The Effect of Structural and Environmental Changes on Litter Decomposition of in Pinus Sylvestris Stands

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Research

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Abstract

Background: Decomposition of litter has an important role in primary production with its influence on nutrient release for plant uptake and carbon flux in forest ecosystems. Thus, understanding the effects of the intervention on litter decomposition is crucial for sustainable forest management. In this study, the effect of structural change and facing slope on litter decomposition in Scots pine stands (*Pinus sylvestris* L.) were investigated.

Results: The decomposition rate of litter decreased as the stand age increased. Litter decomposed more rapidly on northern slopes than southern slopes. Cutting caused to accelerate the decomposition at a rate of up to 58% depending on its intensity. The k values were found to fluctuate though the time from 0.189 in moderately dense canopied stands to 0.317 in open canopied over-mature stands. Stand basal area, incubation time, and remaining carbon concentration of the litter accounted for 75% of the variation in the decomposition constant.

Conclusions: Cutting-induced stand structural changes affected the litter decomposition process in forest ecosystems due to the micro environmental change as well as the change in litterfall composition and chemistry. Heavy treatments can change the litter decomposition process drastically, while moderate thinning may not have a clear effect in the long run. The stand specific k value should be considered to use in forest carbon models for more accurate estimation. Decomposition constant should be calculated by considering stand structure and incubation time of at least 1050 days. Besides, due to the significant effect of canopy closure on decomposition rate, stand specific or recalculated k constants according to stand basal area, incubation time, and remaining carbon concentration of the litter should be recommended to use in forest carbon models for more accurate carbon budget estimation.

Background

Plant litter decomposition through microbes and fungi is the only process allowing recycle of chemical elements in forest ecosystems, and thus crucial for sustaining life on earth (Berg and Laskowski 2005). The decomposition of litter is an important process critical to understand the nutrient dynamics as well as the development of nutrient deficiency in a forest ecosystem and responses of the ecosystems to environmental disturbances (Prescott 2010). The most important product of litter decomposition influences soil productivity and microbial biodiversity (Berg and McClaugherty 2014). In the sense of climate change, decomposition of litter has an important role in primary production with its influence on nutrient release for plant uptake and carbon flux (Rodríguez et al. 2009). Organic matter decaying is an important source of carbon dioxide returned to the atmosphere which is the main greenhouse gas with a role in potential global climate change (Berg and McClaugherty 2014).

Silvicultural cutting treatments, that change the structure of stand by reducing canopy cover and basal area, have been applied in forest stands to maintain the growth or to establish a new generation by forest management. Seed cut, a silvicultural harvesting method, which takes all trees but the seed trees, has been widely used for natural regeneration of trees (Youngblood 1991; Schönenberger and Brang 2004) although much of the forests are regenerated by clear-cutting (Dougherty and Duryea 1991). Scots pine stands are commonly regenerated by using the seed cut method in Turkey. As another silvicultural method, thinning has been a common silvicultural practice applied in the forest to maintain the growth rate of stands for decades in forestry (Pourmajidian et al. 2010; Tian et al. 2010). All kinds of cutting alter the balance of the ecosystem. Although the effects of thinning on the stand growth, litter production, soil properties, and carbon sequestration were well documented, very few studies were conducted on the thinning effect on litter decomposition dynamics in *Pinus sylvestris* forests (del Rio et al. 2017). However, contrasting results have been presented by the studies. For example, Blanco et al. (2011) carried out a study in which two degrees of thinning with a control in young Scots pine stands at two different sites, namely the Mediterranean and continental sites, suggesting that decomposition rate decreased with increasing thinning intensity. In contrast, Kunhamu et al. (2009) suggested that high thinning intensities accelerated the decay rate of litter in an *Acacia mangium* stand. However, Will et al. (1983) reported a non-significant effect of thinning on the decomposition rate of *Pinus radiata* litter.

The effect of climatic factors such as precipitation, temperature, and evapotranspiration and litter chemistry on litter decomposition was determined by many researchers (Johansson 1994; Sariyildiz 2003; Prescott 2010; Kim 2012). However, less study has been carried out to determine the silvicultural cutting influence on the decomposition rate (Cortina and Vallejo 1994; Kunhamu et al. 2009). On the other hand, litterfall components, including needles, cones, branches, differ in chemical composition and thus have different decomposition patterns (Hristovski et al. 2001; Berg 2014). However, most of the studies on litter decomposition have focused on the foliar litterfall so far. Therefore there is a gap of knowledge on the decomposition of total litterfall.

The objective of this study was to evaluate the effects of stand structure and facing slope on litter decomposition. We hypothesized that mass loss and nutrient release are higher i) in sparse canopy cover than in dense canopy, ii) in young stands than in older, and iii) on the southern slope than on the northern slope.

Methods

Study Site

The study was conducted at pure Scots pine stands spreading over Sundiken Mountain range in the inner Anatolia region of Turkey (39º57N, 31°09E) on a well-drained luvisol (IUSS Working Group WRB 2015) developed from mica schist, with a sandy loam texture and pH of 5.6–6.0. Sampling was performed in naturally regenerated stands. The study area has a continental climate with low rainfall, with a mean temperature and rainfall of 9.5 °C and 486 mm, respectively. A detailed description of the study area was given by Çömez et al. (2019).

Sampling procedure

To cover a wide range of life cycle of the forest and to understand the stand structure effect on litter decomposition, sample plots were chosen from three developmental stages, i.e. young, mature, and over-mature stages; and three classes of canopy cover, i.e., open forest (10–40%), moderately dense (40–70%) and very dense canopy (> 70%), except young stands because of the lack of open and moderately dense canopied stands, with four replications, 28 in totally (Table 1). To understand the effect of slope aspect on the decomposition rate, two of the replications were established on the northern slope, while the others on the southern slope. Mature and over-mature stands studied were exposed silvicultural treatments 5 to 8 years before the measurements by the local authority. Litterfall samples were collected by 0.5 × 0.5 m traps for two years to attain enough amounts of litterfall samples to be placed in litter bags. After having collected the samples in each sample plot, litter samples with an air-dried weight of approximately 10 g including needles, bark, branches, and cones, taking into account their share in the total litterfall were filled into the litter bags to determine the overall litter decomposition. The shares of litterfall components are given in Table 1. To determine the litter decomposition rate, 60 litter bags, made from nylon nets with 1 × 1 mm mesh and 20 × 15 cm in size, were filled with litter and placed on the ground of each sample plot. Four litter bag samples were collected from each plot every two to five months for four years. The mean mass loss rate was calculated from the four litter bags of each plot.

Table 1
Some attributes litterfall fractions of the stands studied (n = 4)

Stand structure	**Age**	**Dbh (cm)**	**Mean Height (m)**	**Density (Tree ha^{-1})**	**Basal Area (m^2 ha^{-1})**	**Needles (%)**	**Bark (%)**	**Branches (%)**	**Cones (%)**	**Misc. (%)**
Young	15	4	2	8700	7	87	2	3	3	6
Mature open	93	31	17	200	15	40	8	5	41	7
Mature moderately dense	98	29	19	500	33	58	10	6	19	9
Mature dense	100	29	20	688	45	55	10	10	15	10
Over-mature open	117	43	22	119	18	43	8	13	26	11
Over-mature moderately dense	127	45	24	238	37	47	10	15	14	16
Over-mature dense	110	38	24	400	45	50	10	14	15	11

Laboratory methods

Litter bag samples were oven-dried at 70 ºC until constant weight before the weighting. Mass loss was calculated by Eq. (1):

$$M_R = \frac{M_0 - M_t}{M_0} \times 100$$

1

Where M_R is remaining mass (%), M_0 is the initial mass of litter (g), M_t is the litter mass t time later (g)

Accumulated carbon (C) and nitrogen (N) release were calculated by Eq. (2):

$$C,N_r = M_R \times C,N_{Conc.}$$

2

Where C, N_r is accumulated carbon or nitrogen release (%), M_R is the remaining litter mass (%), C, N_{Conc}. is the carbon or nitrogen concentration of the decomposing litter (%), respectively.

Decomposition constant was calculated by Olson (1963), Eq. (3):

$$k = -log\frac{M_t}{M_0}$$

3

Where k is decomposition constant, M_0 is the initial mass of litter (g), M_t is the litter mass t time later (g)

The samples were analyzed for carbon and nitrogen by the Dumas method using the LECO CNH analyzer (Leco Corporation, St. Joseph, Michigan). Nitrogen and carbon concentrations were standardized to initial concentrations by multiplying their concentrations by remaining mass percent.

Statistical analysis

Data was controlled by the Shapiro–Wilk test for the normal distribution, while the homogeneity of variance by Levene's test. When data normally distributed, variations in the mass loss by time and stand type evaluated by Repeated Measure ANOVA, taking the maturity, canopy, and facing slopes as between-subject factors. All data showed normal distribution and homogeneous variance. The Scheffe test was used to determine the homogenous groups.

Decomposition constant was estimated by multiple regression analysis, using the basal area of the stands m^2 ha^{-1}), stand age (year), the length of the incubation period of the litter (days), and accumulated C and N concentration (%) as independent variables. Equations with the highest R^2, the lowest standard error, and constants with a significant level at $P < 0.05$ were given in this study.

Results

Litter Mass Loss

The remaining mass of the litter and k constant varied significantly with time and stand canopy, as well as slope facing. Interactions between the time and stand canopy affected the litter decomposition. Canopy closure and slope facing also affected significantly decomposition dynamics (Table 2).

Table 2
Repeated measures ANOVA results for the differences in remaining mass and k value

	Remaining mass		**k value**	
	F-value	*p*-value	*F*-value	*p*-value
Within subject effects				
Time	504.520	< 0.0001	12.043	< 0.0001
Time × maturity	0.376	0.727	0.597	0.594
Time × canopy	3.418	0.014	1.544	0.201
Time × slope facing	1.209	0.317	0.289	0.800
Time × slope facing × maturity × canopy	1.684	0.167	0.646	0.668
Between subject effects				
Maturity	0.050	0.826	0.052	0.823
Canopy	4.477	0.031	3.191	0.072
Slope facing	7.035	0.019	7.432	0.016
Maturity × canopy × slope facing	4.912	0.024	4.109	0.039

At the end of the incubation time of 1367 days, 30% of the initial litter mass was remained undecomposed in young stands, while that of almost half in moderately dense and dense ones. Although the remaining mass was higher in the moderately dense forest in mature stands, it was low in dense over-mature stands. Open canopied stands had a lower remaining mass in both mature and over-mature ones. As the canopy became more open, the remaining mass of the litter decreased, except for moderately dense mature stands. An ascending trend was observed in stands from young to over-mature stage in remaining litter mass, from 30% in young stands to 49% in over-mature stands. Decomposition constant was found to be highest in young stands while the lowest in moderately dense mature stands with an increasing tendency from the dense canopy to open and young forest, with the exception of moderately dense mature stands (Table 3).

Table 3
Remaining mass at the end of the study period and overall decomposition constant (k)

Stand structure	Remaining mass (%)	k value
Young	30.09 ± 3.08a	0.349 ± 0.032 c
Open mature	41.01 ± 3.88abc	0.256 ± 0.032 ab
Moderately dense mature	49.32 ± 1.82c	0.189 ± 0.010 a
Dense mature	45.38 ± 4.17bc	0.215 ± 0.025 a
Open over-mature	34.16 ± 4.89ab	0.317 ± 0.046 bc
Moderately dense over-mature	42.17 ± 4.35abc	0.235 ± 0.027 ab
Dense over-mature	49.37 ± 3.96c	0.201 ± 0.022 a
F-value	3.628	4.207
p-value	0.013	0.006
Same letters in the same column donate the same groups		

Remaining masses of the litter were found to be very close to each other between northern and southern slopes in young stands, while those of northern slopes were lower than southern ones in both mature and over-mature stands. Litter was decomposed more in open canopied stands than in both moderately dense and dense canopied ones, except in mature stands on the northern slope. The decomposition process occurred more rapidly on the northern slopes (Fig. 1).

Decomposition constant showed an increase towards to end of the first year in all stands, with the highest in young and the lowest in over-mature dense-canopied stands. After the third year of the incubation, k constants of the moderately dense and dense stands have remained steady, while those of young and over-mature open forests have continued to increase slightly. Differences in k constant between open and moderately dense canopied forests became pronounced after 687 days of incubation (Fig. 2).

Stand basal area alone accounted for 47% of the variation in k constant that calculated for 1367 days, while for 75% of that along with incubation days and remaining C. Basal area, incubation days, and remaining C in the litter were negatively related to k constant (Table 4).

Table 4
Multiple linear regression models based on basal area and elevation to predict the k constant

Model	R^2	SEE		Coefficient	*p*
1	0.469	0.057	Constant	0.323 ± 0.007	< 0.0001
			Basal area	-0.002 ± 0.0002	< 0.0001
3	0.754	0.034	Constant	0.923 ± 0.024	< 0.0001
			Basal area	-0.000376 ± 0.000154	0.015
			Days	-0.000288 ± 0.000012	< 0.0001
			Remaining C	-0.0138 ± 0.000567	< 0.0001

Carbon and nitrogen mineralization

The initial nitrogen concentration of the litter was ranged from 0.92% in dense canopied stands to 1.24% in young stands, with a significant difference ($P < 0.01$) between young stands and the other stands. However, there was no significant difference at the end of the 155 days, with a decline of 0.42 to 0.49% of N concentration. An increasing trend in N concentrations of the litter was observed after the 155 days of incubation, with the effect of treatment and time. Accumulated N was considerably decreased from 1.24–0.92% to 0.37–0.44% through the time and stabilized around 0.45% between the incubation days of 524 and 1137. Subsequently, a slight decrease trend was observed after 1137 days (Fig. 3a-b).

Carbon concentrations of the litter fluctuated from 50–55% through the study period, with a significant difference ($P < 0.01$) according to repeated measures of ANOVA. Initial carbon concentrations among the stands were not significantly different, ranging from 51 to 54%. Cumulative carbon concentrations showed a steady decrease from 53–21%, approximately. At the end of 1367 days of incubation, 24% of the initial carbon remained undecomposed in the dense stands, while that of 15% in young stands (Fig. 3c-d).

Initial N concentrations of the litters were significantly different among the stands, with the highest in young stands and the lowest in dense stands ($P < 0.01$). An increase in the N concentrations from dense stands to the open-canopied as well as the young ones was observed. However, there were no significant differences in initial carbon concentrations among the stands, although litter from dense stands had the highest carbon concentration with a mean of 54% and the moderately dense stands had the lowest with 51% (Table 5).

Table 5
Initial N and C concentrations (%) of litter in stands studied

Stands	N	C
Young	1.235 ± 0.021 b	53.273 ± 0.977 a
Open-canopied	1.054 ± 0.039 a	53.308 ± 0.552 a
Moderately dense	0.948 ± 0.048 a	51.046 ± 2.140 a
Dense	0.920 ± 0.051 a	54.114 ± 0.658 a
F	6.814	1.149
P	0.002	0.350

Remaining litter mass was correlated with the initial N concentration at a significance level of $P < 0.01$. The remaining mass decreased with increasing N concentration of the litterfall (Fig. 4).

Discussion

Litter decomposition

The decomposition of forest litter is a process mainly driven by environmental conditions and the quality of the substrate (Sariyildiz and Kucuk 2008; Berg and McClaugherty 2014; Karishna and Mohan 2017). Silvicultural treatments, such as thinning and seed cutting, can alter environmental conditions as well as production (Prescott et al. 2004; Tian et al. 2010) and composition of litterfall. Besides, the quantity and quality of the forest floor can be changed by residues left in the stand after the cutting treatments. In our study, lower remaining litter mass in young and open canopied forests compared to dense ones indicated that stand structure influenced on the decomposition rate of the forest floor by changing the environmental conditions, namely temperature and moisture in the stands. Besides, thinning operations can affect litterfall composition as suggested by Blanco et al. (2006). Specifically, needle litter was more dominant in young stands, leading to a high decomposition rate due to easily decomposable chemical composition. Cutting in forest results in a decrease of canopy closure and the basal area left, leading to more rainfall and light to reach the soil surface (Prescott et al. 2004; Tian et al. 2010). Thus, the activity of decomposers accelerates, and consequently decomposition rate of the litter increases. Despite low needle litterfall, an easily decomposable fraction due to low lignin and high nitrogen content, but a higher cones fraction, decomposition rates were higher in the open canopied stands, likely due to the prevailing effect of microclimatic condition on soil biota. Unlike the needles, cones have a woody structure, indicating that they include more lignin than needles do (Taylor et al. 1991; Font et al. 2009). High lignin content causes a slow break down in the forest floor (Sariyildiz and Kucuk 2008; Wang et al. 2018). Our results clearly showed that cuttings accelerated the decomposition of litter in a mature stand, meaning an increased carbon emission.

The remaining mass of litter in young stands which had a needle fraction of 87% of the total litterfall was close to some studies regarding needle litter decomposition (Berg and Staaf 1980; Laiho et al. 2004), likely due to similar climatic conditions and a high needles fraction of our study. On the other hand, Sariyildiz and Kucuk (2008) reported a higher decomposition rate compared to our results, likely because their results were for needle litterfall. Pausas (1997) reported that the k values varied between 0.221 and 0.283 for Scots pine stands, which were close to our results for moderately dense and open canopied forests but lower for young and higher for dense ones. An additional explanation may be the suitable climate of their study area with more moist conditions. On the other hand, Sariyildiz (2008) observed a closer decomposition rate to our results for young stand stands, with k values from 0.3 to 0.4. Janušauskaité et al. (2013) reported a lower decomposition rate for northern sites. This may be related to the retarding effect of low temperature on decomposition (Berg 2014; Krishna and Mohan 2017). Enez et al. (2015) found a lower decomposition rate of needle litter on scalped mineral soil than on non-harvesting activity areas under Scots pine stand due to the less microbial activity. Thus, litter decomposition dynamics of young stand might differ from those of mature ones due to the differences in composition of the litterfall and the changes in environmental conditions of the stands.

Many researchers reported that the slope facing affected decomposition rate with the faster on the northern slope than on the southern slope (Sariyildiz and Kucuk 2008; Jasińska et al. 2019). On the other hand, some researchers reported a faster decomposition of litterfall on the south aspects than on the north (Mudrick et al. 1994; Qualls 2016), which was in line with our results. Furthermore, in open canopied mature stands, decomposition rate was found to be faster on southern slopes in comparison to the north in contrast to in the case of the dense canopy, likely due to age- and light-related changes in litterfall composition.

We did not determine the decomposition rates of the litter fractions separately in our study since all litterfall fractions make up the forest floor and decompose together. To take into account only a certain fraction of litterfall such as needles or leaves could result in an overestimation of litter decomposition rate.

Temporal changes in k constant and estimation models

Decomposition constant trends showed different patterns due to changes in the chemical composition of litter and microbial diversity during decomposition process (Yue et al. 2018), indicating that k constant would be stabilized after approximately 1000 days in dense and moderately dense forest, while not in open as well as young stands. In addition, k constant might continue to increase slightly until 1400 days in open-canopied and young stands. Therefore, k values might be underestimated in young stands, as well as heavily thinned stands, in case of incubation time shorter than 1400 days. Our results partly confirmed the Berg et al. (2010), who proposed that 1100 to 2000 days of the period were sufficient for limit values of litter decomposition. Still, there is a need for further studies on the decomposition rate in young and mature stands with heavily treated.

Basal area is an important parameter that can be used for evaluating the stand structure and decreased by silvicultural interventions as well as natural or human-induced disturbances. A decline in the basal area, meaning also a decrease in canopy cover, leads to more sunlight and rainfall to reach the forest floor, favoring the environmental conditions for microbial activity. Therefore, the basal area gave a robust fit with k constant.

Nitrogen and carbon releasing

Our results showed that initial N concentrations of litter were related to the decomposition rate. Higher N concentrations in young stands also supported this relationship. An increase in the N concentration causes to decrease in C: N ratio, which is an index for litter decomposition. Sun et al. (2016) also reported a decreasing trend in N concentration of senesced pine needles from young to older stands. The decreasing trend in N with stand age might be related to changes in soil nutrient availability and forest growth rates during stand development, as pointed out by Sun et al. (2016). Besides, the concentrations tended to increase slightly with the canopy structure of the stands became more open, indicating that cuttings might result in changes in nutrient withdrawal before needle shed in pines in contrast to Blanco et al. (2009) reported. But our results confirm the findings of Berg et al. (1995), who reported that N concentration in needle litter of Scots pine was mainly related to climatic conditions. On the other hand, the initial N concentration of the litter for the dense forests of our study was similar to the results of Blanco et al. (2006) for needle litter of Scots pine stands in sites with a cold wet Mediterranean climate. However, they reported lower values for sites with a cold wet continental climate than our results. They also suggested that thinning affected N concentration of needle litter.

In this study, higher initial N concentration of litter resulted in a higher decomposition rate as revealed by many researchers (Gao et al. 2019; Sariyildiz 2003; Zhang et al. 2008) in contrast to Berg (2000). The enhancing effects of N on decomposition rate may be related to rich microbial diversity supported by the high nutritious value of the litter (Gao et al. 2015), which has a high proportion of needles that contains higher nutrients compared to other litter fractions in young stands. On the other hand, despite the lower nutrient content likely due to the inclusion of a higher portion of fine woody litter, the decomposition rate in open-canopied stands also was higher than in the moderately thinned and un-thinned stands likely because of the prominent effects of temperature and humidity on the decomposition process.

Conclusions

In this study, it was concluded that cutting-induced stand structure change affected the litter decomposition process in forest ecosystems due to the micro environmental change as well as the change in litterfall composition and chemistry. Although moderate thinning could not change the litter decomposition process drastically, heavy treatments could do in the long run. Relatively higher precipitation reaching the forest floor with together temperature due to the decreasing of canopy might cause a rapid N mineralization, thus, leading to needle fall with reach in N concentration. However, there is a need for further researches on the effect of thinning on the nutrient re-translocation process. On the other hand, it is important to use decomposition constant which relies on long term incubation, with at least 1050 days. Besides, due to the significant effect of canopy closure on decomposition rate, stand specific or recalculated k constants according to stand basal area should be recommended to use in forest carbon models for more accurate carbon budget estimation.

Abbreviations

N: nitrogen; C: carbon; k: litter decomposition constant; R^2: coefficient of determination; SEE: standard error of the estimation

Declarations

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Authors' contributions

ÇA, GŞT, and TD conceived the ideas and designed methodology; ÇA and GŞT collected the data; ÇA analyzed carbon and nitrogen concentrations; ÇA and GŞT analyzed the data; AÇ led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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Availability of data and materials

The datasets and materials used during the present study were obtained from the field and laboratory by the authors and are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

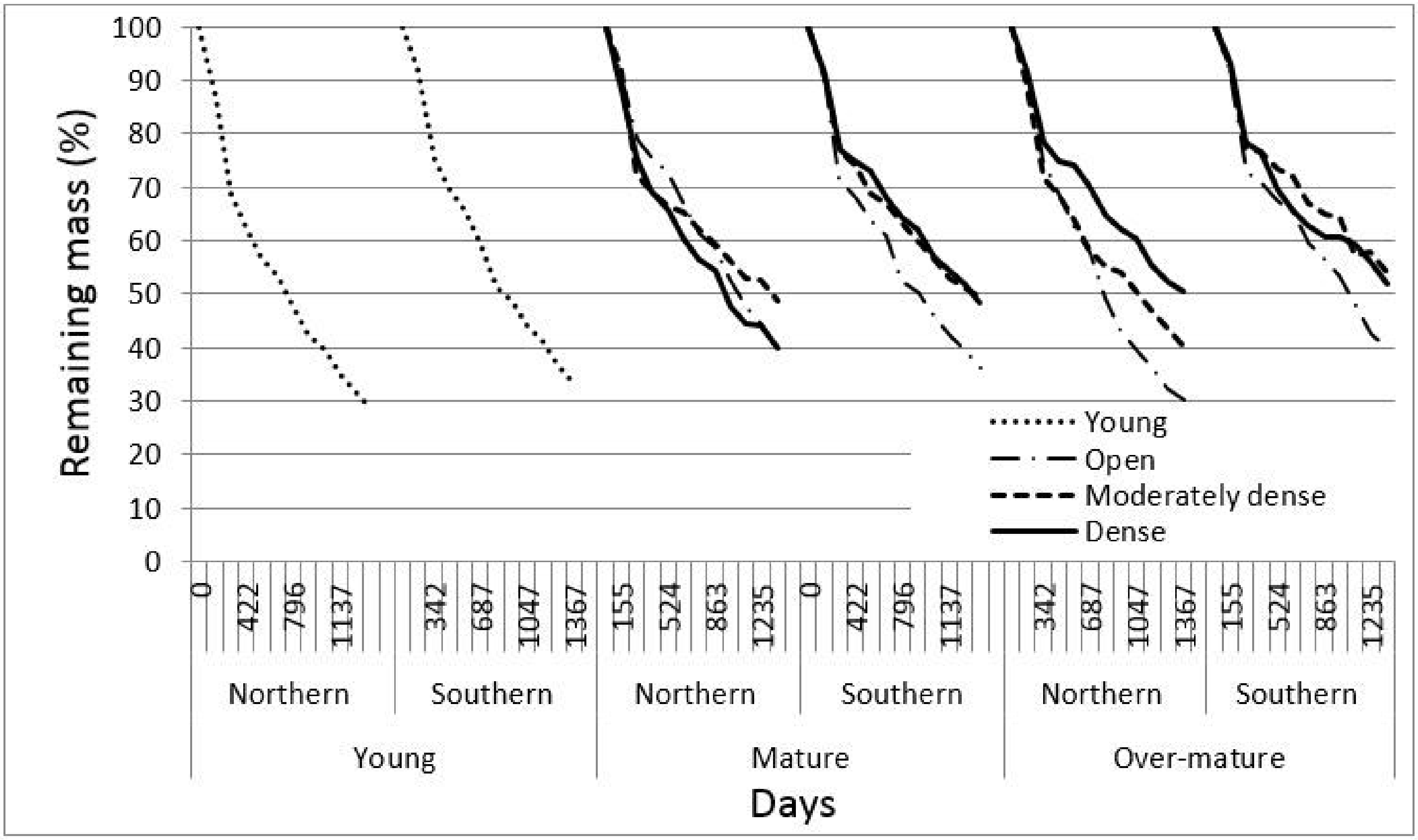

Figure 1

Changes in remaining mass of the litter with facing slopes, stand development, and cano

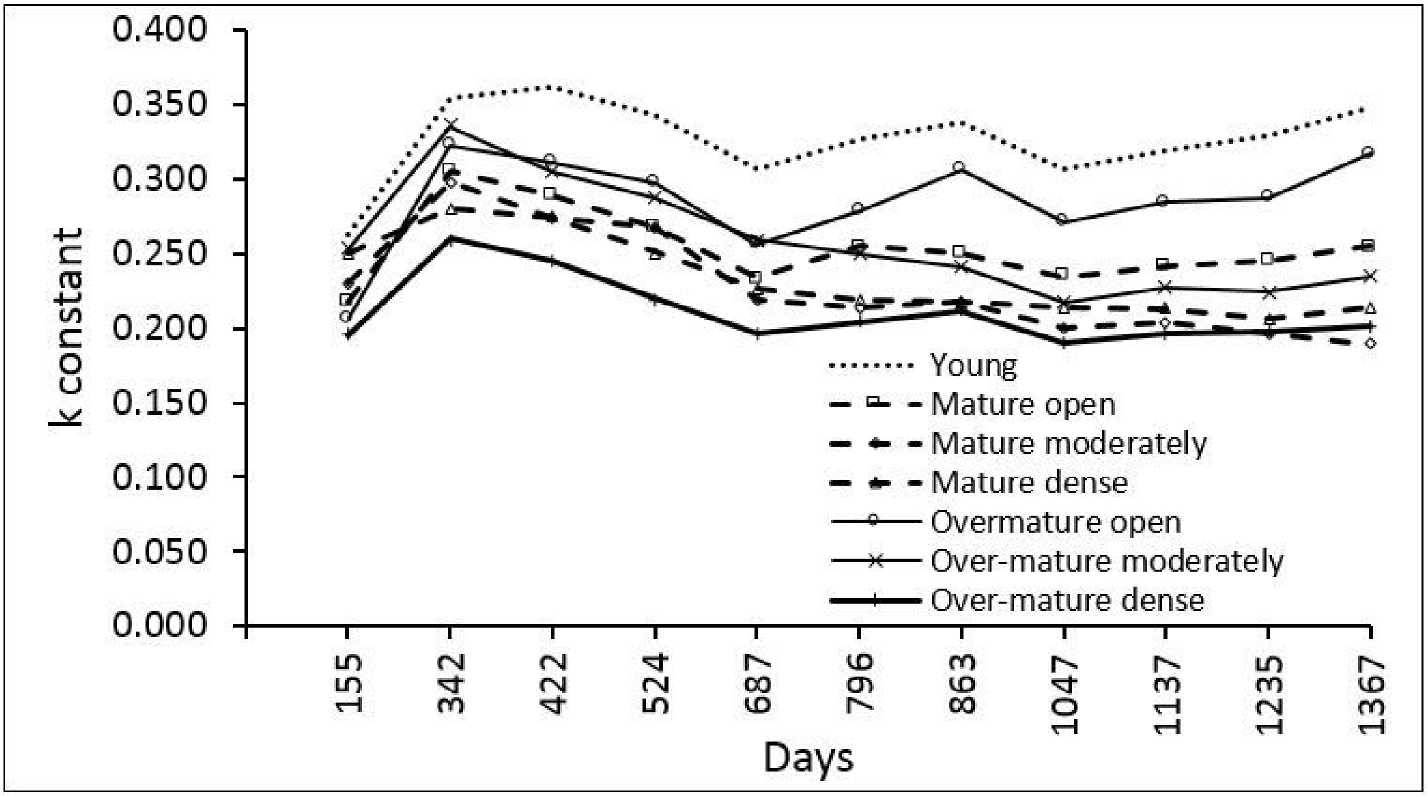

Figure 2

The course of k values according to sampling periods

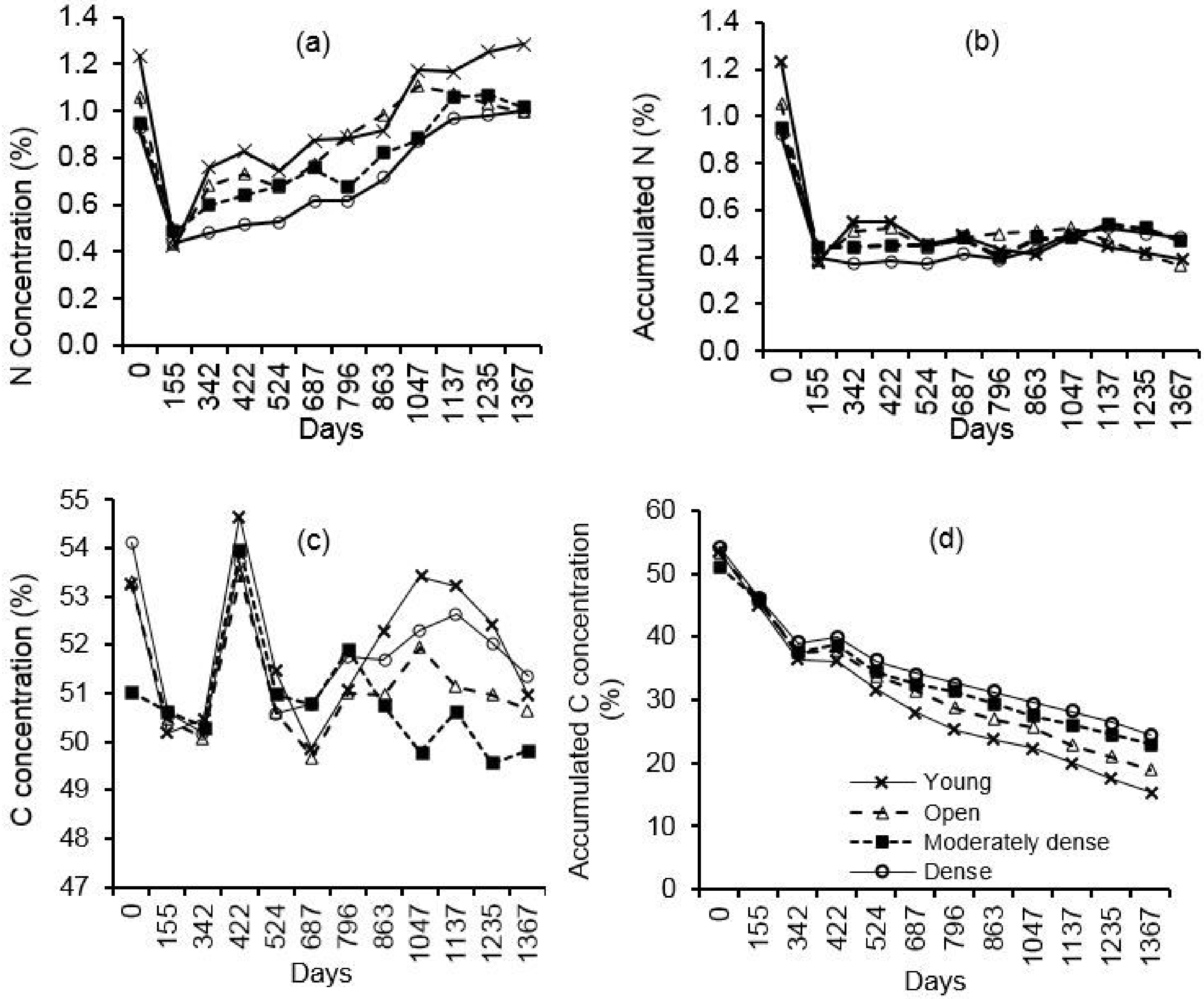

Figure 3

a) N concentration b) accumulated N concentration c) C concentration d) accumulated C concentration of decomposing litter

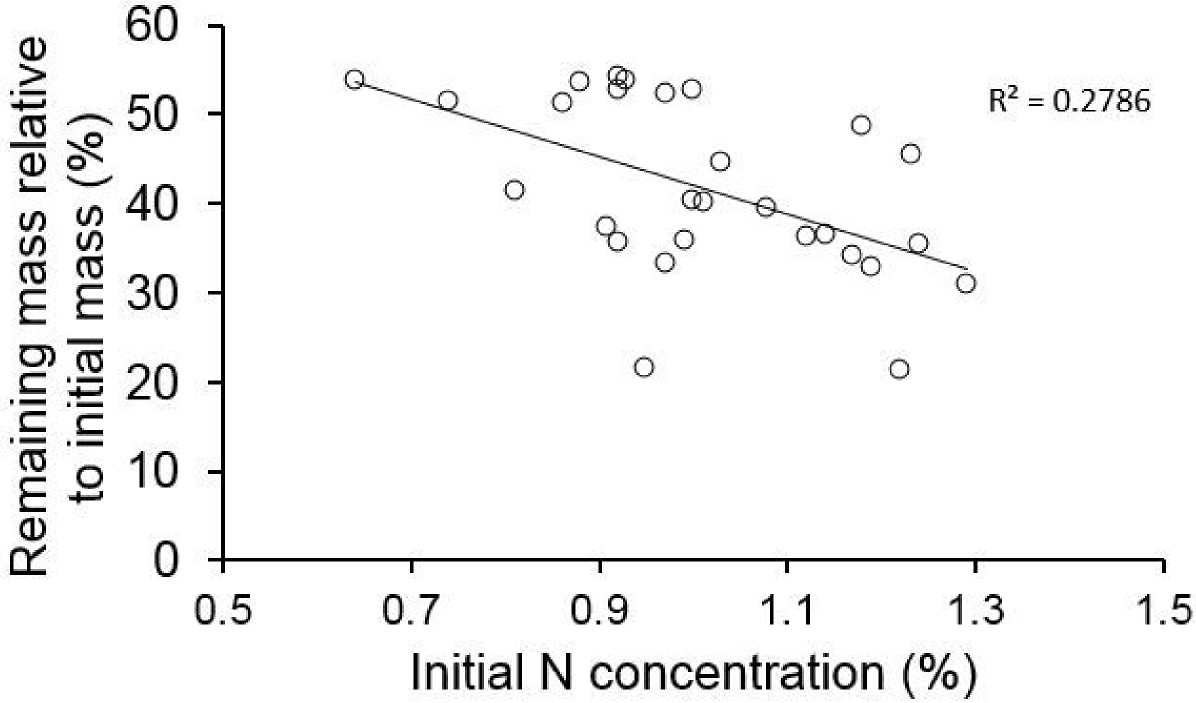

Figure 4

The relationship between remaining mass in April 2016 relative to the initial mass of litter