Nutrient dynamics and early decomposition rates of *Picea abies* needles in combination with *Fagus orientalis* leaf litter in an exogenous ecosystem

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Abstract. The Hyrcanian forests in the Northern Iran are originally poor of coniferous and are considered as a refugium of temperate broad-leaved trees during the Quaternary glaciations. In this study mass loss and nutrients dynamic of Norway spruce needles when combined with oriental beech litter was investigated in a 50-year plantation of pure Norway spruce in the Hyrcanian forests. The litter bags technique was used to monitor the mass loss and nutrients concentration after 60, 120, 180, 270 and 400 days. The results showed that when decomposed alone the mass loss rate of spruce needles was generally lower than what reported in Europe. However, when combined with oriental beech litter the mass loss rate was hastened compared to when decomposed alone. A positive non-additive effect of beech leaf litter was observed on spruce nutrients dynamic. The concentration of N, P, K, and Mg in combined spruce needles with beech litter was generally higher compared to when spruce needles decomposed alone during decomposition time. While the concentration of Mn and Ca in combined spruce needles with beech litter was generally higher than when spruce needles decomposed alone. At the end of the decomposition period the release of Mn and N was significantly higher in combined spruce needles than when it decomposed alone. Based on the stepwise regression N was the only nutrient entered to model which explained 37% of mass loss variation. It was concluded that oriental beech leaf litter drive a non-additive effect on mass loss and nutrient dynamic of Norway spruce needles. Therefore combining the plantation of Norway spruce with oriental beech can result in better regulating of needles decomposition and nutrients cycle.
Keywords decomposition, Hyrcanian forests, Norway spruce, non-additive, oriental beech

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Introduction

Leaf litter decomposition is a key ecological process for nutrient cycles that is essential for forest ecosystem sustainability and net productivity (Purahong et al. 2014). This process is vital pathway for the return of energy, organic matter and nutrients from the vegetation to the soil through litter fall (Aber et al. 1990; Attiwill & Adams, 1993; Kara et al. 2014). Nutrients bound in the organic matter are released to the soil in mineral form during decomposition (Gartner & Cardon, 2004; Titus & Malcolm, 1999; Berg & Laskowski, 1997).

The amount of released nutrients depends on the amount of leaf litter fall and its decomposition rate (Guo & Sims, 1999). On a global scale leaf litter production is generally dependent upon latitude and climate (Liu et al. 2006) while at a regional scale under similar temperature and precipitation regimes it is dependent upon the variation of ecological and physiological characteristics of tree species, site productivity, and physiographic factors (Barnes et al. 1998, Kara, et al. 2014). Decomposition rate is regulated by three main drivers including: decomposer communities, microclimate, and litter quality (Vesterdal 1999; Zhou et al. 2008; Berg et al., 2010).

The initial chemical components such as lignin concentration and contents of nutrients such as nitrogen (N), and the carbon-to-nitrogen (C to N) ratio are some of the most well-known parameters of litter quality (Meentemeyer, 1984; Sariyildiz et al. 2005; Zhou et al., 2008). Differences between tree litter species as regards decomposition rate are closely related to the C to N, and nitrogen-to-phosphorus (N to P) ratios, as well as to contents of calcium (Ca) and manganese (Mn) (Berg at al., 2000; Aponte et al. 2012). The availability of litter as a substrate can influence the microbial decomposers' community and their activity and thus influence decomposition rate (Chapman et al. 2013). On the other hand climate parameters such as mean annual temperature (MAT), mean annual precipitation (MAP) and actual evapotranspiration (AET) have also been reported as essential factors for decomposition rate (Berg & McClaugherty, 2008).

Although several studies have related decomposition rates to climate factors it is commonly recognized that the rate of the microbially mediated decomposition is determined by an interaction of climate and substrate quality (Moorhead et al. 1999; Gholz et al. 2000; Silver & Miya, 2001; Berger & Berger, 2014). All these parameters can vary across the various forest ecosystems and their tree species communities.

In this study we intended to investigate decomposition rates of Norway spruce needle alone and combined with oriental beech leaf litter in a pure Norway spruce plantation as an introduced tree to the original site of oriental beech in the Hyrcanian forests. It is well documented that the mixing of leaf litters often causes non-additive decomposition in which the observed decomposition rate is often enhanced or retarded compared to what is expected when they decompose as single species (Gartner & Cardon, 2004; Chapman et al. 2013). Overall, the interactions of litters from different species in one specific ecosystem influence decomposition rates of individual leaf types in mixes (Gartner & Cardon, 2004). Consequently the nutrient cycles and nutrients' availability in soil can affect plant growth and activity of the decomposer community as well as the structure in soil (Gartner & Cardon, 2004; Chapman et al. 2013).

There are some studies about the decomposition rates of Norway spruce needles when mixed with common beech (*Fagus sylvatica*) leaf litter in different site conditions (e.g., Albers et al. 2004; Berger et al. 2004; Berger et al. 2006; Berger & Berger, 2014). The latest study of Berger & Berger (2014) indicated that the decomposition rate of Norway spruce needle litter was higher in mixed than in spruce stands while the effect of litter species and their mixtures was not significant on

decomposition rates. There is just one report about decomposition rates of Oriental spruce (*Picea orientalis* L.) needles mixed with oriental beech leaf litter indicating that mixed litters had higher decomposition rates than individual beech and spruce litters in both monocultures and mixed stands (Sariyildiz et al. 2005).

The differences in ecosystems and site conditions on one hand and using new species on the other hand makes it impossible to extrapolate the earlier findings to a new situation. So the main objectives of this study is to address the following questions: (i) What is the mass-loss rate of Norway spruce needles in an exogenous ecosystem which is historically poor in conifers? (ii) Does the oriental beech leaf litter increase the decay rates when combined with spruce needles? (iii) Do the nutrient concentrations and release rates differ when spruce litter decomposes individually or combined with beech leaf litter? Finding the answer of these questions is vital to decide about the ecological effect of an exogenous tree on a specific ecosystem in terms of nutrient cycling.

Materials and methods

Study site

This study was conducted in Hyrcanian forests as an exogenous ecosystem to Norway spruce. The Hyrcanian forests ecosystem, also called Caspian forests, covers the southern coast of the Caspian Sea in northern Iran.

The Hyrcanian forests are considered as one of the last remnants of natural deciduous forests in the world because they did not undergo major changes during the Quaternary Period (Shahsavari, 1997; Sagheb-Talebi et al. 2013). These forests are considered as a refugium of temperate broad-leaved trees during the Quaternary glaciations (Zohary, 1973; Sagheb-Talebi et al. 2013). They are rich in broadleaf species, with only a few species of endemic conifer trees including Italian cypress (*Cupressus sempervirens)*, Oriental ar-

bor-vitae (*Platycladus orientalis*), yew (*Taxus* spp.), and Greek juniper (*Juniperusexcelsa*) (Sagheb-Talebi et al. 2013). The sites that are dominated by oriental beech (*Fagus orientalis* lipsky) are the most productive stands of the Hyrcanian region (Sagheb-Talebi et al. 2013). The natural range of oriental beech extends from southeast Bulgaria through Turkey to the Hyrcanian forests. Some areas of these forests have been subjected to plantation with exogenous tree species especially coniferous species like Norway spruce (*Picea abies*) that is native to Europe.

In this study we chose a 50 years old pure stand of a Norway spruce plantation (34.1ha) in Lajim forest, (36º 14'46″N, 53º 7'13″E, and 36º 14'41″N, 53º 7'33″E) Mazandaran province in the central part of the Hyrcanian forests that is naturally covered by broadleaf species such as Oriental beech (*Fagus orientalis*), Persian maple (*Acer velotinum*) and Caucasian alder (*Alnus subcurdata*). However, some part of it have been subjected to stand conversion and plantation with exogenous coniferous trees. Site elevation range is about 850-965m a.s.l., the mean annual precipitation (MAP) and mean annual temperature (MAT) are 17.3°C and 878.4 mm, respectively. The climate is humid and moderate according to De Martonne method (De Martonne, 1926; Aghbash et al. 2014). The soil type is brown, the soil texture is clay with neutral to weak alkaline.

Leaf litter collection and litterbag method

Litter decomposition was determined using the litter-bag technique (Berg & McClaugherty, 2008) under field conditions in a completely random design. Freshly shed leaves of oriental beech were collected from beech stands adjacent to the pure stand of Norway spruce in mid-November after clearing the soil surface (under the canopy) from the previous year leaf litter fall and then let the new leaves fall down. Norway spruce needles were collected from the all sides of the trees crown. The beech

leaf litter was collected by spreading nets underneath the tree crown. The collected needles and leaf litters were air dried in the laboratory. Single-envelop and double-envelop nylon bags (2 mm mesh) with 30×20cm in dimension we reemployed to determine the decomposition rate. 10.00 g air dried litter of each species were placed into bags according to the following way: 20 single-envelope bags with Norway spruce needles, 20 single-envelope bags with oriental beech litter and 20 double-envelope bags with beech and spruce litter separately in each envelope of bags. The bags were located throughout the Norway spruce plantation in October 2010. For the double-envelope bags the lower envelope filled with Norway spruce litter were located on the soil surface allowing nutrients to leach from beech litter from the upper envelope. Decomposition rate and dynamics of nutrients were monitored after 0, 60, 120, 180, 270, and 400 days with 4 replication for each treatment including: pure Norway spruce litter and combined Norway spruce litter with beech litter.

Laboratory analysis

Before analyzing for nutrients, the air-dried litter samples were oven-dried at 70ºC for 24 h. Total N was determined by the Kjeldahl digestion method (Bremner and Mulvaney, 1982). The total content of elements such as Mn, Mg, Ca, and K was measured using atomic absorption spectrometer (Issac, and Johnson, 1975). Available P was measured according to the Olsen method (Olsen and Dean, 1965). Acid-unhydrolyzable residue (AUR) (previously termed Klason lignin) was determined as the ash-free residue from the two-stage H_2SO_4 hydrolysis (Hatfield et al. 1994). The litter nutrient release was calculated as follows:

$$R_{(\%)} = \frac{W_0 C_0 - W_t C_t}{W_0 C_0} \cdot 100$$

where R is nutrient release; W_0 - the initial litter dry weight, W_t - dry weight of the remaining litter in litter bag when it was collected, C_0 - nutrient concentration (mg g^{-1}) in the initial litter, C_t - nutrient concentration (mg g^{-1}) in the remaining litter (Guo and Sims, 1999).

Statistical analysis

One-way ANOVA was used to compare the initial nutrient content of spruce and beech litter. Repeated measures ANOVA (MANOVA) was used to test the mass loss, nutrient concentration and nutrient release of spruce needles during decomposition period, followed by a set of contrasts to examine differences as affected by combination of beech litter. The stepwise regression was employed to find the best combination of chemical characteristics of litter to predict the mass loss as dependent variable.

The probability of F to entry and removal of independent variables was 0.5 and 0.10 respectively (SPSS IBM, New York, U.S.A).

Results

Initial content of nutrients

Initial concentrations of some nutrients such as Mn, Mg, Ca, and N were significantly different between the spruce needles and beech leaf litter while those of P, K, and AUR were not (table 1). As shown in table 1 the initial values of Mn, Mg, and Ca content with 0.21, 3.03, and 10.42 mg g-1, respectively were higher in beech leaf litter than in spruce litter with 0.05, 1.50, and 9.03 mg g^{-1}. In the spruce litter the initial content of N (12.84 mg g^{-1}) was higher than that in beech leaf litter (10.48 mg g^{-1}).

Nutrient concentration during decomposition

The result of repeated measures analysis (MANOVA) showed that the effect of factors including litter combination, time, and litter combination×time (table 2) were statistically

significant for N, P, K, Ca, Mg, and Mn concentration during decomposition.

The concentration of P in the spruce needles after 180 and 400 days of incubation was significantly higher in the combined needles than in the needles that were not combined (Fig. 2a). Two distinctive stages were observed in P concentration for all the litters during the monitoring time. P concentration was at the same level until day120, but increased sharply from day 180. The marginal mean (averaged across all levels) of P concentration was significantly lower (3.18 mg g^{-1}) when spruce needles decomposed alone compared to when it combined with beech litter (3.69 mg g^{-1}) (table 3). It was not significantly difference between beech litter (3.5 mg g^{-1}) and spruce needles alone or combined with beech litter.

The trend in Mn concentration of spruce needles when decomposed alone or combined with beech litter were very similar as compared to that for beech litter with higher fluctuation (Fig. 2b). The post hoc test indicated

(table 3) that the marginal mean of Mn concentration in beech litter (0.2 mg g^{-1}) was significantly higher than that in spruce needles when decomposed alone (0.07 mg g^{-1}) and combined with beech litter (0.06 mg g^{-1}).

The Mg concentration was significantly lower in spruce needles decomposing alone as compared to that combined with beech litter (Fig. 2c). In the day 60 the concentration of Mg increased both in pure spruce needles and when combined with beech litter. However the trend in Mg of beech litter was almost descending during decomposition time. Based on post hoc test (table 3) the marginal mean of Mg was significantly higher in beech litter (2.35 mg g^{-1}) compared to it in spruce needles when decomposed alone (1.31 mg g^{-1}) and when the combined spruce with beech litter (1.63 mg g^{-1}).

The decrease in K concentration was sharper at day 60 for beech litter and spruce needle compare to spruce needles combined with beech litter (Fig. 2d). The marginal mean (ta-

Table 1 Comparing the initial contents (mean ± SE) of lignin/AUR and nutrients (mg g^{-1}) of spruce (S) needles and beech (B) leaf litter using independent *t*-test. The different letters indicates statistically significant difference (p < 0.05)

Litter	P	Mn	Mg	K	Ca	N	AUR	C:N	AUR:N
S	1.27± 0.19	0.05± 0.01[b]	1.50± 0.07[b]	9.76± 0.13	9.03± 0.11[b]	12.84± 0.10[a]	292.66± 8.97	32.95± 0.11[b]	22.78± 0.55[b]
B	1.59± 0.10	0.21± 0.00[a]	3.03± 0.03[a]	9.85± 0.61	10.42± 0.42[a]	10.48± 0.01[b]	270.66± 5.20	39.76± 0.04[a]	25.81± 0.46[a]

Table 2 Repeated measures analysis of variance on the difference (*F* value) in leaf litter N, P, K, Ca, Mn, Mg, and lignin of the litter and spruce and mixture of spruce and beech

Factor	df	N	P	K	Ca	Mn	Mg	AUR
Litter mixing	2	28.68** (136.95)	1.62* (5.43)	22.69** (182.04)	71.10** (35.85)	0.14** (945.93)	6.79** (478.87)	57.42** (151.90)
Time	5	42.28** (268.44)	144.59** (462.09)	216.49** (446.81)	404.85** (71.67)	0.10** (6.91)	2.05** (60.89)	66.89** (28.48)
Time x litter mixing	10	2.89 (18.47)**	2.29** (7.27)	4.87** (10.05)	24.99* (4.42)	0.01** (4.56)	0.38** (11.46)	12.35** (5.25)

Note. The data from table represent the mean square (F value). Level of significance:*- p < 0.05; **- p < 0.01.

Table 3 The result of the Bonferroni post hoc test to compare marginal mean of nutrients.

Nutrients	Litters		
	S	B	S(S+B)
P (mg g^{-1})	3.18^b	3.50^{ab}	3.69^a
N (mg g^{-1})	14.50^b	13.47^c	15.66^a
Ca (mg g^{-1})	16.61^a	13.41^b	13.92^b
K (mg g^{-1})	2.76^c	3.22^b	4.63^a
Mn (mg g^{-1})	0.07^c	0.20^b	0.06^a
Mg (mg g^{-1})	1.31^c	2.35^a	1.63^b
AUR (mg g^{-1})	32.13^a	29.40^b	32.03^a

Note. Abbreviations: B stands for beech litter, S for spruce and S(S+B) for combined.

ble 3) of K concentration in litter combination (4.63mg g^{-1}) was significantly higher than that in beech litter (3.22 mg g^{-1}) and spruce needles (2.76 mg g^{-1}).

The general trend in Ca concentration was similar for all the litters with the concentration at its peak on day 120 (Fig 2e). The Bonferroni post hoc test indicated (table 3) that the marginal mean of Ca concentration was higher in spruce litter decomposing alone (16.61 mg g^{-1}) as compared to when combined with beech litter (13.92 mg g^{-1}) and in beech litter (13.41 mg g^{-1}). However, no significant difference of the marginal mean of Ca concentration was observed between spruce needles combined with beech litter and beech litter.

The concentration of N during decomposition period was significantly higher in spruce needles combined with beech litter than in both spruce needles not combined and beech litter (Fig. 2f). The Bonferroni post hoc test indicated that the marginal mean of N concentration in combined spruce needles with beech litter (15.66 mg g^{-1}) was significantly higher than it in non-combined spruce needles (14.50 mg g^{-1}) and beech litter (13.64 mg g^{-1}).

The trend of AUR concentration was almost the same for spruce needles when decomposed alone and combined with beech litter. It was significantly lower in beech litter up until day 180 but afterward increased sharply and stayed as the same level as in spruce needles. The post hoc test indicated (table 3) that AUR concentration was significantly lower in beech litter

(29.40 mg g^{-1}) compared to that in spruce needles both when decomposed alone (32.13 mg g^{-1}) and combined with beech litter (32.03 mg g^{-1}).

The accumulated mass loss was not significantly different between non-combined spruce needles and those combined with beech litter for the main part of the incubation period (Fig. 2h). However, on day 400 the rate of mass loss (%) in combined spruce needles with beech litter was significantly higher than it in spruce needles alone. The rate of mass loss in beech litter was significantly lower on day 180 and afterward as compared to spruce needles both combined and non-combined.

Litter nutrient release

As shown in the Fig. 3a there was a retention of N in the first steps of decomposition instead of a release. For the spruce needles combined with beech litter no N release was observed until day 270 and afterwards (Fig 3a). For the non-combined spruce needle no N release was observed only on the days 180 and 270. The effect of time, litter combination, and time ×litter combination on N release was statistically significant ($p < 0.01$) according to the results of repeated measures analysis (table 4).

There was no AUR decomposition in the first step of litter decay (Fig. 3b). The rate of AUR decomposition was increasing from the census day 180 to day 400 both for spruce needles alone or combined with beech litter.
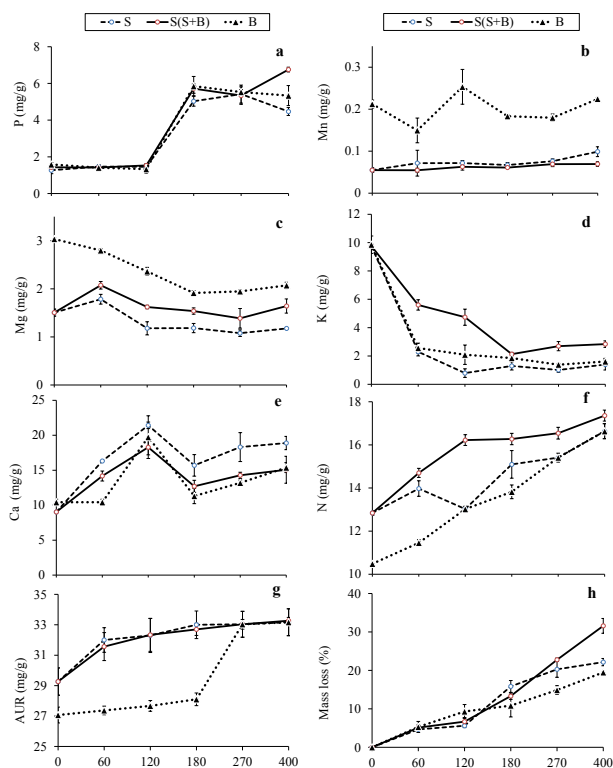
Figure 2 Litter mass loss % (h) and concentrations of the nutrients P(a), Mn(b), Mg (c), K (d), Ca (e), N (f), AUR (g) of spruce needles (S) and when mixed with beech leaf litters S(S+B)

Figure 3 Release (%) and loss of AUR% N(a), AUR (b), Mn (c) of spruce needles (S) and when mixed with beech leaf litters S(S+B) (Mean ± SE)

Different letters indicate significant difference between the mean of nutrient release, when spruce needles decomposed alone (S) and when combined with beech leaf litter (S(S+B))

However it was significantly higher in spruce needles combined with beech litter as compare to spruce needles alone in day 270 and afterwards. The results of repeated measures analysis indicated that the effect of time, litter combination, and time×litter combination on AUR release was statistically significant ($p < 0.01$) (table 3).

No Mn release was observed in spruce needle when decomposed alone (Fig. 3c). While Mn release was observed for spruce needles combined with beech litter during the incubation period except for on day 120. The effect of time, litter combination and time×litter combination on Mn release was significant at $p < 0.01$ (repeated measure analysis) (table 3).

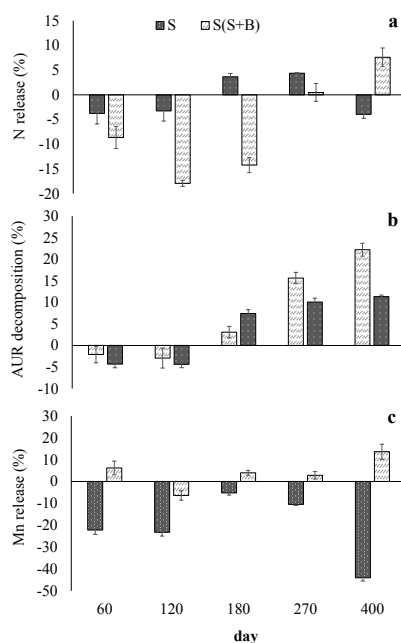According to the result of stepwise regression

N was the only initial chemical characteristic of litters that was entered to the model which could explained 37% of mass loss variation (table 5).

Discussion

Litters combination effect

The finding of our results indicated the positive no-additive effect of beech litter on spruce needles decomposition. The non-additive effects of litter mixing have been frequently reported for different species (Chapman et al. 2013). Based on this hypothesis we investigated the decomposition rates of spruce needles

Table 4 Repeated measures analysis of variance on the difference (*F* value) on release of nutrients (N, Mn and AUR) decomposition of spruce needles when decomposed alone and mixed with beech leaf litter (level of significance *p* < 0.01)

Factor	df	N	Mn	AUR
Litter mixing	1	353.90[**] (52.92)	6289.06[**] (1545.24)	99.82[**] (18.00)
Time	5	473.88[**] (55.85)	728.28[**] (36.49)	123.69[**] (234.25)
Time x litter mixing	5	504.91[**] (59.51)	1650.11[**] (82.68)	1347.06[**] (21.50)

Table 5 Stepwise regression information for dependent variables (Mass loss %) and explanatory variables (P, Mn, Mg, K, Ca, N, AUR, C:N, and AUR:N)

Dependent Variable	Model	Adj. *R* square	*df* Reg.	*df* Res.	*MS* Reg.	*MS* Res.	Sig.
Mass Loss %	N	0.37	1	11	154.3	20.4	0.02

Note. Abbreviations: Adj. *R* square: Adjusted R square, df Reg.: degree of freedom regression, df Res.: degree of freedom residuals, *MS* Reg.: mean of square regression, *MS* Res.: mean of square residuals, Sig.: significance

in an exogenous ecosystem under the influence of nutrient leaching from oriental beech. In other words in this study the spruce needles was not mixed with beech litter but combined. Placing spruce needles and beech in a one bag but in two separate pockets allowed to precisely monitor the effect of nutrient leaching effect from beech on decomposition rates of spruce needles and nutrient dynamics.

Mass loss of litter and litter quality

When decomposed alone the accumulated mass loss of spruce needles was 22.15% after 400 days incubation. The results of Berger & Berger (2014) indicated 31% mass loss of spruce needles after one year. Having the lower C to N and Lignin to N ration in initial spruce needles in Hyrcanian forests did not result in a faster decomposition rate compared to the decomposition in its original ecosystem based on the report of Berger & Berger (2014). However, our results was close to the lower

range of first-year mass loss (19.4-32.8%) that Berg et al. (2000) reported along a climate transect in Sweden.

The ratios of AUR to N and C to N in spruce needles were significantly lower than in beech leaf litter. In the current study the ratio of C to N in spruce needles (32.95) and the ratio of AUR to N (22.78) was lower than the range reported by Berger & Berger (2014) for C to N ratio (53.7-58.4) and AUR to N ratio (30-32.3 mg g⁻¹). The ratios of C to N and AUR to N are of the most important traits of leaf litters explaining the most variations in decomposition rates worldwide (Gartner & Cardon, 2004; Zhang et al.2008; Talbot & Tresder, 2012). In our study although there was a significant difference of initial Mn, Mg, Ca, C to N, AUR to N and N concentration between the beech litter and spruce needles, N was the best initial chemical variable to explain variation of decomposition rate (37%). In contrast the results of Sariyildiz et al. about the decomposition rates of *Picea orientalis* and *Fagus orienta-*

lis indicated that spruce needles decomposed more rapidly than beech litters and initial lignin of litters explained most of the variation of decomposition rates. On the other hand the results of Zhang et al. (2008) indicated that a combination of litter chemical characteristics including C to N, lignin to N, lignin and N could explain over 73% of variations of decay rates worldwide. However, the finding of Berg et al. (2000) indicated the initial Mn content of spruce needles is of the most important factor controlling the site-to-site variation of decomposition rates. There are several studies demonstrating that decomposition rate is controlled not only by litter quality but also by an interaction of climate and substrate quality and microbial community (Silver & Miya, 2001; Zhang et al. 2008; Chapman et al. 2013; Berger & Berger, 2014).

Nutrient dynamics

The nutrient concentrations of spruce needles were significantly affected by the combination with beech leaf litter. When combined with leaf litter of oriental beech, accumulated mass loss did not increase significantly at least until 270 days after incubation. However, at the end of the incubation period (day 400) the mass loss rates of spruce needles combined with beech leaf litter was 9.4% more than in spruce needle alone. This result is consistent with the results of Berger & Berger (2014) that indicated admixing spruce needles with 50-75% beech leaf litter hastened the mass loss rates during the first year of decomposition. Therefore the second question of this study that was whether the oriental beech leaf litter hasten the decay rates when combined with spruce needles, is answered.

The increasing of N concentration in spruce needles both when decomposed alone and combined with beech leaf litter is comparable with the results of previous studies. The results of Alber et al. (2004) indicated that N was accumulated during the first year of decomposition that supports our findings. The

immobilization of N during the first stage of decomposition is the reason of N accumulation (Aber et al. 1990). In our results the initial N content in spruce needles was higher than in the beech leaf litter and the accumulation of N was higher when spruce needles combined with beech leaf litter. However, the N release of spruce needles was higher than it when combined with beech leaf litter. The possible N transfer from beech leaf litter to spruce needles can be explain the changes of N concentration and release in spruce needles when combined with beech litter which is supported by the results of previous studies (Zhang et al. 2014). In the first stages of decomposition the releasing of N can positively affect litter decomposition rates. In other words, the more N release in spruce needles, the more mass loss occur (Berg & McClaugherty, 2008)

The pattern of P concentration varied with time. In our result we observed two stages of P concentration. In the first stage (up to day 120) the concentration of P was low compared to the second stage (days 180-400) that was remarkably increased. There are different reports about P content indicating both release and fixation of P in the first stages of leaf litter decomposition for various species (Titus & Malcolm, 1999; Berg & Laskowski, 1997). In our study the increasing P content after 400 days when spruce needles combined with beech leaf litter is consistent with the results of Berger & Berger (2014) indicated generally the remaining P content of spruce needles increased in the first year of decomposition when combined with beech leaf litter compare to when spruce needles decomposed alone.

The decreasing of K concentration during decomposition period indicated its rapid leaching when spruce needles decompose alone and combined with beech leaf litter. However, a negative non-additive effect of beech leaf litter combination was observed. K is a highly mobile cation that rapidly leaches out from the foliage (Laskowski et al. 1997). Our finding is consistent with the results of Titus & Malcolm (1999) about Sitka spruce needles that indicat-

ed a rapid exponential decrease of K content in the first year with approximately 80% lost. Berger & Berger (2014) observed no decrease in K content of spruce needles when mixed with beech leaf litter (with portion 50% and 50%) in the pure spruce stand in the first year.

Unlike to Ca, the Mg concentration of spruce needles was increased when combined with the beech leaf litter during the decomposition. The study of Berger & Berger (2014) indicated that when spruce needles mixed with beech leaf litter (with portion 50%) the concentration of Mg and Ca in spruce needles decreased more than when the spruce needles decomposed alone after one year of decomposition in the spruce stand. Our finding indicated a positive non-additive effect of beech leaf litter combining on Mn release of spruce needles. Berg et al. (2000) reported that the lignin concentration can be regulated by the concentration of Mn.

The third question of this study that was whether the nutrient concentration and release differs when spruce litter decomposed individually or combined with beech leaf litter is answered. The brief answer is that the combining beech leaf litter to spruce needles increased the concentration of the nutrients such as N, Mg, P and K. While the concentration of the other nutrients such as Ca and Mn and as well as AUR was not affected by the combining beech leaf litter during decomposition period.

Conclusions

Our findings indicated that the combining Norway spruce needles with beech litter can drive non-additive effect on decomposition and nutrients dynamic. The mass loss rate of Norway spruce needles can be increased by combining them with beech litter. The main conclusion of this study is that combining the Norway spruce plantations with oriental beech in the Hyrcanian forests can result in better regulating of spruce needles decomposition and nutrients cycle.

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