Harrison, R.D. (2015) Quantifying the factors affecting leaf litter decomposition across a tropical forest disturbance gradient. *Ecosphere* **6**(12): 1-20.

Rani, S., Benbi, D.K., Rajasekaran, A. and Chauhan, S.K. (2016) Litterfall, decomposition and nutrient release patterns of different tree species in TaranTaran district of Punjab, India. *Journal of Applied and Natural Science* **8**(3): 1260-1266.

Sanderman, J. and Amundson, R. (2003) Biogeochemistry of Decomposition and Detrital Processing. In: *Treatise on Geochemistry*, Editor(s): Heinrich D. Holland, Karl K. Turekian, Pergamon, 003: 249-316, https://doi.org/10.1016/B0-08-043751-6/08131-7.

Singh, M.K., Bhardwaj, K.K., Beniwal, R.S. and Kumari, S. (2017) Quantification of litter fall and decomposition rate in shelterbelt and neem block plantation. *Journal of pharmacognosy and phytochemistry* **6**: 2491-2493.

Smith, P., Cotrufo, M.F., Rumpel, C., Paustian, K., Kuikman, P.J., Elliott, J.A. and Scholes, M. C. (2015) Biogeochemical cycles and biodiversity as key drivers of ecosystem services provided by soils. *Soil* **1**(2): 665-685.

Walker, L.R. and Wardle, D.A. (2014) Plant succession as an integrator of contrasting ecological time scales. *Trends in Ecology and Evolution* **29**(9): 504-510.