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RELATIONSHIPS BETWEEN LITTER AND SOIL ORGANIC MATTER CHARACTERISTICS ALONG PRECIPITATION GRADIENT IN CENTRAL-WESTERN OF ARGENTINA

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Abstract

We assessed if these vegetation characteristics affect the soil organic matter characteristics along a precipitation gradient (500-100mm) in four dry forest sites with similar grazing intensity of central-western of Argentina. The follow litter characteristics were analyzed: total and component biomass, fibers, phenols and labile compounds. These characteristics were related with soil data obtained in the same sites. The litter characteristics did not linearly respond to the precipitation gradient: total biomass was higher in 350mm-site while fiber concentration was lower in 500mm-site than the other sites. Contrarily, phenols and labile compounds did not show significant differences among sites. Correlations were detected only between total litter biomass and soil organic matter and its fractions. We concluded that the relationships between litter and soil organic matter characteristics are defined by an interaction between litter biomass and fiber/phenols ratio. Implication for cattle and logging management practices in dry forest are mentioned.

Keywords: Arid region; Decomposition; Fiber; Humic substance; Phenol.

1. Introduction

Dry forests cover a great area of central-western of Argentina, characterized by an E-W precipitation gradient ranging from 500 to 100 mm. Accordingly, vegetation decreases in terms of density and diversity (Bucher, 1982; Cabido et al., 1993; Iglesias et al., 2011). Most of the dry forest areas in Argentina have been cleared and consequently forest relicts are scarce supporting a high grazing pressure, particularly the Dry Chaco and central Monte eco-regions (Abril and Bucher, 1999; Abril *et al*., 2005; Carrera *et al*., 2009; Guevara *et al*., 2009).

It is accepted that total soil organic matter (SOMt) in dry forest is scarce due to low productivity and low litter decomposition rate, as a consequence of low and unpredictable precipitations (Abril *et al*., 2009; Austin *et al*., 2004; Xie and Steimberger, 2001). Accordingly, the aridity increases agree with SOMt decreases (Feng *et al*., 2002; Feral *et al*., 2003).

It is widely known that SOMt is composed mainly by two fractions with different chemical compositions: a) a fraction that includes compounds of low molecular weight easily metabolized by microorganisms (non-humic substances: NHS) and b) a more stable fractions (humic substances: HS) that include compounds of high molecular weight (humic acids: HA and fulvic acids: FA) which is synthesized in soil from un-decomposed litter (Egli *et al*., 2007; Marinari *et al*., 2010; Prentice and Webb, 2010). In consequence, the quality and quantity of plant litter greatly influences SOMt fractions (Kovaleva and Kovalev, 2009; Poirier *et al*., 2003; Potthast *et al*., 2010).

In dry forest the vegetation presents adaptations to withstand arid conditions (higher sclerophylly) and herbivores (synthesis of anti-herbivore compounds) (Alegre *et al*., 2004; Campanella and Bisigato, 2010). For example, Barchuk and Valiente-Banuet (2006) showed a direct relationship between sclerophylly and precipitation gradient for *Aspidosperma quebracho blanco* tree. The compounds responsible of sclerophylly are compounds of the epidermis in leaves (cutin and waxs) and of the cellular wall (cellulose and lignin), while, the predominant anti-herbivore compounds are phenols and tannins (Alegre *et al*., 2004; Campanella and Bisigato, 2010). Because litter with these chemical compounds is scarcely degraded by microorganisms, the remaining compounds are re-polymerized in soil originating the stable SOMt (Aranda and Oyonarte, 2005; Austin and Ballaré, 2010; Kovaleva and Kovalev, 2009; Lopez *et al*., 2006; Paul 2007; Vivanco and Austin, 2008). For these reasons, it could be assumed that in a precipitation gradient the driest forest would present the highest concentration of litter recalcitrant compounds and in consequence humic substances content.

However, in a previous work (Abril *et al*., 2013) we found that along a precipitation gradient, content and composition of SOMt do not follow the aridity gradient; indeed, it is affected by the type and structure of vegetation and the aboveground litter quantity. This pattern could be explained by the litter chemical composition, however, information about this issue is lacking.

Therefore, our objective was to assess if there are relationships between litter (total and component biomass and fibers, phenols and labile compounds) and soil organic matter (humic and non-humic substances) characteristics along to the precipitation gradient (500-100mm) in dry forests of central-western of Argentina.

2. Materials and Methods

2.1. Study area

The study area covered two eco-regions of dry forest in the central-western of Argentina: Dry Chaco and Monte eco-regions (31°- 32° S and 65°- 68° W) (Abril and Noe, 2007). The Dry Chaco is a dry forest whose tree layer is dominated by *Aspidosperma quebracho-blanco* and, in a lesser degree, by *Prosopis* spp., with an abundant shrub layer of *Larrea divaricata*, *Mimozyganthus carinatus* and *Acacia furcatispina*, and presence of grasses (genera: *Trichloris Gouinia*, *Setaria* and *Pappophorum*) in sites with low woody cover. Mean annual rainfall is 500 mm (concentrated in summer) and mean annual temperature is 20ºC (Cabrera, 1976).

The Monte eco-region is characterized by an extensive shrubland dominated by *Larrea* spp, interspersed with open forest of *Prosopis* spp. The herb layer is composed by grasses, mainly perennial Poaceae C4 species (genera *Pappophorus*, *Digitaria*, *Trichloris*, *Aristida* and *Sporobolus*). Annual rainfall and temperature means range between 80-350 mm (concentrated in summer) and 13-15.5ºC, respectively (Cabrera, 1976).

2.2. Sampling design

The samples were taken along a 500-km transect from Pocho Department (Córdoba province) to Lavalle department (Mendoza province). The sampling design and sites characteristics were described in detail in Abril *et al.* (2013) (Table 1).

In each site, two sets of three composite litter samples (10 subsamples, 0.16m^2), were taken: the first during the wet season (summer, February 2005) and the second during the dry season (winter, September 2005). Special care was taken to sample the four sites within the same week of each season.

2.3. Laboratory analysis

In litter samples, total and plant component (woody plant leaves; woody material; grasses and forbs) biomasses were measured by dry weight (80°C). Litter components were identified by direct observations. For laboratory analysis litter samples were milled and stored at 4°C until processing. Insoluble fibers (cellulose + lignin) were measured by enzymatic gravimetric method (Asp *et al*., 1983) and phenols by Folin-Denis method (Anderson and Ingram, 1989). We calculated the litter net fiber quantity (NF) as insoluble fiber concentration x total litter biomass; and litter labile compounds (LC) as total litter biomass - NF.

2.4. Statistical analyses

Differences in all parameters among sites were analyzed using ANOVA and means were compared using the least significant difference test (LSD; $p \leq 0.05$). We used t-test for comparing wet and dry season. Pearson correlation analysis was performed to test linear relationships between litter and soil data obtained by Abril *et al.* (2013) in the same precipitation gradient, sampling dates and study sites. The InfoStat (2001) software was used.

Table 1: Characteristics in four sites along a precipitation gradient in dry forest of central-western Argentina (mean ± SD). SOMt: total soil organic matter; FA: fulvic acid; HA: humic acid; NHS: non-humic substances; HI: Humification index; and PI: Polimerization index. Data from Abril *et al*. (2013).

	500mm	**350mm**	**200mm**	**100mm**
Coordinates	31° 19′ S 65° 30′ W	32° 19′ S 66° 02′ W	32° 21′ S 66° 55′ W	32° 19′S 68° 00′ W
Vegetation structure	trees 8% shrubs 38% grasses/forbs 12% bare soil 40%	trees 20% shrubs 72% grasses/forbs 13% bare soil 12%	trees 15% shrubs 51% grasses/forbs 30% bare soil 15%	trees 11% shrubs 31% grasses/forbs 40% bare soil 53%
SOMt (mg g^{-1})	18.57 (± 2.37)	24.63 (± 6.72)	15.34 (± 4.11)	13.10 (± 3.28)
FA (mg g^{-1})	1.41 (± 0.21)	2.50 (± 0.55)	1.67 (± 0.65)	0.65 (± 0.34)
HA (mg g^{-1})	2.63 (± 0.70)	3.08 (± 0.65)	1.85 (± 0.74)	1.47 (± 0.80)
NHS (mg g^{-1})	2.63 (± 0.70)	19.05 (± 6.04)	11.82 (± 3.61)	10.98 (± 2.65)
HI	0.22 (± 0.03)	0.23 (± 0.05)	0.23 (± 0.06)	0.16 (± 0.06)
PI	1.86 (± 0.31)	1.24 (± 0.21)	1.16 (± 0.39)	2.61 (± 1.30)

3. Results

3.1. Litter characteristics

Total biomass and litter components did not follow a pattern according to the precipitation gradient. Total biomass was higher in 350mm-site than the other sites (p=0.0268). Litter in all sites was mostly composed by leaves and woody material, whereas grass material was a scarce litter component in all sites. The forbs were higher in 200mm-site (p=0.0005) than other sites and woody material was highest in the 350mm-site (p=0.0051), while woody plant leaves and grass material did not significantly differ (Table 2).

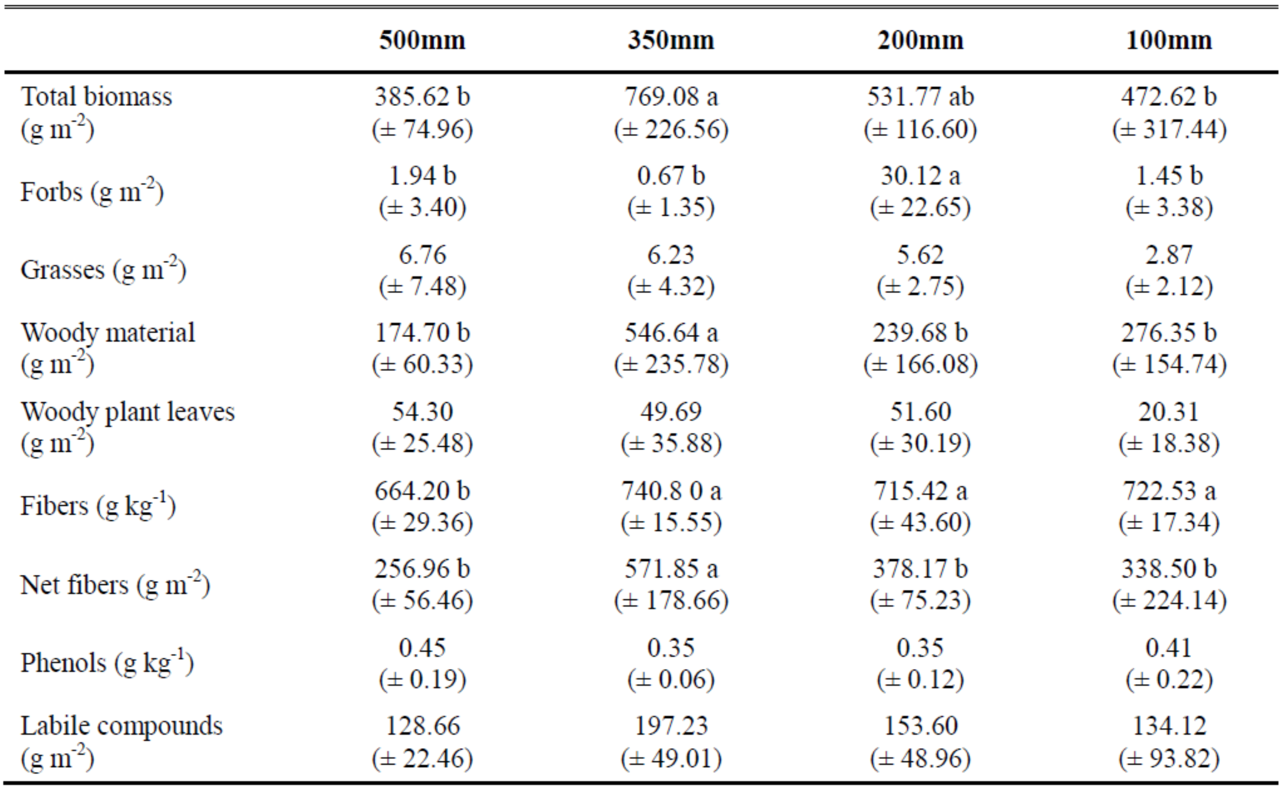
Also, the litter recalcitrant and labile compounds (LC) did not follow a pattern according to the precipitation gradient. The fiber concentration was lower in 500mm-site than the other sites (p=0.0012), while the net fiber (NF) was highest in 350mm-site (p=0.0121). Contrarily, phenols and LC did not show significant differences among sites (Table 2). The woody material showed significant correlations with: a) total biomass (r=0.81, p<0.0001), b) fiber concentration (r=0.84, p<0.0001), c) NF (r=0.84, p<0.0001), and d) LC (r=0.69, p<0.0001).

There were few differences in litter characteristics between wet and dry season at each site. The variables that significantly increased in dry season were: total biomass, woody material, woody plant leaves, and LC at 100mm-site (p= 0.0318, p= 0.0063, p= 0.0282 and p= 0.0436, respectively) and phenols at 500mm-site (p= 0.0027). Contrarily, woody material decreased in dry season in 500mm-site (p= 0.0413) (Fig. 1).

3.2. Relationships litter/SOMt characteristics

The total litter biomass showed significant correlations with NHS (r=0.52, p=0.01), FA (r=0.45, p=0.02), (Fig. 2a), PI (r=-0.63, p=0.001), and SOMt (r=0.49, p=0.01), (Fig. 2b), while the woody material component correlated with SOMt (r= 0.45, p=0.02) and NHS (r= 0.45, p=0.03), (Fig. 2g).The litter recalcitrant compounds did not establish significant correlations with SOMt parameters. However, the amount of NF presented significant correlations with FA (r=0.46, p=0.02), the polymerization index (PI) (r= -0.60, p=0.002), (Fig. 2c), SOMt (r=0.49, p=0.02) and NHS (r=0.50, p=0.01), (Fig. 2d). Moreover, the LC showed correlations with SOMt (r=0.49, p= 0.01), NHS (r=0.53, p=0.007) (Fig. 2f), and PI (r= -0.68, p<0.0001) (Fig. 2e).

Table 2: Litter characteristics in four sites along a precipitation gradient in dry forest of central-western Argentina (mean ± SD). Letters indicate significant differences among sites (LSD test, p≤0.05).



	500mm	350mm	200mm	100mm
Total biomass ($g\ m^{-2}$)	385.62 b (± 74.96)	769.08 a (± 226.56)	531.77 ab (± 116.60)	472.62 b (± 317.44)
Forbs ($g\ m^{-2}$)	1.94 b (± 3.40)	0.67 b (± 1.35)	30.12 a (± 22.65)	1.45 b (± 3.38)
Grasses ($g\ m^{-2}$)	6.76 (± 7.48)	6.23 (± 4.32)	5.62 (± 2.75)	2.87 (± 2.12)
Woody material ($g\ m^{-2}$)	174.70 b (± 60.33)	546.64 a (± 235.78)	239.68 b (± 166.08)	276.35 b (± 154.74)
Woody plant leaves ($g\ m^{-2}$)	54.30 (± 25.48)	49.69 (± 35.88)	51.60 (± 30.19)	20.31 (± 18.38)
Fibers ($g\ kg^{-1}$)	664.20 b (± 29.36)	740.8 0 a (± 15.55)	715.42 a (± 43.60)	722.53 a (± 17.34)
Net fibers ($g\ m^{-2}$)	256.96 b (± 56.46)	571.85 a (± 178.66)	378.17 b (± 75.23)	338.50 b (± 224.14)
Phenols ($g\ kg^{-1}$)	0.45 (± 0.19)	0.35 (± 0.06)	0.35 (± 0.12)	0.41 (± 0.22)
Labile compounds ($g\ m^{-2}$)	128.66 (± 22.46)	197.23 (± 49.01)	153.60 (± 48.96)	134.12 (± 93.82)

4. Discussion

4.1. Litter characteristics

4.1.1. Total and component litter biomass

Despite the expected, our results show that total litter quantity does not linearly respond to precipitation gradient. These findings do not agree with the vegetation changes along precipitation gradient (richness, diversity and productivity) reported for the Great Chaco (Bucher, 1982), and for the same eco-region of this study (Cabido *et al*., 1993; Iglesias *et al*., 2011).

The fact that litter quantity does not linearly respond to the vegetation changes could be due to collected aboveground litter which do not represent exactly the primary productivity. It is well known that primary productivity depend on vegetation characteristics whereas litter quantity deposited aboveground is also affected by decomposition process (Odum and Barret, 2006). There are many factors that interact in decomposition process such as: a) climatic conditions (mainly precipitation regime), b) litter chemical composition, c) photochemical degradation, d) quantity and frequency of litter deposition, and e) characteristics of degrading microbial communities (Carranza *et al*., 2012; Mahaney, 2010; Noe and Abril, 2008; Perez-Harguindeguy *et al*., 2007; Torres *et al*., 2005; Vivanco and Austin, 2008). Another factor that may justify the lack of agreement between the aboveground litter quantity and primary productivity in arid regions is the litter removal by animals. There are evidences indicating a substantial amount of litter removal for forage by goats, ants and termites (Bucher *et al.*, 2003).

The peak of biomass quantity in 350mm-site corresponds to higher tree cover (20%) and major quantity of woody material (546 g m^{-2}). Besides, it is worth to mention that *A. quebracho-blanco* tallest/oldest individuals are the most abundant trees because there are no records of tree logging in 350mm-site (Abril and Noe, 2007; Abril *et al.*, 2005; Barchuk and Valiente-Banuet, 2006). It is mentioned that *A. quebracho-blanco* falls an important quantity of woody material (twin and bark), particularly the old individuals (A. Abril, personal communication, 2005).

The fact that the 100mm-site (the only site located in Monte eco-region) presented similar amount of biomass than the 500mm and 200mm-sites, despite of 100mm-site have the lowest precipitation, could be attributed to: a) 100mm-site present *Prosopis* woodlands that occur in Monte eco-region areas with accessible groundwater (between 8 and 15 m depth) (Alvares *et al*., 2011; Iglesias *et al*., 2011), and b) in Monte the decomposition rate is very low (k= -0.48) due to the unfavorable climatic conditions, allowing aboveground litter accumulation (Noe and Abril, 2008). Conversely, the small litter quantity at 500mm-site (similar to the lowest precipitation sites) could be explained by: a) a high decomposition rate (k=-0.95) reported by Torres *et al.* (2005) in a neighbored undisturbed area; and b) the anthropic disturbance.

Anthropic disturbance modify both litter quality and quantity (Alvarez *et al*., 2009; Iglesias *et al.*, 2011; Mahaney, 2010). For example, Andrioli and Distel (2008) and Cornelissen (1996) mention that grazing decrease palatable species abundance and increases unpalatable species, which produces less litter with larger amounts of secondary compounds. Moreover, Bucher *et al.* (2003) came to a conclusion that the nutritional value of the 500mm-site litter is well within the ranges of optimal values for goat food.

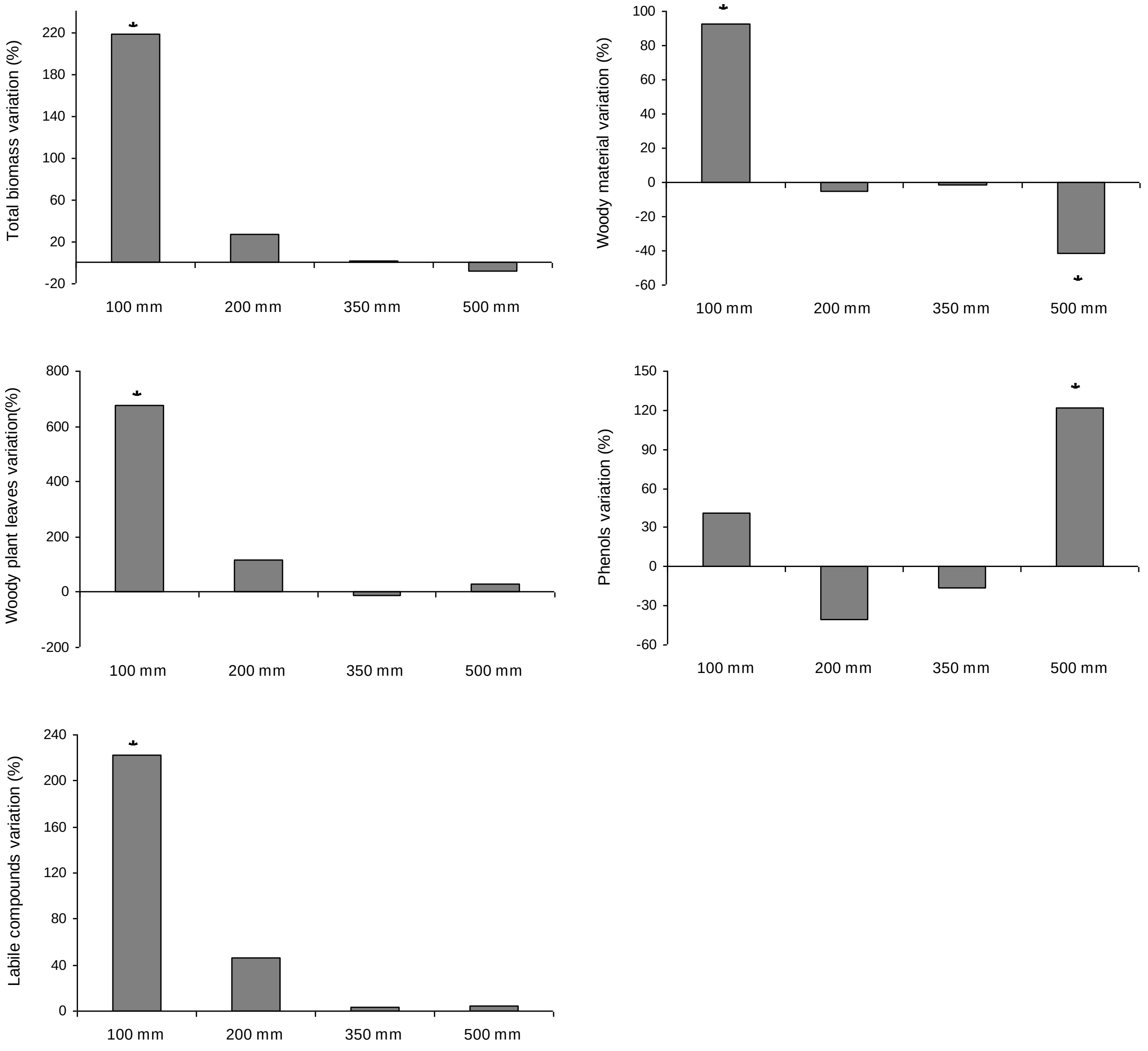


Figure 1: Litter characteristics variation (%) between wet and dry season at each site along a precipitation gradient in dry forest of central-western Argentina. * indicate significant differences.

On the other hand, it is mentioned that logging is an important anthropic disturbance in the dry forest (Abril *et al*., 2005; Iglesias *et al*., 2011). Accordingly, the low litter quantity observed in our results in 500mm-site could be related to a high logging frequency in the last 50 years (Abril *et al*., 2005; Bucher *et al*., 2003; Iglesias *et al*., 2011).

The no substantial variations of grass litter observed among sites and its scarce quantity, reflect that the sites were selected with a similar grazing intensity. Guevara *et al*. (2009) found that in Monte eco-region the grasses biomass decrease 56% in grazed sites respect to fenced areas (livestock exclusion).

Indeed, the higher forbs litter quantity detected in 200mm-site include mainly residues of *Bromelia* sp. It is known that this specie grow associated to sandy soils such as soils of 200mm-site (sand > 95%) (Abril and Noe, 2007; Luti *et al*., 1979; Sercic *et al*., 2006). Moreover, this elevated biomass of *Bromelia* sp. could be probably due to the litter accumulation by low decomposition rate reported for bromeliads in arid zones (Perez-Harguindeguy *et al*., 2000).

4.1.2. Litter chemical characteristics

Contrarily to the reported for sclerophyllous vegetation (Barchuk and Valiente-Banuet, 2006; Cabido *et al*., 1993), the concentration of litter recalcitrant compounds did not respond to the precipitation gradient. It is mention that fiber concentration mainly depend on: a) the quantity and frequency of litter deposition; b) the time since the litter deposition; and c) the climatic conditions that regulate the microbial activity in decomposition process (Carranza *et al*., 2012; Noe and Abril, 2008; Paul, 2007; Torres *et al*., 2005).

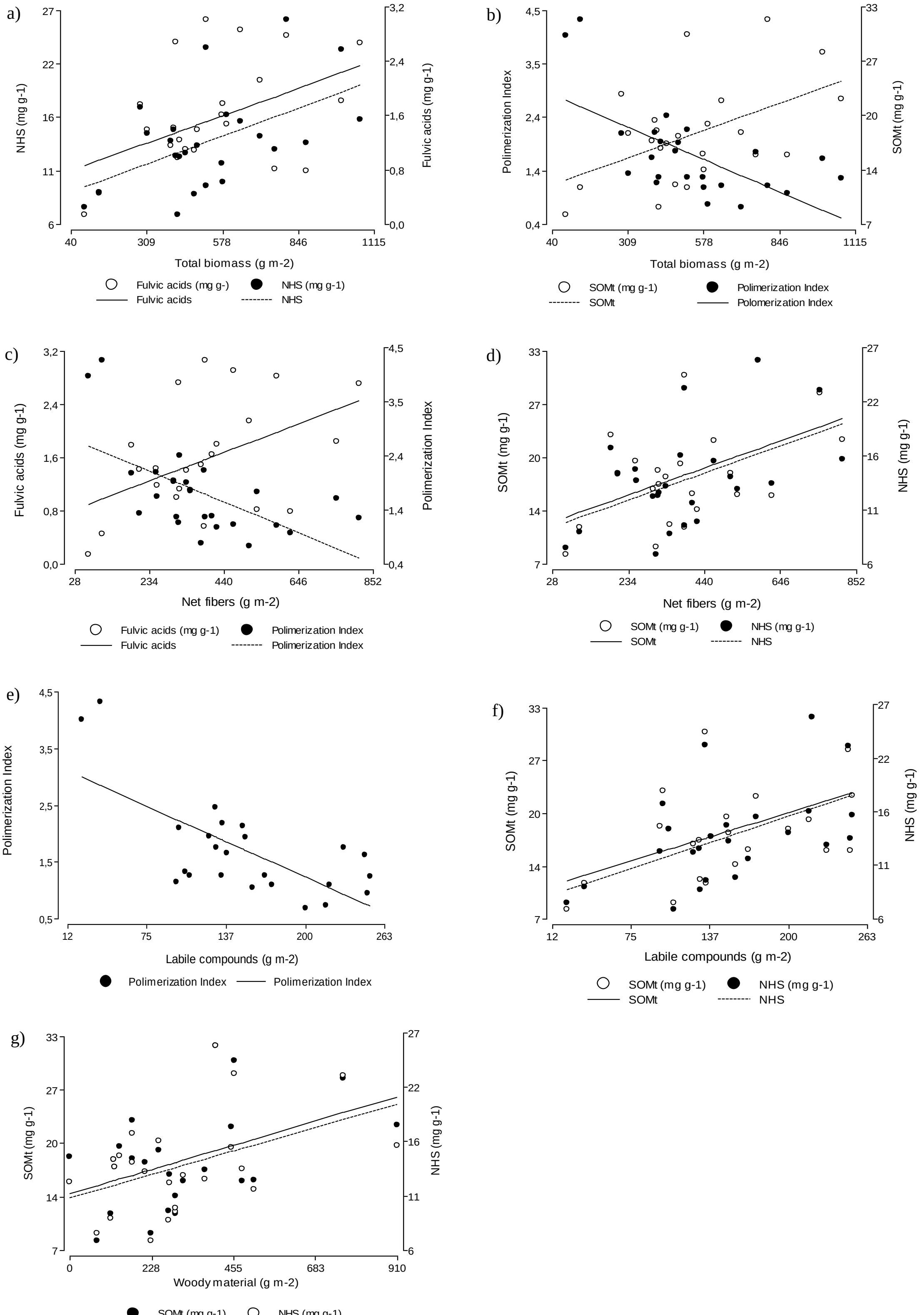


Figure 2: Significant correlations between litter and soil organic matter characteristics along a precipitation gradient in dry forest of central-western Argentina. SOMt: total soil organic matter, NHS: non-humic substance.

From this perspective, the lowest fiber concentration detected in 500mm-site could be related with the highest decomposition rate mentioned above (k=-0.95). This decomposition rate value indicates that in after one year there is not remaining surface residue (including the most recalcitrant compounds such as fibers) (Torres *et al.*, 2005). On the contrary, the high quantity of fibers in the two most arid sites results of the residue accumulation due to the low decomposition rate mentioned above (Noe and Abril, 2008). The high fiber concentration in 350mm-site agrees with the greatest input of woody material.

On the other hand, Austin and Ballaré (2010) mention that in arid regions the decomposition process is influenced by photochemical degradation, which has special relevance in sites with scarce vegetation cover (high UV radiation). However, our findings about fiber content in the site with the lowest vegetation cover (100mm-site=50% bare soil) do not agree with this statement.

The lack of variations in phenols and labile compounds content along the precipitation gradient was unexpected. The no difference in phenol content could be result of the similar anti-herbivores production from vegetation due to the same grazing intensity in all sites. Moreover, similar values of phenol and labile compounds among dry forests have strong relationship with the microbial activity of the decomposition process. Some authors mention that in arid regions decomposition process produces an even litterfall chemical characteristics (Carranza *et al.*, 2012; Noe and Abril, 2008). This can be associated with the similar microbial activity registered by Noe (2012) for the same eco-regions. Then, in agreement with other authors, the microbial communities are the main decomposition factors, instead the litterfall chemical characteristics (Carranza *et al.*, 2012; Dinakaran and Krishnayya, 2010; Noe and Abril, 2008; Strickland, 2009).

4.1.3. Season effect

The fact that seasonally has affected in different ways the total biomass and its components in each site could be related with the vegetation composition (Alvarez *et al.*, 2009). For example, the higher biomass in dry season in 100mm-site corresponds with woody plant leaves increase, in agreement that *Prosopis* sp. trees fall leaves in autumn (Alvarez *et al.*, 2009) and that woody material including great quantity of *Geophroea* sp. barks (A .Abril, personal communication, 2005). Contrarily, the woody material decrease in dry season in 500mm-site reflect woody decomposition during rainfall season (Torres *et al.*, 2005).

The great phenols decrease in 500mm-site during summer could be related with the elevate precipitations concentrated in this season. It is well known that during a precipitation event microorganisms hydrolyze the polymers such as lignin favoring the lixiviation of soluble compounds (phenols) (Abril and Bucher, 1999; Abril *et al.*, 2005; Austin *et al.*, 2004; Bucher *et al.*, 2003; Noe and Abril, 2008).

Only in the lower precipitation site (100mm) was detected a major quantity of labile compounds in dry season, which would be probably due to: a) the less microbial activity registered by Abril and Noe, (2007), in the same site, and b) the higher input of labile compounds from fresh leaf litter in dry season (mentioned above).

4.2. Relationship litter/SOMt fractions

Although the studies that evaluate the relationship between litter and soil characteristics are scarce (Aranda and Oyonarte, 2005; Dinakaran and Krishnayya, 2010; Lopez *et al.*, 2006; Potthast *et al.*, 2010), our findings clearly show that aboveground litter characteristics strongly influence the chemical composition of SOMt. According to the correlation results detected in this work, the mainly factor determining SOMt characteristics is the quantity of litter deposited aboveground, instead the litter chemical composition. This relationship was observed by several authors (Campanella and Bisigato, 2010; Dinakaran and Krishnayya, 2010; Noe, 2012), however, it is not in agreement with Egli *et al.* (2007) and Silveira *et al.* (2011) who mention that the SOMt was dependent on the type of vegetation litter. An exception to this pattern is the100mm-site due to the low quantity of SOMt and of the most of its fractions do not correspond with less litter quantity. Again, this could be attributed to the low litter decomposition rate in this site (k= -0.45) which do not favor the input of organic compounds to soil (Noe and Abril, 2008).

The correlation between litter and less stable SOMt fractions (NHS and FA) is consistent with the humic substance formation dynamics. It is widely known that the input degradated litter compounds to soil contribute to the formation of NHS, which is incorporated in fulvic acids in the first time of humification process (Kovaleva and Kovalev, 2009; Paul, 2007; Poirier *et al.*, 2003). The detected correlations suggest that litter quantity is a key factor in the first time of humic substance formation (FA), but not in humic acid formation, as shown by the negative correlation with PI.

Correlation was not seen between concentration of litter chemical compounds and SOMt fractions. However, the net labile compounds affect the amount of SOMt and NHS. The fact that net fiber has been also correlated with the amount of FA supports the assumption that fibers contribute significantly to the humification process (Lopez *et al.*, 2006). The lack of correlation between woody material and FA would be due to woody material include high tree bark amount which content cork but no fiber (A. Abril, personal communication, 2005).

The recalcitrant compound concentrations alone did not affect the humified fractions of SOMt, but if it is calculate phenol as function of fiber concentration values (fibers $^{\text{phenols}}$), a clear relationship with PI is detected (Fig. 3). This indicates that an interactive effect, resulting from litter characteristics, contributes in the humic substance formation.

According to ecological realistic condition and considering the dynamic of the decomposition process and the time of SOMt formation, we correlated the litter characteristics data from dry season vs. soil characteristics data from wet season and no significant correlations were detected. Contrarily, the inverse correlation (litter characteristics from wet season vs. soil characteristics from dry season) was in total agreement with the annual pattern. This indicate that the delay since decomposition to SOMt formation in arid systems have a strong seasonal factor due to the high microbial activity when the climatic conditions are more favorable (high temperature and precipitations) (Austin *et al.*, 2004; Noe and Abril, 2008; Torres *et al*., 2005).

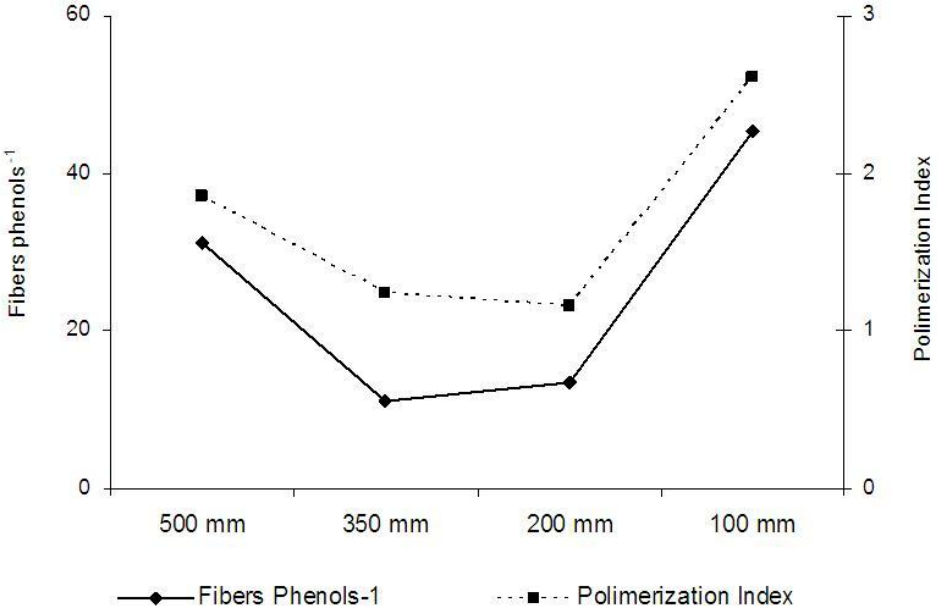


Figure 3: Relationship between fibers-phenols and polymerization index along a precipitation gradient in dry forest of central-western Argentina.

5. Conclusion

We concluded that: a) there are relationships between litter and SOMt characteristics in the precipitation gradient in dry forests of central-western of Argentina, and b) there is not a main factor affecting these relationships, instead the SOMt characteristics are defined by an interaction between litter biomass and fiber/phenols ratio.

To our knowledge, this is the first study which demonstrates the importance of litter characteristics on the SOMt quality in dry forest. Our finding has special relevance to strengthen criteria for cattle and logging management practices in dry forest, which must tend to favor the litter accumulation. This approach opens up a new understanding to the development of policies and programs for conservation, restoration, and sustainable use that depend on management and land planning strategies based on information about forest status, changes and responses.

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