

LITTER DECOMPOSITION OF *Acacia caven* (Molina) Molina AND *Lolium multiflorum* Lam. IN MEDITERRANEAN CLIMATE ECOSYSTEMS

Ingrid Martínez G.¹, Erick Zagal V.^{1*}, Carlos Ovalle M.², Marie-Madeleine Coûteaux³, Neal B. Stolpe¹, and Natalia Valderrama V.⁴

ABSTRACT

The ecosystems of the Mediterranean interior dryland of Chile, dominated by an espinal agroecosystem of *Acacia caven* (Molina) Molina, show low productivity as a result of soil degradation. The objective of this study was to evaluate litter decomposition of *A. caven* and *Lolium multiflorum* Lam. in espinal ecosystems: well preserved (Wp) 50 to 80%, typical (Pd) 25 to 50%, and degraded (De) with 10 to 25% cover. During 420 d and starting in April 2004 until August 2005, weight loss in litter bags and chemical composition (hemicellulose, cellulose, lignin, non-structural components, ash, N, C, C/N ratio, and P) were determined by using near infrared reflectance spectroscopy (NIRS) and the Van Soest protocol. Weight loss ranged from 31 to 52% in *L. multiflorum* and 26 to 40% in *A. caven* after 420 d. During the chemical decomposition process of *L. multiflorum*, cellulose degradation was relevant in the labile phase while lignin was important in the recalcitrant phase. On the other hand, non-structural components and cellulose were degraded in the labile phase and lignin in the recalcitrant stage for *A. caven*. Moreover, both litters improved N concentration during the decomposition process. Espinal ecosystems with higher canopy cover (Pd and Wp) had a positive influence, and showed early effects during the decomposition process, especially in the De espinal ecosystem, probably because of the microenvironmental conditions it generated. A better knowledge of the dynamics of litter decomposition in ecosystems was achieved by using both techniques: litter bags and NIRS.

Key words: canopy cover, weight loss, litter bags, NIRS, principal components.

INTRODUCTION

The *Acacia caven* (Molina) Molina espinal (Ovalle *et al.*, 1990) is the most important silvopastoral ecosystem in central southern Chile. This species is drought-tolerant with a great recovery ability and good root development (Aronson *et al.*, 2002). Studies have indicated that areas with greater hawthorn hedge cover (around 80%) are more humid during the hot months, and more vegetation grows in this microenvironment due to lower temperature oscillation. The influence of greater canopy cover increases

the herbaceous biomass under it, soil organic C (SOC), and soil N thus increasing available moisture for plants (Ovalle *et al.*, 2006; Muñoz *et al.*, 2007a). Fresh or partially decomposed litter as a source of organic matter (OM) in degraded ecosystems is positive for restoring them given the increase of biological activity generating conditions for increased productivity and species biodiversity, and helping ecosystem rehabilitation, elasticity, or resilience to natural alterations such as drought (Ovalle *et al.*, 2006; Verdoodt *et al.*, 2009).

Litter decomposition rate, measured by weight loss, is a well-studied physical parameter; however, it should be complemented with studies of changes in distinct C fractions (Melillo *et al.*, 1989). There are three fractions in the chemical decomposition of OM: easily decomposed labile fraction corresponding to rapidly degraded carbohydrates and proteins; structural material with slower decomposition made up of cellulose and hemicellulose which are the most abundant in litter; and resistant material with a high lignin and polyphenol content considered as one of the most relevant fractions and most resistant to degradation (Fioretto *et al.*, 2005; Berg and Laskowski, 2006). Microbial activity plays

¹Universidad de Concepción, Facultad de Agronomía, Av. Vicente Méndez 595, Chillán, Chile. *Corresponding author (ezagal@udec.cl).

²Instituto de Investigaciones Agropecuarias INIA, Casilla 246, Chillán, Chile.

³Centre National de la Recherche Scientifique, Centre d'Ecologie Fonctionnelle et Evolutive, 1919 Route de Mende, Montpellier Cedex 5, France.

⁴Universidad de Concepción, Facultad de Ingeniería Agrícola, Av. Vicente Méndez 595, Chillán, Chile.

Partial results of this research were presented in VI Congreso Internacional de Ingeniería Agrícola. Chillán, Chile. Enero 2009.

Received: 22 April 2009.

Accepted: 04 September 2009.

an important role in OM decomposition, as well as in nutrient immobilization and mineralization affected by microclimatic conditions (Ritter and Bjørnlund, 2005). Helped by moisture and temperature, litter decomposition in Mediterranean ecosystems temporarily increases (van Meeteren *et al.*, 2008). Initial litter N content is important in decomposition since it regulates the first phase (Su *et al.*, 2004), lignin concentration is more important in advanced stages with a lower response to temperature changes partly explained by the fact that litter decomposition is more rapid at the beginning (van Meeteren *et al.*, 2008).

Litter bags are a technique used to study decomposition processes where plant material is incubated and monitored over time. Although this method creates a microenvironment, it is easily used to study the dynamics of decomposition in samples of known initial weight which can be recovered in field conditions (McTiernan *et al.*, 2003; Berg and Laskowski, 2006).

Near infrared reflectance spectroscopy (NIRS) is an analytical technique that allows determining chemical constituents in different plant tissues and in the soil with a wide range of concentrations (Gillon *et al.*, 2004; Coûteaux *et al.*, 2005; Schimann *et al.*, 2007). The NIRS technique is rapid and non-destructive with exact and reproducible measurements of chemical components in organic materials (McTiernan *et al.*, 2003).

Few studies have compared the effect of tree or canopy cover on litter decomposition processes in Mediterranean ecosystems which allow evaluating rehabilitation practices where decomposition is fundamental in the nutrient cycle. These processes are influenced by the climatic regulation of shrub-tree canopy cover and the quality of organic material of Chilean Mediterranean espinals. The objectives of this study were to investigate *in situ* decomposition of distinct origin materials with litter bags, such as *Acacia caven* and *Lolium multiflorum* Lam. in ecosystems with three shrub-tree canopy cover densities, and evaluate the chemical transformations of material during the degradation process using NIRS.

MATERIALS AND METHODS

Experimental site and assay description

The study was carried out in the Cauquenes Experimental Centre of Instituto de Investigaciones Agropecuarias INIA (35°78' S; 72°20' W) located in the interior dryland of the Maule Region. The climate is sub-humid Mediterranean with an annual precipitation of 695 mm. Annual mean temperature is 14.7 °C with a minimum mean of 4.7 °C and a maximum of 27 °C (Del Pozo and Del Canto, 1999). Soils are Alfisols of the Cauquenes and Maule series which have been classified as Ultic Haploxeralfs and Ultic Palexeralfs, respectively (CIREN,

1994; Stolpe, 2006). Ecosystems of low tree density espinals showed pH of 5.10 and 1.4% organic C content while those with greater canopy cover showed pH of 6.1 and 1.9% organic C. Ecosystems were representative of the area and classified according to hawthorn hedge cover density: degraded espinal (De) with 10 to 25%, typical espinal (Pd) with 25 to 50%, and well preserved espinal (Wp) with 50 to 80% canopy cover. Decomposition of two litters was compared, a leguminous shrub *A. caven* and an annual grass, Italian ryegrass (*L. multiflorum*). These were put into litter bags (12 cm x 20 cm x 2 mm) in 1-m high cages to prevent damage by grazing animals during the experiment. *Acacia caven*, 5 g (dry weight) and 10 g of *L. multiflorum* were put separately in the bags. A total of 720 litter bags were needed for two types of litter, three ecosystems with two replicates for each one, and six sampling dates. The experiment started in May 2004 and samples were collected after 60, 120, 180, 250, 330, and 420 d. A total of 120 bags were randomly selected on each sampling date (10 bags from each site and type of material). Samples were manually cleaned of soil contamination with the help of a magnifying glass, oven-dried for 48 h at 55 °C to determine dry weight of residual material, ground to 1 mm (Cyclotec, Perstop Analytical, Höganäs, Sweden), and stored in plastic bags for chemical analysis.

NIRS prediction equations

Prediction equations were developed based on a European program TROPANDES (Coûteaux *et al.*, 2006) which included material similar to the study and where more than 3500 samples in decomposition were scanned by NIRS (NIR Systems 6500, Perstorp Analytical, Silver Spring, Maryland, USA) (Coûteaux *et al.*, 2005). Spectra of this study were compared with spectra selected in TROPANDES. Extreme spectra (Mahalanobis distance > 3) were considered distant and excluded. The most representative samples were then selected by eliminating similar spectra (Mahalanobis distance < 0.6). The Van Soest protocol (Van Soest and Robertson, 1985) was applied to the selected samples to determine hemicellulose, cellulose, lignin content, as well as non-structural components.

Chemical analysis of plant material

The Van Soest technique was applied to the decomposed material to determine neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) with successive digestions of neutral and acid detergents with the ANKOM^{200/220} fiber analyzer (ANKOM Technology, Fairport, New York, USA). Approximately 1 g of plant material was weighed in F57 filter bags

(ANKOM Technology Corporation, Fairport, New York, USA) to obtain three types of fiber residues. The samples of each digestion were then oven-dried for 48 h. NDF is the structural residue that includes hemicellulose (NDF-ADF), cellulose (ADF-ADL), lignin (ADL), and non-structural components (100-NDF) (McTiernan *et al.*, 2003). Ash content was determined by calcination at 660 °C for 6 h.

Total C and N, and C/N ratio were quantified by dry combustion with an elemental analyzer (Vario MAX CNS, Elementar, Elementar Analysensysteme GMBH, Hanau, Germany). Colorimetry was applied to determine P (Colorimeter Helios Epsilon, Unicam, Berlin, Germany) (Sadzawka, 2006).

In the original incubation material, phenols were measured with a portable digital colorimeter (DR/890, HACH Company, Loveland, Colorado, USA), as well as the previously mentioned components (Table 1).

Statistical methodology

Mass loss (ML) was controlled by two reservoirs: reservoir A corresponding to the initial weight percentage made up of a labile fraction of rapid decomposition over time t (days) with rate k (d^{-1}), a recalcitrant reservoir B that does not decompose and is accumulated and which responds to an asymptotic model: $RW = Ae^{-kt} + B$ where $A + B = 100$. This model is well-adjusted to initially high decomposition (Dalias *et al.*, 2001; Berg and Laskowski, 2006).

Relationships between analyzed variables were established through principal component analysis (PCA) and correlation coefficients ($p < 0.05$). ANOVA was carried out ($p < 0.01$) by the STATISTICA version 6 program (Stat Soft, 2000) to determine the influence of ecosystem covers (E), incubation time (T), and their interaction (E x T) on the decomposition of *A. caven*.

RESULTS AND DISCUSSION

Effect of canopy cover on decomposition

At the end of the measurement period of plant material decomposition, residue was quantified as RW. Final ML in litter decomposition after 14 m did not show any differences for *A. caven* among the distinct canopy covers while the Wp-S2 ecosystem was different from the rest of the ecosystems for *L. multiflorum*. Weight loss as a percentage of initial weight fluctuated between 26 and 40% in *A. caven*, and 31 and 52% in *L. multiflorum* at the end of the study period (Table 2). Decomposition rate (k) in both conditions gave similar results for the three canopy covers. However, the model was not appropriate in *A. caven* for the De-S2 and Pd-S1 ecosystems since the analysis shows that reservoir A is greater than 100 (Table 2) and a constant weight loss is observed for these ecosystems (Figure 1). This can be explained by the heterogeneity of the incubated material, fact which is not observed for *L. multiflorum* since the model did not show this variability. The model used could explain between 54 and 68% of the experimental values determined in *A. caven*, and 69 and 87% in *L. multiflorum*. Despite the results, it was possible to observe a canopy cover effect trend, especially in *L. multiflorum* where reservoir A (Table 2) increases with canopy cover. These differences in litter weight loss are probably due to the interaction of various factors such as initial N content (0.41 in *L. multiflorum* and 1.83% in *A. caven*), an abundance of lignin and phenols in *A. caven* (28% and 53 mg g^{-1} , respectively), and recalcitrant fractions delaying organic matter degradation which are considered as the most important factors in the decomposition process (Berg and Laskowski, 2006).

Table 1. Litter chemical composition before field incubation.

	<i>Acacia caven</i>	<i>Lolium multiflorum</i>
Fiber and other fractions		
Cellulose, %	15 ± 0.09	37 ± 1.22
Hemicellulose, %	20 ± 0.65	31 ± 0.69
Lignin, %	28 ± 0.29	7 ± 0.24
Non-structural compounds (NS), %	37 ± 0.35	25 ± 1.57
Ash, %	7 ± 0.08	8 ± 0.18
Phenols, mg g^{-1}	53.0 ± 0.01	9.5 ± 1.11
Nutrient concentration		
N, %	1.83	0.41
C, %	45.14	39.80
C/N ratio	25	97
P, %	0.06	0.05

± standard deviation.

Table 2. Decomposition rate (k) and weight loss (A) at 420 days for *Acacia caven* and *Lolium multiflorum* litter.

Ecosystem	<i>Acacia caven</i>			<i>Lolium multiflorum</i>		
	k	A	R ²	k	A	R ²
	g d ⁻¹	%		g d ⁻¹	%	
De - S1	0.0065 ± 0.0016 ns	33.44 ± 3.31	0.61	0.0139 ± 0.0026 b	30.71 ± 1.38	0.69
De - S2	0.0006 ± 0.0014 ns	115.70 ± 242.50 ¹	0.53	0.0047 ± 0.0008 b	40.04 ± 3.56	0.82
Pd - S1	0.0012 ± 0.0010 ns	77.49 ± 53.06 ¹	0.68	0.0150 ± 0.0022 b	34.00 ± 1.15	0.78
Pd - S2	0.0162 ± 0.0035 ns	25.85 ± 1.19	0.66	0.0118 ± 0.0013 b	41.57 ± 1.25	0.86
Wp - S1	0.0030 ± 0.0014 ns	39.81 ± 11.42	0.54	0.0065 ± 0.0011 b	42.67 ± 2.84	0.78
Wp - S2	0.0429 ± 0.0229 ns	32.09 ± 1.29	0.62	0.0129 ± 0.0014 a	52.11 ± 1.38	0.87

De: degraded ecosystem; Pd: typical ecosystem; Wp: well preserved ecosystem; S1: site 1; S2: site 2; ± standard deviation; R²: regression coefficient; ns: non significant.

Values with the same letters in the columns are not significant according to Tukey test ($p < 0.05$).

¹This value indicates the applied model is not adequate for this site and condition since $A > 100$.

The decomposition process was faster at the beginning (0-120 d), especially in *L. multiflorum* because of the decomposition of the labile fraction (Figure 1). The presence or accumulation of recalcitrant material in *A. caven* revealed a slower decomposition phase in Mediterranean ecosystems (Reichstein *et al.*, 2002; Su *et al.*, 2004).

Similar studies developed in dense Mediterranean ecosystems showed differences in decomposition after 18 m of litter field incubation (Fioretto *et al.*, 2003). Kim *et al.* (1996) found greater litter decomposition in ecosystems with greater canopy cover in forestry systems after 2 years of study. Although weight loss was not significant among ecosystems in our study, the observed trend shows that as canopy cover increases, weight loss also increases. Thus, determining only weight loss could not be established as an efficient indicator of the litter degradation process during the study period, and it is better to complement these evaluations with chemical parameters that better explain these changes over time.

Chemical transformations of plant material during degradation process

***Acacia caven*.** Principal component analysis determined that the first two components (PC1 and PC2) explained 53% of total variability, and increased to 68% when the third component (PC3) was included. These three components were selected to analyze the study variables (Table 3). The highest positive correlations for PC1 were found in cellulose content ($r = 0.78$), C ($r = 0.75$), and C/N ratio ($r = 0.67$), whereas high negative correlations for ash ($r = -0.76$) and non-structural components ($r = -0.73$) were observed. There was a lower negative correlation with the weight loss variable ($r = -0.51$) indicating that the litter decomposition process was associated more to the interaction of structural and nutritional variables than to the

physical loss of plant material. High negative correlations for PC1 suggest that there was rapid degradation of labile material during the initial decomposition process (Table 3, Figure 1) due to the fact that these easily degraded compounds are more accessible to microbial attack or lixiviation (Bernhard-Reversat, 1999).

The main constituent of the cell wall of *A. caven* in its initial stage were non-structural components with a value of 37% (Table 1), the velocity of litter decomposition is associated with climatic conditions favoring the activity of soil microbial biomass as moisture—in Mediterranean ecosystems particularly associated with precipitation events—(Figure 1) and temperature. As decomposition advances, new and easily degradable soluble components are formed, such as holocellulose (cellulose + hemicellulose) and lignin (McTiernan *et al.*, 2003; Berg and Laskowski, 2006) to increase non-structural components (PC3, $r = 0.61$). The 20% variance explained by PC2 was positively correlated with N from the residual material ($r = 0.91$) and associated with the concentration increase during the decomposition period (Berg and Laskowski, 2006). Finally, PC3 explained 15% of the variability where lignin showed a negative correlation ($r = -0.55$), and indicated lower transformation of recalcitrant materials, thus demonstrating its resistance to microbial decomposition (Martínez-Yrizar *et al.*, 2007).

It is possible to distinguish a wide variable dispersion in the first component (PC1), but most observations were located in the positive axis in the second component (PC2) (Figure 2). It was observed that weight loss was negatively correlated with the C/N ratio, as well as with C content and ash. The C/N ratio in litter decomposition studies decreases during the degradation process because of C-CO₂ loss associated with the metabolism of soil microorganisms while N (organic) concentration increases in the residual material (Coûteaux *et al.*, 1998; McTiernan

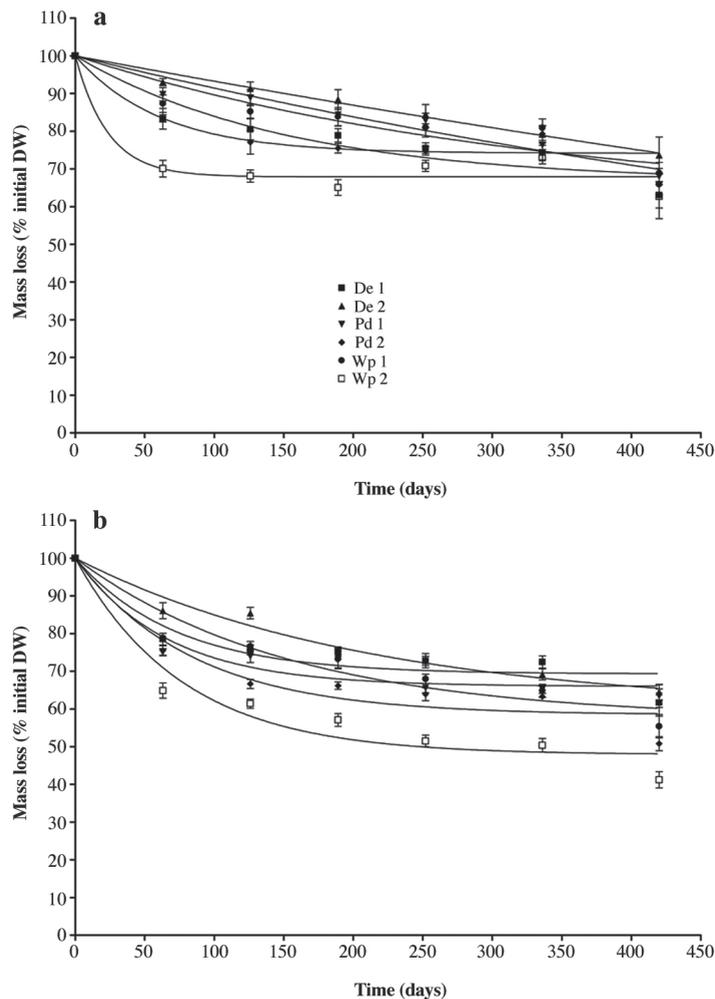


Figure 1. Weight loss as a percentage of initial weight for *Acacia caven* and *Lolium multiflorum* in a degraded ecosystem (De), typical ecosystem (Pd), and well preserved ecosystem (Wp). Vertical bars indicate standard deviation; $n = 10$; ($p < 0.05$).

et al., 2003), dynamics also observed in PC2 for N and C/N ratio (Table 3). The content of P, hemicellulose, and lignin did not show high correlations with the rest of the variables.

The influence of ecosystems (E), time (T), and their interaction (E x T) during the decomposition process with the study variables was evaluated by ANOVA for each principal component (PC1, PC2, and PC3). Analysis detected significant differences for E, T, and their interaction ($p < 0.01$) for the PC1 and PC3 components. The Wp ecosystem exhibited the transformation of chemical components for PC1 (Figure 3a) in the initial phase (0-120 d) and at the end of the decomposition process (330-420 d). On the other hand, Pd and De ecosystems exhibited component transformations into the final period (250 and 330 d, respectively). Transformations in PC3 (Figure 3b) plant material were more marked and similar

for the three ecosystems in the initial phase (0-120 d) of the decomposition process; Pd showed dynamics distinct from the other ecosystems in the rest of the period. Analysis for PC2 produced significance for E and T, but not for their interaction (E x T) which is mainly associated to N content ($r = 0.91$) and indicated a significant increase (Figure 4) of this nutrient 60 d after the material was incubated in the field.

***Lolium multiflorum*.** Principal component analysis determined that the first two components (PC1 and PC2) explained 50% and when third (PC3) was included, it increased to 80% (Table 3). The higher positive correlations for PC1 were for weight loss ($r = 0.84$), N ($r = 0.82$), ash ($r = 0.81$), lignin ($r = 0.79$), and non-structural components ($r = 0.53$), whereas negative correlations were observed for the C/N ratio

Table 3. Correlation matrix of principal components for *Acacia caven* and *Lolium multiflorum*.

Variables	<i>Acacia caven</i>			<i>Lolium multiflorum</i>		
	PC1	PC2	PC3	PC1	PC2	PC3
Weight loss	-0.51	0.52	-0.23	0.84	0.32	0.04
Fiber and other fractions						
Cellulose	0.78	-0.02	-0.18	-0.75	0.56	0.22
Hemicellulose	0.29	0.10	-0.32	0.00	-0.45	0.82
Lignin	0.26	0.27	-0.55	0.79	0.31	0.17
Non-structural components	-0.73	-0.21	0.61	0.53	-0.48	-0.69
Nutrient concentration						
Nitrogen	0.16	0.91	0.17	0.81	-0.48	0.14
Carbon	0.75	0.36	0.43	0.82	0.50	-0.08
C/N Ratio	0.67	-0.55	0.34	-0.74	0.24	-0.32
Phosphorus	-0.35	0.53	0.42	-0.91	-0.30	-0.11
Ash	-0.76	-0.22	-0.35	0.38	0.13	-0.06

PC1: first principal component; PC2: second principal component; PC3: third principal component.

($r = -0.91$), cellulose ($r = -0.75$), and %C ($r = -0.74$). These results would indicate that there was a significant increase in weight loss associated with ash content and an important degradation of structural material such as cellulose (also expressed as %C), as well as a decrease in the C/N ratio during the decomposition period. The main structural constituent for this litter was cellulose (37%) (Table 1). Magid *et al.* (2004) reported that materials with a high concentration of non-structural components and low lignin content showed a rapid decrease in cellulose content and greater decomposition, fact corroborated by

Fioretto *et al.* (2005) when they observed that materials with a cellulose concentration similar to *L. multiflorum* in this study, but with a higher lignin (18%) concentration, exhibited a more rapid initial decomposition (0 to 250 d) which steadily declined up to 18 m. With a lower lignin (7%) concentration in our study, we observed that most of the variables exhibited transformation of chemical composition, process that could be associated during the first months of incubation to precipitation in the winter months affecting lixiviation of the most soluble chemical constituents (Trofymow *et al.*, 2002; Vávřová *et al.*, 2009).

As for *A. caven*, there was an increase in N (PC1, $r = 0.82$) during the decomposition period of *L. multiflorum* which is explained by the loss of C-CO₂ associated with the metabolism of soil microorganisms while N (organic) concentration increases in the residual material (Berg and Laskowski, 2006). The high positive correlation in lignin content ($r = 0.79$; Table 3) shows the most active role of this fraction and a greater concentration in the residual material, typical of the recalcitrant phase of the decomposition process which slightly influences the increase of material decomposition velocity in more advanced decomposition stages.

The variance ratio explained by PC2 was 16% and had a greater correlation with cellulose ($r = 0.56$), whereas PC3 was 14% with a high positive correlation for hemicellulose ($r = 0.82$) and a negative correlation for non-structural components ($r = -0.69$). Hemicellulose in this litter was the second constituent with the highest concentration, 31% content (Table 1), which coincides with results obtained by Luxhøi *et al.* (2002) in distinct species with values fluctuating between 16 and 41%. It is difficult to degrade both

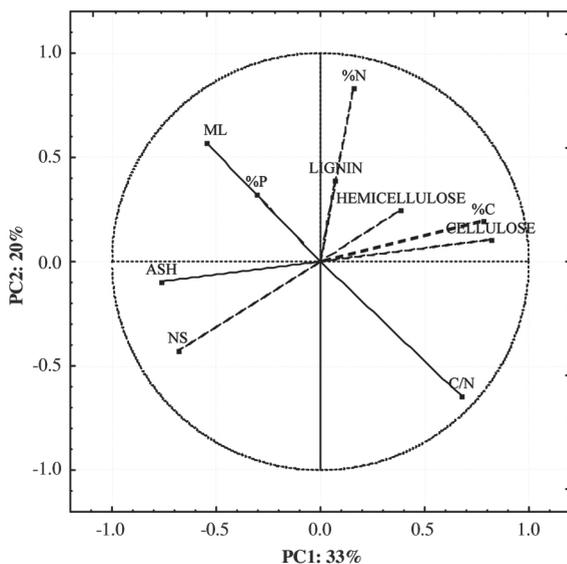


Figure 2. Two-dimensional graph for PC1 and PC2 of *Acacia caven* litter with the variables under study. ML: mass loss.

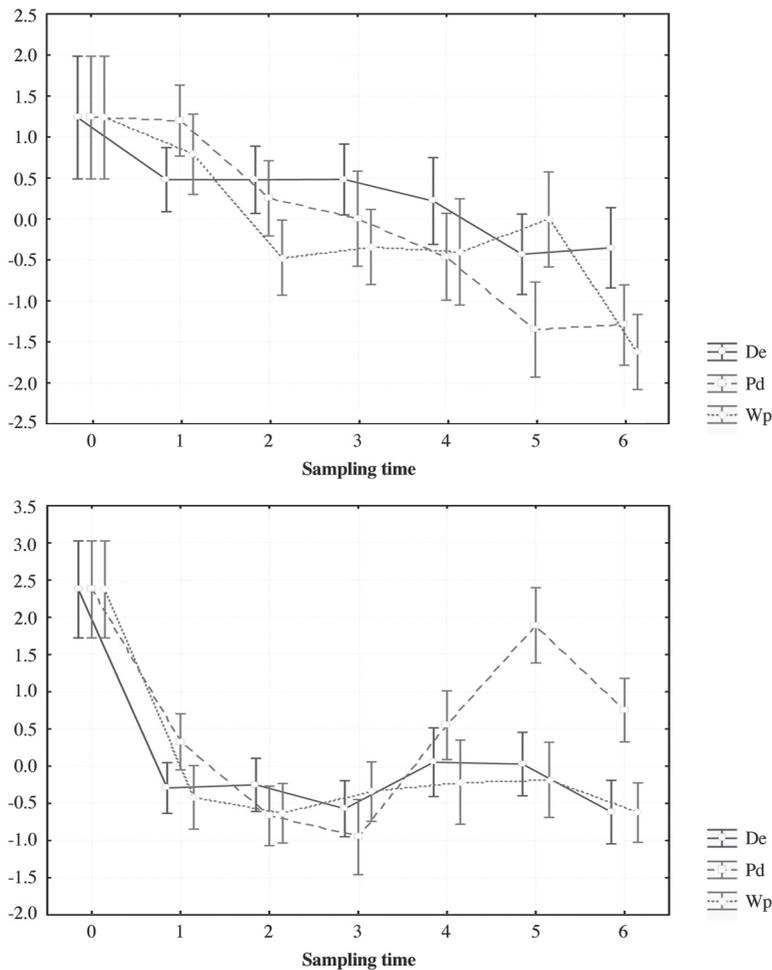


Figure 3. ANOVA ($p < 0.001$) for PC1 (a) and PC3 (b) factors for *Acacia caven*. De = degraded, Pd = typical, and Wp = well preserved. Time 0 = initial stage of material. Time 1, 2, 3, 4, 5, and 6 = 60, 120, 180, 250, 330, and 420 d, respectively.

hemicellulose and lignin; however, the lignin fraction appears as the principal recalcitrant component controlling the decomposition process after the initial phase. Figure 5 shows the results for PC1 and PC2 where most of the observations were accumulated in the axes extremes for the first component, though hemicellulose stands out for its distinct value and is not correlated with PC1 or negatively correlated with PC2. Observations for the second component were concentrated in the central axis, thus demonstrating a low correlation between variables.

Influence of chemical composition and ecosystems on decomposition

During the decomposition process, *A. caven* was controlled by non-structural component degradation in the labile phase, by cellulose content, and to a lesser degree, lignin in the recalcitrant phase (Table 3). Both high N content and high C/N ratio suggest influence in the initial

decomposition phase although a high lignin concentration (Table 1) could be related to a large proportion of recalcitrant N (Berg, 1986). The labile phase for *L. multiflorum* was controlled by cellulose degradation, by lignin, and to a lesser degree, hemicellulose in the recalcitrant phase (Table 3), results coinciding with those found by Magid *et al.* (2004).

The first decomposition phase took place during the rainy months, indicating that it was regulated for climatic conditions and a decrease in decomposition velocity during the dry season for both species (Figure 1). The alternation of wet and dry seasons in Mediterranean zones is what most influences biological activity and litter decomposition (Fioretto *et al.*, 2007). Other authors conclude that litter decomposition is selective and would be linked to the quality of the substrate (Coûteaux *et al.*, 1995). Canopy cover in Mediterranean conditions has a positive effect on litter decomposition (García-Pausas *et al.*, 2004; Su *et al.*, 2004).

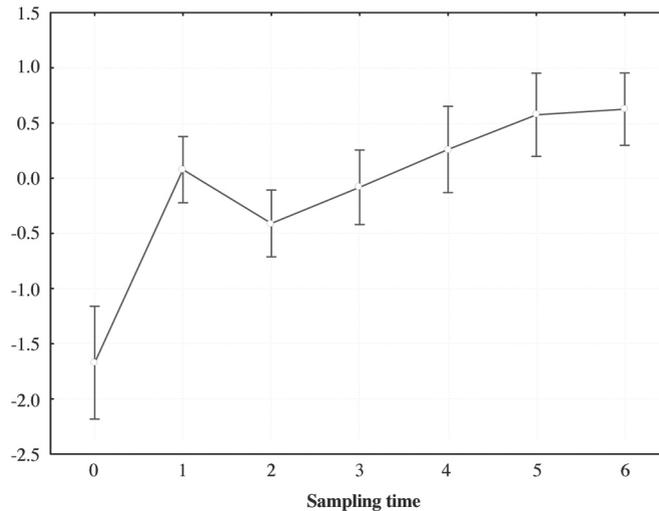


Figure 4. ANOVA ($p < 0.001$) PC2 factor for *Acacia caven*. Time 0 = material in initial stage. Time 1, 2, 3, 4, 5, 6 = 60, 120, 180, 250, 330, and 420 d, respectively.

Microenvironmental conditions in well preserved ecosystems increase nutrient concentration as compared to ecosystems that are degraded or surrounded by bare areas (Ovalle and Avendaño, 1988; Carrera *et al.*, 2009; Ovalle *et al.*, 2006). An ecosystem with greater canopy cover decreases element loss, protecting nutrients liberated in the decomposition (Babbar and Ewel, 1989) so that the combination of litter chemical characteristics and the degree of cover had a positive influence on the chemical and physical transformations of each material.

Dynamics similar to those reported in this study suggest that water in the soil and climate are relevant factors in the transformation of chemical constituents during litter decomposition (McTiernan, 2003). These factors also have an influence on landscape heterogeneity and on characteristics such as OM, N, and P as a consequence of the direct relationship between aerial biomass, canopy cover, and the generated microclimate, all of which would also contribute to soil fertility (Ovalle and Avendaño, 1988; Ovalle *et al.*, 2006; Muñoz *et al.*, 2007b).

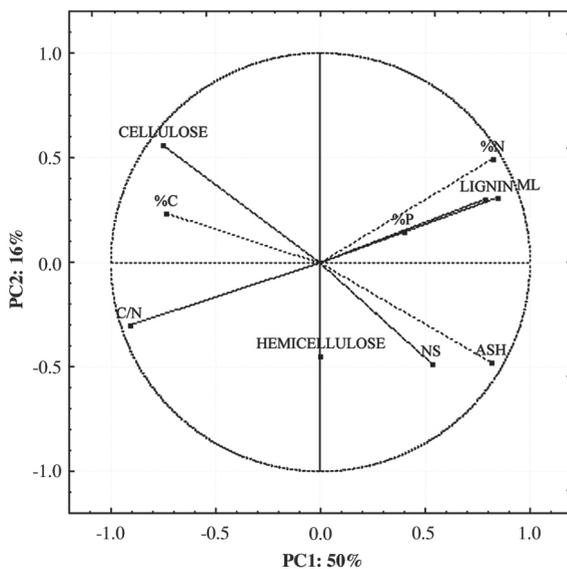


Figure 5. Two-dimensional graph for *Lolium multiflorum*, correlations of PC1 and PC2 principal components with each variable under study.

CONCLUSIONS

Decomposition of organic material in espinal ecosystems in Mediterranean Chile was influenced by the material chemical composition. *Lolium multiflorum* had a higher weight loss during the study period and the decomposition process was controlled by cellulose degradation in the labile phase, by lignin, and to a lesser extent, by hemicellulose in the recalcitrant phase. On the other hand, for *A. caven*, decomposition in the labile phase was controlled by non-structural component degradation, by cellulose, and to a lesser degree, by lignin content in the recalcitrant phase. Canopy cover showed a positive effect on decomposition. The highest decomposition velocity coincided with the rainy period, whereas the lowest velocity occurred during the dry season. Better knowledge of the dynamics of plant material decomposition in ecosystems was achieved through the complementary use of the two techniques applied: quantification of weight loss with litter and quantification of chemical transformations of material by NIRS.

ACKNOWLEDGEMENTS

Research was financed by FONDECYT (Project N° 1030883), and by the Instituto de Investigaciones Agropecuarias INIA, Cauquenes Experimental Centre for its contribution of study sites, as well as support staff. The authors acknowledge the contribution of the Teresa Aravena, an agricultural technician, and the Centre National de la Recherche Scientifique, Centre d'Ecologie Fonctionnelle et Evolutive (CEFE-CNRS) in France for the stay of I. Martínez in that country, for NIRS, and Van Soest analysis.

RESUMEN

Descomposición de hojarascas de *Acacia caven* (Molina) Molina y *Lolium multiflorum* Lam. en ecosistemas de clima mediterráneo. Los ecosistemas del secano interior mediterráneo de Chile presentan una baja productividad debido a la degradación de los suelos, dominados por un agroecosistema espinal de *Acacia caven* (Molina) Molina. El objetivo de este estudio fue evaluar la descomposición de hojarascas de *A. caven* y *Lolium multiflorum* Lam., en ecosistemas espinales: densos (Wp) con cobertura de 50-80%, poco densos (Pd) 25-50% y degradados (De) 10-25%. Se determinó la pérdida de peso usando bolsas de malla, durante 420 días comenzando en abril de 2004, y la composición química del material: hemicelulosa, celulosa, lignina, componentes no estructurales, cenizas, N, C, relación C/N y P; usando espectroscopía de reflectancia en el infrarrojo cercano (NIRS). Los resultados indicaron que la pérdida de peso fue mayor en *L. multiflorum* (31-52%) que en *A. caven* (26-40%). La descomposición del material estuvo influenciada por su composición química, en *L. multiflorum* gobernada en su fase lábil por la degradación de celulosa y en su fase recalcitrante por lignina; en cambio en *A. caven* por los componentes no estructurales y celulosa en su fase lábil, y en su fase recalcitrante por lignina. Debido a la descomposición ambos materiales incrementaron su concentración de N. Los ecosistemas espinales de mayor cobertura de árboles (De y Pd) tuvieron una influencia positiva, mostrando una descomposición más temprana, especialmente en el ecosistema De, probablemente por las condiciones microambientales generadas. Un mejor conocimiento de la dinámica de descomposición de hojarascas en los ecosistemas, se logró a través del uso de las dos técnicas usadas.

Palabras clave: cobertura de árboles, pérdida de peso, bolsas de malla, NIRS, componentes principales.

LITERATURE CITED

- Aronson, J., C. Ovalle, J. Avendaño, L. Longeri, and A. Del Pozo. 2002. Agroforestry tree selection in central Chile: biological nitrogen fixation and early plant growth in six dryland species. *Agroforestry Systems* 56:155-166.
- Babbar, L., y J. Ewel. 1989. Descomposición del follaje en diversos ecosistemas sucesionales tropicales. *Biotropica* 21:20-29.
- Berg, B. 1986. The influence of experimental acidification on nutrient release and decomposition rates of needle and root litter in the forest floor. *Forest Ecology and Management* 15:195-213.
- Berg, B., and R. Laskowski. 2006. Advances in ecological research. Litter decomposition: A guide to carbon and nutrient turnover. 421 p. Vol. 38. Elsevier Academic Press, San Diego, California, USA.
- Bernhard-Reversat, F. 1999. Changes in relationships between initial litter quality and CO₂ release during early laboratory decomposition of tropical leaf litters. *European Journal of Soil Biology* 34:117-122.
- Carrera, A.L., M.J. Mazzarino, M.B Bertiller, H.F. del Valle, and E.M. Carretero. 2009. Plant impacts on nitrogen and carbon cycling in the Monte phytoecogeographical Province, Argentina. *Journal of Arid Environments* 73:192-201.
- CIREN. 1994. Estudio agrológico. VII Región. Descripción de suelos, materiales y símbolos. Publicación N° 117. 660 p. Centro de Información de Recursos Naturales (CIREN), Santiago, Chile.
- Coûteaux, M.M., P. Bottner, and B. Berg. 1995. Litter decomposition, climate and litter quality. *Tree* 10:63-66.
- Coûteaux, M.M., D. Hervé, and S. Beck. 2006. Decomposition of plant litter and roots in a long fallow system (Bolivian Altiplano). *Ecología en Bolivia* 41:85-102.
- Coûteaux, M.M., K.B. McTiernan, B. Berg, D. Szuberla, P. Dardene, and P. Bottner. 1998. Chemical composition and carbon mineralization potential of Scots pine needles at different stages of decomposition. *Soil Biology & Biochemistry* 30:583-595.
- Coûteaux, M.M., L. Sarmiento, D. Hervé, and D. Acevedo. 2005. Determination of water-soluble and total extractable polyphenolics in biomass, necromass and decomposing plant material using near-infrared reflectance spectroscopy (NIRS). *Soil Biology & Biochemistry* 37:795-799.
- Dalias, P., J.M. Anderson, P. Bottner, and M.M. Coûteaux. 2001. Long-term effects of temperature on carbon mineralisation processes. *Soil Biology & Biochemistry* 33:1049-1057.

- Del Pozo, A., y P. Del Canto. 1999. Áreas agroclimáticas y sistemas productivos en la VII y VIII Regiones. Instituto de Investigaciones Agropecuarias (INIA), Centro Regional de Investigación Quilmapu, Chillán, Chile.
- Fiorotto, A., C. Di Nardo, S. Papa, and A. Fuggi. 2005. Lignin and cellulose degradation and nitrogen dynamics during decomposition of three leaf litter species in a Mediterranean ecosystem. *Soil Biology & Biochemistry* 37:1083-1091.
- Fiorotto, A., S. Papa, and A. Fuggi. 2003. Litter-fall and litter decomposition in a low Mediterranean shrubland. *Biology and Fertility of Soils* 39:37-44.
- Fiorotto, A., S. Papa, A. Pellegrino, and A. Fuggi. 2007. Decomposition dynamics of *Myrtus communis* and *Quercus ilex* leaf litter: Mass loss, microbial activity and quality change. *Applied Soil Ecology* 36:32-40.
- García-Pausas, J., P. Casals, and J. Romanya. 2004. Litter decomposition and faunal activity in Mediterranean forest soil: Effects of N content and the moss layer. *Soil Biology & Biochemistry* 36:989-997.
- Gillon, D., F. Dauriac, M. Deshayes, J.C. Valette, and C. Moro. 2004. Estimation of foliage moisture content using near infrared reflectance spectroscopy. *Agricultural and Forest Meteorology* 124:51-62.
- Kim, C., T.L. Sharik, and M.F. Jurgensen. 1996. Canopy cover effects on mass loss and nitrogen and phosphorus dynamics from decomposing litter in oak and pine stands in northern Lower Michigan. *Forest Ecology and Management* 80:13-20.
- Luxhøi, J., J. Magid, D. Tscherko, and E. Kandeler. 2002. Dynamics of invertase, xylanase and coupled quality indices of decomposing green and brown plant residues. *Soil Biology & Biochemistry* 34:501-508.
- Magid, J., J. Luxhøi, and O. Lyshede. 2004. Decomposition of plant residues at low temperatures separates turnover of nitrogen and energy rich components in time. *Plant and Soil* 258:351-365.
- Martínez-Yrizar, A., S. Núñez, and A. Búrquez. 2007. Leaf litter decomposition in a southern Sonoran Desert ecosystem, northwestern Mexico: Effects of habitat and litter quality. *Acta Oecologica* 32:291-300.
- McTiernan, K., M. Coûteaux, B. Berg, M. Berg, R. Calvo de Anta, A. Gallardo, *et al.* 2003. Changes in chemical composition of *Pinus sylvestris* needle litter during decomposition along a European coniferous forest climatic transect. *Soil Biology & Biochemistry* 35:801-812.
- Melillo, J.M., J.D. Aber, A.E. Linkins, A. Ricca, B. Fry, and K.J. Nadelhoffer. 1989. Carbon and nitrogen dynamics along the decay continuum: plant litter to soil organic matter. *Plant and Soil* 115:189-198.
- Muñoz, C., E. Zagal, and C. Ovalle. 2007a. Distribution of soil organic carbon stock in an Alfisol profile in Mediterranean Chilean ecosystems. *Revista de la Ciencia del Suelo y Nutrición Vegetal* 7:15-27.
- Muñoz, C., E. Zagal, and C. Ovalle. 2007b. Influence of trees on soil organic matter in Mediterranean agroforestry systems: an example from the Espinal of central Chile. *European Journal of Soil Science* 58:728-735.
- Ovalle C., A. Aronson, A. Del Pozo, and J. Avendaño. 1990. The espinal: agroforestry systems of the Mediterranean-type climate region of Chile. *Agroforestry Systems* 10:213-239.
- Ovalle, C., e J. Avendaño. 1988. Interactions de la strate ligneuse avec le strate herbacée dans les formations d'*Acacia caven* (Mol.) Hook et Am. au Chili. II. Influence de l'arbre sur quelques elements du milieu microclimatic et sol. *Oecologia Plantarum* 9:113-134.
- Ovalle, C., A. Del Pozo, M. Casado, B. Acosta, and J.M. de Miguel. 2006. Consequences of landscape heterogeneity on grassland diversity and productivity in the Espinal agroforestry system of central Chile. *Landscape Ecology* 21:585-594.
- Reichstein, M., J.D. Tenhunen, O. Roupsard, J.M. Ourcival, S. Rambal, S. Dore, and R. Valentini. 2002. Ecosystem respiration in two Mediterranean evergreen Holm Oak forests: drought effects and decomposition dynamics. *Functional Ecology* 16:27-39.
- Ritter, E., and L. Bjørnlund. 2005. Nitrogen availability and nematode populations in soil and litter gap formation in a semi-natural beech-dominated forest. *Applied Soil Ecology* 28:175-189.
- Sadzawka, A., M.A. Carrasco, R. Grez, M.L. Mora, H. Flores, y A. Neaman. 2006. Métodos de análisis recomendados para los suelos de Chile. Revisión 2006. Serie Actas INIA N° 34. Instituto de Investigaciones Agropecuarias, Santiago, Chile.
- Schimann, H., R. Joffre, J.C. Roggy, R. Lensi, and A.M. Domenach. 2007. Evaluation of the recovery of microbial functions during soil restoration using near-infrared spectroscopy. *Applied Soil Ecology* 37:223-232.
- Stat Soft. 2000. STATISTICA for Windows. Stat Soft, Tulsa, Oklahoma, USA.
- Stolpe, N.B. 2006. Descripción de los principales suelos de la VIII Región de Chile. Universidad de Concepción, Facultad de Agronomía, Departamento de Suelos y Recursos Naturales, Chillán, Chile.
- Su, Y., H. Zhao, Y. Li, and H. Cui. 2004. Carbon mineralization potential in soils of different habitats in the semiarid horquin sandy land: a laboratory experiment. *Arid Land Research and Management* 18:39-50.

- Trofymow, J.A., T.R. Moore, B. Titus, C. Prescott, I. Morrison, M. Siltanen, *et al.* 2002. Rates of litter decomposition over 6 years in Canadian forests: influence of litter quality and climate. *Canadian Journal of Forest Research* 32:789-804.
- van Meeteren, M.J.M., A. Tietema, E.E. van Loon, and J.M. Verstraten. 2008. Microbial dynamics and litter decomposition under a changed climate in a Dutch heathland. *Applied Soil Ecology* 38:119-127.
- Van Soest, P.J., and J.B. Robertson. 1985. Analysis of forage and fibrous foods: A laboratory manual for animal science. 613 p. Cornell University, Ithaca, New York, USA.
- Vávřová, P., T. Penttilä, and R. Laiho. 2009. Decomposition of Scots pine fine woody debris in boreal conditions: Implications for estimating carbon pools and fluxes. *Forest Ecology and Management* 257:401-412.
- Verdoodt, A., S. Mureithi, L. Ye, and E. Van Ranst. 2009. Chronosequence analysis of two enclosure management strategies in degraded rangeland of semi-arid Kenya. *Agriculture Ecosystems & Environment* 129:332-339.