Turk J Agric For
32 (2008) 547-559

Litter Mass Loss Rates in Deciduous and Coniferous Trees in Artvin, Northeast Turkey: Relationships with Litter Quality, Microclimate, and Soil Characteristics

Temel SARIYILDIZ*, Mehmet KÜÇÜK

Artvin Çoruh University, Forestry Department, 08000 Artvin - TURKEY

Received: 16.01.2008

Abstract: Plant litter decomposition is controlled by both biotic and abiotic factors. It has been widely hypothesized that litter quality and climatic and soil conditions regulate decomposition. The present study examined the decomposition of native forest tree litter on 2 aspects (the north and the south) and at 3 altitudes (top, middle, and bottom) on each aspect in Artvin province to determine the influence of litter quality, microclimate, and soil characteristics on the rate of decomposition. A litter-bag experiment was performed using beech, oak, fir, and pine litter. The litter bags were placed on the north- and south-facing sites and at 3 altitudes on each aspect and were sampled every 6 months for 2 years. The dominant rate-regulating factor on the litter mass loss rates was found to be the lignin concentration of the litter. The litter from oak and pine contained relatively low lignin levels, and these litter types exhibited significantly faster rates of decay than the highly lignified beech and fir litter. The litter placed on the north-facing site decomposed much faster compared to the south-facing site, and the litter placed at the top altitude on each aspect showed the lowest decay rates compared to either the bottom or middle position throughout the study period. The microclimate and soil characteristics also helped to explain the variation in the litter mass losses, but their effects were less and also showed variations according to the aspects. On the north-facing sites, behind the initial lignin concentration, the litter decomposition was limited by actual evapotranspiration (AET), whereas on the south-facing sites the limiting factor on litter decomposition was soil temperature. However, when the 2 aspects were considered together, lignin concentrations and soil respiration rates were found to be better predictors of the mass loss rates in these forest ecosystems.

Key Words: Litter decomposition, litter quality, topography, microclimate, soil factors

Doğu Karadeniz Bölgesi, Artvin Yöresi, Yapraklı ve İğne Yapraklı Ormanlarının Ölü Örtü Kütle Azalma Oranları: Ölü Örtünün Kimyasal Yapısının, Mikroiklim ve Toprak Özelliklerinin Ayrışma ile Olan İlişkisi

Özet: Ölü örtü ayrışması hem biyotik hem de biyotik olmayan faktörler tarafından kontrol edilmektedir. Ölü örtü ayrışması genel olarak, ölü örtünün kimyasal yapısı ve ortamın iklim ve toprak şartları tarafından kontrol edilmektedir. Buradaki çalışmamızda ise, Artvin yöresinde, farklı bakı ve yükseltide yayılış gösteren doğal ormanlık alanlarda yaygın olarak yetişen bazı ağaç türlerinin yaprak ölü örtülerinin ayrışma oranları çalışılarak, ölü örtü ayrışmasında materyalin kimyasal yapısının, ayrışma ortamının mikroiklim şartlarının ve toprak özelliklerinin etkileri ortaya konulmaya çalışılmıştır. Arazi ortamında ölü örtü ayrışma deneyi için kayın, meşe, göknar ve sarıçam türlerinin yaprak ölü örtüleri kullanılmıştır. Arazide ölü örtü ayrışmasını araştırmak için, özel olarak hazırlanan ölü örtü torbaları (litter bags) içerisine konulan yaprak ölü örtü örneklerinin (yaprak yada ibre), iki farklı bakıya (kuzey ve güney) ve her bir bakının üç farklı yükseltisine (üst, orta, ve alt) yerleştirilmesiyle başlamış ve daha sonra her 6 ayda bir arazi örneklemesi yapılarak 2 yıl süreyle takip edilmiştir. Sonuçlar ölü örtü ayrışmasını etkileyen en baskın faktörün, ayrışan materyalin başlangıçta içerdiği lignin değerinin olduğunu göstermiştir. Yaprak ölü örtüsünde daha az lignin içeren meşe ve sarıçam türleri yapısında daha fazla lignin içeren kayın ve göknar türlerine göre daha hızlı ayrışmıştır. Türlerin yaprak ölü örtüleri bakıya gore karşılaştırıldığında en hızlı ayrışma kuzey bakıda, yükseltiye göre karşılaştırıldığında ise en hızlı ayrışma alt yükseltilerde gerçekleşmiştir. Mikroiklim ve toprak özellikleri, bakıya göre farklılık göstermekle birlikte, ayrışma üzerinde etkili olduğu tespit edilmiştir. Kuzey bakıda, gerçek evapotranspirasyon ayrışmayı sınırlarken, güney bakıda toprak sıcaklığının etkili olduğu bulunmuştur. Her iki bakı da dikkate alındığında ise ölü örtü ayrışması üzerinde ayrışan materyalin içerdiği lignin miktarının ve ayrışmanın gerçekleştiği ortamın toprak solunum oranının ölü örtü ayrışma oranları üzerinde belirliyici faktörler olduğu ortaya konulmuştur.

Anahtar Sözcükler: Ölü örtü ayrışması, ölü örtü kimyasal yapısı, topografya, mikroiklim, toprak özellikleri

* Correspondence to: t_sariyildiz@yahoo.com

Introduction

Decomposition rate and nutrient release patterns of plant litter are influenced by environmental conditions (Trofymow et al., 2002; Kurz-Besson et al., 2005, 2006), the nature of the micro-organisms and soil fauna active in the decomposition process (Neely et al., 1991; Cox et al., 2001), and by litter quality (Swift et al., 1979; Heal et al., 1997). During last 3 decades, concerns over the potential effects of increased atmospheric CO_2 concentrations on climatic changes, litter chemical compositions, and plant litter decomposition rates have spurred researchers on the topics (Aerts, 2006), and many studies have been carried out in many ecosystems using a variety of species in order to understand and also formulate the interactions between these 3 main rate regulating factors on litter decomposition (Johansson et al., 1995). Many studies (Aerts, 1997; Bottner et al., 2000; Yanai et al., 2003) have adapted the litter bag approach in situ to determine the effects of climate and litter quality on decomposition rates. Conventionally decomposition rates, measured as mass loss, have been related to a number of physical climatic variables (e.g. soil temperature and soil moisture), but more frequently the property used has been that of actual evapotranspiration (AET) (Murphy et al., 1998; Couteaux et al., 2001, Liski et al., 2003). A broad regional-scale study presented by Berg et al. (1993), who incubated standard *Pinus sylvestris* L. needle litter over 39 experimental sites in Europe with climatic regions spanning from the subarctic to the subtropical and Mediterranean, showed that actual evapotranspiration (AET) explained 50% of the variation in mass loss rates. In small-scale studies, however, structural and elemental components of plant residues have been recognized as an important predictor of their potential decomposition rates (McClaugherty and Berg, 1987; Fioretto et al., 1998). Most of these studies have shown that if the lignin concentrations are over about 20%, the processes of litter decomposition are mainly dominated and governed by initial lignin concentration (Aber et al., 1990; Sariyildiz and Anderson 2003a,b).

In most small-scale studies, however, the environmental conditions in which litter decomposition experiments took place were generally considered similar. A number of studies have shown that even at small-scale areas, topographical landforms (aspects and altitudes) can create different environmental conditions that alter local microclimate and soil characteristics (Barnes et al., 1998), and in turn these changes can retard or accelerate litter decomposition rates through negative or positive effects on the activity of organisms. Very few studies have investigated the effects of the changes by topographical landforms on decomposition rates of a given species (Mudrick et al., 1994; Vitousek et al., 1994; Scowcroft et al., 2000). We have recently investigated and shown for beech (*Fagus orientalis* Lipsky.), oak (*Quercus robur* L.), fir (*Abies nordmanniana* Spach.) and pine (*Pinus sylvestris* L.) tree species growing in Artvin province that aspects and altitudes that varied significantly in soil chemical characteristics can result in significant intra- and inter-specific variation in litter quality variables of the tree species, and these variations in turn affect their decomposition rates (Sariyildiz et al., 2005a). The results of the previous study have illustrated an important point that, in this mountainous region, litter quality of a given species can define the potential rates of microbial decomposition, but the effects of biotic and abiotic environmental factors on microbial decomposition rates in the region were not investigated in that study. Therefore, we carried out the present study to investigate and formulate the effects of litter quality and microclimate and soil characteristics on the litter decay rates of the same 3 species. In order to achieve our objectives, we used beech, fir, oak, and pine litter originated from the bottom altitude on the north aspect. The litter for each tree species was placed on 2 aspects (north- and south-facing) and on 3 slopes (top, middle, and bottom) on each aspect. The litter was sampled every 6 months for 2 years. The site differences in microclimate, soil respiration rates, and soil physical and chemical properties were extensively analyzed. At the end of the study, the local relationships between the litter decomposition rates and (i) climate, (ii) soil physical and chemical properties, and (iii) initial litter quality variables were evaluated and formulated using all litter decomposition results.

Materials and Methods

Study areas

This study was carried out in Artvin province, north-east Turkey, (41° 51' N, 41° 06' E). The foliar litter of beech, oak, fir and pine trees was collected from the study area, located 8 km southwest of Artvin city. In the area, 3 altitudes were selected at the top (1300 m), middle (1000 m), and bottom (700 m) on north and south aspects. The north- and south-facing sites were commonly forested by *Picea orientalis*, *Fagus orientalis*, *Abies nordmanniana* ssp. *nordmanniana*, *Pinus silvestris*, *Castanae sativa,* and *Quercus* spp. either pure or in species mixture.

The parent rock of the study area was mostly granite covered with a sandy loam, shallow soil and an organic layer of humus form mor under spruce, mor-like moder under beech and fir, mull-like moder under oak and pine, and mull under chestnut (Sariyildiz 2003; Sariyildiz et al., 2005b). The soil profiles showed distinct A and C horizons; the mineral B-horizon was almost absent.

The data for meteorological variables were taken from Artvin Meteorology Station located on the north aspect and was in the vicinity of the study catchments (1980-2005 meteorological data at 597 m) (Meteorology Office, 2005). Two automatic mobile meteorology stations (Davis Instrument 6161C Cabled Vantage Pro 2 with standard radiation shield) were also used to monitor different meteorological variables between the north and south aspect. Climate is generally characterized by cold winters and semi-arid summers. Mean annual precipitation in lower elevations was 719 mm, with the highest amounts in January (110.9 mm), and the lowest amount in August (29.5 mm). Average monthly temperature ranges from 20.5 °C in June to 2.4 °C in January. The climate data were used to calculate the water balance variables on 2 aspects and at 3 slopes on each aspect based on the procedures of Thornthwaite and Matter (1957) (Table 1).

Sample collection, preparation and analyses

Foliar litter of beech, oak, fir and pine was sampled in September 2003 from the bottom slope on the north-facing aspect. The selected beech, fir, and pine trees were approximately 90-100 years old and 25-30 m high, and oak trees were 70-80 years old and 15-20 m high. Freshly fallen foliar litter was collected from 5 trees and bulked to form a representative sample for each tree species. Material showed no signs of discoloration or of obvious mycelial development at this stage. The litter samples were air-dried in the laboratory and then oven-dried at 40 °C for 48 h. The oven-dried foliar litter was slightly crushed by hand, and the largest fragments of petiole in leaf samples were removed. All samples were then stored in plastic bags at 6 °C until required for chemical analyses.

Soil samples were also collected in September 2003 under the 4 tree species growing on the north- and south-facing and on 3 slope positions on each aspect. The soil samples were collected in an area of 0.5   0.5 m^2 at a distance of 2 m from the base of the trunk. The soil samples were taken at the depth of 20 cm. The moist field samples were air-dried and then sieved (<2 mm) to remove stones, roots, and macrofauna, and bulked to give a single representative soil sample for each slope on each aspect.

Soil dry mass, pH (H_2O), CEC (cation exchange capacity), percent BS (base saturation), soil texture (sand, silt, and clay), organic matter, field capacity, wilting point, and plant available water were determined using the methods as described by Anderson and Ingram (1993) and Allen (1989) (Table 1). All analyses were carried out in triplicate.

The stored leaf and needle litter was oven-dried at 85 °C, and then ground in a laboratory mill to a mesh fraction less than 1 mm. The ground litter was then analyzed for organic carbon, total nitrogen, ADF (acid detergent fiber), lignin, and cellulose. Organic C was determined by oxidation method (Nelson and Sommers 1982). Total N was determined by Kjeldahl digestion (Allen 1989) followed by analysis of ammonium through the indophenol method using an auto-analyzer (Bemas; Burkhard, Uxbridge, UK). Acid detergent fiber (ADF), a-cellulose, and lignin were determined using the ADF-sulphuric lignin method of Rowland and Roberts (1994). Organic analyses were carried out in triplicate.

Field incubations

The bags were 20 cm   20 cm with a mesh size of 1.5 mm to allow for inclusion of mesofauna but exclusion of macrofaunal decomposers. About 3 g of air-dried material was placed in each bag (Swift et al., 1979; Heal et al., 1997). Samples were also taken to determine a correction factor to calculate the initial oven dry mass of the material at 85 °C.

The number of litter-bags used during the 2-year experiment was 288 (4 species   2 aspects (north-and south-facing slopes)   3 altitudes (top, middle, and bottom)   4 removal dates   3 replicates = 288 bags). The litter-bags with foliar litter of 1 of the 4 tree species were numbered and fixed to the ground of the corresponding sites (north- *vs* south-facing, 3 altitudes, each) with metal pegs. Three litter-bags of each litter species were harvested from each site at 6-month intervals of decomposition for 2 years to follow the continuum of

Table 1: Location and calculated microclimate and soil characteristics of the north- and south-facing sites and the 3 altitudes on each aspect.

		Microclimate factors							Soil characteristics											
Aspect	Altitude	Elevation (m)	AVGT (°C)	PRECIP (mm)	PET (mm)	AET (mm)	DEF (mm)	SUR (mm)	pH (H_2O)	CEC (meq 100 g^{-1})	BS (%)	Sand (%)	Silt (%)	Clay (%)	OM (%)	FC (%)	WP (%)	PAW (%)	Soil Tem. (°C)	Soil Respiration $gCm^{-2}d^{-1}$
	Top	1300	8.12	1071	595	484	62	538	5.7	17	54	63	23	14	12.5	35.9	26.1	9.75	13.9	1.203
North	Middle	1000	10.4	921	659	514	146	408	5.9	19	57	83	6	11	8.27	22.6	14.1	8.45	14.2	1.352
	Bottom	700	12.6	771	734	533	250	288	6.2	21	60	70	10	20	4.37	20.8	18	2.80	15.9	1.588
	Top	1300	12.8	1071	697	489	110	484	5.2	14	46	70	13	17	10.5	24.7	17.3	9.59	13.0	0.961
South	Middle	1000	14.3	921	754	544	210	377	5.4	16	50	68	13	19	6.68	25.3	16.5	8.80	13.7	1.152
	Bottom	700	15.8	771	815	587	319	273	5.6	18	54	78	8	14	6.71	20.1	19.0	1.08	14.6	1.372

CEC: Cation exchange capacity, BS: Base status, OM: Organic matter, FC: Field capacity, WP: Wilting point, PAW: Plant available water, AVGT: Average annual temperature, PRECIP: Annual precipitation, PET: Potential evapotranspiration, AET: Actual evapotranspiration, SUR: Soil moisture surplus, DEF: Soil moisture deficit.

litter decay over time. Percentage loss of initial mass was calculated after drying the samples at 85 °C. Soil respiration rates were also determined in the same sites in which the litter decomposition experiments were carried out using the soda-lime method (Edwards 1982; Raich et al. 1990). At the same time, soil temperature was also measured at 5 cm soil depth in the morning.

Data analysis

The percentage of dry mass remaining in the litter bags (%RM) was calculated from the weight of litter (Wt) at each sampling period (t), and the initial mass (Wo) using the formula: %RM = (Wt/Wo) 100. Decomposition constant rate (k) was calculated from the percentage of dry mass remaining using an exponential decay model (Olson 1963): $W_t/W_o = e^{-kt}$, where W_t/W_o is the fraction of initial mass remaining at time t, and t is the elapsed time (year) and k is the decomposition constant (year^{-1}). As suggested by Olson (1963), the time required for 95% mass loss was calculated as $T_{95} = 3/k$. The coefficients of determinant (r^2) which indicate the goodness of fit of the data to the model was determined using MS EXCEL 2003 and SPSS. Simple Pearson correlation coefficients were calculated between decay constant rates (k) and litter quality variables, soil factors, and climate factors using the SPSS program (Version 11.5 for Windows). The correlation analysis was first performed for each aspect and then for the 2 aspects together. Stepwise multiple linear regression analysis was also performed to determine how much of the total variability in mass loss rates can be explained by microclimate, litter quality, and soil characteristics together.

Results

Differences in microclimate and soil characteristics between aspects and slopes

The calculated microclimate factors of the studied sites are given in Table 1. The 2 aspects and the 3 altitudes on each aspect showed variations in calculated microclimatic factors. For example, the calculated average annual temperature (AVGT), potential evapotranspiration (PET), and actual evapotranspiration (AET) values were higher on the south-facing sites compared to the north-facing sites, and they all showed an increase from top to the bottom (Table 1). Annual precipitation (PRECIP), however, was considered the same on each aspect and altitude.

Mean soil characteristics also showed differences according to aspects and altitudes (Table 1). For example, mean cation exchange capacity (CEC) and base status (BS) showed an increase from the top slope to the bottom altitude, whereas organic matter, field capacity, wilting point, and plant available water showed a decrease (Table 1). Soil respiration rates also showed a decrease with increasing altitude, but showed higher values on the north-facing sites compared the south-facing sites (Table 1). It was noted that soil respiration rates had a good correlation with soil temperature values on each aspect (Figure 1).

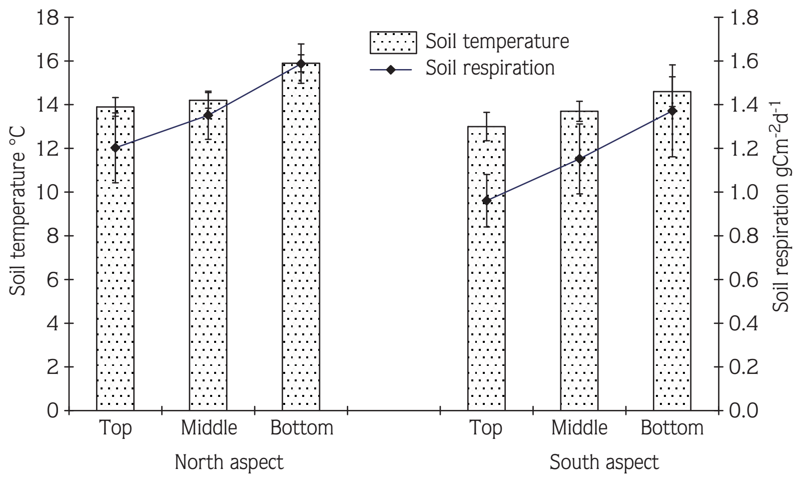

Figure 1. Relationships between soil temperature and soil respiration rates from the north- and south-facing sites and at the 3 altitudes on each site. Vertical bars represent the standard error of the mean.

Variation in litter chemistry

Total carbon concentration was 47%, 48%, 46%, and 47% for beech, fir, oak, and pine litter, respectively. Beech and oak litter showed higher nitrogen (1.4%) than fir and pine litter (1.3%). Carbon : N ratio in pine and fir was also higher (36.2 : 1 and 36.9 : 1, respectively) compared to beech and oak litter (33.6 : 1 and 32.9 : 1, respectively). Beech and fir had higher ADF (68% and 61%, respectively) and lignin (41% and 32%, respectively) than pine and oak (51% and 48% for ADF and 28% and 25% for lignin, respectively). Cellulose concentration was 27%, 28%, 22%, and 23% for beech, fir, oak, and pine litter, respectively. Oak and pine showed lower lignin : N ratio (17.9 : 1 and 21.5 : 1, respectively) than beech and fir litter (29.2 : 1 and 24.6 : 1, respectively).

Decomposition among species, aspects, and altitudes

Of the 4 tree species, oak showed the highest decay constant rate, followed by pine, fir, and beech litter at each sampling interval (Table 2). The general trend showed that all tree litter decomposed much faster on north-facing site compared to south-facing site (Figure 2). Much mass loss occurred in beech, fir, pine, and oak litter in the first year when 27.5%, 33.6%, 35.4%, and 43.3% of their original dry masses respectively were lost on the north-facing site, and on the south-facing sites were 21.6%, 28.9%, 31.4%, and 38.0% for beech, fir, pine, and oak, respectively. During the same period, mass losses on the bottom slope were highest, intermediate on the middle slope, and lowest on the top altitude on each aspect (Figure 3). For the first year decomposition, the

Table 2. Annual decay rates, k (n = 3), for the standard beech, fir, pine, and oak litter on the top, middle, and bottom altitudes for the north- and south-facing sites calculated from a single negative exponential model, and measured (n = 3) percent mass remaining at the end of the study (2 years). Values are means ± SE. Coefficients of determinant (r^2) are presented to indicate goodness of fit of the data to the model.

Aspect	Slope Position	Litter Type	k ± se	r^2	% Mass remaining ± se	T_{95} (y)
North	Top	Beech	-.286 ± 0.005	0.977	56.4 ± 0.51	10.5
		Fir	-.369 ± 0.006	0.959	47.8 ± 0.60	8.1
		Pine	-.385 ± 0.005	0.939	46.3 ± 0.51	7.8
		Oak	-.482 ± 0.011	0.939	38.2 ± 0.88	6.2
	Middle	Beech	-.300 ± 0.002	0.944	54.8 ± 0.17	10.0
		Fir	-.393 ± 0.007	0.952	45.6 ± 0.69	7.6
		Pine	-.436 ± 0.008	0.932	41.8 ± 0.67	6.9
		Oak	-.535 ± 0.006	0.927	34.3 ± 0.44	5.6
	Bottom	Beech	-.313 ± 0.008	0.932	53.4 ± 0.84	9.6
		Fir	-.420 ± 0.012	0.941	43.2 ± 1.07	7.1
		Pine	-.472 ± 0.010	0.914	38.9 ± 0.75	6.4
		Oak	-.574 ± 0.015	0.922	31.7 ± 0.95	5.2
South	Top	Beech	-.252 ± 0.004	0.979	60.4 ± 0.59	11.9
		Fir	-.314 ± 0.008	0.981	53.8 ± 0.86	9.6
		Pine	-.362 ± 0.008	0.971	48.5 ± 0.82	8.3
		Oak	-.429 ± 0.008	0.962	42.4 ± 0.69	7.0
	Middle	Beech	-.268 ± 0.010	0.979	58.5 ± 1.17	11.2
		Fir	-.335 ± 0.009	0.980	51.1 ± 0.87	9.0
		Pine	-.375 ± 0.008	0.955	47.3 ± 0.79	8.0
		Oak	-.439 ± 0.004	0.943	41.6 ± 0.32	6.8
	Bottom	Beech	-.295 ± 0.005	0.968	55.4 ± 0.53	10.2
		Fir	-.387 ± 0.010	0.958	46.1 ± 0.95	7.6
		Pine	-.406 ± 0.006	0.926	44.4 ± 0.52	7.4
		Oak	-.508 ± 0.013	0.929	36.2 ± 0.98	5.9

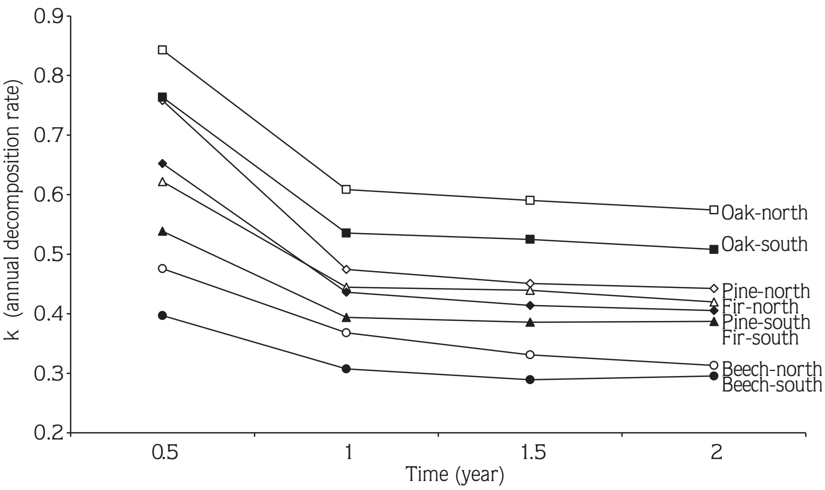

Figure 2. The differences in decay constant rates (k) of beech, fir, pine, and oak litter between the north- and south-facing sites are illustrated for the bottom altitude.

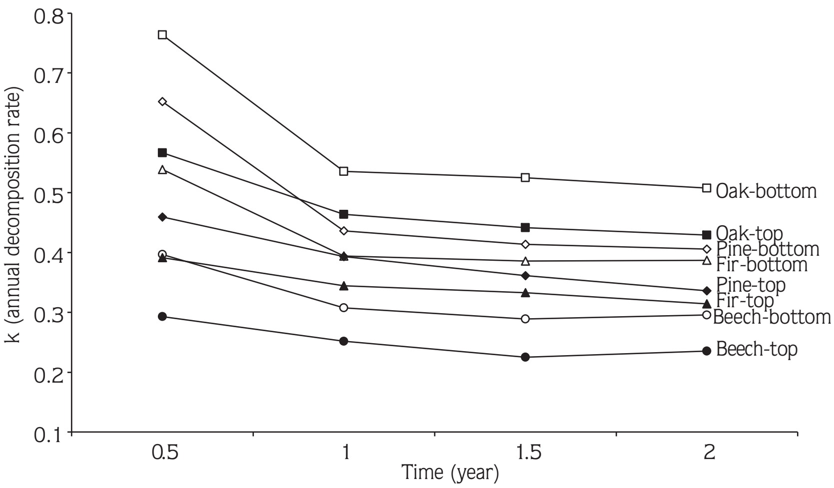

Figure 3. The differences in decay constant rates (k) of beech, fir, pine, and oak litter between the altitudes are illustrated between the bottom and top altitude on the south- facing site.

differences in litter mass losses between the top and bottom altitude on the north-facing site were 7.4% for beech, 5.6% for fir, 4.9% for pine, and 5.8% for oak, and on the south-facing site it was 9.3% for beech, 6.3% for fir, 4.8% for pine, and 6.1% for oak. At the end of the second year, mean mass losses recorded on the north-facing site for beech, fir, pine, and oak were still higher (45.1%, 54.5%, 57.7%, and 65.3%, respectively) compared to the south-facing site (41.9%, 49.8%, 53.4%, and 59.9%, respectively). Final mass losses for the altitudes were remained in the altitude order as bottom > middle > top for all species. The differences in litter mass losses between the top and bottom slope on the north-facing site were 3.0% for beech, 4.6% for fir, 7.4% for pine, and 6.5% for oak, and on the south-facing site they were 5.0%, 7.3%, 4.1%, and 6.2%, respectively.

The results showed that aspect and altitude had a significant effect on litter decomposition parameter for the overall 2-year period. For example, at the end of the second year, percent mass remaining in beech litter on the north aspect was 56.4% for the top slope, 54.8% for the middle slope, and 53.4% for the bottom slope, whereas on the south aspect it was 60.4% for the top slope, 58.5% for the middle slope, and 55.4% for the bottom slope (Table 2).

Effects of microclimate, soil characteristics, and litter quality on litter mass loss

A correlation matrix was created for each aspect and then the 2 aspects together using the data from all sites in order to determine the degree of relationship between the litter mass losses and the microclimatic, litter quality, and soil characteristics. On the north-facing site, among the litter quality variables, initial lignin gave the best correlation value with the coefficient (r) of -0.929 and, ADF and lignin : N ratio also gave a good fit with the values for r of -0.915 and -0.867, respectively (P < 0.001) (Table 3). Among the climate variables, AVGT, PET, AET, PRECIP, SUR, and DEF showed lower but significant relationship with the litter mass loss rates (Table 3).

The correlation matrix created for the south-facing site (Table 3) also showed that initial lignin had the best correlation value with the coefficient of -0.911 and, ADF and lignin : N ratio had the second good fit with values for r of -0.899 and -0.855, respectively (P < 0.001), which

Table 3. Pearson correlation coefficients for the relationships between litter mass losses on the north-, south- and north/south-facing sites and initial litter quality, microclimatic and soil parameters.

Parameters / Sites	Litter mass loss		
	North aspect	South aspect	North and South aspect together
Litter quality			
Lignin	-.929***	-.911***	-.881***
ADF	-.915***	-.899***	-.866***
Lignin : N	-.867***	-.855***	-.824***
N	-.059	-.043	-.049
C : N	-.118	-.124	-.116
Microclimate			
AVGT	.288*	.329*	ns
PRECIP	-.287*	-.329*	-.294*
PET	.286*	.332*	ns
AET	.388*	.327*	ns
DEF	.285*	.331*	ns
SUR	-.288*	-.329*	-.238*
Soil characteristics			
Soil respiration	.282*	.432*	.504**
Soil temperature	ns	.335*	.383*
CEC	.287*	.329*	.210*
BS	.287*	.329*	.316*
OM	-.288*	ns	-.386*
SAND	ns	,305*	.328*
SILT	ns	-.328*	-.290*
FC	ns	-.317*	ns
WP	ns	.283*	-.326*
PAW	-.262*	-.334*	-.310*

Note: Abbreviations are explained in Table 1.
Asterisks refer the level of significance; *, P < 0.05; **, P < 0.01; ***, P < 0.001.
ns for not significant

were lower compared to the north-facing site. The correlation coefficients between the litter mass losses and the climate and soil factors on the south-facing site were higher compared to the north-facing site (Table 3). This result meant that, on the south-facing site, the soil and climatic variables are more efficient on the litter mass loss rates compared to the north-facing site.

The correlation matrix created for the 2 aspects together using the data from the 3 altitudes on the north and south aspect (Table 3) also showed the usefulness of the initial lignin concentration to explain the variation in the litter mass loss rates with a value for correlation coefficient (r) of -0.881. ADF and lignin : N ratio gave a good fit with values for r of -0.866 and -0.824, respectively ($P < 0.001$). Main differences noted using all the data together was that only 2 microclimatic variables showed a good correlation with the mass losses, PRECIP, and SUR ($r = -0.294$ and -0.238, $P < 0.05$, respectively). However, behind the litter quality variables, the soil characteristics, especially soil respiration ($r = 0.504$, $P < 0.01$), were better predictors than the microclimatic variables (Table 3).

A stepwise multiple linear analysis performed for the north-facing site showed that combining the litter quality variable (lignin) and the climate factor (AET) increased the value for R^2_{adj} from 0.860 to 0.994 (Table 4). The use of the 3 factors (lignin, AET and, lignin : N ratio) increased the R^2_{adj} value to 0.981. The model for initial lignin and AET and lignin: N ratio is:

Mass loss (%) = 42.67 – 0.840 (initial lignin %) + 0.108 (AET mm) – 0.530 (Lignin : N ratio) (R^2_{adj} = 0.981, $P < 0.001$).

For the south-facing site, however, combining the litter quality variable (lignin) and the soil factor (soil temperature) increased the value for R^2_{adj} from 0.825 to 0.939 (Table 4). The use of the 3 factors (lignin, soil temperature, and lignin : N ratio) increased the R^2_{adj} value to 0.979. The model for initial lignin and soil temperature and lignin: N ratio is:

Mass loss (%) = 40.11 – 0.738 (initial lignin %) + 3.562 (Soil temperature ^oC) – 0.501 (Lignin: N ratio) (R^2_{adj} = 0.979, $P < 0.001$).

For the 2 aspects, this time, the litter quality variable (lignin) and the soil factor (soil respiration) increased the value for R^2_{adj} from 0.873 to 0.937 (Table 4). The use of the 3 factors (lignin, soil respiration, and lignin: N ratio) increased the R^2_{adj} value to 0.972. The model for initial lignin and soil respiration, and lignin : N ratio is:

Mass loss (%) = 73.47 – 0.789 (initial lignin %) + 15.66 (Soil respiration) – 0.515 (Lignin: N ratio) (R^2_{adj} = 0.972, $P < 0.001$).

Discussion

Present study has intended to determine the role of the microclimate, soil characteristic, and litter quality variables on the litter mass loss rates of beech, fir, oak, and pine tree species growing within a small region at which the topographical landforms (aspects and altitudes) can significantly alter its microclimate and soil characteristics. Interpretation of the litter quality and microclimate and soil characteristics effects is precluded by the lack of site replicates. However, variations in the decomposition rates of beech, oak, fir, and pine litter exposed to north and south aspect and at 3 altitudes on each aspect illustrate the importance of initial litter quality and site quality effects on decomposition processes. Linear regression of the litter mass losses showed that the dominant rate-regulating factor for the litter mass loss rates was the initial lignin concentration of the litter. This result is in agreement with the findings of Aber et al. (1990), Berg et al. (1993), and Berg and Meentemeyer (2002) who stated that, within a small region, litter quality is the best predictor of the litter mass loss rates. The microclimate and soil characteristics also helped to explain the variation in the litter mass losses, but they hardly affect the litter decomposition and also showed variations according to the aspects.

On the north-facing site, the combination of the litter quality variable (lignin concentration and lignin : N ratios) and the microclimate factor (AET) helped to explain about 99% of the sites' variability on the litter mass losses, and was sufficiently significant to be used in a model in this type of forest ecosystem within a small region. Nitrogen concentration has been shown in many studies as the most important factor limiting litter decomposition since it determines the growth and turnover of the microbial biomass mineralizing the organic carbon. Therefore, the C:N ratio remains an important feature of the formulae for litter from annual crops and from woody plants containing less than 10%-15% lignin because most of C and N they contain are in compounds susceptible to microbial attack (McClaugherty and Berg 1987; Heal et

Table 4. A stepwise multiple linear regression between litter mass losses, and litter quality variables, microclimate and soil factors for all 4 tree species decomposed on the north- and south-facing site and at 3 altitudes on each aspect .

	Stepwise multiple linear regression					
	r	r^2	r^2_{adj}	F	P	n
North aspect						
Lignin	0.929	0.864	0.860	215.8	<0.001	36
Lignin and AET	0.973	0.947	0.994	293.9	<0.001	36
Lignin and AET and Lignin: N	0.991	0.983	0.981	610.9	<0.001	36
Mass loss (%) =37.73 – 1.176 (initial lignin %) + 0.108 (AET mm)						
Mass loss (%) =42.67 – 0.840 (initial lignin %) + 0.108 (AET mm) – 0.530 (Lignin: N ratio)						
South aspect						
Lignin	0.911	0.830	0.825	166.3	<0.001	36
Lignin and soil temperature	0.971	0.942	0.939	269.0	<0.001	36
Lignin and Soil temperature and Lignin: N	0.990	0.981	0.979	538.9	<0.001	36
Mass loss (%) = 35.43 – 1.055 (initial lignin %) + 3.562 (Soil temperature °C)						
Mass loss (%) = 40.11 – 0.738 (initial lignin %) + 3.562 (Soil temperature °C) – 0.501 (Lignin: N ratio)						
North and South aspect combined						
Lignin	0.881	0.776	0.873	242.2	<0.001	72
Lignin and soil respiration	0.969	0.939	0.937	530.8	<0.001	72
Lignin and soil respiration and Lignin: N	0.986	0.973	0.972	815.2	<0.001	72
Mass loss (%) = 68.65 – 1.115 (initial lignin %) + 15.66 (soil respiration)						
Mass loss (%) = 73.47 – 0.789 (initial lignin %) + 15.66 (soil respiration) – 0.515 (Lignin: N ratio)						

al., 1997). In this present study, lignin concentration increased from 25% in oak, 28% pine, 32% fir, and 41% beech; it dominated decomposition rates irrespective of other constituents. This result indicates for the north-facing site that under similar AET values the lower the initial lignin concentration the higher the litter decay rates, but with the same initial lignin concentration the litter decay rates show an increase with increasing AET as shown by many researchers (Couteaux et al., 1995; Aerts 1997, Bottner et al., 2000). For the south-facing site, however, the combination of the litter quality variables (lignin concentration and lignin : N ratios) and the soil temperature together explained about 98% of the sites' variability on the mass loss rates. Under similar soil temperature values, the lower initial lignin concentration the higher the litter decay rates, but with the same initial lignin concentration, the litter decay rates show an increase with increasing soil temperature. When all the data from the 2 aspects were used, the results showed the initial lignin concentration, lignin : N ratios, and soil respiration rates together explained about 97% of variability on litter mass loss.

It was surprising to see that the single microclimate and soil characteristics studied here showed lower relationships with the litter mass loss rates. The less effect of microclimate and soil characteristics on the litter decay rates could be attributed the quality of the litter. Fierer et al. (2005) have stated for example that the temperature sensitivity of litter decomposition is dependent on the quality of the carbon compounds, especially lignin, in litter; litter higher in C-based secondary compounds (i.e. low litter quality) is more sensitive to temperature change than litter with high-quality C compounds. A field study of litter decomposition along elevational gradients in the Hawaiian Islands by Vitousek et al. (1994) indicated that the rate of litter decomposition increased 4 to 11-fold for a 10 °C increase in air temperature, but they also stated that this increase in litter decomposition rate with increasing air temperature strongly depended on the site and quality of the litter. In this present study, C-based secondary compounds, for example ADF concentrations (mostly lignin + cellulose), increased from 48% in oak litter to 68% in beech litter, and thus it could be reasonable to say that, because of the higher C-based secondary compounds found in the litter, especially high lignin concentrations, the litter quality dominated the litter mass loss rates, regardless of the microclimate or soil conditions.

Soil respiration rates determined as a sign of the activity of decomposer organisms here appeared to be a good indicator of the litter mass loss rates (Neely et al., 1991, Prescott, 1996, Walse et al., 1998). Initially we expected that the litter placed on the south-facing sites (with higher air temperature) would decay faster than the same litter on the south-facing sites (with lower air temperature). The differences in air temperature between the north and south facing sites were 4.7 °C for the top, 3.9 °C for the middle, and 3.2 °C for the bottom altitude. However, the results showed that the litter on the north-facing sites decayed much faster. Soil temperature values showed a trend contrary to the air temperature with lower values on the south-facing sites compared to the north-facing sites (Table 1). It could the main reason that higher soil temperature values accelerated the activity of the microorganisms via increasing the soil respiration rates, and thus enhanced the decay rates of litter on the north-facing sites. A good relationship between soil respiration rates and soil temperature values supported this explanation (Figure 1). When all the data were considered for the statistical analysis, soil respiration rates also gave a good correlation with the litter mass loss rates, following the initial lignin concentration (Table 4). Therefore, soil respiration rates could be used as a predictor of litter mass loss rates in such an environment for future studies.

In conclusion, this study has shown that the litter quality and microclimate and soil characteristics created by the topographical landforms on the litter mass loss rates are important factors regulating litter decomposition rates in these types of forest ecosystems. However, the importance of one factor over the others depends on factors such as the litter quality of the decaying material and site quality of the location in which the litter decomposition takes place. Several attempts have been made to produce simple, general models of litter mass loss with dual effects of the abiotic and litter quality variables. Of the several regression models generated, r^2 values rarely exceeded 0.80 (Upadhyay et al., 1989; Johansson et al., 1995). However, in the present study, using litter quality variables and microclimate or soil factors, r^2 values reached over 0.97. To our knowledge, these relationships between the litter mass loss rates and the litter quality, microclimate and soil conditions are the first one ever reported within a small-scale site, and even the highest ones compared to the broad-scale studies.

Acknowledgements

The authors would like to thank Artvin Forestry Commission for permission to collect plant litter and soil samples, and to carry out the litter decomposition experiment at Kafkasör area in Artvin. We are also grateful for the helpful comments from 3 reviewers and the Editor in the revision of this paper.

References

Aber, J.D., J.M. Melillo and C.A. McClaugherty. 1990. Predicting long term pattern of mass loss, nitrogen dynamics and soil organic matter formation from fine litter chemistry in temperate forest ecosystems. Can. J. Bot. 68: 2201-2269

Aerts, R. 1997. Climate, leaf litter chemistry and leaf litter decomposition in terrestrial ecosystems: a triangular relationship. Oikos. 79: 439-449.

Aerts, R. 2006. The freezer defrosting: Global warming and litter decomposition rates in cold biomes. J. Ecol. 94: 713-724.

Allen, S.E. 1989. Chemical Analysis of Ecological Materials. Blackwell Scientific Publications, Oxford.

Anderson, J.M. and J.S.I. Ingram. 1993. Tropical Soil Biology and Fertility. A Handbook for Methods. CAB International, Oxon.

Barnes, B.V., D.R. Zak., S.R. Denton and S.H Spurr. 1998. Forest Ecology. 4th edition. John Wiley and Sons, New York.

Berg, B., M. Berg, P. Bottner, E. Box, A. Breymeyer, de Anta R. Calvo, M.M. Coûteaux, A. Gallardo, A. Escudero, W. Kartz, M. Madeira, E. Mälkönen, C. McClaugherty, V. Meentemeyer, F. Mu oz, P. Piussi, J. Remacle and de Santo A. Virzo. 1993. Litter mass loss rates in pine forests of Europe and Eastern United States: some relationships with climate and litter quality. Biogeochemistry. 20: 127-159.

Berg, B. and V. Meentemeyer. 2002. Litter quality in European transect versus carbon storage potential. Plant Soil. 242: 83-92.

Bottner, P., M.M. Couteaux, J.M. Aderson, B. Berg, G. Billes, T. Bolger, H. Casabianca, J. Romanya and P. Rovira. 2000. Decomposition of ^{13}C labelled plant material in a European 60°-40° latitudinal transect of coniferous forest soils: simulation of climate change by translocation of soils. Soil Biol. Biochem. 32:527-543

Couteaux, M.M., P. Bottner and B. Berg. 1995. Litter decomposition, climate and litter quality. Trends in Ecol. Evol. 10: 63-66.

Couteaux, M.M., P. Bottner, J.M. Anderson, B. Berg, T. Bolger, P. Casals, J. Romanya, J.M. Thiery and V.R. Vallejo. 2001. Decomposition of ^{13}C labelled standard plant material in a latitudinal transect of European coniferous forests: differential impact of climate on the decomposition of soil organic matter compartments. Biogeochemistry. 54: 147-170.

Cox, P., S.P. Wilkinson and J.M. Anderson. 2001. Effects of fungal inocula on the decomposition of lignin and structural polysaccharides in *Pinus sylvestris* litter. Biol. Fertil. Soils. 33: 246-251.

Edwards, N.T. 1982. The use of soda-lime for measuring respiration rates in terrestrial systems. Pedobiologia. 23: 321-330.

Fierer, N., J.M. Craine, K. McLauchlan and J.P. Schimel. 2005. Litter quality and the temperature sensitivity of decomposition. Ecology. 86: 320-326.

Fioretto, A., A. Musacchio, G. Andolfi, A. Virzo De Santo. 1998. Decomposition dynamics of litters of various pine species in a Corsican pine forest. Soil Biol. Biochem. 30: 721–727.

Heal, O.W., J.M. Anderson and M.J. Swift. 1997. Plant litter quality and decomposition: An historical overview. In Driven by Nature: Plant Litter Quality and Decomposition, Cadisch G, Giller K E (eds), CAB International Wallingford, UK, pp. 3-45.

Johansson, M.B., B. Berg and V. Meentemeyer. 1995. Litter mass-loss rates in late stages of decomposition in a climatic transect of pine forests. Long-term decomposition in a Scots pine forest. IX. Can. J. Botany. 73: 1509-1521.

Kurz-Besson, C., M.M. Couteaux, J.M. Thiery, B. Berg and J. Remacle. 2005. A comparison of litterbag and direct observation methods of Scots pine needle decomposition measurement. Soil Biol. Biochem. 37: 2315-2318.

Kurz-Besson, C., M.M. Couteaux, B. Berg., J. Remacle, C. Ribeiro, J. Romanya and J.M. Thiery. 2006. A climate response function explaining most of the variation of the forest floor needle mass and the needle decomposition in pine forest across Europe. Plant Soil. 285: 97-114.

Liski, J., A. Nissinen, M. Erhard and O. Taskinen. 2003. Climatic effects on litter decomposition from artic tundra to tropical rainforest. Global Change Biol. 9: 575-584.

McClaugherty, C. and B. Berg. 1987. Cellulose, lignin and nitrogen concentrations as rate regulating factors in late stages of forest litter decomposition. Pedobiologia. 30: 101-112.

Meteorology Office. 2005. DMİ Artvin Meteorology Station, Artvin.

Mudrick, D.A., M. Hoosein, R.R. Hicks and E.C. Townsend. 1994. Decomposition of leaf litter in an Appalachian forest: effects of leaf species, aspect, slope position and time. For. Ecol. Man. 68: 231-250.

Murphy, K.L., J.M. Klopatek and C.C. Klopatek. 1998. The effects of litter quality and climate on decomposition along an elevational gradient. Ecol. Appl. 8: 1061-1071.

Neely, C.L., M.H. Beare, W. Hargrove and D.C. Coleman. 1991. Relationships between fungal and bacterial substrate-induced respiration, biomass and plant residue decomposition. Soil Biol. Biochem. 23: 947-954.

Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon and organic matter. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis. Am Soc Agr Madison, Wisconsin.

Olson, J.S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. Ecology. 44: 322-331.

Prescott, C.E. 1996. Influence of forest floor type on rates of litter decomposition in microcosms. Soil Biol. Biochem. 28: 1319-1325.

Raich, J.W., R.D. Bowden and P.A. Steudler. 1990. Comparison of two static chamber techniques for determining carbon dioxide efflux from forest soils. Soil Sci. Soc. Am. J. 54: 1754-1757.

Rowland, A.P. and J.D. Roberts. 1994. Lignin and cellulose fractionation in decomposition studies using Acid-Detergent Fibre methods. Com. Soil. Sci. Plant. Anal. 25: 269-277.

Sariyildiz, T. 2003. Litter decomposition of *Picea orientalis, Pinus sylvestris* and *Castanea sativa* trees grown in Artvin in relation to their initial litter quality variables. Turk. J. Agr. For. 27: 237-243.

Sariyildiz, T. and J.M. Anderson. 2003a. Decomposition of sun and shade leaves from three deciduous tree species, as affected by their chemical composition. Biol. Fer. Soils. 37: 137-146.

Sariyildiz, T. and J.M. Anderson. 2003b. Interactions between litter quality, decomposition and soil fertility: a laboratory study. Soil Biol. Biochem. 35: 391-399.

Sariyildiz, T., J.M. Anderson and M. Kucuk. 2005a. Effects of tree species and topography on soil chemistry, litter quality and decomposition in Northeast Turkey. Soil Biol. Biochem. 37: 1695-1706.

Sariyildiz, T., A. Tufekcioglu and M. Kucuk. 2005b. Comparison of decomposition rates of beech (*Fagus orientalis* Lipsky) and spruce (*Picea orientalis* (L.) Link) litter in pure and mixed stands of both species in Artvin, Turkey. Turk. J. Agr. For. 29: 429-438.

Scowcroft, P.G., D.R. Turner and P.M. Vitousek. 2000. Decomposition of *Metrosideros polymorpha* leaf litter along elevational gradients in Hawaii. Global Change Biol. 6: 73-85.

Swift, M.J., O.W. Heal and J.M. Anderson. 1979. Decomposition in Terrestrial Ecosystems. Blackwell Scientific Publications, Oxford.

Thornthwaite, C.W. and J.R. Mather. 1957. Instructions and tables for computing potential evapotranspiration and the water budget. Publ. Climat. 10: 185-311.

Trofymow, J.A., T.R. Moore, B. Titus, C. Prescott, I. Morrison, M. Siltanen, S. Smith, J. Fyles, R. Wein, C. Camire, L. Duschene, L. Kozak, M. Kranabetter and S. Visser. 2002. Rates of litter decomposition over 6 years in Canadian forests: Influence of litter quality and climate. Can. J. For. Res. 32: 789-804.

Upadhyay, V.P., J.S. Singh and V. Meentemeyer. 1989. Dynamics and weight loss of leaf litter in central Himalayan forests: Abiotic versus litter quality influences. J. Ecol. 77: 147-161.

Vitousek, P.M., D.R. Turner, W.J. Parton and R.L. Sandford. 1994. Litter decomposition on the Mauna Loa environmental matrix, Hawaii: Patterns, mechanisms and models. Ecology. 75: 418-429.

Walse, C., B. Berg and H. Sverdrup. 1998. Review and synthesis of experimental data on organic matter decomposition with respect to the effect of temperature, moisture, and acidity. Envir. Rev. 6: 25-40.

Yanai, R.D., S.V. Stehman, M.A. Arthur, C.E. Prescott, A.J. Friedland, T.G. Siccama and D. Binkley. 2003. Detecting change in forest floor carbon. Soil Sci. Soc. Am. J. 67: 1583-1593.